ASSESSMENT OF ANCIENT LAND USE IN ABANDONED SETTLEMENTS AND FIELDS - A STUDY OF PREHISTORIC AND MEDIEVAL LAND USE AND ITS INFLUENCE UPON SOIL PROPERTIES ON HOLNE MOOR, DARTMOOR, ENGLAND

by

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SUMMARY

Ignorance about the pattern of ancient land use within prehistoric and medieval fields on Dartmoor and elsewhere provided the catalyst for the research reported in this thesis, which explores new ways of assessing past land use in abandoned enclosures. The first chapter provides a brief, critical evaluation of relevant earlier archaeological research; the limitations of current procedures, which reveal little about pastoral land use, are discussed and it is concluded that, although there have been few scientifically rigorous studies of the soils in ancient settlements and fields, soil analysis accompanied by explicit modelling of the interaction of agricultural land use and soils could provide new information about past land use, but only within a framework of research that defines the natural trajectories of soil development as a prerequisite to the isolation of 'land use-deflected' pedogenesis.

In Chapter 2, a review of some of the principal features of moorland soils is followed by an assessment of the ways in which they may have been modified by recent, 'extensive' land use. Information provided by pedological and agricultural research is then used to formulate models of changes in the physical and chemical properties of soil that might be expected to occur as a result of various forms of 'intensive' agricultural land use; particular attention is paid to the pattern of phosphorus redistribution in pastoral enclosures.

An environmental and cultural history of Holne Moor on Dartmoor is presented in Chapter 3, and it is shown that this area possesses archaeological and pedological features that make it eminently suitable as a study area within which to test ideas and predictions about the way in which early land use may have modified soil properties; the chapter concludes with an account of the fieldwork and laboratory strategies that have been used to investigate the soils within this study area.

The results of a field survey of the soils and vegetation on Holne Moor are described and interpreted in Chapter 4; it is concluded that many of the properties of the surface soils reflect a combination of features acquired during medieval farming and during subsequent pedogenetic reversion. The pattern of soil properties is shown to be consistent with a pattern of land use that can be inferred from archaeological investigations of the medieval enclosures themselves and provides additional information about land use within the enclosures and the sequence of land abandonment.

Quantitative investigations of soil phosphorus and organic matter are reported and analysed in Chapter 5. Palaeosol studies provide evidence of the general course of pedogenesis and also allow the conclusion that significant changes in soil phosphorus have occurred since prehistoric times and even over the past thousand years. Analyses of soils in prehistoric houses and monuments, and in the fields of nearby, modern farms are then used to establish a picture of the way in which the soils of the study area have responded to phosphorus inputs and agricultural management. Conclusions reached as a result of these studies, together with the models offered in Chapter 2, form the basis for interpretation of investigations of the soils within medieval and prehistoric agricultural enclosures; these are described in the concluding sections of the chapter, where it is shown that patterns consistent with the models can be identified within these ancient enclosures.

Some of the more important conclusions arising from this research are set out in Chapter 6; the primary conclusions are that very detailed information about medieval land use can be, and has been obtained through intensive field survey alone, and that analysis of soil phosphorus can provide important, new information about the agricultural use of both medieval and prehistoric enclosures.

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All the unacknowledged data and analysis presented in the thesis stem entirely from my own fieldwork, laboratory work and documentary research. However, as indicated in chapters 2 and 3, some of the data appears here due to the assistance of, or fruitful collaboration with, other researchers. Rothamsted Experimental Station, Harpenden, undertook total phosphorus analyses of sixty soil samples, and I am grateful to Dr G.E.G. Mattingly and Dr O. Talibudeen for arranging this work, and for helpful discussions. Unpublished maps of the distribution of cattle and their excreta in a pasture were provided by Dr. D.J. Briggs of the Department of Geography, Sheffield University, to whom I have also turned for advice on innumerable occasions. David Maguire at Bristol University undertook the tedious task of identifying and counting pollen grains extracted from the soils of Holne Moor, and I am also indebted to Christine Williams, who collaborated with me during the initial stages of the palynological work. None of these researchers is responsible for the interpretation of data offered in this thesis.

Fieldwork on Dartmoor in all seasons could not have been sustained without the friendly welcome and generous material assistance provided by many of the present commoners of Holne and Spitchwick, and in particular I must thank Algernon May of Rowbrook Farm and Norman Perryman of West Stoke Farm who also allowed me to take soil samples from their fields.

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Most important of all, I welcome this opportunity formally to thank my supervisor, colleague and friend, Andrew Fleming, for his encouragement, criticism and advice over many years. His research into the prehistory of Dartmoor inspired the work reported here. More specifically, I am indebted to him for making available his maps of the prehistoric features on Holne Moor which, after modification, have been used as baseline maps in this thesis, and for obtaining permission for my activities within the wider framework of the Dartmoor Reave Project from the Dartmoor National Park Authority and the commoners of Holne. He also made valuable comments on the draft of the thesis.

As explained in chapter 3, knowledge about the medieval and post-medieval history of Holne Moor gained by archaeological fieldwork and subsequent analysis represents the result of a very enjoyable and instructive period of joint work by Andrew and myself; the principal account of this work is appearing elsewhere (Fleming and Ralph: in press). During this research, in particular, I was able to learn much by drawing upon the specialised knowledge of Devon's history possessed by Dr H.S.A. Fox, Elizabeth Gawne, Dr T Greeves and John Somers Cocks.

ABBREVIATIONS AND LAY-OUT

Basic or derived S.I. units are used throughout this thesis; data presented in other units in the original publication have been converted using standard conversion factors. Abbreviation of S.I. units follows international convention. All heights are above mean sea level at Newlyn (a.s.l.). Dates are given either in radiocarbon years (bc or ad) or calendar years (BC or AD). All statistical terms carry their conventional meanings; abbreviations used in the text and tables include: $\bar{x}$ (= sample mean), SD (= standard deviation), SE (= standard error), CV (= coefficient of variation, r (= coefficient of correlation) and CD (= coefficient of determination). The letter D has been used in some of the tables in the appendices to indicate 'difference' (between tabulated values).

Volume 1 contains the text. References, appendices, figures, and the tables for Chapter 5 are in volume 2. A note on citation precedes the list of references, and a note on the lay-out, keys and conventions used in figures has also been placed before the first figure. A detailed list of the contents of the appendices (which should be read in conjunction with Chapter 3, section 3.3) precedes Appendix 1.

All tables and figures are numbered according to the chapter in which they are introduced; tables and figures for the appendices carry a prefix A followed by the appendix number. For convenience, tables for Chapters 2 , 3 and 4, and for the appendices (there are no tables for Chapters 1 and 6) have been placed in the main text or appendix text, usually on the page following that in which they have first been mentioned. However, the more numerous tables for Chapter 5 and all figures have been placed after the appendices in volume 2.

PREFACE

The river Dart, which gave its name to the largest of the upland plateaux of south-western Britain, cuts a steep, deep gorge through the edge of the granite laccolith and its aureole of metamorphic rocks before emerging onto the lowlands at the ancient Stannary town of Ashburton. To the south of the gorge lies the wet and windswept plateau of Holne Moor, held today, as most of it has been for a thousand years and perhaps much more, as the common lands of the 'men of Devon'. For much of this time the Moor's only permanent inhabitants have been the wildlife and the sheep, cattle and ponies that have grazed its heathery pastures. But it has not always been so.

Criss-crossing fences of stone and earth trace out long-abandoned agricultural enclosures of the middle ages and themselves override still more ancient boundaries which form a small segment of the largest, most complete prehistoric landscape that survives today in Europe. Memory does not reach, nor written documents reveal, the remote events to which these ancient boundaries were witness, while traditional archaeological approaches have had only limited success in confirming our conjectures about the purposes of these enclosures. There is irony here, for as the harsh environment held back the tide of agriculture and thus preserved the architecture of antiquity, it created the acid soils that have taken their toll on the archaeological documents. No bones survive to speak of ancient herds and flocks, so one must look afresh for evidence if one is to learn, not merely speculate. The chapters that follow document a search for suitable, new ways to investigate the primary functions of these ancient fields.

A field can be thought to consist of two components, its architectural features and its soil. Archaeologists have often studied field boundaries, walls, ditches, gates and the like, as well as some soil features such as ridge and furrow and plough marks, but they have paid much less attention to the physical and chemical properties of the soil itself; some of the more important or instructive of these earlier investigations are briefly discussed in the first chapter. The following chapter explores some of the literature of soil and agricultural science in a search for those traces of tillage and pasturage that might be expected to survive the ravages of time, and for information that would allow one to understand and predict the likely transformations that post-agricultural pedogenesis would impose on such ancient artifacts. Later chapters consist primarily of an account of the investigations undertaken on Holne Moor; the soil within the enclosures and other archaeological features on this plateau serve as a testing ground for the conjectures of earlier chapters; some are confirmed, some are refined and some are rejected.

Although strongly committed to the investigative techniques of pedology, the primary purpose of the project remains firmly an archaeological one and both the selection and the analytical treatment presented here reflect this orientation. Where the pedologist might be interested in the broad pattern, the archaeologist may gain more by looking at exceptions to the pattern. On this basis, much has been omitted that might have been of interest to the pedologist; it is hoped that this can be rectified elsewhere.

1. ARCHAEOLOGICAL CONTEXT

'the fence in farming is analogous to the wheel in mechanisati n as a first inventive step' (Fraser 1975:111).

1.1 Introduction

Knowledge of the disposition of the productive resources exploited by a society is one of the keys to comprehension of its economic, social and political organisation. In a society whose economy is dominated by agricultural production the manner in which land is partitioned and utilised will reflect the structure of economic activity, which itself will be the product of an interaction between, on the one hand, environmental opportunities and constraints, and on the other hand, the purposes and requirements of the exploiting community or communities. Over much of the modern world intensive agricultural exploitation of land is concomitant with its enclosure, and it has long been so.

Abandoned field systems and land boundaries of historic and prehistoric age can be found all across the globe - in the New and the Old World. In northern and western Europe these relic landscapes constitute a major class of prehistoric artifacts and have much to tell us about the societies that created them (Bradley 1978a). However, as yet, scant consideration has been given to the social and political implications of prehistoric land enclosure and attention has been focussed instead on its economic function; a circumstance that has arisen at least partly because the latter is perceived as more readily recoverable than the former. Although, as Fleming (1978b) has shown, one may fruitfully explore social and political implications and, in particular, draw inferences about territoriality in the absence of full knowledge of the economic purposes of enclosure, it is also true that the latter remains an important prerequisite for many aspects of field system analysis. The designs of the enclosers must include many elements which were more firmly linked to agricultural tactics than socio-political considerations, and it is as well to isolate these elements at least <u>en route</u> to a wider appreciation of the evidence p ovided by ancient land divisions.

If analysis can reveal a history of land use within specific enclosures, then the analyst would also be favourably placed to assess the relative contribution of livestock and crops to total agricultural production in prehistoric communities, a conundrum to which Clark (1952:116) could find no obvious answer. Despite the transformation in the study of prehistoric economy represented by 'site catchment analysis' (Vita-Finzi and Higgs 1970) and the simultaneous advances in techniques used to recover and interpret plant and animal food residues from archaeological sites (Higgs 1972) this problem is still with us (Dennell 1979). Indeed, by increasing our awareness of the amount of inter- and intra-site variation in food residues and of the factors which may contribute to such variation, the methodological advances of the last three decades have prompted increased reticence to view the fugitive patterns of residua as mirror images of production or consumption or even initial deposition.

Analysts of the economic functions of field systems have another important role to play. Where a history of land use can be established on the evidence provided by the enclosures alone, one has a means of independently testing models of land use and food production arising from examination of other archaeological and documentary sources. Since equifinality and indeterminancy plague interpretation of many types of archaeological data and allow the generation of a plethora of models capable of explaining their pattern, the acquisition of new types of data to circumscribe the area of useful speculation is a highly desirable objective.

Ancient abandoned fields in Denmark were noticed as early as the 12th century (Hatt 1931) and the occurrence of place-names such as Yolland, Yelland etc., on the fringes of Dartmoor show that the Saxon settlers of south-western Britain had recognised traces of old farmlands even earlier (Somers Cocks 1970a); references to lynchets in 10th century Charters may indicate observations of abandoned prehistoric fields in other parts of Britain (Curwen and Curwen 1923). Antiquaries and topographers of the mid-17th century also recognised early land divisions of stone and more perishable materials revealed by removal of blanket and fen peat deposits in Ireland and northern England (Briggs, C.S. 1978). The classic examples of 'Celtic' fields on the chalk downlands of southern England were scrutinised by Stukeley and by Colt-Hoare in the late 18th and early 19th centuries (Bowen 1961), but systematic investigation of ancient field systems, their mapping and interpretation, only began shortly after the First World War under the stimulus of the then new technique of aerial survey and photography (Crawford 1923, Curwen and Curwen 1923).

Fieldwork, to establish the extent, character and chronology of the surviving field systems continued through the inter-war years in Britain (Curwen 1927, 1938b, 1938c, Crawford and Keiller 1928, Hedley 1931, Holleyman 1935, Holleyman and Curwen 1935, Shorter 1°38) and also in Europe (van Giffen 1928, Hatt 1931, Curwen 1932, 1938a). During this early work in Britain the numerous large-scale systems on the chalk downs received most attention but enclosures and fields in the south-western Peninsula, in Yorkshire, Northumberland, Scotland and Wales were also investigated at this time. Much debate centered on the recognition and explanation of differences between fields of prehistoric and historic age (e.g. Hedley 1931, Curwen 1938b) and this period also witnessed the initiation of a controversy about the character and age of 'strip' lynchets (Orwin and Orwin 1938, Curwen 1939) which has been periodically resurrected ever since (Orwin and Orwin 1954, Macnab 1965, Taylor 1966, Whittington 1976). Later work widened the scope of studies both geographically and chronologically (Mills 1949, Rhodes 1950, Boon 1 50, Fox 1954a, Applebaum 1954, 1958) and, for the first time, an attempt was made to model, in detail, the land use within a set of enclosures (Applebaum 1954).

The publication of Bowen's influential monograph, Ancient Fields (1961) provided a landmark in the study of early enclosures. This volume offered a useful bibliography, defined and classified agricultural features in the landscape and discussed the processes which led to their formation. Although orientated towards explication of prehistoric remains, Bowen also discussed, without rancour, the distribution and chronology of such later features as 'strip' lynchets and ridge-and-furrow (1961:40-50).

However, post-prehistoric field systems have been the subject, in their own right, of a very substantial literature produced by historical research extending over several generations (Gray 1915, Baker and Butlin 1973, Dodgshon 1980). The cited works reviewed and summarised the knowledge and ideas of their times and, it is assumed here, authentically indicate the range and nature of these extensive enquiries. Studies of enclosure in the historic period often benefit from the opportunity to scan documents but they suffer from the rarity of unaltered, abandoned fields of historic age, particularly fr the earliest post-Roman period. In consequence the student of historic enclosure, who wishes to look at the field evidence, must often consider, force majeure, not abandoned fields, but the traces of earlier fields and cultivation within contemporary enclosed land (e.g. Ber sford 1948, Rawson 1953, Eyre 1955, Clark 1960, Taylor 1974) or the few surviving 'relic' agricultural landscapes typified by Laxton (Orwin and Orwin 1938, 1954) and the Great Field at Braunton (Hoskins and Finberg 1952).

The more or less altered condition of the 'relics' and the m ny changes wrought by successive generations of farmers in present-day farmland raise problems of interpretation analogous to those faced by a prehistorian who studies 'Celtic' fields initially constructed in prehistoric times but often re-used in Romano-British and later periods. Although fieldwork in modern farming landscapes cannot take advantage of the 'purity' that a short period of use can sometimes provide in the case of prehistoric fields, this disadvantage is at least balanced by the gains that accrue to text-aided field studies which have been shown to be very fruitful (e.g. Beresford 1957, Hoskins 1967, 1973, Hewlett 1973, Taylor, C.C. 1975, Hall 1981).

In addition to these successes, one must also point to the rarity of studies, which exploit by archaeological enquiry, the traces of abandoned historic enclosures found mainly in contemporary marginal land (Yates 1965). The investigations of Fowler and Thomas (1962), Bowen and Fowler (1962), Tubbs and Jones (1964), Tubbs and Dimbleby (1965) and Barker and Lawson (1971), provide exceptions that draw attention to this lacuna but can hardly be regarded as filling it. It is perhaps significant that several of these projects arose out of field studies and excavation of prehistoric enclosures.

In contrast, archaeological research into prehistoric fields has proceeded apace, particularly during the last two decades. The scope and volume of this work can be judged from the published proceedings of a symposium (Bowen and Fowler 1978), though much detailed work remains largely unpublished. The volume cited was self-consciously devoted to a survey of recent field evidence and the provision of a very valuable corpus of the traces that survive both in areas of intensively-used enclosed land, where destruction is a major concern, and in the marginal areas where extensive land use poses little threat. The editors believed that the collection and ordering of the facts was the primary task facing agrarian archaeology today (Bowen and Fowler 1978:v), nd they and most of their contributors abstained from interpretation, social, political or economic, of the land enclosures they documented.

One may doubt whether anyone can in fact collect data in the absence of models of the phenomena studied and to proceed ostensibly along such lines is to run a risk of transferring away from the known bias produced by the myopia of problem-orientated research to an unknown, unconscious preselection of the significant. Fortunately one can find, at least in the most recent literature, a move away from this positivist-orientated tradition and serious attempts to transform the now large body of fieldwork into useful evidence for prehistoric agricultural economy (e.g. Lindquist 1974, Brongers 1976, Bakker 1977, Bowen 1978, Bradley 1978a, 1978b, Pryor 1976, 1978, 1980, Fleming 1971, 1977a,1978b, 1979a).

In these latter publications, a broad picture of economic strategy was often presented, though in some instances the arguments supposed a knowledge of the specific use of particular enclosures and fields. In these, as in many other studies (e.g. Curwen 1927, Fox 1954b, 1955, Mercer 1970, 1978), field use has usually been inferred from such evidence as the size and shape of the enclosures, the nature of their boundaries, the presence or absence of lynchets, ploughmarks and traces of manuring, and, very rarely, the qualities of the soil in the long-abandoned fields. As the brief review presented in this chapter will demonstrate, much of the evidence for field use is equivocal or of limited scope and application, and to this extent unsatisfactory. Although it can be legitimately and relevantly employed as one of the many types of data which may be woven together to support broad models of agricultural economy, assessments of the economic function of abandoned enclosures will only be able to play a more positive, hypothesis-testing role when, and if, further investigation and new techniques using more rigorous criteria enhance their credibility.

1.2 Assessment of land use in ancient abandoned fields

Many forms of palaeo-economic evidence - artifacts, structures, food refuse and general palaeo-environmental studies - can be used to construct or test overall models of ancient agricultural systems and sometimes they can be linked to particular agricultural practices (e.g. ploughing or crop rotation), but they are rarely if ever capable of indicating the land use history of specific fields. In consequence, this brief review will only consider the evidence for field use that has been obtained through study of the fields themselves. It is convenient to recognise three types of evidence: artifacts of cultivation, boundaries and soil.

1.2.1 Artifacts of cultivation

Artifacts arising from cultivation comprise signs of clearance (cairns), deformation of the land surface (lynchets, ridge and furrow, 'lazy beds') or sub-surface (ard, plough and spade marks) and accidental or deliberate incorporation within the soil of exogenous materials as a result of soil treatments associated with cropping. With the exception of the latter, cultivation artifacts usually provide unambiguous evidence of arable episodes but, unfortunately, arable episodes do not necessarily leave unambiguous traces of this kind. The survival of sub-surface deformation can usually be attributed to propitious events - as occurred at Gwithian in Cornwall, where rapid, deep burial by wind-blown sand preserved spade and plough marks of prehistoric and medieval age (Megaw et al 1961, Fowler and Thomas 1962) - and the creation of surface deformation may only occur as a result of specific agricultural practices - thus ridge and furrow arises from ploughing in 'lands', while sizeable and thus indisputable cultivation lynchets will only be formed when ploughing occurs on slopes and is repeatedly confined to the same boundaries (Bowen 1961, 1978). Nor is it easy to establish the date and significance of events recorded by cultivation artifacts. Although, in some cases, overlying features may provide a terminus ante quem, many of the plough marks and lynchets within field systems can only be dated by far from satisfactory arguments based on the pottery incorporated within lynchets - Overton Down site XI A in Wiltshire (Fowler 1966, 1967, Fowler and Evans 1967) provides an instructive example. Bowen (1961) discussed the many factors affecting lynchet accumulation rates and suggested that there was a need for experimental studies; however, farmers sometimes return soil to the eroding upper parts of their fields (Tapley-Soper 1 6) and the size of lynchets will never provide more than an uncertain and very crude guide to the importance of cultivation episodes in ancient fields.

Although it has long been known that ancient manuring of arable land can leave detectable soil chemical anomalies, chemical analysis of the soils in ancient fields has very rarely been undertaken (see 1.2.3). Instead, archaeologists have relied on diverse forms of evidence for this agricultural practice (see review by Bradley 1978b:41), none of which provide unambiguous support for the proposition that deliberate manuring occurred within the prehistoric fields of Britain. Rhodes (1950) seems to have been responsible for initiating the current dogma which maintains that the pottery found within field systems was scattered there when domestic rubbish was used as manure. However, as Lindquist (1974) pointed out, other, equally plausible explanations - losses during sowing and harvesting, ploughed-over settlements - must be considered. Arguments similar to those of Rhodes were used by Megaw <u>et al</u> (1961, see also Fowler and Thomas 1962, Fowler 1971), who suggested that the buried fields at Gwithian had been manured with domestic rubbish and with seaweed; however, the 'very tiny' mussels, periwinkles and beach pebbles in the fields' soil could be natural components of these dune sand deposits (Gilbertson: in lit. 1980) and thus may have no cultural significance. An analogous explanation for the presence of 'foreign stones' at Ashey Down on the Isle of Wight (Drewett 1972), which was thought to indicate Iron age or Romano-British manuring, is even less credible, since some of these stones were found in contexts unaffected by such ploughing. A more satisfactory but still ambiguous case for early manuring was advanced by Dimbleby and Evans (1974), who thought that 'mucking out' of animal bedding might be responsible for high values of <u>Pteridium</u> spores and microscopic fern fragments in soils buried beneath prehistoric earthworks. Although ingenious, their arguments and evidence do not appear to have eliminated the possibility that the phenomena may have been due to differential decomposition of pollen and spores or might even reflect a local presence of bracken on these soils.

1.2.2 Boundaries

Many authors have sought to reveal the use of ancient fields from a consideration of their boundaries; they have pleaded their architecture and construction, the size and shape of the land they enclose, the overall pattern they present, the presence or absence of routeways and the relevance of gaps, their position, type and size, as witnesses to the intentions of the enclosers. These speculative attributions of function can always be questioned and credibility accrues most readily to cases where different aspects of boundary (and other) evidence tend to point in a single direction - the ditched 'stock' enclosures studied by Pryor (1978, 1980) are a good example.

As Baker and Butlin (1973:31) pointed out, functional interpretation of field structures often suffers from the problems presented by equifinality and indeterminancy; nowhere is this better demonstrated than in the case of speculations based on the size and shape of enclosures. The irregular 'corn plots' of Curwen (1927) became the 'animal pounds' of later writers (e.g. Fox 1954a, Barber 1970, Hamond 1979), and 'fieldways' thought to be associated with the management of arable land (Curwen and Curwen 1923) may not always be distinguishable from 'droveways' which could have been used by livestock farmers (Fleming 1979a, Pryor 1980). Although the size and shape of fields may in some cases be linked to agricultural practices (Nightingale 1953, Eyre 1955), the similarity of the rectilinear field systems established during the second millennium bc in such diverse environments as the Fenland borders (Pryor 1980), the chalk Downs of southern Britain (Curwen 1938b) and the granite hills of the south-western Peninsula (Fleming 1978b) seems more likely to reflect the social and political milieu of these enclosures than their agricultural function.

Even the most immediate purpose of a boundary may be obscure; discussions are frequently prefaced by a platitude concerning the difficulty of 'reconstructing' the nature of the original boundary, a necessity that flows from the subsequent argument. This often takes the form of attributing to the boundary in question features for which there is little or no direct evidence, but whose presence is demanded if the boundary is to be interpreted as having posed an effective barrier to livestock or wild animals. Since palynological evidence suggests that in Europe hedgerows may have as long a history as farming itself (Groenman-van Waateringe 1972, 1978), and since these boundaries may leave few traces (but see Robinson 1978a, 1978b and Rahtz 1962), it is always possible for an imaginative prehistorian to clothe his landscape with any number of effective boundaries. However, diminutive, apparently ineffective boundaries can be interpreted as merely 'markers' of field bounds (Fowler and Evans 1967) or larger parcels of land (Fleming 1978b). In any case, there is no necessary link between the purposes of enclosure and boundary forms; effective boundaries may be required to protect any crop, including the grass in permanent pastures, but controlled grazing could have occurred within fields that lacked such boundaries for livestock can be hobbled, tethered or simply watched and manipulated by herdsman.

None of these strictures alter the fact that a combination of different aspects of boundary evidence can be used to tell plausible and consistent stories (e.g. the Grippers Hill enclosures on Dartmoor described and interpreted by Fox (1955)). When linked to other types of evidence, such as cultivation artifacts, it cannot be doubted that in some instances a function of enclosure can be determined (e.g. cultivation within the lynchetted fields of the chalk Downs). However, one should not lose sight of the possibility that other activities, less well, or not documented by these types of evidence may also have played an important role in these agricultural enclosures (e.g. regular pastoral use during long fallows).

1.2.3 Soil

There is an abundant literature reporting on the changes in soil properties that occur within enclosed agricultural land as a result of contemporary arable and pastoral land use (see 2.3); they include removal, addition and redistribution of nutrients, alteration of soil structure and texture, physical mixing of surface horizons and losses or gains of organic matter. Some changes can be so substantial and persistent that, even after hundreds and, perhaps, thousands of years, they continue to promote patterns of vegetational diversity which can reveal the location of long-abandoned fields (for examples see Thomas 1960, Feachem 1973, Berlin et al 1977); the disturbed soils of old arable land are commonly colonised by gorse and bracken (Tubbs and J 1964, Rymer 1976) and this has often been observed on the granite soils of Dartmoor (Havinden and Wilkinson 1970, Dearing 1977).

There have also been many investigations of soils in archaeological contexts which testify to the effects of human activities on the development and properties of soils. At one end of a spectrum lie the studies of Dimbleby (1952, 1962, 1965, 1975), who attempted to isolate the role of farming clearances as a factor in the development of podzolised soils in upland Britain (for a recent review of this still controversial subject see Ball (1975)), and those of Evans (1971) and Limbrey (1975), who suggested that clearance and cultivation may also have been an important factor in the development of sols lessivé (for critical review see Fisher (n.d. ms accepted for publication)). At the other end of the spectrum lie the innumerable, small-scale investigations of soils during archaeological excavations, whose methods and goals were described, indeed prescribed, by Cornwall (1958).

It is, therefore, somewhat surprising to find that few archaeologists have chosen to examine soil profiles or to analyse physical and chemical properties of soil samples as a means of detecting and assessing ancient land use in long-abandoned fields and that there has been no attempt to use the large amount of information published by experimental agricultural stations as a basis for systematic modelling of the way in which farming activities may have altered the soils in these enclosures. Two soil surveyors, Hughes and Aladjem (1911), appear to have been the first people to notice chemical anomalies in ancient farmland; they attributed enhanced values of total soil phosphorus in the soils surrounding an ancient Egyptian town to long-continued manuring with city refuse. Their analytical methods seem to have been as good or better than those used in most subsequent studies of this kind, which have mainly been confined to Scandanavia (Arrhenius 1931, 1938, 1955, Hatt 1931, Christensen 1935, 1940, Provan 1973, Farbregd 1977, Bakkevig 1980, 1981). Although Curwen (1932) quickly recognised the value of such investigations, research of this type has only rarely been undertaken in Britain (e.g. Dauncey 1952, Craddock 1980 - note also the unpublished studies by Kosse (cited by Denford 1975) and by Bowen (cited by Bradley 1978b)). In North America also, despite many chemical investigations of settlement sites (e.g. Cook and Heizer 1965), similar work on ancient fields and routeways remains uncommon (e.g. Arrhenius 1963, Eidt 1977, Berlin et al 1977). Moreover, the scientific value of many of these studies is lessened or even negated by reliance on analytical procedures of unproven scientific worth (e.g. Craddock 1980) or by the inadequacy of sampling (e.g. Eidt 1977, see White 1978).

Provan's (1973) study of the land surrounding a farm at Bjellandsøynae in south-west Norway, which was thought to have been founded in the Migration period but which may have been occupied as late as the 17th century, is perhaps the most scientifically rigorous attempt to use pedological data as a means of assessing ancient land use that has been undertaken in Europe. Unusual features of this work include explicit assessment of the influence of natural factors that could affect the spatial patterning of soil properties, statistical assessment of numerical results, examination and sampling of several soil horizons and allowance for variation in soil bulk density. Unfortunately, no land boundaries or lynchets were observed and the extent of 'cultivated' land had to be inferred from the location of cairns and from the patterns of various soil properties, which were only partially concordant. Although enrichment of phosphorus due to manuring may have occurred on this site, contemporary sheep populations may be responsible for some of the anomalies since, pace Provan (1973:40), sheep pens are not the only places in a flock's grazing territory that may show nutrient enhancement due to animal transfers (see 2.2.3 and 2.3.1). This criticism spotlights the need for study of contemporary animal redistribution of nutrients as a means of 'predicting' patterns created by both recent and ancient pastoral land use; despite Arrhenius' early demonstration of phosphorus enrihment on routeways (1938) and within 'livestock' enclosures (1955), some prehistorians (e.g. Bradley 1978b:41) continue to assume that phosphorus enrichment must reflect the practice of manuring.

In addition to chemical studies, Provan (1973) mapped soil profile morphology and concluded that cultivation had created 'islands' of what he classified as 'Brown podzolic soils' among the natural 'sea' of 'Iron-humus podzols'; this seems to be an instance of a process involving homogenisation of surface horizons and destruction of eluvial zones and iron-pans, which has been most thoroughly studied in Ireland by Conry (1970, 1972a, 1972b) and his associates (Conry et al 1972). In these studies, land reclaimed from the 'waste' during relatively recent historic times and still under more or less intensive agricultural use was examined and compared with unaffected soils buried beneath boundaries. The soil's morphological features alone provided more information about the process of reclamation than could be gained from scanning historical records; cultivation had destr yed organic surface accumulations and intermixed them with underlying eluvial mineral soil. In some cases, Iron-pan stagnopodzols had been transformed into soils barely distinguishable from Typical brown podzolic soils.

Decreasing organic matter content (strongly correlated with soil colour) was found to be linked to the intensity of reclamation and duration of subsequent cultivation. Continuing addition of fertilizing materials including lime and manures had changed soil reaction and base saturation.

In Britain, similar changes have been observed in Wales (Crampton 1965a), in the New Forest (Tubbs and [illegible] 1964), on Dartmoor (Dearing 1977) and in Scotland (Mitchell and Jarvis 1958), where, as in east Lancashire (Crompton 1952, 1953), the reversion of arable and grassland soils after farm abandonment was also observed; in old grassland, 'mull' A horizons produced by reclamation and lengthy pastoral use had subsequently redeveloped a significant accumulation of 'mor' humus (a similar thin peat was present on the 'Brown podzolic soils' at Provan's site). In some old plough lands, a thin very shallow iron-pan had developed since the land had been abandoned. Proudfoot (1958) also found iron-pans in land abandoned for about a hundred years but these ran along the base of the plough layer; he inferred that a similar process might have followed Neolithic land abandonment. Nevertheless, the persistence of signs of reclamation may be considerable; at Provan's site, the land had certainly been abandoned for three hundred years and much earlier abandonment is possible. Clearly field examination of soils which may have been subjected to intensive forms of land use within the last thousand years could prove a valuable tool to those assessing the functions of ancient enclosures but, so far, archaeologists have made little systematic use of this type of evidence.

Instead, the archaeological literature abounds with 'interpretations' of field characteristics of soils that are thought in some way to be anomalous or uncharacteristic. As examples one may include Limbrey's (1975:331-332) assertion that fine mottling in an Orkney soil might have arisen through intense micro-organism activity centered on particles of raw humus provided by ancient manures, Fox's (1954b:34) belief that the eluvial character of the sub-peat mineral soil on the site of Kes Tor on Dartmoor was a product of ancient cultivation, and sundry analogous remarks by Megaw *et al* (1961:210 - a dark, 'earthy' soil created by manuring) and Mercer (1970:35 - a dark brown, organic but gritty soil that was 'in no way naturally deposited' and was 'taken to represent a layer of previous cultivation' (*sic*)). Such *ad hoc* responses to field observations are unsatisfactory as scientific hypotheses since in most instances it would be difficult, and in some cases impossible, to refute the conjectures; moreover, in the instances cited, and in many other cases, such views have been put forward unaccompanied by the sort of intensive investigation which, by eliminating more prosaic explanations, would provide a justification for the idiosyncratic explanation that is proffered.

1.2.4 Conclusions

Present assessments of the past use of abandoned enclosures usually consist of a synthesis of many different forms of evidence and lines of argument, each of which have their own interpretative value, problems and limitations. At the moment, cultivation artifacts provide the most reliable information about field use, but their absence may be of little significance, they can be difficult to date, and they cannot reliably inform one as to the importance of cultivation vis-a-vis pastoral activities during the life of an enclosure.

When obvious artifacts of cultivation are absent, people have tended to resort to boundary evidence, but in many cases the latter, partly due to the vagaries of survival, can be employed to sustain almost any argument. This is an area of research which could benefit from experimental studies designed to establish the interpretative guidelines within which it would be most appropriate and fruitful for the prehistorian's imagination to roam.

Sometimes neither boundaries nor unambiguous artifacts of cultivation are visible and in several cases this circumstance has prompted investigations of soils. There are, of course, other instances where the latter has been studied in its own right, but in either circumstance methodological problems often cast doubt on the value of these studies, which have rarely been accompanied by adequate comparative investigations.

If agricultural practices like manure spreading, the folding of livestock onto arable land, infield-outfield arrangements, long grass fallows, regular convertible husbandry or the enclosure of permanent grazing land, were features of the farming strategies of communities, whose activities are either undocumented or inadequately recorded in written sources, then palaeo-economic models of these societies should be able to take account of such practices. However, such inclusion is rarely justified by present knowledge; there is clearly a need for much better supporting evidence of these important agricultural innovations than has yet been advanced.

Despite the frequently poor quality of previous archaeological investigations of soil within abandoned enclosures, there are indications that soil characteristics may be able to provide such supporting evidence, and may be particularly important in identifying pastoral land use. In this context, twenty years ago, Heizer remarked that 'we might be very much surprised by how much we could learn. . . I think the vista is unlimited' (1960:292). Curiously, such studies are still rare, systematic ones even scarcer. These circumstances, in particular, led to the pedological orientation of the research reported in this thesis.

Previous studies of the soils within abandoned fields, few as they are, provide only a little guidance, but they do point to the value of survey of the morphological characteristics of soils as a way of tracing more recent agricultural disturbances, and it is also evident that more exacting investigations involving quantitative chemical analysis will be needed to increase scientific knowledge of the imprint of farming activities in the more remote periods. Such studies need to be accompanied by explicit modelling of the products of the interaction between soil and agricultural land use, by a framework of research that accepts the need to monitor the processes and products of 'normal' pedogenesis as a prerequisite to the isolation of 'deflected' pedogenesis and by rigorous sampling and analytical procedures; as Proudfoot (1976:111) asserted in the wider context of soil phosphorus studies within archaeology as a whole, 'Research needs to be conducted much more systematically than has often been the case in the past'.

2. PEDOLOGICAL CONTEXT

'The vast activities of man as a soil modifier have not been as yet fully incorporated into the body of pedological investigations or into its general conceptual framework' (Yaalon and Yaron 1966:272).

2.1 Introduction

In the scientific study of soils there is a major divide between research whose primary orientation is toward agriculture - the realm of the agrobiologist, the agrologist and the agronomist - and research whose foremost intention is investigation of the factors and processes that create soils - the realm of the pedologist. Although there are valuable syntheses of the research in each of these fields (e.g. Russell 1973, Birkeland 1974), little effort has been made to integrate the work in models that could be used to predict the soil's '. . . response to various management and agrotechnical measures' and investigations of the human factor in soil formation '. . . only occasionally . . . serve as an object of pedological study' (Yaalon and Yaron 1966:276, 272, see also Bidwell and Hole 1965, Commonwealth Agricultural Bureau S 770, 1965).

Yaalon and Yaron (1966) argued that it was desirable to place the genesis of man-modified soils within a system quite separate and distinct from the natural systems of pedogenesis, but they suggested that this metapedogenetic system could be functionally analysed in a scheme formally analogous to Jenny's (1941, 1958, 1961a) fundamental equations of pedogenesis. Metapedogenetic process factors ($m_1, m_2, . . m_n$) representing such activities as cropping, cultivation, fertilisation, etc. could replace the natural factors (cl, o, r, p, t) in such equations. However, man's activities may not always eclipse the natural factors and it can be argued that in many cases an adequate factorial explanation requires their inclusion. Thus for a man-modified soil S produced by cultivation and fertilisation of a natural soil s, one could write $S = f(cl, o, r, s, t, m_1, m_2, . . m_n)$ though, as many authors have suggested (see Crocker 1952), it is more appropriate to remove the referant t, and, as McLaren proposed (cited in Crocker 1952), place it in a separate equation. This approach is used in Fig 2.1 to illustrate the complexities of the genetic pathways of soils created in land subjected to intermittent agricultural activity. Despite Yaalon's (1975) optimism and the undoubted value, both philosophical and practical of this factorial approach to explanation of soil development, it seems unlikely that such equations can be 'solved' but they do illustrate well the relationships between soils on different trajectories and their complexity draws attention to the need to hold 'constant' as many factors as possible in any study of pedogenesis and metapedogenesis.

As will be shown later (see 3.2.1), the chosen, moorland study area which lies on a gently-domed plateau consisting of a single pedomorphic surface with a uniform soil parent material, comes close to satisfying the requirements of this Baconian approach so far as natural soil-forming factors are concerned. Moreover, the regularity of the layout of ancient land boundaries on this plateau suggests that neither in medieval nor prehistoric times were boundaries sited to respond to pre-existing inequalities in soil properties; thus the application of the totality of metapedogenetic factors can be regarded, like the natural factors, as 'independent', though clearly there is likely to be wholesale interaction between individual metapedogenetic factors.

One can also envisage interaction between metapedogenetic and pedogenetic factors both during and after agricultural episodes; indeed one of the most challenging tasks facing those who wish to isolate the products of metapedogenesis in ancient fields lies in the assessment of the way in which subsequent pedogenesis has altered the soils left by farmers. This problem can be tackled using two, double-pronged approaches. First, one can examine what is already known about pedogenetic and matapedogenetic processes in soils, a task attempted in the succeeding sections of this chapter; secondly, field investigations can include not only the soils in the enclosures that form the principal subject of this enquiry but also 'virgin' and buried soils, which provide direct evidence of the course of pedogenesis, and soils known to have been affected by recent and ancient metapedogenetic factors. These studies are of particular importance since there have, in fact, been very few enquiries into the way in which metapedogenetic factors affect soils of the type found in the study area.

One cannot, of course, study the soil in its entirety and both the reviews of previous work and the investigations in the field and laboratory must involve selection. Attention has, in fact, been paid to morphological soil characteristics that can be assessed during field examination, to quantitative evaluation of soil phosphorus fractions and soil organic matter, and to measurements of basic physical parameters of the soil (soil bulk density, stone content); the rationale behind the selection of these parameters needs only brief consideration here. The desirability of examining field profile morphology has been discussed earlier (see 1.2.3) and the need for basic physical evaluation will be discussed later (see 3.3.2); the special utility of soil phosphorus (as opposed to the study of other elements) in archaeological studies has been adequately explained elsewhere on several occasions (e.g. Cook and Heizer 1965: chapter 2, Proudfoot 1976) and needs no further consideration. The inclusion of soil organic matter as a property worthy of study, despite the ease with which it returns to steady-state after agricultural intervention (see 2.3.3.2), reflects the need to take account of variations in soil bulk density due to variation in organic matter accumulation and, of equal importance, the fact that in moorland soils a very high proportion of soil phosphorus may be found in the soil organic fraction. In these soils, there is also the possibility that soil organic matter levels disturbed by historical land use episodes may not yet have returned to steady-state levels (see 2.3.3.2). Many other soil properties are altered by agricultural activities but there is little evidence that, for example, the soil damage (poaching) caused by grazing animals lasts for more than a few years (Gradwell 1966, 1968) or that agricultural operations leave a substantial imprint in the form of altered levels of micro-nutrients and other trace elements (Ure et al 1979, see also Prabhakaran Nair and Cottenie 1970). Macronutrients such as Ca, Mg and K certainly can be substantially altered but in humid regions these more easily-soluble soil elements suffer heavy leaching losses in the course of soil development (Simonson 1970) and it is unlikely that metapedogenetically-induced anomalies among these elements will prove traceable in any but the most recently abandoned fields.

The rest of this chapter, then, is devoted to review of relevant pedological and agricultural studies and is presented in three parts. Section 2.2 considers the natural system, which can be thought to provide 'noise' that must be filtered out, if metapedogenetic 'signals' are to be heard; section 2.3 evaluates the nature and pattern of such signals in modern agro-ecosystems. In the concluding section, 2.4, an attempt is made to link these two areas of knowledge and so provide the models, which should both guide the sampling and analytical strategy and should be confirmed or refuted by the analyses of such samples.

2.2 Pedology of moorlands

This section is presented in five parts. The first three parts offer very brief reviews of the principal characteristics of moorland soils and of what is known about the phosphorus and organic matter in these soils; most of this type of information has been summarised in elementary or in some cases more advanced soil science texts. Subsequently, more detailed consideration is given to the way in which modern land use of moorlands affects the soil; an area of knowledge that does not appear to have been adequately reviewed elsewhere. Unlike the previous sections, it considers what are essentially metapedogenetic factors and has been included in this section rather than the following section because, like natural variation in soil properties and analytical error, the influence of modern land use is regarded here mainly as 'noise' which must be identified and filtered out. Such a division is possible since the influence on soil properties of present-day extensive land use is mainly very different from that of more intensive agricultural interventions. The section concludes with a short summary of the main findings of the review.

2.2.1 Factors and processes affecting moorland soils

Moorland soils and the factors and processes that may have contributed to their genesis have been the subject of considerable pedological research, at least in part, because in many regions only these upland areas provide examples of soils whose characteristics are thought to be largely the product of natural processes. Since a succinct and up-to-date account of the nature and distribution in time and space of the principal soil-forming processes (podzolisation, gleying, peat formation) that dominate moorland pedogenesis has recently appeared in the archaeological literature (Ball 1975), this section offers only the briefest of summaries of matters particularly relevant to discussion in succeeding chapters.

The genesis of many moorland soil features can be firmly linked to climatic conditions - high rainfall, low temperatures and low rates of evaporation - which provide a potential for strong leaching, weak weathering and gleying. Parent materials of hard, acid rocks, which often give rise to coarse-textured soils, are common in Britain's uplands and are a further factor contributing to high rates of leaching.

They also impose a relatively low ceiling to the supply of plant nutrients available to the soil-organism ecosystems that could evolve in these areas and promote soil acidity, itself a factor in the production of 'mor' humus. In turn, low levels of plant nutrition and the formation of 'mor' humus contribute to the effectiveness of the podzolisation process, the former by increasing polyphenol values, the latter by increasing the proportion of polyphenols that survive the passage into the soil environment (Coulson et al 1960a, 1960b, Davies et al 1964a, 1964b, Davies 1970). The same factors offer much in the way of an explanation for the accumulation of a discrete, acid surface layer of stable and long-lived organic matter. Vegetation with a low base but high polyphenol content produces an acid litter in which decomposition is impeded both by low bacteria and earth-worm activity and by the alteration of proteins and cellulose to forms that are more resistant to breakdown.

Once established, the surface layer of organic matter causes waterlogging and anaerobic conditions, which promote iron mobilisation through microbial reduction of ferric oxide, and this process may play a major part in the formation of thin iron-pans (Crompton 1952, 1956, Crampton 1963, 1965a, Damman 1965). Surface waterlogging may also contribute to subsoil gleying, but the latter may sometimes be linked to the presence at the base of many moorland soils of an indurated layer which may be of periglacial origin (Fitzpatrick 1956, see also Stewart 1961, Romans 1962, Crampton 1965b). Eventually, the low infiltration characteristics of a thick mat of organic matter may divert a high proportion of rainfall input, decreasing vertical transfer and increasing overland flow (Trudgill 1977: 70). In concert with relatively low rates of chemical weathering in cold upland soils, this mechanism may be responsible for the rarity of strongly bleached eluvial horizons in moorland soils, though in part at least their leached character lies concealed beneath a veil of humus staining.

Varying spatial incidence of these processes, substantially controlled by topography through its influence on drainage, produces a wide variety of soil types in catenary sequences (e.g. Crampton 1965a: Fig 2). Gleyed soils surmounted by deep peat are usually found in depressions and on higher flat plateaux; freely-drained brown podzolic soils, lacking significant 'mor' accumulation and in which iron, aluminium and organic matter may have been little mobilised, typically occupy the more steeply sloping land. Between these extremes lie the podzolised soils with thinner peat surfaces - the stagnopodzols - which may be more or less gleyed, or be freely-drained in their surface layers and/or their subsoils. They may have thin iron-pans or more patchy but discrete pockets of sesquioxide accumulation and/or diffuse zones of illuvial deposition of iron, aluminium and organic matter. As will be described in chapter 4, this type of soil dominates the study area.

The genesis of these moorland podzols may have been influenced by early clearance of upland woodlands (Dimbleby 1962) but such activities may simply have accelerated pedogenetic trends that were already developing (Ball 1975). Although individual podzol features (iron-pans, E horizons, 'mor' layers) can emerge very rapidly when suitable soils are subjected to a change in land use and/or vegetation (Crompton 1952, Dimbleby 1962), Jenny's (1941) widely-quoted review of Tamm's studies of Swedish podzols suggests that typical podzols may take between 1500 and 3000 years to develop, while later American research by Franzmeier and Whiteside (1963a, 1963b, and Franzmeier et al 1963) suggests a more extended period of up to 8000 years may sometimes be necessary. However, there have been substantial changes in climate during post-glacial times (see 3.2.1), and it should not necessarily be assumed that present soil characteristics represent the product of a single, simple and 'inevitable' trajectory of soil development; research in Scotland (Romans and Robertson 1975) and in Wales (Crampton 1962, 1963, 1965a, 1966, 1967) indicates considerable variety in the timing and spatial patterning of soil development in moorlands and some of this variety was thought to be linked to spatial variation in climatic variables and to climatic change.

2.2.2 Phosphorus in moorlands

This section provides a brief review of knowledge about phosphorus in moorland soil-organism ecosystems as an essential background against which one may compare the observations from the study area on Holne Moor. Unfortunately, there have been no previous pedological studies of soil phosphorus on Dartmoor or the other granite plateaux of south-west Britain. The review falls into two parts; in the first section, emphasis is placed upon the relationship between soil and non-soil components of the ecosystem; in the second part, the forms and patterns of phosphorus in moorland-type soils are described and their alteration and transformation during the course of pedogenesis is discussed.

2.2.2.1 Phosphorus in the soil-organism ecosystem

There is no single study or group of studies that describe and explain phosphorus content and transfers among all the components of any one moorland stagnopodzol-based ecosystem, but several studies whose major concern lies in the operations of the non-soil component do provide nutrient budgets for ecosystems of broadly similar character (e.g. Heal and Perkins 1976, 1978, see also Crisp 1966, Gore 1968, Chapman 1967, 1970, 1979, Chapman et al 1975a, 1975b, Robertson and Davies 1965). Such budgets typically reveal that the amount of nutrients held in the living floral (and, where it has been studied, the faunal) element in the system forms a small proportion of the amount stored in the soil components. Nor does consideration of dead organic material (litter) significantly alter this picture. In five of the six systems studied by Robertson and Davies (stagnopodzols and podzols on Scottish heather moors sampled to 15-17.5 cm), more than 96% of the phosphorus in the system lay below the litter layer. Nor do these budgets reveal any simple relationship between the total phosphorus content of the soil component and the amount circulating in the superimposed system; there is in fact a remarkable similarity in the general magnitude of the amount of phosphorus held in the non-soil components (ca. 5-15 kg P ha^{-1}), particularly the dead biomass (typically less than 5 kg P ha^{-1}), within a wide range of ecosystems developed on a number of different parent materials. It is therefore possible to make a valid estimate of the phosphorus content of a moorland ecosystem by analysing samples drawn from the soil component alone. One may also conclude that the notorious deficiency of phosphorus in moorlands (Gimingham 1972) and upland grasslands (Newbould 1974, 1975) stems from the low availability of the forms taken by this element in moorland soils rather than an absolute deficiency. Evidence of similar deficiencies in coniferous and deciduous woodlands (Harrison 1978, 1979) and agricultural grasslands (Hanley 1937, McDonnell and Walsh 1957) tends to support the generalisation that in minimally-managed and natural ecosystems phosphorus availability may often be a major factor controlling production (see also Walker and Adams 1958, Perkins 1978, Katznelson 1977). If so, one might expect substantial covariation of phosphorus and organic matter properties in the soils of such systems.

Another aspect revealed by these studies concerns the boundaries of the sampled systems and the depth to which present biological elements in the system are active. Many analysts restricted attention to the upper

20 cm of the soil but Chapman (1970) showed that on the Dorset heathlands, 8% of the rooting systems lay below this depth; during the long periods of time considered in studies of ancient fields, even this small proportion of the roots could transform to organic forms and/or extract and redistribute very substantial amounts of phosphorus and in so doing substantially alter the vertical distribution of phosphorus established during periods when the system was dominated by metapedogenetic processes. Chapman (1970) also pointed out that failure to remove all living or recently dead organisms from soil samples meant that most studies did not achieve a rigorous separation of soil and other components of the ecosystem; however, although desirable, such separation raises both practical and theoretical problems; in common with the vast bulk of previously reported studies, no systematic attempt was made to remove such material from the samples analysed in this study (see 3.3.2) though rooting patterns and depths were monitored (together with evidence of other disturbances, e.g. animal burrows) in order to assess the depth of soil affected by the biological components in the system.

The biological components in the system also cause lateral redistribution of nutrients. The magnitude of such transfers can be judged from the budgets presented by Rawes and Heal (1978) and Perkins (1978); although the contribution of birds, invertebrates, small herbivores and carnivores has only rarely been investigated, it is apparent that in the heterogeneous landscape of the Moor House National Nature Reserve, these organisms' capacity to transfer nutrients may match in size the redistribution of nutrients by larger fauna such as sheep and cattle (the size of transfers by these grazing animals is considered in sections 2.2.4 and 2.3.1.1).

Finally, one must consider here the input of phosphorus to moorland ecosystems in precipitation (the contribution of dust has rarely been separately assessed). Estimates of phosphorus input are provided by or can be calculated from data in Gore (1968), Allen et al (1968), Chapman (1967, 1975a), Williams (1976) and Hood (1977), though some of the figures in these sources may have been affected by contamination from, for example, bird droppings. Moreover, current rainfall input may be greater than it has been in the past, since pollution from industrial and agricultural sources has substantially increased the levels of airborne nutrients during the last century (Williams 1976: 196-197). Additional data and critical comment appeared in Ryden et al (1973:20-21) and Cooke (1976:12-13). The latter author regarded the 'rural' value given by McCarty et al (cited in Cooke 1976) as reliable

(0.0003 mg P l^{-1}), though this is an order of magnitude lower than an estimate by White (cited by Ryden et al 1973); the only British studies with values close to these estimates are those by Chapman (0.001 mg P l^{-1}) and Hood (less than 0.004 mg P l^{-1}). If the present average annual precipitation in the Holne Moor study area (1773 mm - see 3.2.1) is taken to approximate the likely rainfall over the past three millennia, one can estimate the order of magnitude of phosphorus input since the floruit of prehistoric activity in the second millennium bc (see 3.2.2). Applying Chapman's value one obtains a figure of ca. 53 kg P ha^{-1} (0.018 kg ha^{-1} $year^{-1}$) and this is bracketed by estimates based on the figures of White (160 kg P ha^{-1}) and McCarty (16 kg P ha^{-1}), which represent, respectively, ca. 8% and 0.8% of the phosphorus present in the study area soils (to a depth of 40 cm below the mineral soil surface - see chapter 5). The figures accepted here are an order of magnitude lower than most modern estimates but seem likely to give a better approximation of the long-term input; a consequence of accepting these figures is that the leaching rates that need to be postulated to explain long-term declines in the phosphorus content of soils that have been inferred from chronosequence studies (e.g. Walker and Syers 1976) are much lower than would otherwise be the case. This output from the system is considered in the next section.

2.2.2.2 Soil phosphorus

Although, as a major element in plant nutrition, soil phosphorus has been extensively studied by agrologists, there remain many intractable problems; it has not yet proved possible to identify all the forms of phosphorus present even in well-studied agricultural soils and there is at present no definitive method for determining the proportion of soil phosphorus in inorganic and organic combination. Moreover, aside from the information provided in a very valuable series of chronosequence studies in New Zealand (Walker 1965, Walker and Syers 1976), there have been relatively few studies of the phosphorus in virgin soils and even fewer deal with moorland soils of stagnopodzol type.

Proudfoot (1976) has provided an up-to-date summary of nowledge about the forms of phosphorus known or thought to be present in soils and in particular has drawn attention to and described the system of phosphorus fractionation used both during the initial series of the aforementioned chronosequence studies and by Floate (1962), whose research provides the best available information about moorland soil phosphorus in Britain. With minor modifications this system of fractionation was adopted for the work on Holne Moor and the conventional notation associated with it, which was described and tabulated by Proudfoot (1976), will be used in the following discussion and in chapter 5 (the rationale behind the selection of this procedure and discussion of the phosphorus fractions isolated in these studies appears in section 3.3.2; a precise description of analytical methods appears in Appendix 3).

Since atmospheric input of phosphorus is very low and since in most soil environments this element is relatively immobile, the total amounts in soils (Pt) tend to reflect closely the amounts present in their parent materials (Simonson 1970), but this relationship will be most clearly observed among younger soils, since over long periods of time losses of phosphorus caused by leaching can be substantial (Walkers and Syers 1976). A chrono-toposequence study by Adams _et al_ (1975, see also Adams and Walker 1975) confirms this trend among soils developed on _in situ_ granite and valley-side 'drift' of weathered granite - the type of parent material found on Dartmoor - though in Adam's study the time during which it was estimated that 80% of the initial phosphorus had been lost was not determined. There do not appear to have been any studies of leaching rates and/or nett long-term losses of phosphorus from moorland stagnopodzols; the nearest analogues for which such information is available appear to be the Franz Josef series of 'gleyed podzols' in New Zealand (Walker and Syers 1976, see also Stevens and Walker 1970:345), though higher precipitation on these soils (5090 mm year^{-1}) might be expected to have produced greater loss rates than are likely in the Holne Moor study area.

Nett losses from the Franz Josef sequence are shown in Table 2.1; the decline in the loss rate over time tends to confirm the observations of Franzmeier and Whiteside (1963a, 1963b, Franzmeier _et al_ 1963), who found that an illuvial phosphorus horizon emerged early in the genesis of podzols and long preceded the appearance of sesquioxide accumulations. The nett loss rate of 0.03 kg P ha^{-1}year^{-1} during the interval 5000-12000 years (after commencement of soil formation) probably overestimates the rate one should expect in the study area during the past three thousand years and as a first approximation a rate of 0.02 kg P ha^{-1}year^{-1} may be more appropriate. This rate of nett loss can be set against the estimates of rainfall input discussed in section 2.2.2.1 to produce estimates of leaching rates as shown in Table 2.2. These rates are similar to the leaching estimates recorded for arable and herbage plots at the Saxmundham Experimental Station (Williams 1976: Table 12) but lower than

Table 2.1 Nett phosphorus losses from the soils in the Franz Josef chronosequence in New Zealand[≠]

Overall nett loss rates after different periods of soil development

Period (years)	Nett loss rate ($kgPha^{-1}year^{-1}$)
0 - 1,000	0.54
0 - 5,000	0.17
0 - 12,000	0.09
0 - 22,000	0.06

Nett loss rates during specific stages of soil development

Stage (years)	Nett loss rate ($kgPha^{-1}year^{-1}$)
0 - 1,000	0.54
1,000 - 5,000	0.08
5,000 - 12,000	0.03
12,000 - 22,000	0.02

[≠]calculated from data in Walker and Syers (1976: Table 2)

Table 2.2 Estimates of phosphorus leaching rates in the study area during the last three millennia based on an assumed nett loss rate of 0.02 $kgPha^{-1}year^{-1}$.

Estimated concentration of phosphorus in precipitation[(a)] ($mgP\ L^{-1}$)	Estimated leaching rate ($kg\ P\ ha^{-1}year^{-1}$)
0.0003	0.025
0.001	0.038
0.003	0.073

(a) see text, section 2.2.2.1

many of the estimates of rates in intensively-managed land discussed by Cooke and Williams (1970, 1973) and Cooke (1976) which typically lie between 0.15 and 0.30 kg P $ha^{-1} year^{-1}$; the estimates in Table 2.2 imply leaching losses of 76-220 kg P ha^{-1} over the past 3000 years.

The decline in phosphorus during pedogenesis is accompanied by changes in the forms of phosphorus. Phosphorus is mainly present in unweathered parent materials in the form of apatite, but, in soils developed in acidic parent materials affected by high rainf ll, organic forms (Po) tend to dominate after the initial stages of soil development (Walker 1965, Walker and Syers 1976) and apatite, if it survives at all, is likely to be confined to the coarser soil fractions (see Williams and Saunders 1956a, Kaila 1963, Floate 1965) in the B horizons, where its persistence may be due to relatively weak weathering even in strongly acid podzols. Inorganic secondary forms of phosphorus associated with iron and aluminium in the clay fraction will usually account for the balance of phosphorus in moderately-weathered acidic soils of the type encountered in the study area.

Although there has been more recent research into the transformations of soil phosphorus during the course of pedogenesis (e.g. Walker and Syers 1976), the models of such changes presented by Floate (1962) are consistent with the later work and, since they utilise the phosphorus fractionation scheme adopted for the present work, provide a more appropriate framework for this discussion. Floate (1962:196-200) developed a model for the changes in phosphorus fractions that could be expected to occur in soils developed in previously weathered parent materials (soils of 'secondary weathering') and this is illustrated in Fig. 2.2, which reproduces his Fig. 8.4 (prior weathering of the soil parent material in the study area is discussed in 3.2.1). At time zero only inorganic phosphorus is present, either as Pf (mainly occluded Fe-P and Al-P) or Pa (apatite plus non-occluded Fe-P and Al-P). Floate thought that in the initial stages a relatively high level of easily-soluble Pa would support a vigorous, nutrient-demanding plant community that would withdraw phosphorus from the soil solution at rates which could only be met by dissolution of Pa <u>and</u> Pf. This release, and the accumulation of Po would be greatest in the more intensely weathered surface layers. From the results of later fractionation studies, one can postulate that within the Pa fraction there will be an e pansion of non-occluded forms at the expense of apatite. In later stages, decreasing availability of bases through continued leaching and diminishing supplies of the more easily-soluble forms of phosphorus lead to the dominance of less nutrient-demanding communities and consequentially a weakening of the organic cycle. At this point, dissolution of Pf ceases and this fraction takes instead the role of a phosphorus sink. Floate argued that at this point the relatively low demand for phosphorus would be satisfied by very slow mineralisation of Po, which by then would be the dominant fraction. This model is analogous to that presented by Larsen (1967) in which phosphorus demand is seen to cause shifts between labile and non-labile phosphorus forms.

The relationship between Floate's observations and this model is not without some ambiguities as he himself recognised. On the one hand he interpreted high Pf values in the subsoils of certain profiles as evidence of their status as soils of secondary weathering (Floate 1962: 173-175, 184-185), but later (1962: 198-200) suggested that some of this fraction was the product of the current cycle of soil formation; fractionation of the parent material of one profile supported his contention of a dual origin for Pf, but the genesis of Pf in other profiles was not clearly established. One can also argue that the nett profile changes shown in Fig. 2.2 may be accomplished by changes of different sign in upper and lower parts of the soil profile; to a certain extent, the changes along the horizontal axis, which are depicted as the result of increased weathering and leaching (and may be regarded as a time axis), parallel the differences between surface and subsoil horizons. One can envisage simultaneous dissolution of Pf in strongly-weathered eluvial horizons and accumulation of this fraction (and/or Pa and Po) in the subsoils.

The vertical distribution of phosphorus in podzols was discussed by Cook and Heizer (1965:14-16) and Proudfoot (1976) and examples from soils similar to those of the study area have been provided by Shipley and Romans (1961/63), Romans and Durno (1970/71), Floate (1962, 1965) and Rennie (1956). Although there is a pattern of eluvial minima and illuvial maxima in all cases (and in many other types of soil - see Smeck and Runge 1971, Smeck 1973), there is, as Proudfoot (1976:104) pointed out, considerable variety in the pattern of accumulation of different phosphorus fractions. Plant root extraction tends to create a surface accumulation of phosphorus, which in moorland soils is dominated by Po, and at the same time assists leaching processes to reduce the amount of easily-soluble Pa in the subjacent eluvial horizon. Inorganic and organic illuvial horizons do not always coincide (e.g. Floate 1962: Fig. 5.5) and usually the Po accumulation seems to occur at a higher level in the profile than Pa and Pf accumulations, either of which may be present (see Floate 1962, 1965). In stagnopodzols, C:Po ratios (like C:N ratios) are very wide (Floate 1962:110-118, Table 5.7) and share the pattern, found in many other soils (Barrow 1961), of a narrowing of the ratio with increasing depth in the profile; this may reflect differences in the rate of mineralisation of the constituents of organic matter during degradation, but knowledge of the factors affecting C:Po ratios is far from perfect (Barrow 1961, Dalal 1977). One thing is quite clear; there is a very wide variety in the degree and pattern of vertical differentiation imposed by phosphorus redistribution and this variance precludes the identification of any specific 'natural' pattern of vertical distribution.

Lateral redistribution of phosphorus and, indeed, lateral variation in phosphorus has rarely been studied and there is no direct evidence that re-distributive movement of the type observed by Smeck and Runge (1971), which they attributed to overland flow after snowmelt, occurs in moorland stagnopodzols. However, in somewhat drier brown earths and podzols in Sweden, Mattson et al (1950a, 1950b, 1950c), who examined the vertical distribution of phosphorus along 5 m slope transects in which the hydrological status of the profiles varied substantially, found distributions of concentration values consistent with an hypothesis of downslope movement of phosphorus though differences in profile weights of phosphorus were not determined. Where substantial hydrological variation is present, any attempt to explain vertical and lateral patterns of phosphorus must clearly take into account the possibility of surface and subsoil lateral translocation.

2.2.3 Organic matter in moorland soils

To a large extent, estimation of the organic matter content of soils in the study area, although essential, was undertaken as a subservient part of the pedological studies. This relegation to a secondary role affected the choice of methods of measurement; during soil mapping, reliance was placed upon field estimations controlled by laboratory estimates of loss-on-ignition (LOI) and the latter technique provided all the quantitative determinations that have been used in conjunction with quantitative analyses of soil phosphorus. Although in soils like that of the study area, where carbonates are absent and clays only present in relatively small amounts (see 3.3.2), there would seem to be little reason to prefer estimations of organic matter content based on carbon estimates (whose own limitations have recently been reviewed by Metson et al (1979)) over those produced by the older, simpler and rapid LOI technique, this method permits only relatively coarse statements to be made about org nic matter content and dynamics of soils in the study area. In these circumstances, no useful purpose would be served by a detailed review of investigations of organic matter in moorland soils and this section is included only in order that certain assumptions, which inform the work reported in later chapters, be made explicit.

The special circumstances of organic matter decomposition and accumulation in moorland soils, which typically result in the accumulation of a thin layer of 'mor' humus or peat overlying the mineral soil have already been noted (see 2.2.1); this process has important consequences. Unlike mineral soils in which the level of organic matt r normally reaches a steady-state balance of production and deco position after a few hundred years (see Birkeland 1974:163 and section 2.3.3.2), organic surface accumulations on moorlands may, even after thou nds of years of soil development, still be increasing. Maltby and Cr btree (1976), who investigated organic matter accumulation on Exmoor, an area of moorland in many ways similar to that of the study area and lying only some 70 km north of Holne Moor, showed that there had been nett accumulation of organic matter on both blanket bog and 'peaty gley' s ils within the past 150 years. Furthermore, they argued that the rate of accumulation since AD 1833 (56-100 g m^{-2} $year^{-1}$) had been ten times higher than the rate for the period 600 BC to AD 1833 (6-17 g m^{-2} $year^{-1}$). They also found that the organic-rich surface horizon of a mineral soil had reached or closely approached steady state within less than 150 year. .

One must note, however, that the earlier, slower rate of accumulation could include periods of standstill and even erosional episodes and may not provide a realistic indication of annual increments. Stratigraphic variation in peat quality in their study and in other studies (e.g. the soils described by Taylor and Smith 1972) shows that surface accumulations on moorland soils have not necessarily arisen by continuous, steady growth. Taylor and Smith (1972) distinguished an early phase of 'mor' accumulation under Ericaceous vegetation and a later phase of regenerative peat formation associated with Molinia caerulea and Nardus stricta; they thought the changes might have been due to a late onset of gleying, itself a result of changes in mineral soil porosity due to podzol weathering processes. On the other hand, Maltby and Crabtree (1976) attributed the change in accumulation rat s on Exmoor to cultural factors; they argued that higher grazing pre ure and more frequent moor burning prior to the 19th century must be considered as contributory factors, but admitted their inability to evaluate such factors (this hypothesis is considered further in the next section).

The second aspect worth stressing here is the considerable stability of organic compounds in soils. It has long been known that B horizon humus included much less easily decomposed fractions (Walsman 1936), but more recent study of residual C^{14} activity (Perrin et al 1964, Tamm and Holmen 1967, Jenkinson and Rayner 1977, O'Brien and Stout 1978) demonstrates that some of the organically-combined carbon may persist in soils for many thousands of years. O'Brien and Stout (1978) found that whereas a modern carbon fraction declined systematically with depth, an older carbon fraction was more uniformly distributed in the profile and thus contributed a much higher proportion to the total carbon in the subsoil. Clearly one should not assume that variation in the amount and distribution of organic compounds (including organically-complexed phosphorus) necessarily relates solely to current and recent carbon cycling. Earlier patterns of production, modified by decay and translocation, may still exert an important influence on the soil organic matter; this may be particularly important in the mineral soils of stagnopodzols which to some extent become sealed-off from current cycling processes after the accumulation of a surface peat layer. There does not appear to have been any significant research into the changes in organic matter dynamics that must accompany the transition from a podzolic mineral soil into a stagnopodzol, but it is worth noting that Maltby and Crabtree (1976) argued, on the basis of pollen correlations, that on Exmoor this change occurred at about 600 BC, and that this shift from steady-state to accumulation has been attributed by Merryfield and Moore (1974, see also Moore 1975) to a combination of botanical, pedological, climatic and cultural factors.

2.2.4 Modern land use and moorland soils

To obtain a reliable picture of the effects upon soil properties of early land use, one must obviously filter out the confounding effects of more recent or contemporary land use, which in the study area includes tin mining, peat extraction and moorland grazing of unimproved pastures. However, when certain activities are known to have commenced in historical times, but have continued down to the present or (more or less) recent past, a more difficult conceptual problem arises. At what point does one cease to regard such activities as 'noise' (a l bel that carries with it the implication that affected are s will be ignored) and instead start viewing it as a 'signal' that is worthy of investigation and analysis?

Sometimes, an answer to this demarcation problem lies in considering the historical context. Evidence of peat cutting practices in medieval times may be thought to have more intrinsic interest than evidence of similar activities in recent times, for which other sources already provide adequate information. This approach assumes th t one can put a date to the events and this is not always possible. oreov r, what may be 'interesting signals' in one context can become 'noise' in another (e.g. medieval peat cutting in a prehistoric field). There is no simple resolution of these problems and so, at both a conceptual and practical level, an eclectic approach has been adopted.

The imprint of some forms of very recent moorland utilisation are not hard to find. Soils in areas near modern roads have been ffected by construction of roadside banks and drainage channels, and by off-road use of motor vehicles, which leads to mutilation of the thin peat surface and even erosion of the underlying mineral soil. Similar damage, albeit usually on a smaller scale, occurs along the preferred routes of recent hikers, cattle, sheep and ponies. Such areas have mainly been ignored. However, man, his vehicles and his animals have caused analogous damage in earlier times and when traces of this can be confidently identified and placed within an historical context, they can be and have been employed as important evidence of earlier patterns of land use (see Fleming and Ralph: in press, and chapter 4).

Tin workings scar the landscape of Holne Moor on a scale that ranges from small pits and waste heaps along the lodes, through ravines and waste heaps of much larger size, to complete transformations of valley form. Rabbit warren construction often accompanied tin working and contributes its toll of soil disturbance. Some workings can be dated to quite recent times, many are undated and still others are known or thought to have considerable antiquity. There is little doubt that a similar variety in age characterises the trenches dug by peat cutt rs, which in some instances can be clearly identified by the well-def'ned, typically straight edges that bound these often quite slight depressions. In such cases, as with tinning works and warrens, avoidance of such areas poses no problem, but it has been thought worthwhile on some occasions to investigate areas affected by such activities in order to observe in detail how the soil has been affected by the initial disturbance and to assess its subsequent alteration by soil-forming processes. This knowledge can then be used to assess the probable cause and sometimes age of soil anomalies that otherwise would be difficult to identify; unfortunately, it seems that peat cutters, warreners and tinners do not always leave distinct surface deformation as evidence of their activities.

Since the field observations in the study area provide the best available evidence of the effects on soils of these kinds of disturbance, further consideration of these matters must follow the introduction of this evidence (see 4.3.1). However other activities may also have left their imprint upon the soils of the study area but cannot be properly assessed solely or at all from the information gathered on Holne Moor; among the most important of these are the effects of moor burning and other practices of moorland farmers such as bracken cutting, as well as the changes caused by the grazing behaviour of moorland animals. All of these influences may be supposed to have affected the study area in the past, and there is abundant evidence on Holne Moor of recent moor burning and of the transfer of nutrients to sheep camps. However, investigation of the changes wrought by such events lay beyond the scope of this enquiry and their significance must initially be evaluated from information provided by previous researchers.

In the following discussion, emphasis is placed on the way soil phosphorus may have been affected; concurrent alteration to the organic matter in the soil-organism ecosystem is only briefly considered. This treatment reflects both the emphasis of the Holne Moor studies and the greater resilience of the organic soil fraction.

Bracken harvesting

There is a long history of the use of bracken for a wide variety of purposes in Britain and elsewhere (Rymer 1976). The use of this plant for fuel and thatch, bedding, litter, composts and manures, medicine and food for people, pigs, horses and even rabbits in warrens are all purposes that might have led to the gathering of this material from stands in the study area. Local informants testify to the cutting of bracken, both for litter and to reduce its infestation, on nearby Spitchwick Common within this century.

The amount of nutrients and dry matter in a standing crop of bracken can vary ten to twenty-fold during a season (Berry 1917, Berry et al 1918, Ferguson and Armitage 1944) and Hunter (1953) observed that higher concentrations of phosphorus occur in the fronds of plants growing on soils with higher acetic acid-soluble phosphorus. However, this data does not allow one to assess whether bracken removal would reduce, maintain or increase underlying differences in total soil phosphorus. From the data provided by Berry et al (1918) and Hunter (1953), order of magnitude estimates of the likely maximum phosphorus reduction can be made; these estimates range from 1 kg P ha^{-1} (spring) to 25 kg P ha^{-1} (summer) from a single year's harvest. Clearly, if there is reason to suppose that, historically, bracken stands have preferentially occupied certain areas, then it must be possible that soil phosphorus levels in such areas have been significantly reduced. The wide range in potential losses of phosphorus (and dry matter, which, by reducing litter input, could alter soil organic matter levels) cannot be more closely evaluated.

Moor burning

Changes in the amount of nutrients within moorland soil-organism ecosystems affected by moor burning have been studied several times (Elliot 1953, Whittaker 1960, Kenworthy 1964, Allen 1964, Allen et al 1969, Evans and Allen 1971) and the results of this work have been reviewed (Gimingham 1972: Chapters 10 and 11). It was noted in section 2.2.2.1 that only about 4% of the phosphorus in moorland ecosystems is present in the vegetation and litter and is thus directly affected by moorland burning; the research cited shows that phosphorus losses even from this small fraction of the pool are themselves extremely small. Losses in smoke are affected by the temperature and duration of the burn, but are very unlikely to exceed 5% of the amount initially present in the vegetation; in typical burns, less than 1% may be lost (Kenworthy 1964, Allen 1964). Since some nutrients 'lost' in burning may be redeposited by condensation (Allen 1964) or fall to the ground (Evans and Allen 1971) at no great distance from the burn, nett smoke losses may be rather lower. A standing crop of heather usually contains about 5 kg P ha^{-1} (see Robertson and Davies 1965, Gimingham 1972: Table 26) and so if nett losses of 0.5% occur, each burn could reduce the phosphorus in the ecosystem by 0.025 kg ha^{-1}. Even on the unlikely supposition that the study area has been burnt with an average frequency of once every twenty five years for the past three millennia, the total smoke loss would not exceed 3 kg ha^{-1}; a quantity so small that this source of soil variation can be safely ignored even on the time scale of this study.

Early research on sandy podzols with very thin 'mor' humus layers (Elliot 1953) suggested that a more significant loss might occur as a result of enhanced leaching rates after nutrients were released by burning. However, later work by Allen (1964) showed that when a thicker 'mor' humus or thin peat was present, nearly all the nutrients derived from heather ash were retained within the top 2 cm of the soil profile. Similar conclusions were reached in still later studies of a wider range of soils (Allen et al 1971) and, taken together, there is no evidence in these studies that moor burning increases phosphorus leaching losses in soils where an organic surface greater than 5 cm thick is present. On the other hand, it is possible to suggest that burning may slightly increase the rate of movement of phosphorus from the organic surface to the underlying mineral soil and that where the former is particularly thin (as occurs, for example, in peat cut profiles), such movements might be more substantially increased. The conclusion that there is no evidence for increased leaching losses of phosphorus is at variance with Allen's (1964: Table 13) 'very approximate' estimate of an 0.1 kg ha^{-1} loss per burn and Gimingham's (1972: 220) view that 'doubtless some (phosphorus) is lost by leaching' but it is unclear how the former estimate was calculated, while the latter is essentially a speculation. The conclusion is moreover fully in accord with Kenworthy's (1964:97) view that 'burning may temporarily arrest the loss of phosphate from the system'.

The latter idea was, at least in part, based on Kenworthy's (1964:56) finding that ashing of *Calluna* litter may lead to the creation of relatively insoluble iron phosphates. If such a process occurs during moor burning, it could enhance the values of the Pa or Pf fractions of soil phosphorus in the mor humus layers of moorland soils. Gimingham (1972:220) stated that no such accumulation had been observed and concluded that the relative insolubility was a temporary phenomenon; unfortunately, Gimingham did not cite any studies in support of his contentions and this author has been unable to locate any relevant research.

It is possible that changes in erosion and surface runoff accompany moor burning and that these factors have a more substantial effect upon soil phosphorus levels than those considered above, but there is little evidence to confirm or deny such a speculation. If burning results in the deposition of relatively insoluble phosphates, it is unlikely that surface water will carry an unusual load of dissolv d phosphorus, but movement of ash particles might promote incre· sed downslope surf ce movement of phosphorus and even increased catchm nt losses. If burning is poorly controlled so that litter and pe· t horizons are damaged, erosion rates might also be increased with simil r consequences.

Although deep, unstable blanl et bog depos'ts can erode rap'ly resulting in heavy nutrient losses (Crisp 1966, see also Heal and Smith 1978), evidence for significant erosion of the thin peats of ta no-podzols has not been located. The field evidence from Holne Moor itself suggests that at present these soils have considerable st bility under their normal moorland cover; there are no signs of recent, active erosion even on burnt areas and sloping land (see 4.3.1). However, no substantial areas have been burnt in the last decade (see 3.2.1) and the extent to which moor burning increases erosion rates cannot be properly assessed. One must, therefore, conclude that phosphorus losses arising from moor burning cannot be fully evaluated, but that losses in s oke or by leaching from soils with surface peats, like those found in the study area, are nil or insignificant. Unless erosion rates are s riously increased, even repetitive, preferential burning of specific are s w'll not significantly change total phosphorus values, though it might increase values of relatively insoluble inorganic forms. Since burning is merely one part of a system for exploitation of upland grazin land, it may be that changes caused by burning interact with changes caused by grazing and that nett changes do occur; this possibility is considered later in this section.

The amount of organic matter in the soil-organism ecosystem, at least temporarily, may be much more seriously affected by moor burning. Although changes in carbon are rarely studied, losses of nitrogen were monitored in many of the studies cited above. Unfortunately, although very large losses of nitrogen have been identified (mainly lost in smoke) in all studies, there is no agreement about the effect of such losses on the contemporary nitrogen budget of the system (Gimingh m 1972:221). As is the case with several other soil nutrients, the e nitrogen losses may be balanced by present rainfall inputs, though some studies suggest nett loss despite this input, while others indicate an excess of this element.

Such variety of evidence and opinion about the present budget precludes any firm conclusion about long-term budgets. It could be that long-continued, regular burning reduces soil organic matter levels below those that would be present in unburnt ecosystems; this could involve a continual decline or the establishment of low steady-state levels. Alternatively such burning may simply maintain initial organic matter levels in an artificial steady-state or despite burning nett accumulation may occur. As Maltby and Crabtree (1976, and see 2.2.3) postulated, burning combined with grazing pressures could depress long-term apparent accumulation rates, though this might represent the sum of periods of loss and gain, but there can be no certainty that this is the case, since burning, by eliminating the later stages in the developmental sequence of Calluna stands, not only increases the palatability and nutritional quality of moorland forage but is also thought to raise productivity above the levels that would be achieved by uneven-aged natural stands (Gimingham 1972: Chapter 8). Although such increased production might be balanced by greater grazing pressure during the pioneer phase of even-aged stands (Kenworthy 1964), such grazing typically removes less than 30% of the available biomass and much of this is returned in excreta. There would not appear to be sufficient information to resolve these questions, but it is possible to suggest an additional factor that deserves consideration when an explanation is sought for the much higher rates of organic matter accumulation in modern times. This tenfold increase has occurred during a period when atmospheric nutrient inputs have increased substantially; the three to four-fold increase in rainwater nitrogen during this century (Williams 1976:197) and similar or perhaps even greater increases in rainwater phosphorus (see 2.2.2.1) are particularly notable, since moorland ecosystems are thought to be deficient in both these elements and the rainwater supply may therefore have a critical effect on productivity. The deleterious effects of pollution since the industrial revolution are well-known; such possible benefits seem to have been overlooked.

It is unfortunate that the most intensive and detailed research into carbon cycling and transfers in soils affected by burning has been confined to the sandy, phosphorus-deficient Iron-humus podzols of Dorset (Chapman 1967, 1970, 1979, Chapman et al 1975a, 1975b, Chapman and Webb 1978). These studies do suggest that the level of organic matter in the root zone of such soils may have reached steady-state after some 400 to 500 years with about 10 to 30 g m^{-2} of organic matter moving into the lower subsoil each year. However, since rates of primary production, litter decomposition and soil transfers in these relatively dry and warm soils, which have insignificant surface organic layers, are almost certainly substantially different from upland moorlands like those of the study area, the data are of limited value in this context.

Moorland grazing

It is exceedingly difficult to estimate the changes to soil properties that may have occurred due to moorland grazing by sheep, cattle and ponies. Two aspects must be considered in detail: the removal of phosphorus from the system due to the cropping of both domestic and wild herbivores and the redistribution or transfer of phosphorus within the system caused by spatial variation in grazing intensity and excretal output.

In order to estimate even the general order of magnitude of phosphorus removal, it would be necessary, in the first place, to specify the density of animals, in summer and winter, throughout the time period under consideration. Ideally, one would also like to know relative numbers of different species, the age and sex structure of the flocks and herds and the nature of the exploitation strategy, since such factors determine nett removal of nutrients in, for example, carcasses and wool. Without considerable new research, it would be impossible to make accurate estimates of such parameters even for very recent and contemporary exploitation of the study area. However, there is a small amount of information about modern grazing densities on Dartmoor (Perkins et al 1970, Sayer 1970) and this can be compared with similar data from the northern Pennines and Snowdonia, where in each case there have been detailed studies of nutrient removal and transfers (Heal and Perkins 1976, 1978, see also Crisp 1966); together, the latter studies provide values for these fluxes which almost certainly span the extremes of variation that may have occurred in the Holne Moor study area.

Table 2.3 brings together estimates of grazing density made in each of the studies cited above; the Dartmoor transect 3d is an estimate of the animal population of the study area itself, plus immediately adjacent areas, produced by aerial survey in 1969. Although aggregation of animals produces substantial variance in grazing density estimates, the similarity of the Holne Moor value to the estimated mean of all subsidiary transects suggests the figure may closely approximate the true picture at that time. If so, it is clear that grazing in the northern Pennines provides the best analogue for contemporary exploitation of the study area and, in view of the considerably greater fertility of the Llyn Llydaw grasslands where grazing density is some fifty times higher than it is on Dartmoor, may also be the best guide to earlier, historical periods as well.

Table 2.3 Sheep stocking densities in British moorlands and montane grassland

Location and reference	Comment		Sheep ha^{-1}	Cattle ha^{-1}	ponies ha^{-1}
Northern Pennines (Moor House National Nature Reserve) (Crisp 1966)	Rough Site catchment, Blanket bog and stagnopodzols.		0.217	-	-
Scotland (Grant and Milne 1973)	Range of estimated densities in *Calluna* moorland on stagnopodzols		0.2 - 0.7	-	-
Dartmoor (Perkins *et al* 1970: Table 8)	Transect 3d (Holne Moor study area), June		0.307	-	-
	All subsidiary transects ($\bar{x}$ value), June		0.330	-	-
Vegetation patterns (Sayer 1970)	'Damp Heather Moor' ($\bar{x}$ values) South Dartmoor, Summer		0.343	0.188	0.131
	'*Calluna-Molinia* Grassland'		0.687	0.279	0.141
Seasonal patterns (Perkins *et al* 1970: Table 10)	South Dartmoor, Main Transect ($\bar{x}$ values)			cattle and ponies ha^{-1}	
		March	0.276	0.016	
		June	0.848	0.065	
		August	1.086	0.104	
		November	0.655	0.109	
			eu ha^{-1}		
Snowdonia, Wales Llyn Llydaw	Grassland, summer grazing ($\bar{x}$ values)	1970	12.7	(= *ca.* 16 sheep ha^{-1})	
		1971	12.6		

Grazing of an area of blanket bog and grassland within the Moor House National Nature Reserve, the Rough Sike catchment, was confined to the summer months and was thought to have resulted in a nett annual removal of 0.0072–0.0168 kg ha^{-1} of phosphorus in carcasses and wool (Crisp 1966). A later estimate of the loss from the entire Reserve, which has a far higher proportion of better grassland pasturage (Rawes 1971) was an order of magnitude higher (0.0716 kg $ha^{-1}year^{-1}$), but the information provided by Rawes also showed that mean grazing density of the Reserve as a whole (8500 sheep in 3850 ha) is ten times higher (2.208 sheep ha^{-1}) than that of the Rough Sike catchment. If the Rough Sike estimate is adjusted to allow for the slightly higher grazing density in the study area, a rate of annual removal of 0.0102–0.02 8 kg ha^{-1} is produced, but this too probably underestimates losses from Holne Moor since sheep graze this moor throughout the year. An accurate allowance for this difference is probably impossible to calculate, but the increased losses are certainly less than proportional to the extra time spent on the moor. An estimate of around 0.025 kg $ha^{-1}year^{-1}$ is therefore unlikely to be seriously in error. This would imply losses of phosphorus of 75 kg ha^{-1} during 3000 years of grazing. The Llyn Llydaw estimate of losses of 0.8 kg P $ha^{-1}year^{-1}$ (Perkins 1978:Table 6) stands in stark contrast; this level of exploitation, if continued for three thousand years, would remove an amount of phosphorus (2400 kg ha^{-1}) greater than three-quarters of that present in the upper 30 cm of the Llyn Llydaw soils. Error in the estimation of these small values when linked to the large multiplier, coupled with the uncertainties discussed above, must force one to question the utility of these estimates of long-term changes, but they do at least provide some indication of the potential losses of nutrients caused by grazing in moorland ecosystems.

Since only a small proportion of the phosphorus in the herbage consumed by a grazing animal is retained in its tissues and the major portion is returned to the soil in excreta (Davies et al 1962, Barrow and Lambourne 1962, Hilder 1966a), the problems presented by uncertainty about the overall removal of phosphorus fade into insignificance beside the potential difficulties which excretal redistribution of nutrients and variation in grazing intensity could create. In consequence this source of variability must be considered in some detail. In part, the topic will be discussed at a later stage for predictably, but still ironically, the transfer of nutrients by grazing animals is, at one and the same time, the most serious form of interference arising from modern land use and potentially one of the most important metapedogenetic processes that may be used to identify ancient field functions (see 2.3.1.1).

In the discussions immediately below and later, attention is largely restricted to patterns of dung deposition, and urine is usually ignored. In part, this reflects the nature of the information provided in studies of excretal distribution, which tend to report dung deposition because it is easier to monitor. However, since all the principal herbivores considered here display a strong tendency to deposit dung and urine in the same areas (Petersen et al 1956 (cattle), Hilder 1966a (sheep), Odberg and Francis-Smith 1976 (horse)), this limitation is unlikely to produce any significant inaccuracies in estimating the spatial patterns of redistribution of any nutrient. In any case, with phosphorus, the element which is of primary interest in this study, any differences between the distribution of dung and urine will be of little consequence, since the overwhelming bulk of excretal phosphorus appears in the dung of these animals (Davies et al 1962, Barrow and Lambourne 1962).

Spatial inequalities in the distribution of soil phosphorus may be imposed by grazing animals if they habitually show spatial preferences in their grazing or excretal behaviour or in a combination of these activities. Thus selective, regular burning of particular areas, by increasing the grazing intensity (Gimingham 1972:214) could increase phosphorus removal in such areas, but this heavier grazing might well be accompanied by greater returns in excreta (Rawes and Welch 1966), which could balance or even exceed the extra losses. However, important spatial inequalities can arise even in the absence of such deliberate stimuli.

There is abundant evidence of the transfer of nutrients to preferred resting areas ('camps') by sheep and cattle and to voiding areas ('lavatories') by horses (Arnold and Dudzinski 1978:92-96). In addition, Brasher and Perkins (1978, see also Perkins 1978) have suggested that a more general pattern of heterogeneity may arise as a result of the behaviour of grazing sheep. These authors argued that inequalities in the spatial distribution of sheep excreta within study plots at Llyn Llydaw, although reflecting present differences in sward productivity and thus grazing utilisation, must also have been the root cause of such differences in productivity and soil nutrient status, because the soil parent material could be considered as entirely homogenous. In essence, they suggested the existence of a feed-back system, whereby greater amounts of soil nutrients from excretal return promote higher productivity, which in turn raises herbage utili ation (of herbage which has, moreover, higher nutrient concentrations) and thus greater excretal returns. In the relatively short span of their investigation, they were not able to demonstrate an intensification of the system. These two mechanisms for the creation of spatial inequalities of soil phosphorus are quite distinct and will be considered separately.

It is not difficult to identify and avoid modern sheep camps in the study area for, like the bedding or resting sites of wild sheep (Geist 1971:259, 275, 277) and other domestic flocks (During and Radcliffe 1962, Gillingham and During 1973), they are characterised by striking vegetational and sometimes erosional anomalies (see also 2.3.1.1). In any case the slow decomposition rate on cool, acid Calluna moorlands (White 1960) ensures a very dense cover of dung in such areas. Nor can there be any doubt that such accumulations of excreta increase phosphorus values in the camps' soils at the expense of surrounding pastures (Gillingham and During 1973, Hilder 1964). However estimation of the level of enrichment in camp soils is more difficult to assess from available data. Although increases in the values of phosphorus fractions (so-called 'available' phosphorus) within the soils of sheep folds (Czerwinski and Tatur 1974, see also Jakubczyk 1974), sheep 'benches' (terraced resting sites on steep slopes) (Radcliffe 1968) and camps in small (Hilder 1964) and large paddocks (Gillingham and During 1973) have been reported, this type of data does not allow one to estimate changes in total soil phosphorus. Once again, an indirect estimation can be made by considering information provided by several studies in other areas. One must consider the rate of transfer, the size of sheep camps and their catchment, as well as the longevity of their use.

Hilder (1966b) observed that 31-46% of total excretal output was deposited on camp areas by sheep grazing within 1.2 ha enclosures, while Brasher and Perkins (1978) noted that an estimate of total dung output based on herbage consumption and digestibility exceeded measured dung deposition, a difference they attributed to transfer to night camping areas. It is possible that some of the 25% of total dung missing from the Llyn Llydaw site plots accumulated on non-plot grazing areas, but the similarity to Hilder's estimates is striking. If Brasher and Perkin's reasoning is accepted, their figure for the transfer of 1.2 kg $ha^{-1}year^{-1}$ of phosphorus to camps can be utilised to assess the significance of these transfers. Before doing so, however, one must take into account the effect of variation in the nutrient content of sheep dung and of differences in grazing intensity.

The concentration of phosphorus in sheep faeces varies substantially, reflecting variation in pasture fertility (Bromfield 1961), and so, the Llyn Llydaw mean summer season values of 4.5 - 5.3 mg g^{-1} (Brasher and Perkins 1978: Table 5) may not be typical of sheep dung in Britain's usually phosphorus-deficient moorland ecosystems. Since estimations of the phosphorus in dung from such environments are rare, this hypothesis was examined by analysing faeces of sheep, horses and cattle grazing in the study area on Holne Moor. As expected, these samples had lower concentrations of phosphorus (2.1 to 3.1 mg g^{-1}; see 5.2.2 .2). However, there are also sizeable seasonal changes in the concentration of phosphorus in sheep dung. In Australia (Bromfield 1 61) and in Scotland (Field et al 1974), these have been found to be inversely correlated with the size of the faecal dry matter output, but this relationship is not evident in the samples from Snowdonia. Brasher and Perking (1978) in fact suggest a direct correlation of these variables, though estimates of increments and the standing crop of dung at Llyn Llydaw (1978: Table 4) seem to vary substantially from year to year, even when allowance is made for variation in measurement techniques.

Samples taken from the Llyn Llydaw site in August had a phosphorus value around 5.7 mg g^{-1} (1978: Fig. 6), nearly twice as high as the August samples from Holne Moor. This difference suggests that, if the relationship of phosphorus concentration to faecal dry matter output is similar on both sites, then the rate of phosphorus transfer to sheep camps on Holne Moor may be only half that observed at Llyn Llydaw (i.e. about 0.5 - 0.7 kg $ha^{-1}year^{-1}$). But even this figure must be an overestimate, since it does not allow for differences in grazing intensity.

Since the amount of dung deposited is, in general, proportional to sheep density (White 1960), it seems reasonable to assume that the rate of nutrient transfer due to dung deposition is also proportional to sheep density. If so, then transfer rates on Holne Moor may be some fifty times lower than those operating at Llyn Llydaw (see Table 2.3, for comparative stocking rates). If this factor and the variation in phosphorus concentration in dung are taken into account, one might expect the rate of transfer on Holne Moor to lie between 0.010 and 0.014 kg $ha^{-1}year^{-1}$. A slightly greater rate of 0.02 kg $ha^{-1}year^{-1}$ would make allowance for winter grazing on Holne, which certainly occurs today, but which does not occur at Llyn Llydaw. If it is accepted that, despite the many assumptions involved in its calculation, this figure is a reasonable guide to the significance of animal transfers of phosphorus in moorlands, then one must allow that in three thousand years, this process may have led to the transfer of some 60 kg ha^{-1} of phosphorus from soils in the study area. It is more important but more difficult to estimate the effect this has had on the soils in receiving sites - the sheep camp soils themselves.

For this calculation, one needs to know the size of camps and the area grazed by the occupants of the camp. Observations in Australian paddocks (Hilder 1964, 1966a, 1966b) showed that the camp area extended to no more than 6.25% of the paddock area and that the vast bulk of dung deposition occurred on a mere 2-3% of the paddock (an area of 250 - 350 m^{-2}). However free-ranging sheep seem to form looser night-time aggregations. Little detailed information is available, but Gillingham and During (1973) reported that, in an area with 'moderately steep' relief where camps were mainly sited on flatter ridge tops and basins, the total area covered by several camping zones equalled 0.81 ha, which represented 6.4% of the 12.58 ha paddock to which the Romney flocks were confined. Arnold and Dudzinski (1978: Figs. 1.22a, b, c) illustrated a dispersed camping pattern with sheep in a similar-sized rangeland paddock in Australia. The observations of Scottish Blackface by Hewson and Wilson (1979) and of Soay sheep by Boyd et al (1964) are also consistent with this hypothesis.

It is difficult to judge whether the similarity in the proportion of paddock utilised for camping in the small enclosures at Armidale (Hilder 1964) and the larger paddock in New Zealand (Gillingham and During 1973) is accidental or reflects a behavioural consistency; unfortunately the latter authors did not report stocking density. In the Dartmoor study area, contemporary camp foci (i.e. the zone of most intense dung deposition) have been estimated to cover about 1000 m^2, though one discontinuous zone of deposition just outside the study area may be as much as two or three times larger and thus more similar in size to those illustrated by Arnold and Dudzinski (1978: Figs. 1.22a, b). In addition to these very heavily-used, 'formal' night camps, there are also more diffuse areas used persistently, though less frequently, for daytime (and perhaps some night-time) resting (a fuller description of these phenomena within the study area is given in section 3.2.2). Day camps, which may be established beneath shade, were also observed by Squires (1974) and Arnold and Dudzinski (1978: 30-31, Fig. 1.22c) in the very different environments of dry lands in Australia. Deposition of dung in such day-time resting areas implies that rather less than 25% of dung output (the proportion missing from study plots at Llyn

Llydaw) may in fact fall within the more formal night camps of free-ranging sheep, though a rather higher proportion may be characteristic of camps in small enclosures. In addition to the complications caused by separation of day and night resting areas, seasonal switches in camp sites and small scale movements of position due to changing temperatures within winter have also been observed (Arnold and Dudzinski 1978: Figs. 1.22 a, b, 1.23) and must extend the area affected by nutrient transfers. Unfortunately, such observations have only been made in an environment very different from that of the study area.

From these data one could suggest that, in the 120 ha study area, some 7.56 ha (6.3%) might have a positive balance for nutrient transfer. At a transfer rate of 0.02 kg ha^{-1}year^{-1}, this would give an effective input of about 0.3 kg ha^{-1}year^{-1} of phosphorus to these areas as a whole. If deposition is mainly confined to 2% of the catchment, it would imply a higher input of about 1.0 kg ha^{-1}year^{-1}. Alternatively, camp input may be estimated by utilising information about the home range behaviour of free-ranging sheep.

Hewson and Wilson (1979) studied Scottish Blackface sheep (the main breed found in the study area) at Lochaber in north-west Scotland, where they found that individual sheep ranges, which included coastal greens of relatively high fertility, covered 10 - 25 ha. However, in the Cheviot Hills of south-east Scotland, Hunter (1964, see also Hunter and Davies 1963, Hunter and Milner 1963 and Griffiths 1970) identified home range groups of 16 - 52 Scottish Blackface, which grazed collective home ranges of between 32 and 40 ha. Although the latter study concerned sheep groups confined by fencing to a 141.6 ha 'heft' in which stocking density was, at 1.1 sheep ha^{-1}, somewhat higher than that of the study area, it probably provides a better analogue for the habitat provided by Holne Moor. From both these studies and from the research of Boyd et al (1964) with the sheep on the island of St Kilda, it can be inferred that free-ranging sheep groups display strong fidelity to these ranges, a fidelity which may also extend to their camp locations (see 2.3.1.1). Unfortunately, the relationship of a camp and a home range group does not appear to have been specifically studied, though Hunter (1964) did state that home ranges partially overlapped and that the camp of one group lay within the home range of another group, thus implying that, as one might expect, sheep which graze together also camp together. Overlapping ranges are also apparent in later studies by Hunter and Davies (1963). Examination of the sheep location maps (Hunter 1964: Figs. 2A-F), which do not include night-time records, nevertheless suggests the possibility that there is not a straightforward one-to-one relationship between camps and groups and that sheep from different groups may to some extent share camp sites (see also Arnold and Dudzinski 1978: 51-59, Fig. 2.1).

The grazing density of 0.307 sheep ha^{-1} assumed to be typical of the 120 ha study area on Holne Moor (see Table 2.3) implies that one may expect to find some 37 sheep in this area. They may belong to one or two home range groups and in the latter case, their ranges mmay overlap. No systematic night-time investigations have been made, but only two zones within the study area are known to have served as camps within recent years. If again, one assumes a rate of transfer of 0.02 kg $ha^{-1}year^{-1}$ and a catchment of 35 ha for any one camp, some 0.7 kg of phosphorus could be transferred each year to the soil of that camp. This represents an effective input into a camp of 1000 m^{-2} of 7.0 kg $ha^{-1}year^{-1}$, a rate seven times higher than that calculated earlier, and a rate which almost certainly overestimates effective input through underestimation of the area that has a positive nutrient balance.

Gillingham and During (1973) employed herbage and dung measurements to estimate the rate of input of phosphorus to the camp soils of a 12.54 ha paddock in New Zealand. Their estimate of 28.6 kg $ha^{-1}year^{-1}$ is much larger than either of the estimates calculated above and implies a far higher rate of transfer (2.0 kg $ha^{-1}year^{-1}$) than occurs even in the rich pastures of Llyn Llydaw (1.2 kg $ha^{-1}year^{-1}$). However, this is not surprising since New Zealand pastures, for climatic reasons, produce far higher yields than British pastures (Sears 1950) and the specific paddock studied had received phosphorus fertilisers and must have been grazed at a much higher stocking density than that of the study area.

Since no other transfer rates have been found in the literature, it is suggested that the speculative rates calculated above do form the best estimate that can be made of transfers in the study area. They imply that if the life of a camp is limited to ten years, soil phosphorus values in their soils could be increased by as much as 70 kg ha^{-1} or as little as 10 kg ha^{-1}, and that wider areas of diffuse, lesser enrichment used for a similar period of time (e.g. day resting sites) might have soil phosphorus values increased by about 3 kg ha^{-1}. At least one definite statement can be made in conclusion: substantial anomalies in soil phosphorus may have arisen even during periods when land use in the study area has been confined to sheep grazing of rough pastures.

Free-ranging cattle and horses also establish camps (see 2.3.1.1) but there seems to be little information about their behaviour in moorlands and no specific research into the nutrient transfer rates of these species either on moorlands or in enclosed pastures (but see section 2.3.1.1 for a review of their behaviour in enclosed land); in consequence the influence of these other herbivores will not be considered here. This omission is probably of little importance since the higher density and different behaviour of sheep almost certainly mean that this species provides the 'worst case' situation. However, it is necessary to discuss Brasher and Perkin's (1978) suggestion that grazing may give rise to more general patterns of heterogeneity.

The evidence provided by these authors and their associates (Heal and Perkins 1978: Chapters 14-20) leaves no doubt that, in the relatively phosphorus-rich environment of Llyn Llydaw, a strongly correlated pattern of phosphorus in herbage and dung was found also to be linked to the spatial pattern of 0.5 N acetic acid-soluble phosphorus in the surface soil, and that these patterns may well be maintained rather than diluted by present sheep grazing behaviour. However, it can be questioned whether these anomalies have arisen from variation in the intensity of grazing and excretal output; a hypothesis which would imply that there had been, at least, an initial stage when the system had experienced intensification. Present intensification was not claimed and cannot be inferred from their data. Nor, in this author's opinion, can an assumption of perfect homogeneity in soil parent material be sustained by the published evidence.

Although there have been intensive studies of the soils of the area, and of the soils in the site plots themselves (Ball and Williams 1968, 1971, Ball et al 1969, Ball 1978) only a few total soil nutrient values have been reported. The published total soil phosphorus values (Ball 1978: Table 3) show a range of subsoil variation (1091 - 1396 mg P kg^{-1} ignited soil) similar to, but slightly greater than the range in surface soils (1135 - 1266 mg P kg^{-1} ignited soil). In both cases the range appears to be small, but it can hardly be regarded as insignificant when set against the much smaller range in the values for extractable phosphorus (7.68 - 21.25 mg P kg^{-1}, Perkins et al 1978: Table 9). The mean value for this soil phosphorus fraction (12.87 mg P kg^{-1}, Ball 1978: Table 5) represents only 1% of the phosphorus in these soils.

The soils of the Llyn Llydaw plots were thought to have been maintained at a relatively high level of fertility by periodic erosion and were also thought to have been affected by nutrient flushes from easily weathered surface rocks (Perkins 1978, see also Ball et al 1969).

In these circumstances, it would not be surprising to find that both total soil phosphorus and the small proportion of soil phosphorus circulating in the ecosystem exhibit lateral variability; it does not seem to be necessary to invoke grazing inequalities as the agent of initiation. The extent to which grazing may have accentuated the pattern remains an open question. Ball (1978) emphasised that present differences in extractable soil phosphorus evident among the plots were confined solely to the surface soils. This observation is consistent with a model of the feed-back system operating at Llyn Llydaw and probably in many other pastoral ecosystems in which most of the nutrients cycle in a loop between herbage, dung and litter that allows very little permanent transfer to the wider soil component of the ecosystem, an aspect that will be considered later in this section. Nutrients transferred to camps provide an exception to this general model. While, no doubt the mechanism postulated by Brasher and Perkins could have an effect on total soil phosphorus, their evidence falls short of demonstrating the operation of such a process.

Rawes and Heal (1978) also suggested that sheep grazing might lead to soil nutrient inequalities through inter-habitat transfers - in their case from areas of blanket bog to Agrostis-Festuca grasslands. The suggestion differs from that of Brasher and Perkins only in the spatial scale of transfers and needs to be treated with similar caution and scepticism. These authors themselves emphasised the tiny magnitude of the calculated values and doubted the significance of the estimates due to the errors involved in their calculation; in addition it can be doubted whether even the basic assumptions that '. . . all food ingested on the blanket bog was transferred to other vegetation types and that all the dung and urine deposited on the bog originated from the nutrient-rich _Agrosto_ - _Festucetum_ . . .' (Rawes and Heal 1978:235) are realistic. Moreover the balance of consumption and excretal return within the blanket bog was drawn up without any measured values for the consumption in that habitat and utilised excretal nutrient values taken from the literature (Rawes 1971). In this author's view, there is no justification for an _a priori_ assumption, nor any clear evidence, that in the long run inter-habitat nutrient movement necessarily results in a nett transfer of nutrients from one habitat-type to another except in the special cases provided by animal resting sites. On the contrary, the observed spatial correlations in nutrient concentrations in dung, herbage and soil point to a large degree of conservation of nutrients within habitats, so far as the influence of the large grazing herbivores is concerned.

Some of the problems of identifying the effect of grazing on the organic matter of moorland soils were discussed earlier in the context of moor burning-grazing interaction. It was concluded that although burning produces large losses of nitrogen, its effect on long-term butgets of nitrogen could not be assessed from present data. owever, it is clear that the direct effects of grazing have a relatively insignificant effect on the nitrogen budget of upland ecosystems. Nitrogen budgets for the Moor House area (Crisp 1966, Rawes and Heal 1978) show that removal of nitrogen in carcasses and wool (0.05 kg $ha^{-1}year$) amounts to less than 1% of annual nitrogen input in rain, a proportional so small that even in pre-industrial revolution times, when input must have been much smaller, it is unlikely that removal by grazing was a significant factor in the budget. In any case, the Moor House estimates show that nitrogen fixation alone may be capable of more than balancing the books of the Rough Sike catchment, even including the large losses caused by peat erosion. Such comparisons bring out the considerable difficulty of arguing that grazing may have significantly altered the values of soil constituents such as nitrogen and carbon, which are freely obtainable from atmospheric sources.

Dry matter consumption and production estimates provide another way of examining how far one should regard grazing as a significant influence upon soil organic matter values and accumulation rates. The information provided by Gimingham (1972: Chapters 8, 9; and in particular Tables 1 7, 18) can be used to arrive at a first approximation. It is clear that when biomass of moorland communities (10,000 - 20,000 kg ha^{-1}) and estimates of above-ground dry matter production (2000 - 3000 kg $ha^{-1}year^{-1}$) are set against the annual sheep intake of dry matter (180 - 450 kg) and allowance is made for grazing intensities of the type encountered on moorlands like those of the study area (0.307 sheep ha^{-1}, see Table 2.3), the amount utilised (55 - 138 kg $ha^{-1}year^{-1}$) is but a very small fraction of the above-ground part of the soil-organism ecosystem. When, in addition, below-ground production (450 kg $ha^{-1}year^{-1}$) and the fact that returns in excreta typically amoun to some 40% of herbage consumption (range of digestibility 45 - 75%, Eadie 1967, Floate <u>et al</u> 1973, Field <u>et al</u> 1974, Milne <u>et al</u> 1976) are taken into account, the amount of dry matter actually lost from the system as a result of grazing (33 - 83 kg $ha^{-1}year^{-1}$) may be a mere 0.5 - 1.5% of total organic matter production. Substantially higher grazing densities than those assumed in the above calcul·tions can be envisaged without upsetting the general conclusion that if a small, consequent reduction in the amount of organic matter that becomes available for incorporation in the soil via the litter pathway occurs, it is unlikely to result in any detectable reduction in soil org^anic matter levels.

Indirect effects of grazing may in fact be more important than the direct effect of herbivore consumption. For example, on the relatively dry mineral soils at Llyn Llydaw, organic m· tter decomposition rates were slightly higher and soil loss-on-ignition and carbon values slightly lower on the most heavily grazed plots. This may in part have been due to the effects of heavier treading and higher nutrient supplies from excreta, but was thought to be mainly attributable to vegetational differences, which were themselves at least partly a by-product of soil differences (Perkins et al 1978). On the other hand, as a result of his investigations in damper, poorer soils, Floate (1970) emphasised how an increased return of nutrients in dung due to heavier grazing densities may lead to increases in dry matter production though this could occur as a result of more rapid circulation of nutrients rather than increases in the total nutrient pool. Grazing experiments in New Zealand (Sears 1950) typically showed lower yields from plots grazed without excretal returns, but in at least one case (Sears and Thurston 1953, Metson and Hurst 1953) no differences in dry matter production or total soil nitrogen and carbon could be found between grazed plots that had or had not received a normal full return of excreta. In perhaps the only reported experiment of its kind to take place on a stagnopodzol soil, Floate (1971, see also Floate et al 1973) showed that although higher grazing intensity (together with a variety of soil treatments) had altered organic carbon percentages in surface horizons and had changed the quality of organic matter (lower C:N ratio), these changes had not been accompanied by any significant changes in the total weight of organic carbon or total nitrogen in the upper 10 cm of soil. Taken together, these studies suggest that grazing in itself is unlikely to have had a significant effect on soil organic matter in the soils of the study area, even if one assumes that present grazing densities are somewhat lower than those which may have occurred in earlier, historical times.

The latter experiment suggests too that the substanti amounts of nitrogen and carbon transferred to sheep camps in excreta may not have a large direct effect on soil organic matter levels even in these areas. However, studies in New Zealand found that enhanced nutrient levels in camps did increase dry matter production in these zones. Gillingham and During (1973) demonstrated this phenomenon and cited another study which showed that dry matter production had more than doubled in camp areas. In addition, During and Radcliffe (1968, see also Radcliffe 1968), found that soils from sheep benches had higher percentages of carbon and nitrogen and lower C:N ratios, so it may well be that in the long run (and this may only be relevant to old camp sites) organic matter production and soil values may be higher in such areas. Certainly, modern sites where peat has been eroded must show much lower values.

In this section an attempt has been made to demonstrate and quantify the rather serious effect on soil properties of modern and recent land use in moorlands. These activities clearly make it more difficult to identify with certainty the effects of earlier land use, even of a much more intensive character. A resolution of the problems presented here can only be achieved when information about the soils of the study area is surveyed against the background provided by this discussion and the later review of metapedogenetic factors, processes and artifacts.

2.2.5 Summary and conclusions

The review and discussion in preceding sections has attempted to survey a substantial and varied literature which, it was thought, could generate coherent expectations about the natural patterns produced by pedogenesis in the soils of the study area; a necessary step, if one is to isolate those characteristics of present soils that may be attributed to metapedogenesis. In particular, this exercise sought to identify factors affecting phosphorus in the soil-organism ecosystem and the nature and magnitude of patterns and changes in this element that could be predicted from present knowledge. For brevity's sake only the most important conclusions concerning soil phosphorus will be reiterated here.

In most moorland ecosystems, the supply of phosphorus to plants by the soil component is very low and this shortage may be one of the principal factors determining the productivity of the above-ground components of the ecosystem. Certainly the latter contains only a very small proportion of the total phosphorus, which is, at least notionally, within the system, while carbon compounds produced by the system contain substantially lower amounts of phosphorus than are usually encountered in, for example, agro-ecosystems where phosphorus supply is assured by management. One practical consequence of this state of affairs is that sampling of the soil component alone can provide an adequate measure of the total phosphorus in the system.

The deficiency of phosphorus arises from a variety of causes: often the soil parent materials on which the system is based have a low phosphorus content; high rainfall promotes translocation of phosphorus and thus impoverishment, particularly of near surface horizons; cool, wet and acid soils increase the proportion of phosphorus which accumulates in organic forms and which only become available as plant nutrients through very slow mineralisation; the same conditions allow only weak weathering of apatites, but are conducive to the formation of highly insoluble inorganic forms of phosphorus. This variety of more or less distinct forms of soil phosphorus, each of which have different ecological significance demands that analysis of the system should include their separate identification and quantification. The vertical redistribution of soil phosphorus imposed by leaching and plant transfer also requires one to investigate complete soil profiles, not simply surface patterns. The variety of patterns of vertical distribution in podzolic soils allows no prediction as to the precise form of subsurface accumulation.

Despite the small amounts of phosphorus cycling within moorland ecosystems, which ensure very low rates of change - gains, losses or transfers (see Table 2.4 which summarises some of the estimates made in previous sections), large changes may be expected to have occurred over the long period of time that is encompassed by this study of ancient fields. Both natural and man-induced processes will have caused losses, gains and redistribution of phosphorus in the system and may also have altered the pattern of long-term transformation of phosphorus compounds in the system. Fig. 2.3, adapted from the work of Floate (1962) and of Walker and Syers (1976) attempts to summarise the probable natural trajectories of these transformations in moorland soils of the type found in the study area. It assumes a parent material of 'secondary weathering' type and also allows for a substantial change in the phosphorus system when organic matter dynamics change and peat starts to accumulate. Once again, this prediction appears as a necessary prerequisite to the identification of anomalous trajectories in the formation of these phosphorus compounds.

Table 2.4 Summary of estimates of the magnitude of phosphorus inputs, transfers and outputs for the soils of the Holne Moor study area based on published data.†

	kg P $ha^{-1} year^{-1}$	kg P ha^{-1} in 3×10^3 years
Precipitation input	+0.005/+0.053	+16/+160
Leaching output	-0.025/0.073	-76/-220
Nett change	-0.02	-60
Moor burning(1)		
Smoke	-0.001	-3
Leaching	0.0	0
Erosion	No estimate	No estimate
Grazing(2)		
Output from		
Grazing (removal of harvest)	-0.025	-75
Areas (removal to camps)	-0.02	-60
Input to		
Night camps	+1.0/+7.0	no estimate
Day camps	+0.3/+1.0	no estimate
Bracken cutting	-1.0/-25.0	no estimate

† For sources of data and discussion see text, section 2.2.4.

(1) Assumes land burnt every 25 years.

(2) Assumes grazing similar to present exploitation.

Explication of the natural pattern of soil form·tion now allows sensible assessment of the possibility that metapedogenetic processes set in motion by early agricultural intervention can still be identified in modern moorland soils. It thus provides the b·sis for selective review of metapedogenetic factors and processes which forms the subject of the next section.

2.3 Pedology and agriculture

Metapedogenetic factors such as cultivation and intens've livestock rearing induce processes like soil homogenisation and nutrient transfer which in turn create artifacts: plough layers that repl·ce natural soil horizons; soils that have abnormally high or low amounts of nutrients, and so on. This section reviews studies which indicate the effect upon soil properties of agricultural activities as a basis for generating, at a later stage, precise, descriptive models of soil characters within agricultural enclosures. If one invokes the principle of uniformitarianism, then, after due allowance has been made for the transformations caused by subsequent pedogenesis, such models can serve to predict the artifacts that should be found if an ancient enclosure has been used for the purposes specified in the model. Justification for assuming uniformity must be considered when specific metapedogenetic factors are discussed.

In some measure this review anticipates the levelling effects of subsequent pedogenesis. As noted in the introduction (2.1), many metapedogenetic factors and processes can be ignored as ephemeras within the time scale of this study; as in earlier sections the emphasis is on soil nutrients, particularly phosphorus, and to a much lesser extent organic matter. With these quantifiable soil properties, the effect of agricultural activities can be considered in terms of changes to arithmetic mean values and to the dispersion of values in the samples contributing to that mean; one may also examine how both these parameters vary laterally or vertically within the soil body. Most of these aspects will be considered together, first in pastoral land, then in arable land. However, assessment of the patterns of vertical distribution of soil phosphorus observed in arable and pastoral land, and consideration of the changes to soil organic matter that accompany these different farming strategies, are most efficiently handled by direct comparison and are therefore treated in a separate section. A final section utilises the information in these earlier sections to assess how convertible husbandry, ley farming or other forms of rotational land use might be identified. No attempt is made to summarise these reviews since the opinions and observations in this section are effectively recapitulated in the models presented in the subsequent section.

2.3.1 Pastoral land use

The preceding review of the effects of modern land use upon moorland soils (see 2.2.4) has already indicated that grazing animals can substantially alter the pattern of nutrients even when free-ranging animals graze at very low densities. Analogous changes occur in enclosed pasture land, where the effects are intensified and, moreover, produce more predictable spatial patterns. In addition to these transfers of nutrients within the system, it is necessary to consider changes in lateral variability of nutrients and the overall losses from and gains to the system.

Quantitative evaluation of losses and gains in the soil component of intensive grazing agro-ecosystems requires accurate specification of many parameters of the system; even the most recent attempt to collate such information about contemporary systems had to conclude that considerably more research into nutrient fluxes was needed (Frissel 1978). At the most basic level, one needs to know the magnitude of transfers between soil, plant and animal components of the system and whether the system is open or closed. Although the nature of fluxes which cross system boundaries may be different, these basic requirements apply as forcibly to analyses of individual parcels of land within a defined agro-ecosystem as they do to the system as a whole. In either case, herbage uptake of nutrients, the species and density of livestock and the nature of their exploitation are factors that combine to govern the rate of soil nutrient utilisation and thus losses, transfers and gains in the system.

There is, of course, a total absence of data of this kind (and much else besides) for the agro-ecosystems that constructed and used the ancient enclosures of the study area, a lacuna that is the very raison d'être of the research reported in this thesis. Although it was thought profitable to attempt a quantitative estimate of changes that may have been wrought by relatively simple extensive grazing systems of the kind which today characterise the exploitation of many moorland areas, a similar approach is not suited to the current task. It is not that there is an absence of utilisable contemporary information (though specific research into nutrient transfer rates and measurements of soil phosphorus which can be used to assess the resultant pattern of anomalies are only available for sheep). On the contrary, it is th abundance and variety of information about intensive agro-ecosystems that renders the approach unsuitable, for it indicates their multiformity and thus, unless one believes that early agricultural communities were necessarily far simpler, the need for numerous, diverse quantitative models in order to encompass even a small proportion of the many options, both strategic and tactical, that may have been available to the ancient inhabitants of Holne Moor. Any quantitative evaluation of ancient agro-ecosystems must therefore, for economy's sake, be predic·ted upon and mediated by at least some quantitative information recovered from the system itself; a task that must be left until a later stage.

Nevertheless, much qualitative information from contemporary systems can be used to examine the range, nature and probable sign of changes and this can serve as a guide to appropri te sampling strategies and later assessment of results. Contemporary pastoral agro-ecosystems will therefore be considered under two main headings: changes in the lateral distribution of nutrients and changes in the total store of nutrients.

2.3.1.1 Changes in the lateral distribution of nutrients

Lateral transfers of nutrients within pastoral agro-ecosystems involve both inter- and intra-field movements. The latter largely reflect the natural behaviour of livestock, while the former, which will be considered first, occur mainly as a result of deliberate stock management policies.

Significant inter-field transfers probably only occur when animals are regularly transferred to different paddocks for day and night grazing. Today, this practice is mainly encountered on dairy farms where, for convenience, the cows are kept in fields close to milking sheds between evening and morning milking periods. There is no doubt that in these circumstances an imbalance in herbage consumption and excretal return can lead to a transfer of nutrients from day to night paddocks (Goodall 1951), but studies which report the amount of time spent in grazing and the frequency of excretal return in day and night paddocks (Castle et al 1960, Hancock 1950, Goodall 1951, Wardrop 1953, MacLusky 1960) indicate a considerable range of values for these parameters, which suggests that the rate of transfer may vary substantially. Although affected by weather and changes in day length, da time grazi g typically accounts for half or more of daily herbage intak , but usually less than half the daily return of excreta. Most studies only indicate the number of defecations and emphasise the higher frequency during the night, but Goodall (1951) also assessed the weight of faeces and found that this also rose during the night. As a result, he calculated that although only 40% of grazing occurred in the night paddock, 46% of the dung would be deposited there. In the day paddock, an even greater disproportion would occur (60% of grazing, 43% of dung) with the balance (11% of dung) left in roadways, yards and milking sheds.

Sears (1953) showed that similar 'day and night' grazing by sheep caused analogous transfers of soil nutrients and these experiments (discussed by Goodall 1951) also demonstrated how rapidly such transfers could increase soil fertility in the night paddock. Within two years, dry matter production was 20% higher in the night paddock than the day paddock. In part, higher night-time excretal return by sheep may reflect a high frequency of defecation immediately after rising from rest (see Geist 1971: 2 77), but, as with cattle, it may also be due to an increase in the size of droppings during the night resting period (see Donald 1968, Donald and Leslie 1969). Clearly variation in the rate of such transfers will occur solely as a result of altering the timing of animal movements, but it is worth noting that at whatever time it occurs, the process of moving animals itself involves a significant loss of nutrients from paddocks.

Since no grazing occurs in roadways, yards and milking sheds, transfers to such areas equal the gains and, unless steps are taken to remove droppings, could cause very large rises in soil nutrients in these areas. Goodall's (1951) estimate of 11% dung deposition in these zones is matched by the 12% estimate of Castle et al (1950) and lies between the extremes of 24% (Wardrop 1953) and 2% (Hancock 1950) reported in other studies. Goodall calculated that nutrient gain in these areas could exceed nett gain to the night paddock by more than 60%; since the night paddock is likely to cover a larger area, relative enhancement of soil nutrients per unit area could be even greater. The precise amounts will no doubt be affected by the length of droveroads traversed and the general speed of milking operations, but it is a matter of common observation that routes regularly used by farm animals are liberally spattered with dung.

Casual, but deliberate and frequent observations by this author in droveroads presently in use near to the study area suggest that dung is not deposited randomly along these routes. Although at present no quantitative evaluation is available, one can perceive two patterns. As one might expect, deposition seems to be most dense close to field entrances, whose construction, on Dartmoor and elsewhere, often involved a widening of the drove both for ease in handling animals moving to and from the fields and no doubt because of congestion at these nodes. The second pattern commonly encountered is linear concentration along preferred pathways within wide droveroads; although pathways may occur at any location across a droveroad, one almost invariably finds that deposition is abnormally high close to one or both banks or walls of the drove. These patterns arose mainly from the movements of horse and cattle, but it is not inconceivable that similar patterns would result from sheep movements for although, if driven, sheep bunch together across the entire width of a drove, sheep left to their own devices often walk in single file (Geist 1971:112-114, Pls 30, 31, Arnold and Dudzinski 1978: 69-71, Squires 1974) as horses and cattle usually tend to do.

Nor need inter-field fertility transfer be limited to agro-ecosystems that exploit cows for milk products. Not only is it possible that dairy exploitation of sheep may have involved similar strategies to those reported by Goodall for cows, but higher risks of predation in earlier periods may have led to the use of night paddocks sited close to occupied farm buildings for the purpose of protection. Moreover this motivation, which could apply to any type of livestock, might also be reinforced by a desire for a dung input on plots which could then be used as high-yielding arable land. It seems unlikely that the substantial changes in floristic composition and growth rates that accompany fertility transfer of this kind (e.g. Sears 1950: Plate 8) would not have attracted notice and exploitation.

Avoidance of predator losses could also have provided a strong reason for nightly enclosure within field systems of animals allowed to graze unfenced common pastures under the watchful eye of a shepherd during the day. If farm boundaries are regarded as the limits of an agro-ecosystem, as implied here, then transfers arising in this fashion represent an input to the total store of nutrients in the system, whose implications will be considered later (see 2.3.1.2).

Although the presence of nutrient anomalies on routeways within ancient field systems may assist in their functional interpretation and thus by extension provide information about the use of associated fields, pastoral use of the latter can be more directly inferred from the presence of nutrient patterns within the fields themselves. Moreover the patterns created by intra-field nutrient transfers differ as a function of the grazing species; if such patterns can be discerned within ancient fields, a very detailed picture of livestock exploit t'on may be recoverable.

There are large differences in the amount and type of inform' tion available in the literature concerning the intra-field transfers of various species. Much is known about sheep and detailed spatial patterns of dung deposition and resultant nutrient patterns h' v been published (e.g. Hilder 1964, 1966b). Cattle also have been subject d to several investigations (e.g. Petersen et al 1956, Richards and Wolton 1976), though spatial patterns typically have been summ rised by st tistics rather than cartography. Although horse bel aviour too has been studied intensively (e.g. Odberg and Francis-Smith 1976, 1977), only a little information is available about the nutrients transferred within their paddocks. If the ancient fields of the study are were used y grazing animals, it seems likely that cattle, sheep and horse, alone or in combination, were the principal occupants; for this re'son the review is limited to these species. Nor does the review below extend to an exhaustive discussion of what is known about the causes of spatially patterned behaviour in grazing animals; causation is considered when it can contribute to predictions. Fuller discussion of ethological aspects can often be found in the articles cited and have been reviewed by Tribe (1950), Hafez (1968), Squires (1975), and Arnold and Dudzinski (1978). The effects on pastures of fouling by dung were reviewed by Marsh and Campling (1970), and more general discussions of the influence of the grazing animal on pastures have been provided by Hilder (1 66a), Barrow (1967) and Watkin and Clements (1978).

Sheep

Nutrient transfers to sheep camps have already been discussed in some detail in section 2.2.4. Substantial losses of phosphorus from grazed areas and matching gains in the camps are accompanied by changes in vegetation (Hilder 1966a, During and Radcliffe 1962, Geist 1971:259, 275, 277, Gillingham and During 1973), which include areas of bare, eroded soil, increases in weed species, changes in clover: gr ss ratios and luxuriant growth at camp edges. Hilder (1966b) noted that, judging by the literature available to him, the phenomena had received relatively little attention and that in consequence (Hilder 1966a) there must be considerable doubt about the relevance to normal paddock grazing of trials and experiments on very small plots where such patterns might either be absent or much attenuated. His research with Merino sheep in Australian paddocks (see also Hilder and Mottershead 1963, Hilder 1964) showed that variations in stocking density (7–40 sheep ha^{-1}) and in size of enclosures (0.4–37.2 ha) produce only very small changes to the basic pattern of nutrient redistribution, which is well-illustrated by the diagrams showing the distribution of dung (Hilder 1964:Fig. 1, reproduced here as Fig. 2.4, see also Hilder 1966a:Fig. 1) and exchangeable potassium (Hilder 1964: Fig. 2, reproduced here as Fig. 2.5) in some of the Armidale paddocks. Higher stocking densities were associated with a small increase in camp size and a large increase in the weight of dung deposited in the camps, but there was little change in the proportion of dung falling within camps or in the fraction of the paddocks which became enriched in nutrients. It was noted that camp areas were often located in the corners of enclosures that lay adjacent to other enclosures where sheep were present (this pattern shows clearly in a photograph by Hilder published in Hafez (1968: Plate 11)).

The principal questions which arise from this research concern the degree of confidence with which one may assume that such behaviour will have occurred in much earlier flocks and the extent to which a camping site becomes permanently located in a particular part of a pasture. Hilder (1966b) suggested that variation between breeds, in climate, in topography, in flock size, in vegetation and in the management of flocks could all affect the pattern. There are still relatively few sources of information that provide guidance in answering these questions, but there is sufficient data to dispel the notion that camping is peculiar to Merino sheep or to sheep in environments similar to those found at Armidale. There is no doubt, for example, that camping behaviour is characteristic of hill sheep in Britain. Sometimes the specific breed is mentioned in the literature: South Country Cheviots (Hunter 1962); Scottish Blackface (Hunter 1964); North Country Cheviots (Griffiths 1970); Swaledales (Rawes 1971). The sheep within the Llyn Llydaw study area in Snowdonia (see 2.2.4) are probably of Welsh Mountain type. These studies alone demonstrate that free-ranging sheep, at least, exhibit camping behaviour under a wide variety of climatic, topographic and vegetational conditions and at several different grazing densities.

Gillingham and During's (1973) study of nutrient transfers caused by Romney sheep in New Zealand extends the range of habitats still further and adds a lowland breed to the list of sheep known to exhibit camping behaviour. This study also falls in the gap between the widely ranging sheep of upland Britain and the Merinos of Armidale, whose behaviour was mainly studied in small enclosures of 0.4-1.2 ha. Earlier observations in New Zealand (Sears et al 1948) confirm that nutrient transfer to camps in hill pastures and in enclosures is a common occurrence. In one account, Sears (1951), brought out another aspect of the spatial incidence of transfers when he stated that '. . . the habit of "camping" in particular places, especially along fence boundaries on small enclosures, results in large amounts of dung and urine being deposited on these areas' (1951: 3, but my emphasis).

The same locational preference was observed in a British study of dung deposition (Donald and Leslie 1969), but this research and similar, earlier work by Crofton (1952, 1954, 1958) on the distribution of parasites in the sheep dung on pastures, is of limited relevance in this context due to the short time span of the observations. Interpretation of the results of the earliest studies of this type (Crofton 1954) is also made more difficult because, at least initially, Crofton assumed that the non-random pattern of dung reflected non-random grazing patterns produced by the tendency for some lowland sheep to graze as a group, unlike, for example, hill sheep, who tend to graze in a unit consisting of one or two ewes and their lambs. It must be emphasised here that although aggregation during grazing may itself, especially in the short-term, produce some heterogeneity in dung distribution, it is evident from both later studies by Crofton (1958) and by Donald and Leslie (1969), as well as all the other studies cited above, that the main contribution to inequalities of dung in sheep pastures results from night-time deposition in resting areas. It might be possible to separate the patterns produced by daytime grazing aggregation, which is a habit of varying incidence in modern sheep confined to enclosures, from those produced by night-time resting behaviour on the basis of variation in dung size, but no such research has been reported. In this author's view, it is the confusion caused by the different patterns of day and night deposition that is responsible for an apparent conflict in the results reported by Crofton (1958) and those of Donald and Lselie (1969), rather than, as the latter authors thought, a conflict produced by differences in the time scale of their respective studies. The conflict is of some importance since it has a bearing on the problem of determining the permanence of camp areas.

Donald and Leslie (1969) found that, during the short period of their observations, there was a strong tendency for dung to be deposited in the same limited zones in successive periods. This is consistent with the degree of permanency which can be inferred from the substantial changes in soil nutrients and vegetation observed in all the Australian and New Zealand paddocks discussed earlier, but was thought to be inconsistent with Crofton's (1958) observations. These, perhaps incorrectly, have been taken as evidence for a regular movement of a night resting area around a pasture every few days. However, Crofton's (1954) stated method of assessing dung distribution was designed to measure dung increments in successive periods, rather than the more easily measured standing crop of dung (the measure used by Hilder (1966b), who found that the standing crop reached a steady-state after 4 months), and he only alluded to the standing crop of dung in his statement that '. . . there tended to be no great increase in the contamination of an area' (Crofton 1958:256 but my emphasis). The significance of this statement and of the study as a whole cannot be properly assessed, since vital information on, for example, enclosure size, stocking density, how recently the flocks had been introduced to the pasture and, most important, the duration of observations, were not reported, though Crofton (1958:255) did admit that no night observations were made.

In contrast, Donald and Leslie (1969) reported all these parameters and their study revealed several aspects worth noting. Experimental enclosures of 0.1–0.4 ha were stocked with Clun Forest sheep, another lowland breed, at densities between 20 and 80 sheep ha^{-1}, yet despite these relatively high densities in small enclosures, the behavioural pattern was, except in the smallest enclosures, almost identical to the patterns observed in the Armidale paddocks. Indeed, these authors were even able to observe the tendency for a resting area to be established by the fence adjacent to a field with another flock. Only the smallest enclosures, of about the size of a sheep-fold (and with stocking densities of 50 and 80 sheep ha^{-1}), showed departures from the pattern.

In addition to the studies of domestic sheep reviewed above, these is evidence of persistent use of specific night resting areas among North American wild sheep (Geist 1971:259, 275, 277) and the report by Boyd et al (1964) strongly suggests that Soay feral sheep also display this behaviour. These facts argue strongly that camping behaviour is not of recent origin, but is of great antiquity; that it is not limited to certain breeds, but is, perhaps in varying degree, common to the genus *Ovis* as a whole; and, particularly in view of its prevalence among British hill sheep, may reasonably be thought to have characterised the behaviour of any flocks grazed within the ancient enclosures of the study area. Only deliberate stock management policies are likely to have prevented an uneven return of excreta and although an early 16th century agricultural treatise advised shepherds to drive sheep about in order to ensure an even spread of droppings (Fussell 1955), it is hard to imagine this occurring at night in any era. Hilder's (1966b) investigation suggested that even rotational grazing rather than set-stocking would have little effect on the pattern; the most even distribution on a rotationally grazed paddock left a quarter of the dung on 10% of the paddock area and this was an atypically even example.

The best evidence for permanence in camp location is also provided by the Armidale studies. Hilder (1964) made his investigations after some 6-7 years of continuous grazing. If camp locations seen at that time had been recently adopted or indeed if camp location had shifted to a significant extent at any time during that period, it seems unlikely that Hilder would have been able to observe the very precise correspondance between relatively recent dung deposition and the pattern of soil nutrient enhancement. The surface patterns of exchangeable K (see Fig. 2.5), mainly the result of urine deposition, might be relatively ephemeral, but this cannot also be said of the matching pattern of phosphorus (Hilder and Mottershead 1963: Table 1), and in any case K enrichment was also found to have affected soils to a depth of 70 cm (Hilder 1964: Table 2). These data suggest long-continued use of the same campsites and the more than three-fold anomaly in available phosphorus in the New Zealand paddock examined by Gillingham and During (1973: Table 3) argues in the same direction.

Hilder (unpublished information cited in McBride et al (1967)) has observed that the 'regular' camps may be shunned if they become excessively wet and that soft faeces also seems to induce movement of camping sites. The apparent contradiction between this evidence for mobility and the strong evidence of long-used 'regular' camps suggests that such moves are usually temporary and that the sheep tend to return to old sites. This supposition is supported by more recent observations at Armidale. Lynch et al (1980) showed that sheep newly-introduced to an experimental paddock may even adopt old camping sites established by earlier flocks, though whether such re-use is related to environmental patterns created by earlier camping or instead reflects the same constellation of factors that governed the selection of these areas by earlier flocks is unclear. Unfortunately, there is still considerable ignorance about the reasons why certain areas are preferred.

From the positions reported in the literature surveye above, it is possible, however, to make some generalisations, although the causes of these consistencies may be poorly understood. Earlier, it was noted that camps in adjacent fields may be sited close together t corners or at other points along a joint boundary. Observations by Dean and Rice (1974) suggest that a zone near the boundaries of a field may be more frequently visited by sheep (and cattle and bison) during daytime activities too, though this tendency was not strongly evident with sheep in one of the two enclosures (of 10-20 ha size) studied. Sheltering behaviour may be an important factor determining camp position and more general resting spots, at least in areas where strong, cold winds accompanied by rain occur with any frequency (McBride et al 1967). The use of shelter by sheep has been reviewed by Arnold and Dudzinski (1978:32-39, 84-86); much of the very detailed Australian research (e.g. Lynch and Alexander 1976, 1977, Lynch et al 1980) is of limited relevance, since climatic conditions at Armidale are usually very different from those encountered in the study area. The most relevant observations available seem to be those of Munro (1961, 1962) and Griffiths (1966), which concern free-ranging sheep in upland Britain.

There is no doubt that with high wind speeds, sheep do move to sheltered areas, at times to continue grazing, but also when seeking resting areas. It is also clear that sheep will make use of the shelter provided to windward and, to a greater degree, to leeward of a field wall or hedge. When conditions are poor both sheep and cattle will tend to move with the wind to the leeward end of an enclosure (Arnold and Dudzinski 1978:38-39). In the absence of substantial topographic variation and gradients, which do seem to influence camp locations (e.g. the use of ridges, plateau top locations and rocky areas among cliffs), one may be justified in expecting camps to be located by boundaries, particularly in corners and probably on the leeward sides of a field. In Australia, trees influence camp locations by providing shelter from summer heat, but today, in the study area, only horses persistently and regularly have been observed using such shelter. Water availability is another factor of little or no importance to sheep in the study area.

To summarise then, very high levels of soil phosphorus and other plant nutrients may be found in small, camp areas of sheep enclosures and lesser enrichment may occur close to walls and other structures which provide shelter. Such anomalies arise principally through positive accumulation caused by abnormally high rates of dung deposition. Where heavy treading has destroyed vegetation cover or where herbage is constantly affected by faeces contamination, a low level of nutrient consumption will also contribute to the formation of these anomalies. With sheep, this factor is probably of minor importance, since urine-affected herbage is readily consumed (Keogh 1973) and the small, relatively rapidly decomposed dung pellets tend to cause rejection for only a brief period. With cattle and horses, however, this factor may be more important.

Cattle

Aside from the movement of fertility on dairy farms discussed earlier, the transfer of nutrients by cattle has mainly attracted attention because fouling by dung in cattle pastures leads to at least temporary rejection of contaminated herbage and this in turn can reduce the productivity of beef and dairy farms (Marsh and Campling 1970). Experimental studies of dung deposition have often employed grazing management schemes (strip or fold grazing, frequent rotation among small plots) which closely control animal movements (e.g. MacLusky 1960) and moreover typically involve grazing at very high stocking densities (e.g. MacDiarmid and Watkin 1972). Such strategies are unlikely to be representative of those which occurred in pre-modern times since, for example, close control often involves equipment such as portable electric fences, and very high stocking densities usually require very substantial inputs of inorganic fertilisers. In consequence much of the data recovered in these studies is of limited relevance to the objectives pursued here and if taken at face value may even provide a misleading picture.

With sheep, the main emphasis in review was an assessment of the overall pattern made by major transfers to particular zones and the same emphasis is placed here. Discussion of the pattern of nutrient re-distribution <u>within</u> zones (e.g. alteration to the variance of a nutrient distribution in sheep non-camping areas) is deferred to a later stage, since differences in such patterns are best isolated by direct inter-species comparisons. This distinction is not merely one of scale, but broadly reflects the differences between the pattern of excretal return associated with normal grazing activities and that associated with other activities such as resting, sheltering, drinking etc. Mathematical models of cattle dung distribution designed to fit empirical data patterns (Petersen <u>et al</u> 1956, Richards and Wolton 1976) have not usually attempted to make this distinction but have instead subsumed all excretal return in a single formulation, although their authors were clearly aware of the contribution of different activity patterns. Exceptionally, Hakamata and Hirashima (1978) did attempt a mathematical separation of dung 'clumps' produced in areas of special attraction. They found that such clumps could be easily identified on their original maps of dung distribution and that clump sizes associated with non-grazing activities were mainly much larger than clumps which arose during normal grazing, though dung distribution in grazed areas was also non-random and was best represented by a negative binomial distribution curve.

There are very few studies of cattle that provide the type of information about nutrient redistribution that is available for sheep, but the special features which attract an unusual quantity of dung have long been known. They include resting areas, sheltered zones, and areas adjacent to water sources, gates and the boundaries of enclosures (Marsh and Campling 1970). A location may often fall into more than one of these categories. For example, a sizeable hedge or shelterbelt of trees along a boundary can lead to heavy defecation adjacent to that boundary (Powell 1967), but areas adjacent to fences which offer no protection from the weather are also more frequented than central parts of the pasture (Dean and Rice 1974). Resting or lying areas, where, particularly at night, cattle congregate (these are usually referred to as 'stock camps') may often be located in sheltered areas, particularly in winter (see Castle and Halley 1953, MacDiarmid and Watkin 1972).

Not all studies which mention this type of information report identical patterns of behaviour. In some cases information may have been omitted through irrelevance to the particular purposes of the study, but at times it is clear that the behaviour pattern was not present. Thus Hakamata and Hirashima (1978) found major dung clumps around water troughs and salt licks but specified that they did not observe the 'fence' effect which had been noted by Petersen et al.(1956). Few authors provide more than descriptive, qualitative information on this topic. Although the studies which have sought to describe dung distributions mathematically clearly started by preparing distribution maps, none of these maps was published. Only two studies publish relevant maps. The earliest, by Beruldsen and Morgan (1934, 1938) consists of a set of maps drawn at intervals over a period of two years. These depict the variegated pattern of grazing that is the result, in large measure, of rejection of herbage adjacent to dung patches (see also Marten and Donker 1964 : Fig 1). Unfortunately only a very small segment (0.04 ha or 2%) of the 2.02 ha paddock was mapped and, as the authors intended, these maps mainly illustrate the relatively short-lived nature of the patterns produced by the deposition of small dung clumps in the grazing area of a field. The far more persistent patterns in horse enclosures also mapped by these authors are discussed later in this section. The later study, by MacDiarmid and Watkin (1 72), is more useful for it records dung deposition over two entire, medium and small-sized enclosures, though these were grazed at very high densities. The schematic maps produced would appear to be a summary of a series of observations rather than a representation of the standing crop or dung increment. Summer grazing at a density of 55 cattle ha^{-1} in the smallest enclosure (0.72 ha) produced a very uniform distribution of dung (perhaps emphasised by schematic cartography), but winter grazing in a larger field (1.86 ha) at a lower density (39 cattle ha^{-1}) clearly showed a pattern of extra dung deposition along a tree-sheltered area adjacent to a fence. However this pattern was undoubtedly affected by the presentation of hay feeds in this area.

MacDiarmid and Watkin (1972) thought that the difference in patterns was entirely due to seasonally-induced requirements for extra shelter and food, but it may be that size of enclosure and density of stocking also affected the pattern. In this connection one may note that Petersen et al (1956) found no significant differences between the pattern of excretal distribution in an 0.4 ha field and a 3.1 ha field, which was also of very different shape. But grazing densities in these fields were low, and in any case difference was assessed from the statistical frequency of dung distribution rather than a direct measure of spatial pattern. Richards and Wolton (1976) certainly thought that high stocking densities would reduce an animal's opportunity to select areas of pasture for both grazing and camping and it is a commonplace that understocked pastures often include large areas that are little used and where, in consequence, the grass grows tall and rank (see Thomas 1949). Although, as MacDiarmid and Watkin (1972) commented, their study provided no evidence of intra-field fertility drift in the summer paddocks, this is unlikely to be the case in less intensively grazed pastures and their study does clearly illustrate how a need for shelter could lead to nutrient redistribution during winter months.

Most farmers seem to believe that cattle have a greater need for shelter than is typical of sheep (Munro 1961); even hill cattle tend to be kept on lower, less exposed pastures during the winter months. Many studies mention that cattle react to wind and rain by moving to the leeward side of a pasture (e.g. Hancock 1950, Arnold and Dudz'nski 1978:38-39), and Reinhardt et al (1978) observed this behaviour even within a very small night 'pound'. The transfer of nutrients that this could create might also be reinforced by the tendency for sheep and cattle to graze more intensively on the windward side of a pasture when only light winds are blowing (Arnold and Dudzinski 1078:84). These causes of fertility movement, which one might expect to be most significant under low intensity grazing regimes (e.g. set-stocking at low densities) cross-cut the distinction made earlier, since like camping they are directly associated with grazing activities, albeit modified and directed by sheltering behaviour. Two unpublished studies of dung distribution and nutrient transfer (Briggs: personal communication, Salmon 1980) within cattle pastures provide evidence that supports these speculations and so are briefly presented here with the consent of the individual researchers.

Salmon (1980) examined inter alia the distribution of a standing crop of dung on a grass ley at Portland, Dorset; she also measured sodium bicarbonate-extractable phosphorus in the surface soil (0-10 cm) of the pasture. Figs. 2.6 and 2.7 illustrate the patterns found in a 3.0 ha field grazed for six weeks at a density of 33 cattle (Fresians) ha^{-1}. There is clearly a general concordance in the patterns of dung and soil phosphorus, a very notable feature in land that is not in permanent pasture but is utilised in a barley rotation. Mean values of soil phosphorus in the areas of highest dung density (in the north and east of the field) were, at 140 mg kg^{-1}, some 50% higher than the mean value of samples taken from all other areas of the field (92 mg kg^{-1}). Dominant winds come from the south and west and Salmon (1980:14, 18) ascribed the eastern dung concentrations to the establishment of a resting area in this leeward portion of the pasture. Concentrations of dung along the northern fence, which she described as a latrine area, were affected by the water trough location and by the positioning of mobile milking stations to the west of the water trough. The increase in phosphorus on northern and eastern sides of the field represents precisely the pattern that one would expect to find if sheltering and camping were causing the type of transfers discussed above. It is particularly notable, however, that the gate area is free of dung thoug the area had been heavily trampled and showed marked increases in so'l bulk density, whose pattern within the field as a whole largely cop'ed the phosphorus pattern (i.e. soil phosphorus and bulk density were positively correlated). Since the pre-grazing pattern of nutrient is unknown, one cannot determine from this d ta w at proporti n of the pasture has gained or lost nutrients, but comparison of Salmon's f'eld with the field described immediately below suggests th t a proportion not substantially smaller than the area with P values great r than 100 mg kg^{-1} could be in positive balance.

Briggs (unpublished) examined a 3.90 ha enclosure in western Ireland grazed by a herd of 14 heifers. Figs. 2.8 and 2.9 illustrate the distribution of a standing crop of dung and the pattern of animal locations and activities; the latter is a summary of 58 hourly observations taken during the daylight hours (08.00-18.00) over a period of six days. Dominant winds are south westerly and it is notable that the patterns are in many respects similar to those found in the Dorset study. Three principal differences can be observed. In this field, areas close to gates do seem to attract some extra dung deposition, though the gate in the north east corner might be expected to have received an excess merely as a result of its location in the leeward corner of the field. The concentration of dung towards the northern boundary is less dense but extends into a wider area of the field than was noted in the Dorset field. Finally, the concentrations along the western boundary, which would appear to be at variance with the expected pattern, in fact confirm the importance of shelter as an important factor controlling the location of dung. This area lies adjacent to a steep bluff which, by deflecting the wind upwards, probably provides an area of exceptional shelter on the windward side of the field. If the distribution seen here is representative of the long term pattern in the field, then again one can suggest transfer to leeward as an important part of intra-field nutrient redistribution.

The activity patterns provide further information. Briggs (personal communication) considers that 'camp' areas had been established in two places in the north east corner (these are clearly indicated by the concentrations of lying animals) and other resting spots were also selected towards the center and western half of the field. Although these are daytime observations, the camp location is analogous to that observed in Dorset and makes similar use of a more sheltered spot. However, it is very noticeable that these areas do not contain very dense clumps of dung. Instead, strong concentrations of dung occur close by the camps, and, much less clearly, by some of the day resting sites. Perhaps cattle, like sheep, may sometimes relocate a camp to avoid dense patches of wet excreta. Reinhardt _et al_ (1978), who studied _Bos indicus_ in an

0.04 ha night enclosure, found that individual animals showed very marked preferences for a specific lying zone, but that the actual spot used within such a zone varied from night to night.

Each of these studies confirm Powell's (1 67) hypothesis that, in general, sheltering areas are associated with high dung density and, since neither of them was a winter study, that summer weather, perhaps particularly in windy areas, may be nearly as potent a force as winter weather in creating fertility transfer. These studies also confirm that at moderate grazing densities the establishment of stock camps may well be a typical feature of cattle behaviour not only among free-ranging animals in very large enclosures (Arnold and Dudzinski 1978: 30-31), but also in much smaller paddocks, as suggested by Hafez and Schein (1962). However, one can also note that although some strong concentrations occur, the general pattern of distribution is one of diffuse, wide zones, which may include camping areas. The extremely sharp fell-off in dung and nutrient values seen in sheep enclosures (see Figs. 2.4 and 2.5) does not appear to be a feature of cattle pastures.

Salmon's (1980) phosphorus data provides the best indication that the patterns observed may have some degree of permanence. But, if the link between nutrient transfer and sheltering behaviour is a sound one, then it is likely that predictable patterns are normally present in these pastures. Indeed, it may be that leeward transfer is a more regular, predictable feature than transfers due to camping. There are indications in the literature (e.g. McBride et al 1967:152) that camping behaviour among cattle is less developed than it is among sheep. There is also no clear evidence for the antiquity of this behaviour in cattle, though the fact that it is seen in free-ranging animals and is perhaps most clearly observed among enclosed cattle only if they are grazed at low densities with minimal spatial control over their movements, may be viewed as evidence that the pattern is a basic, natural one. Where modern farming techniques are most oppressive the pattern seems either to be lost or becomes much attenuated.

It may be possible to distinguish the overall pattern of nutrient redistribution by cattle from patterns produced by sheep. Camp anomalies should be less well-defined and probably substantially lower in value. Deposition along fence lines and other transfer patterns associated with sheltering may well coalesce with those produced by stock camps and although variety in wind direction must suggest that all boundary zones may show some enrichment, it may be that a dominant wind will be marred by a leeward transfer movement. Since cattle make greater use of water and shelter, major anomalies could occur at the sites of ancient trees or watering facilities, if these were present. Candidates for such an explanation would include apparently inexplicable nutrient anomalies in, for example, the center of a field. Gates may be characterised by high nutrient values, perhaps to a lesser degree if they are located on the windward side of a pasture. Other aspects of cattle and sheep patterns that may help to distinguish the presence of these animals in ancient fields will be considered after the basic patterns produced by horses have been outlined.

Horses

Like that of sheep and cattle, the eliminative and grazing behaviour of horses, coupled with sheltering and social interactions, leads to the redistribution of soil nutrients (rnold and Dudzinski 1978: 96). However, in the case of horses there seem to be considerable differences between the patterns of transfer created by free- ranging animals and those created by horses confined to small paddocks. Differences between the sexes are also evident.

Free-ranging horses congregate at night or when taking shelter from sun, rain and wind, for which purpose they may often utilise the shelter offered by trees and bushes (Arnold and Dudzinski 1978:30-33, Figs. 1.22a, b, c, Tyler 1972: 97). Arnold and Dudzinski (1978:92-96) imply and the observations of Collery (1974) tend to confirm that night resting areas accumulated unusual amounts of dung. Tyler's study established little about night-time behaviour and he was silent on this particular aspect, but he did note that when congregated in shelter, horses '. . . walked a few yards from the shade to defecate and then returned' (Tyler 1972:104). It may well be that captive horses in large or medium-sized enclosures grazed at low densities may also exhibit these types of behaviour.

The only pertinent observations available are those of Collery (1974), who studied a group of Connemara ponies on an Irish hill farm. These animals were allowed to graze some 400 ha of rough pastures during the summer, but were confined to the bounds of a 14 ha farm during the winter. Unfortunately, it is not clear whether the farm area was effectively sub-divided into smaller enclosures or, as occurs on some hill farms on Dartmoor, were allowed to graze freely the entire or a large part of the farms' enclosed land. The exact number (and thus density) of ponies in a typical winter is also not reported, but from the information provided one may infer that some 15 - 20 animals may have been present. It is clear that in winter these ponies slept together, typically in the lee of a hedge, and that their habitual sleeping areas were heavily contaminated by faeces. Collery specifically noted that grazing and defecation patterns typical of small paddocks (discussed below) were absent from these pastures, and Tyler (1972: 103-104) emphasised that the grazing and eliminative activities of free-ranging New Forest ponies also did not create such patterns.

Although only two studies (Beruldsen and Morgan 1934, 1938, Odberg and Francis-Smith 1976) provide maps which allow one to assess the extent and arrangement of nutrient transfer zones in smaller enclosures, the reports of many other researchers and reviewers (e.g. Taylor 1954, Hafez et al 1962, Dirven and De Vries 1973) confirm that under these conditions horses typically establish 'roughs' or 'eliminative areas', which they reserve for defecation and urination, and 'lawns' in which they graze. Such roughs have been shown to contain anomalously high levels of potassium (Archer 1973) and also ammonium lactate acetic acid-extractable phosphorus and magnesium (Dirven and De Vries 1973) in their soils. Sometimes bare areas may be present near gates, drinking troughs and along fences shared with other horse paddocks and these areas may be used for rolling, but they do not seem to attract dung or grazing, except for the removal of the long herbage often seen close to a fence (Odberg and Francis-Smith 1976). The most detailed studies of the behaviour which gives rise to roughs and lawns are those by Odberg and Francis-Smith (1976, 1977) and unfortunately the horses they studied were removed from the pasture at night or during rainy weather so that patterns which might be created at these times could not be observed. None of the other studies cited provide any indication as to whether or not sheltering or camping behaviour occurred in small paddocks.

Each of the studies which attempted to quantify the areas affected by roughs and lawns (Beruldsen and Morgan 1934, 1938, Odberg and Francis-Smith 1976) indicated that only 50% of the pasture had been retained for heavy grazing, some 30 - 40% usually lay in the ungrazed roughs (though these areas sometimes exceeded 50% of the pasture), with the balance either moderately grazed or consisting of bare patch areas. Beruldsen and Morgan (1934, 1938) found that unlike the irregularities created by avoidance of dung by cattle, rough areas in horse paddocks were persistent features; their position did not alter during two years of study and even when the original patterns had been apparently grazed off by sheep, further grazing by horses re-established them in the same positions. Unfortunately, the location of roughs cannot be properly predicted from the available information. Odberg and Francis-Smith (1976) stated that they had not yet discovered any regularities in shape or relative position of lawns and roughs. However, the pattern shown on their map (1976: Fig. 1), the only map available covering a whole pasture, contained several elements which this author has almost invariably found to be present in small paddocks: the presence of more than a single rough area; the location of roughs away from the boundaries of the paddock; and the presence of a rough close to a paddock gate. In effect most roughs form islands within the grazing areas; sometimes they are subdivided merely by a small path which, as Odberg and Francis-Smith noted, often ends in a Y-shaped expansion into a grazing area. 'Island' roughs are visible in the photographs published by Archer (1972).

If observations of patterns as yet offer little of predictive value, an understanding of the behaviour that produces rough formation may be of some assistance. Although an aversion to consuming herbage close to faeces may tend to reduce the incidence of helminthic reinfestation, it is evident that social factors also play an important role in this behaviour pattern. Odberg and Francis-Smith (1977) regarded the grouping of faeces within well-defined eliminative areas as the result of 'scent marking' behaviour - a common phenomenon among mammals. Free-living horses often place their dung on the defecation or urination of another horse, and sometimes communal piles develop. With stallions, this behaviour was described as a '. . . part of a ritualised aggressive encounter' (1977: 28). There is evidence for selection of a specific rough; sometimes a horse, after sniffing on one area, would move to another rough before defecating (Odberg and Francis-Smith 1976). The different eliminative behaviour of mares and stallions also affects the pattern. Stallions may persistently use a single small area (Hafez et al 1962, Odberg and Francis-Smith 1977) while mares spread their dung more widely across the roughs. These observations suggest that in a field grazed by both sexes, one should expect some very strong anomalies within areas of lesser enrichment. It can also be argued that, since eliminative behaviour in small paddocks seems to be a perversion of patterns of natural behaviour that may well have been present among the wild ancestors of domestic stock rather than an entirely novel feature emerging only among domesticated horses, the pattern could well have been established early on in the history of enclosure of these animals.

To make use of a knowledge of the 'rough-lawn' phenomenon, its applicable conditions must be defined as tightly as possible. Its absence from the field areas studied by Collery and from the pastures grazed by free-ranging ponies in the New Forest have already been noted. Beruldsen and Morgan (1938) recommended the use of sheep and cattle to graze off and 'clean up' horse paddocks; Archer (1972) also recommended cattle for this purpose. Taylor (1954) stated that when cattle and horses grazed the same land, the roughs were eaten off and thereafter horse defecation occurred indiscriminately across a pasture, though no specific evidence for this view was presented. Tyler (1972: 103-104) noted Taylor's comments and added that the New Forest ponies did in fact share their grazing areas with cattle. Collery (1974) did not mention the presence or absence of other animals on the pastures grazed by the Connemara ponies. This data allows one to suppose that mixed grazing of either sheep or cattle or both these species with horses may eliminate or attenuate the nutrient transfer behaviour of the horses, but leaves open to question whether or not the absence of rough-lawn quartering of pasture in the last two cited studies was an effect produced by the presence of other species or was instead a reflection of free-grazing conditions and consequent relatively low stocking densities.

There is no clear evidence for the separate effects of field size and stocking density. Roughs have been observed with stocking densities of 7.4 horses ha^{-1} in a 4 ha paddock (Beruldsen and Morgan 1934), of 5.4 horses ha^{-1} in an 0.74 ha paddock (Odberg and Francis 1976) and 1-2 horses ha^{-1} in paddocks varying in size from 0.25 - 1.60 ha (Dirven and De Vries 1 973). However they were not seen in a 5 ha paddock grazed at 1.2 horses ha^{-1} (Odberg and Francis-Smith 1976), nor in Collery's study, where one may guess at a density near 1 - 1.5 horses ha^{-1} in land totalling 14 ha. From this limited data base one may cautiously infer that the pattern could be present in any pasture smaller than about 5 ha, and that its presence in such fields would tend to imply stocking densities greater than about 2 horses ha^{-1}. A further implication would be that the horses had not been accompanied by other species in such pastures.

The size or proportion of roughs may also be affected by stocking density. Francis-Smith (1977) stated that the roughs were grazed more during August when there was probably a reduction in herbage availability, and Odberg and Francis-Smith (1976) mention nibbling at the edges of roughs when lawns became over-grazed during dry weather. If higher stocking densities were practiced, there might well be a reduction in the proportion of the pasture affected by defecations. However, Beruldsen and Morgan (1934) observed serious grazing in the roughs only during the spring when herbage was abundant; at this time the fresh growth in the roughs was utilised.

To summarise, it is evident that with very low stocking densities and in very large pastures, the only patterns left by horses may be somewhat similar to those found with sheep: enrichment of night resting areas, and perhaps enrichment of sheltered areas by hedges, trees and walls. At higher densities a very characteristic pattern may emerge, which might have some similarities to patterns in cattle pastures, if, for example, a rough were established in the leeward side of a pasture. There is some evidence for the view that nutrient transfer to field edges will be much less marked in horse paddocks, but it has to be acknowledged that as yet there is too little information about horse behaviour in fields to allow confident predictions.

Lateral heterogeneity of nutrient transfers

In the discussion above, a distinction was drawn between different scales of heterogeneity which with sheep, and to a lesser extent with cattle and horses, reflected differences between the pattern of excretal return produced during grazing and that associated with other activities. In some cases the behavioural distinction is not straightforward, but the distinction of the scale is crucial to an understanding of assessments of the heterogeneity of dung distribution in pastures. For example, Arnold and Dudzinski (1978: 95-96) estimated the lateral heterogeneity of dung in a very large (ca.16.5 ha) paddock grazed by sheep, horses and cattle. They concluded that cattle produced the most uniform return of nutrients and sheep the least uniform. However, these authors only assessed differences in the amount of dung deposited within eight very large zones, which together covered the entire pasture. Thus each zone included grazing areas, stock camps, sheltering areas and so on. Despite the large differences in spatial patterning discussed above, it is evident that at this large scale of analysis dung distribution by sheep (Donald and Leslie 1969) and by cattle (Petersen et al 1956 , Richards and Wolton 1976, Hakamata and Hirashima 1978) can be fitted well to negative binomial distribution curves. H kamata and Hirashima (1978) extended the results of earlier work by examining the influence of the sampling quandrat size. This allowed them to identify and then exclude from analysis the clumping associated with non-grazing activities. However, the important conclusion emerged that despite these exclusions cattle dung distribution was still strongly s ewed and the negative binomial distribution remained a good fit to the empirical data.

No analogous information has been published for sheep, and no quantitative study of horse dung distribution of any type is available. However it seems highly unlikely that removal of camping areas from a sheep dung distribution would have as small an effect as was observed with cattle. In the absence of quantitative information and analysis, it is only possible, but nevertheless profitable, to make qualitative judgements about heterogeneity within specific major zones such as grazing areas as opposed to whole pastures. Barrow (1967) made this distinction and pointed out that at equal grazing densities (i.e. 1 cow = 5 or 6 sheep) cattle will produce fewer defecations, but that the area covered by each deposit will be larger. Even on the basis of this observation, one would have grounds for expecting that grazing areas in cattle pastures might show greater heterogeneity than the equivalent zones in a sheep enclosure. When one examines the concept of 'coverage' more closely, this expectation is strengthened.

Cattle produce 10 - 12 dung pats each day which collectively cover (assuming no overlap) some 0.7 - 1.1 m^2 (Marsh and Campling 1970). Sheep defecate 6 - 8 times a day (Spedding 1971: Table 12.1) and their smaller faeces undoubtedly cover a much smaller area, though the actual coverage of an individual act of defecation has never been established. However although even the daily dung output of 5 sheep (c. 2.9 kg Dry matter, Spedding 1971: Table 12.1) weighs less, and probably covers less ground than a single cow (4 - 6 kg Dry matter, Marsh and Campling 1970, Spedding 1971: Table 12.1), it will be spread across a very much larger area of the pasture. Donald and Leslie (1969) found that a single sheep produced between 30 and 45 discrete deposits on the pasture each day because when defecating on the move, a single act of defecation produced numerous small deposits. Dispersion was maximised when faeces consisted of firm pellets rather than soft unformed masses. Thus the 30 - 40 defecations of five sheep will actually be deposited as some 150 - 225 discrete entities, a dispersion that must produce a more even return of nutrients than the 10 - 12 dung deposits of cattle.

This conclusion that, when grazing areas alone are considered, sheep will produce a markedly more even return of dung than cattle, at least in the long run, is supported by opinions encountered in the literature (e.g. Beruldsen and Morgan 1938, Barrow 1967) but cannot be fairly assessed in a quantitative manner from published inform·tion. Although a comparison can be made between the variability of dung weight among quadrats of a sheep paddock published by Hilder (1964: Fig. 1), and the variability in the numbers of dung pats in quadrats of the cattle pasture studied by Briggs (unpublished) see Figs. 2.4 and 2.8, a comparison that appears to confirm the conclusion, differences in quadr⁻t size and the unit of analysis make this procedure unsound.

In large pastures where roughs are absent, horses might produce a pattern of returns similar to that of cattle, but there is very little data available to evaluate this contention. In smaller paddocks where roughs receive the vast bulk of the dung return, natural patterns and levels of soil nutrient variability in the lawnareas may be little affected by grazing horses, though such areas should, like sheep and cattle grazing areas, show a nett loss of nutrients.

Grazing removal of nutrients by sheep at all but perhaps the lowest of stocking densities is also very even compared to that of cattle due to the effect of the latter's strong aversion to consumption adjacent to dung deposits, which by surviving longer than sheep deposits may continue to affect the pasture utilisation for months or even as much as one and a half years (Norman and Green 1958). This phenomenon must tend to reinforce the differences initiated by the acts of defecation. Although, again, there is little data, one may guess that lawn areas in small horse enclosures are grazed as evenly as sheep grazed areas, and since the absence of lawns and roughs in larger horse pastures has been attributed to a loss of the offensive odour of dung before a horse is likely to return to graze the area concerned (Arnold and Dudzinski 1978: 96; the low grazing density is assumed to lead to a long time interval between grazing at any one spot), it may be that horse pastures in very large enclosures will also be grazed uniformly.

No attempt will be made here to assess variability within camping and sheltering areas. Not only is there a serious lack of data, but there is evidence that the extra traffic generated within these areas disperses droppings (Boswell and Smith 1976), a part of the general mixing of materials that arises in these often poached areas of a pasture. It may be that dispersal of this type produces a relatively even if anomalously high nutrient return. Little grazing occurs within these areas.

Finally one must consider the effects of mixed grazing on the pattern of nutrient return. It has already been noted that such a strategy would eliminate or attenuate the rough-lawn pattern of horses, and it may also be supposed that the unevenness of cattle grazing would be reduced under these conditions, since sheep will tend to graze down the long grass near cow dung patches and so prevent the build-up of areas of rank grass. However, it does not seem likely that the pattern of sheep or cattle dung return will be much affected by joint grazing, and in particular sheltering and camping habits are unlikely to be changed. Arnold and Dudzinski (1978: Figs. 1.22a, b, c) illustrated the pattern of day and night resting areas of sheep, cattle and horses, jointly grazing a large paddock, which suggests that in general, each of these species will tend to establish separate camps but these may not be substantially spatially displaced from each other. Clearly a blurring or over-printing of patterns created by a number of different activities could occur, but the final pattern of nutrient distribution that might result cannot be easily predicted. The same is true of grazing strategies which graze different species alternately on the same pasture. A consideration, and it can be no more than this, of the evidence reviewed above, suggests that the very heavy transfer of nutrients to sheep camps should make it possible to identify the presence of this species despite these interfering factors, while an indication of substantial leeward transfers might, somewhat less securely, indicate the grazing of cattle. Diffuse, but sharp-edged and large, 'islands' of anomalously high nutrient values might be taken to indicate that, for a period at least, horses alone grazed in a pasture. Smaller islands, probably with higher overall values, could be interpreted as sheltering or watering areas which might reflect the behaviour of any of these species, though horses and cattle are more likely to use these facilities.

These matters will be further considered when the observations made in this section are summarised in a series of spatial models (see 2.4.1).

2.3.1.2 Changes in the total store of nutrients

To assess loss or gain to an agro-ecosystem one must first define its boundaries. In studies of modern systems, 'the farm' is often chosen as the unit of analysis and the 'farmgate' is recognised as the principal passageway for nutrients flowing in and out of the system.

Although it may be possible to identify 'a farm' within an archaeological landscape and provide estimates of its nutrient flows and balance, such a unit has not yet been discovered among the field systems of the study area. If, as Fleming (1980a) has speculated, the construction and management of the prehistoric field systems involved the participation of a large community, it might be that no unit corresponding to the modern conception of 'a farm' was present.

Even if this were true, it does not necessarily imply that land use within these systems presented a picture of monotonous uniformity. If varied farming strategies were pursued, flows of nutrients between areas specialising in particular activities may well have occurred and would contribute to the present pattern of nutrients within the archaeological landscape. It may well be that future research and analysis will suggest the presence of socio-economic units for whom it would be profitable to attempt to draw up individual balance sheets, but for the present, only a brief indication of the types of activity which would affect such balances seems worthwhile.

Whereas a more or less credible case can be made for believing that even detailed patterns of lateral transfer in ancient agro-ecosystems may have been very similar to those observed on modern farms, it would of course be absurd to extend such reasoning by analogy to assessments of the overall losses and gains in such systems; to apply uniformitarianism in such a context is to follow along the road trodden by, for example, Rhodes (1950:13), who thought that the management of permanent fields must have involved manuring, fallowing and crop rotation (see also Curwen 1927:286, Limbrey 1975:169). Arguments that invoke only 'commonsense' as a means of knowing the past, in fact only reveal an author's own prejudices. In any case, today in many parts of the temperate regions of the world and particularly in western Europe, the use of large quantities of inorganic fertilisers and the integration of most farming production within a market economy has undoubtedly changed the nature and substantially raised the level of inputs and outputs from modern agro-ecosystems to well above the levels that are likely to have occurred in earlier systems. But none of this need deter one from utilising contemporary understanding of nutrient flows as a means of indicating <u>possible</u> nutrient pathways in earlier times.

Even 'natural' atmospheric inputs and leaching and erosional outputs of nutrients may also be higher today than they were in the past, but these aspects, which have been touched on earlier (see 2.2.2), will not be discussed in this section. Instead, the ability of agricultural activities to reduce or augment the rates of loss or gain caused by these types of processes will be considered when differences in the vertical distribution of soil nutrients in arable and pastoral land are compared (see 2.3.3.1). This discussion then is limited to a brief account of the observable overland flow of nutrients that could have arisen as a result of the adoption of particular farming strategies.

Imports and exports of farming produce constitute the most visible and obvious source of changes to the total store of nutrients in an agro-ecosystem. Crops of legumes and cereals, even grass as hay, may have been exported or imported by ancient agricultural units within the study area. Similarly, livestock or their products - carcasses, wool, leather, cheese, milk and butter - may all have flowed in and out of the systems or system of which only a residual total nutrient store survives to be examined and analysed.

Earlier it was pointed out (see 2.2.4) that the vast bulk of nutrients consumed by grazing animals is returned to the land in excret' , and that in consequence export of livestock or livestock products reduces the total store of nutrients only at a very low rate (phosphorus loss due to 'rough' grazing: 0.025 kg $ha^{-1} year^{-1}$). Even if it is assumed that the productivity of the early agro-ecosystems was markedly higher, and allowed grazing at densities twenty times greater (i.e. 6.14 sheep ha^{-1}) than those currently observed in the study area, export of phosphorus in wool, carcasses and leather could hardly exceed 0.5 kg $ha^{-1} year^{-1}$. These figures assume the presence of some 700 sheep or 140 cattle or a mix of these animals within the fields of the 120 ha study area. If the system or parts of it specialised in the more nutrient-demanding activities such as intensive dairy farming, slightly higher losses could occur, but these would still be small by comparison with losses that might have been incurred through an export of harvested plants (see 2.3.2.2). Indeed, if annual cropping of wheat occurred, this could have removed phosphorus at five to ten times the rate grazing animals are likely to have achieved. Of course annual cropping may not have occurred even on folded or manured land; if fallow or grass rotations separated arable production, possible annual losses of phosphorus in grain will obviously vary widely depending on the particular rotation or fallow frequency, but only if cropping was restricted to less than one year in five would livestock induced losses be likely to exceed arable losses.

It may be thought that all these estimates over-emphasise the likely amount of export of materials from a system which may have been largely self-sufficient, but a strategy that involved exchange of animal products in return for grain must be allowed as one of the more plausible ways of exploiting an area of upland. If such a strategy was pursued, it is evident that it could have led to a nett gain of nutrients in upland agro-ecosystems and it is worth considering how such gains might by distributed.

If imported grain was fed to animals on the land, the gains could be distributed widely as part of the general transference of fertility discussed earlier (see 2.3.1.1). Similarly if animals were quartered, or if such grain was consumed by the human population, the residues (human waste, animal litter or bedding) could be distributed on the land as manures. Indeed, if such redistribution was not practised, the consumption of imported or locally produced food would in time lead to a massive transfer of nutrients to animal quarters and with less certainty to human living quarters or areas adjacent to them. Such transfers might well surpass the movements into animal camps. Of course, redistribution of nutrients in farmyard manure derived from locally produced foodstuffs could not change the total store of nutrients, but unless care was taken to balance nutrient returns in manures against nutrient removals in the hay and grain crops such transfers could lead to inter-field transfers of fertility. Although the use of manures and fertilisers on grassland can markedly raise liveweight increases, it seems more likely that the limited supply of these materials would have been reserved for cropland, and so discussion of manure production occurs when nutrient movements in arable land are considered (see 2.3.2.2).

The import of produce is not the only way a pastoral system might achieve a nett gain of nutrients. It was noted earlier that 'day and night' grazing, involving the use of areas beyond the bounds of enclosed land, could increase fertility in the system (see 2.3.1.1) at the expense of nearby land. Alternatively or additionally, the transfer of meadow hay from areas beyond the boundaries to animals grazing within the field system would have a like effect. Similar movements of fertility among small-scale agricultural units operating the system can also be envisaged.

Many modern agro-ecosystems maintain their high productivity only by dint of continual, high level inputs of nutrients, but in many cases, and p articularly with phosphorus, these far exceed the output of elements in exported products. Even improvement of hill pastures of the limited type typified by the experimental farm of the Hill Farming Research Organisation in Scotland indicate substantial nett gains of phosphorus to the system (Newbould and Floate 1978: Table 7). Nor does the data reviewed above suggest that, in the absence of an opportunity to use such fertiliser inputs, the early agro-ecosystems of the study area must necessarily have been losing nutrients at a substantial rate. On the contrary, careful husbandry of wastes, particularly if coupled with imports of nutrients from any of the possible sources specified, could have kept the system in balance or even produced small gains. Certainly there seems no reason to suppose that pastoral farming, albeit at lower levels of productivity than are customary today, would lead to a repid reduction of fertility within the system.

2.3.2 Arable land use

As was the case with pastoral farming strategies, one could put forward a wide variety of possible quantitative models for arable production and its effect on the soil nutrients within early agro-ecosystems of the study area, but for reasons discussed earlier (see 2.3.1.2) this will not be attempted here. Instead, assessment of nutrient changes in arable land will again be limited to reviewing information about contemporary systems in order to indicate the range, nature and probable sign of changes in the system. This task is at the same time simpler and more difficult than equivalent assessments of the effects of pastoral land use.

This paradox stems from the fact that with arable land use, the ways in which nutrients may be transferred, lost or gained depend principally on the pattern of human activities instead of, for example, the specific behaviour of different types of livestock. On the one hand, speculation on the likely nature of arable farming practices is easy, but on the other hand, it is very much harder to make a case for confident predictions about the distribution of nutrients that will characterise such systems.

Changes to the land in arable agro-ecosystems will also be considered under two headings: changes in the lateral distribution of nutrients, and changes in the total store of nutrients.

2.3.2.1 Changes in the lateral distribution of nutrients

Although there is archaeological evidence for the use of ards or ploughs in Britain long before the construction of even the prehistoric field systems presently known on Dartmoor, archaeological investigations within the study area have yet to cast any light on the state of arable farming technology during the floruit of these earlier systems, but have demonstrated that a plough or ard was employed during later, historical cultivations (see 3.2.2). Even at this basic level, one is therefore obliged to deal, not with certainties or probabilities, but merely with possibilities. The small amount of archaeological evidence for prehistoric cultivation in the study area, which is by no means unequivocal, does not indicate anything about the methods used to prepare the land for crops, yet different methods - ards or spades or digging sticks - may have a considerable influence on the pattern of cultivation within an enclosure. If ploughing occurred, headland areas and, in at least some circumstances, positive and negative lynchetting might be expected, whereas if cultivation involved only spades or digging sticks, headlands would be unnecessary and lynchet formation much retarded or absent. Cultivation of any type is likely to have had some effect on the distribution of nutrients within the cropped area, but only the presence of headlands creates areas within arable fields comparable to the major zones of nutrient transfer found in pastoral land. The nutrient status of headlands and nutrient movement associated with lynchetting will be considered first.

Headlands and lynchets

When untreated control plots have not been included in an agricultural experiment, investigators of the soil changes that have accompanied cropping treatments sometimes examine the soils in headlands on the supposition that samples from such areas may be representative of the unaltered 'virgin' soil of the field. It is certainly possible that areas within headlands may retain soil characteristics, including nutrient levels and variability, in an unaltered natural state. It is also possible that these and other characteristics may be seriously affected as a by-product of the activities that occur in the cropping area, or indeed in other ways.

Field edges are places where a variety of substances including artifacts and the residua of meals taken during ploughing, sowing and harvesting, plant remains and stones removed from the cropping area during hand weeding or seed bed preparation may accumulate. If paths along the headlands were used by animals, this too could transfer nutrients to such areas. Sometimes headlands may be spaded over or even ploughed after the main cropping area has been tilled, though in the latter case small zones in the corners of a field might survive untouched. If windrowing was practiced much more substantial changes would occur, which would make the soils in a headland completely unrepresentative of either the field's cropped area or the virgin soil. Fussell (1955) described this practice which is known to have been employed in Essex from at least the 16th until the 19th century. Soils on the headlands would be ploughed or dug up and thrown into hillocks incorporating layers of dung. Later this 'compost' would be spread like dung on the cropping area. Bearing in mind the winter leaching losses of nutrients from such a pile, it is difficult even to guess the sign of the change that this activity might promote in headland soils.

Downslope movement of soil caused either by the physical displacement of a plough and probably to a lesser extent by spade cultivation, or by 'natural' erosion processes, whose rates of activity are substantially enhanced when the natural vegetation cover is removed or ploughed under, could transfer large amounts of nutrients away from areas of negative lynchetting into positive lynchets. It was noted earlier that phosphorus, like other nutrients, tends to accumulate in the topsoil and that a large proportion of secondary phosphorus is associated with the finer soil fractions (see 2.2.2.2); both circumstances ensure that the soil transferred by surface runoff or plough action will be particularly rich in nutrients. Negative lynchets may therefore not only be more stony (Limbrey 1975:331), but should also be particularly deficient in nutrients. Conversely, positive lynchets should trap nutrients and, if fines carried in runoff have contributed heavily to lynchet formation, might also be less stony.

Cropping areas

Nutrient values within the cropping area of a field may be altered by crop removal of nutrients, by manurial additives or by physical rearrangement of topsoil and subsoil, which, for example, may occur when ridges are built. In the latter case, all three processes could contribute to the creation of linear nutrient anomalies which, if the ridges had not survived, would be difficult to observe without very intensive sampling.

In the extensive literature devoted to the effects on soil of cropping and manuring, there are relatively few assessments of changes in the lateral patterning of nutrients and most of these only indicate the overall alteration to the variance of samples (see Beckett and Webster 1971). Exceptionally, Draycott *et al* (1977) mapped the values of agriculturally relevant fractions of soil nutrients w'thin the fields of the Brooms Barn experimental farm, but this land had received large quantities of inorganic fertilisers applied by modern agricultural equipment. In consequence, it can be doubted whether this and many other studies of similarly treated land can sensibly be viewed as suitable analogues for the sort of patterns one should expect in ancient fields.

Early work by Jenny (1941) is of interest since his report of the effects of 60 years of cropping of a prairie soil concerned land that had received no additives of any kind. Although sometimes cited (e.g. Proudfoot 1976) as a study that compared arable with virgin land, this, it must be noted, is not strictly true. The 'virgin' ·rea had in fact been 'pastured and cut for hay' (Jenny 1941:235). Nor is this a mere quibble since several studies have shown that the activities of grazing animals (see 2.3.1.1) do substantially alter the variance of soil samples recovered from grazed areas and that their variance may be raised above those encountered in 'waste' lands and cultivated fields even when the latter have received additives (Gallagher and Herlihy 1963, Beckett and Webster 1971). Nevertheless, Jenny's study did demonstrate that samples from land cultivated and cropped without manures may exhibit very low variance, which presumably arises mainly from the physical mixing of soil during ploughing and harrowing, but may in part reflect crop removal of nutrients. The latter is likely to be greatest where the nutrient-supplying power of the soil is highest, so that in time cropping should tend to iron out nutrient anomalies. Jenny studied carbon and nitrogen changes and one might expect that with less easily-altered, less mobile soil components, the rate of reduction of variance arising in this fashion would be substantially lower. Only a very small proportion of soil phosphorus is available to and utilised by the plant component of the ecosystem (see 2.2.2.1) and consequently one might expect that with this element, physical mixing is the dominant process tending to reduce variance.

Although cultivation with hand tools may locally mix the soil at least as efficiently as a plough, it seems possible that the latter may displace soil over greater distances. Roper (1976) studied the dispersion of bifacial lithics in a ploughed field; her data suggests that over a period of years artifacts may be shifted several metres by plough action and soil clods are just as mobile. Warren and Johnston (1967) assessed soil movement between plots on the Hoosfield Continuous B'rley Experiment at Rothamsted from changes in pH and total phosphorus in paths and no P plots alongside the plots receiving P fertilisers. Despite the fact that every care had been taken to minimise movement during cultivations, soil had been displaced across the 1.6 m path and 'soil analysis showed extra P for a distance of several yards into the no P plots' (1967:332). Similar, if slightly smaller, movements have also been detected on Broadbalk (Johnston 1969a). Both these reports emphasise the very smooth change in values across the plots. Clearly plough movement of soil over long periods is substantial and produces very thorough mixing; one may well be justified in expecting hand cultivated areas to have higher variability.

The effects of ploughing and harrowing are just as important on land that has received manurial additions. With the exception of deliberate placement on or within long-lived ridges, any manures, however haphazardly they may be placed initially, will tend to be thoroughly intermixed within the soil affected by a plough. It is hard to conceive of a degree of manure spreading inefficiency that, combined with later plough mixing, would ultimately give rise to levels of soil nutrient variance greater than would be encountered in cattle and perhaps horse pastures; though land grazed by sheep might be of similar quality or have even lower variance (see 2.3.1.1).

This general conclusion is supported by the studies of variability reviewed by Beckett and Webster (1971), but in view of the small number of studies of 'waste' lands that are available, it is difficult to determine whether manured arable land is likely to be more or less variable than adjacent 'virgin' land. The frequency, efficiency and length of cultivation and of manuring are all likely to affect one side of the comparison, while the extent to which uncultivated land has truly preserved its virginity against marauding herbivores may also vary widely.

It follows from the observations made above, that no reliable predictions about the differences between headlands and cropped areas can be made. Even if headlands retain virgin characters, one cannot even predict whether nutrient levels will be higher or lower than cropped areas, much less can one predict differences in variance, unless a cropping and treatment history is available. The same problems confront any attempt to evaluate changes in the total store of nutrients in arable fields.

2.3.2.2 Changes in the total store of nutrients

Some of the more general considerations that affect assessments of agro-ecosystem losses and gains have already been discussed see 2.3.1.2) and will not be repeated here. The purpose of this section is briefly to enumerate and assess the principal ways in which act'viti s associated with arable farming may produce immediate losses or gains in arable land.

Since, within the soil component of the ecosystem, nutrients are typically concentrated in the uppermost layer of soil, the practice f deturfing land prior to cultivation could have a very substantial effect on the nutrient store within a field. The upper 10 cm of a topsoil with a phosphorus concentration of 550 mg kg^{-1} and a bulk density of 0.9 g cm^{-3} (parameters that may have been typical of the study area prior to agricultural intervention) contains 495 kg ha^{-1} of phosphorus. If turves of this depth were sliced off and then used for construction purposes, for example in reaves, as postulated by Fleming (1978b), two consequences are apparent. First, the surviving remnants of the re·ve-based boundary and immediately adjacent soils should be substantially enriched in nutrients; secondly, potential crop yields on the land so affected would have been, perhaps catastrophically, reduced, an effect which could have persisted for many years. In view of this, it seems most likely that, if turves were used in the construction of boundaries or houses, they would have been obtained from areas outside the bounds of enclosed land (further discussion of boundary construction within the study area appears in section 3.2.2). It also seems probable that if deturfing was a necessary precursor to tillage, then a way would have been sought to return the nutrients in the turves to the cropping area.

This return could be achieved in two ways. A rapid return could be ensured if resort was made to the now traditional Devonshire practice of 'Denshiring' or beat-burning, which is recorded in Devon as early as 1246 (Finberg 1951:91-92). It involved drying the turves until much of the soil adhering to roots could be removed, and stacking the remaining turf fragments in heaps to which straw was added before they were burnt. The ashes would then be spread across the field. Like moor burning, this procedure would involve a loss of the more volatile elements such as nitrogen and the conversion of organic phosphorus to inorganic forms, some of which might be relatively insoluble (see 2.2.4). Alternatively, turf piles could be left to compost more slowly before being forked out onto the land; this process being perhaps less wasteful of volatile nutrients, but involving more le^ching losses during the compost stage. Fither process might leave probably slight nutrient anomalies to mark the site of ancient turf piles, but subsequent ploughing makes it unlikely that observable anomalies would survive. If extra turves were cut from areas beyond the bounds and added to the turf piles, a nutrient gain similar in kind, but potentially much larger in value, to the import of nutrients by 'day and night' grazing or meadow hay cutting, could result.

The subsequent cultivation, in itself, would not alter the total store of soil phosphorus (changes to soil organic matter and alteration of erosion and leaching rates are considered in section 2.3.3), but cropping would remove substantial amounts of nutrients, which might either be transferred within the system (human or animal consumption) or exported, as grain, beyond its bounds. It is not at all easy to estimate losses of phosphorus due to cropping in early agricultural systems because the amount of phosphorus removed by a harvest varies substantially as a function of crop yield, which itself can only be estimated to within rather wide limits. Several sources have been used to establish the most likely range of crop yield values. Table 2.5 shows yields typical of Devon in the post-war period as well as estimated of yields on two farms close to the study area. Comparison with yields typically gained on English farms prior to 1940 (Table 2.6) indicates that yields in Devon today are markedly higher; this no doubt reflects in part the use of improved strains of cereals, but increased use of inorganic fertilisers in the post-war period must also be a factor. Table 2.5 also shows that local farms on the granite at altitudes identical to that of the study area only obtain just over half of the grain yield of lowland farmers, who have the advantage of better soils and climate. However, it is unlikely that the present differential is a simple direct reflection of environmental factors. With a potential for higher yields, it pays lowland farmers to invest heavily in fertilisers, pesticides, herbicides and the like, while even the best yields achieved on upland farms cannot justify as high a level of crop investment. A natural differential of around two-thirds seems to be a reasonable estimate.

The pre-war yields in Table 2.6 are far higher than the yields recorded on medieval farms in England. Table 2.7 summarises the records of yields obtained on one of the estates of Tavistock Abbey in the 15th century. These seem to provide the best available guide to possible yields in Devon at this period. The last column in this Table applies a

Table 2.5 Some modern grain yields on Devon farms ($t\ ha^{-1}$)

	Wheat	Barley	Oats
Devon, Teign Valley and surrounding region [a]	4.52	3.39	3.77-5.02
Rowbrook farm [b]	ND	1.8 - 2.1 (sometimes 2.5, and very rarely 3.7)	
West Stoke farm [c]	ND	ND	2.5

(a) Clayden (1964: 73)

(b) Information from Mr Algernon May

(c) Information from Mr Norman Perryman

Table 2.6 Typical arable yields and uptake of phosphorus on English farms before 1940 [(a)]

Crop	Yield (t ha^{-1})			Phosphorus uptake (kg ha^{-1})			Phosphorus in crop (%)	Ash wt. (kg ha^{-1})		
	grain	straw	total	grain	straw	total	grain + straw	grain	straw	total
Wheat	2.0	3.5	5.5	7.0	3.4	10.4	0.189	34	159	193
Oats	2.1	3.2	5.3	6.4	3.1	9.5	0.179	57	157	214
Beans	2.0	2.2	4.2	11.2	3.0	14.2	0.338	65	111	176
Turnips	42	13	55	11.0	5.3	16.3	0.165	244	164	408
Hay	-	-	3.7	-	-	6.1	0.030	-	-	228

(a) Russell (1973: Table 2.1)

Table 2.7 Medieval grain yields, Hurdwick harvests, Tavistock Abbey, Devon[a]

Crop		bushels/acre[1]	Statute bushels/acre	t ha^{-1}	t ha^{-1} (2)
Wheat	$\bar{x}$ & SD	11.73 3.02	12.32 3.17	0.83 0.21	0.55
	Range	7.7 -18.65	8.09 - 19.59	0.54 - 1.32	0.36 - 0.88
9 out of 13 years		>10	>10.50	>0.71	>0.47
Rye	$\bar{x}$ & SD	17.47 5.66	18.35 5.94	1.23 0.40	0.82
	Range	10.56 - 27.58	11.90 - 28.97	0.75 - 1.95	0.50 - 1.30
7 out of 13 years		>15	>15.75	>1.06	>0.71
Oats	$\bar{x}$ & SD	17.50 6.35	18.38 6.67	1.23 0.45	0.82
	Range	7.76 - 25.57	8.15 - 26.86	0.55 - 1.81	0.37 - 1.21
9 out of 13 years		>17	>17.86	>1.20	>0.80
Small Oats	$\bar{x}$ & SD	26.69 14.80	28.03 15.54	1.89 1.05	1.26
	Range	14.57 - 59.19	15.30 - 62.17	1.03 - 4.18	0.69 - 2.79
10 out of 13 years		>17	>17.86	>1.20	>0.80

(a) Finberg (1951: Tables IX and X). All data refers to 13 years between 1412 and 1537.

(1) These data seem to be 'Exeter' bushels (25% larger than statute bushels) and 'Devon' acres (19% larger than statute acres (see Finberg 1951: 30-31, 113); column 2 shows statute measurement equivalent values and column 3 shows metric equivalent values calculated from the adjusted, statute bushel/acre data.

(2) The values in column 4, calculated by the author, equal 2/3 rds of the values in column 3.

two-thirds differential to the original figures, which allows one to estimate that crop yields in the study area might have lain between 0.55 and 1.26 t ha^{-1}, depending on the crop concerned. The range of yields shown in the Tavistock records are not unlike those obtained in some of the classic experiments at Rothamsted shown in Tables 2.8, 2.9 and 2.10, though this is only true if comparisons are limited to the plots which received no fertilisers or farmyard manures (FYM) during a period of continuous cropping. Finberg (1951:86-115) described the arable husbandry of the Tavistock estates in some detail and indicated the use of large quantities of shell sand, the application of FYM and beat-burning on their fields. The latter item implies convertible husbandry of some type. It is therefore somewhat surprising that the medieval yields recorded are so much lower than those obtained on the FYM plots of, for example, the Broadbalk (Tables 2.8 and 2.9) and do not even reach yields obtained on the No Treatment plots in the years after a 'one in four' bare fallow had been introduced (Table 2.9). This is not the place to assess whether medieval crop records provide an accurate guide to the grain harvested from the fields, but it can be argued that the Rothamsted experiments may be as worthy a guide to ancient crop yields. If this is accepted, the Rothamsted results can be employed to support a suggestion that with fallowing or convertible husbandry and some use of FYM, yields in the study area might have been markedly better than the lowest estimates given above; for wheat, a normal range of perhaps 0.7 - 1.0 t ha^{-1} seems feasible, with occasional poorer harvests down to 0.5 t ha^{-1}, while oats, a crop better suited to the damp climate of south-west Britain, might have yielded perhaps 30% more grain.

The amount of phosphorus removed by crops appears to depend mainly on the yield. Luxury uptake seems to have been virtually absent on the Broadbalk plots under continuous wheat (Table 2.8), though barley grown on the Exhaustion Land (Table 2.11) did show slightly higher concentrations of phosphorus in the grain from plots which had received FYM before 1901. Russell's (1973) data on English crop yields (Table 2.6) shows a similar relationship between crop yield and phosphorus uptake to that found in the Broadbalk crops (Table 2.8) and this general relationship has therefore been used to estimate the range of phosphorus losses that could have accompanied various levels of cropping success (Table 2.12). If it were assumed that luxury uptake as seen on the Exhaustion land occurred, then this Table would slightly underestimate removals for cropping with FYM. These figures

Table 2.8 Wheat yields and phosphorus uptake per harvest on the Broadbalk, Rothamsted 1862-1871[a]

Plot and	Mean wheat yield (t ha^{-1})			Phosphorus uptake (kg ha^{-1})	Phosphorus in dry matter (%)		Phosphorus in crop (%)[2]
treatment	grain	straw	total	grain + straw	grain	straw	grain + straw
28 FYM[1]	2.67	4.27	6.94	13.3	0.436	0.098	0.192
3 none	1.03	1.44	2.47	4.7	0.439	0.091	0.190

(a) Johnston (1969b: Table 4.7); Garner and Dyke (1969: Tables 3.16, 3.17).

(1) Annual dressings of FYM (35.1 t ha^{-1}) provided 33.6 kg P ha^{-1} (see Garner and Dyke 1969:31)
(2) calculated by author.

Table 2.9 Mean grain yields per harvest (t ha^{-1}) on the Broadbalk, Rothamsted (continuous cropping of wheat)[a]

Plot and treatment		Early years		Middle years		Weed years[1]	Fallow years[1]	
		1852-61	1862-71	1892-1901	1902-11	1922-25	1935-44	1945-54
2B	FYM	2.41	2.67	2.85	2.62	1.64	2.61	2.96
3	none	1.12	1.03	0.89	0.80	0.39	1.31	1.36

(a) Garner and Dyke (1969: Table 3.16)

(1) Weed infestation lowered yields and led to the introduction of a one year bare fallow break in every four years.

Table 2.10 Annual grain yields (t ha^{-1}) on the Exhaustion Land, Rothamsted, 1902-1922 (continuous cropping of barley).[a]

Plots and Treatment	1902	1903	1904	1905	1906	1907-11[1]	1912-16[1]	1917-22[1]
3, 4 'old FYM'	4.19	2.68	2.85	1.81	2.66	1.29	1.26	1.24
1,2,5,6 'No phosphorous manures'	2.07	0.71	1.08	0.38	0.89	0.54	0.80	0.75

(a) Johnston and Poulton (1977: Table 8).

(1) mean harvest yields.

Table 2.11 Barley yields and phosphorous uptake per harvest on the Exhaustion Land, Rothamsted, 1949-74 (continuous cropping of barley).[a]

Plots and Treatment	Range of barley yields ($t\ ha^{-1}$)		Phosphorous uptake ($kg\ ha^{-1}$)			Phosphorous in dry matter (%)	
	grain	straw	grain	straw	total	grain	straw
3, 4 'Old FYM'[1]	3.03 - 4.75	2.02 - 3.30	10.47	1.25	11.72	0.356	0.052
1, 2, 5, 6 'No phosphorus manures' (2)	1.59 - 2.02	1.24 - 1.92	3.96	0.70	4.66	0.278	0.057

(a) Johnston and Poulton (1977: Tables 2, 4, 9, 10 and 11)

(1) 26 dressings of FYM (35.1 $t\ ha^{-1}$) supplying in all 1025 $Kg\ P\ ha^{-1}$ *were given* to these plots before 1901; no subsequent phosphorous manures.

(2) All plots given annual nitrogen dressings after 1941; note that slight variations in plot treatments are not given here.

Table 2.12 Estimated phosphorous uptakes in grain and straw per harvest of wheat. [a]

	wheat grain yield		Phosphorus uptake (kg ha^{-1})	
t ha^{-1}	lb/acre [1]	bushel/acre [1]	FYM	No treatments
0.50	446	7.4	2.49	2.28
0.75	669	11.4	3.73	3.42
1.00	892	14.9	4.97	4.57
1.25	1115	18.6	6.22	5.71
2.00	1784	29.8	9.95	9.13

(a) calculated by the author from Broadbalk data (given here in Table 2 .8).

(1) These columns indicate non-metric equivalent values; column 3 uses statute bushels and acres.

suggest that a wheat harvest would rarely have removed less than 2.5 kg ha^{-1} of phosphorus and that removals of 3.5 - 5.0 kg ha^{-1} would be typical. These estimates probably also enclose the range of values associated with other kinds of crops, though a good harvest of oats might have taken rather more than wheat. Table 2.6 indicates that cropping of beans also might have removed more phosphorus than cropping of wheat.

These estimates assume that both grain and straw were removed from the fields. If much of the straw stubble was ploughed under, grazed off or burnt off, phosphorus losses would be lower, but not substantially different, because most of the phosphorus in the crop is found within the grain (Tables 2.6, 2.8 and 2.11). It seems possible that stubble burning, like Denshiring, might convert organic phosphorus in plant residues into relatively insoluble, inorganic forms of phosphorus (see 2.2.4). Phosphorus losses in harvests may also have been offset by a return of human and animal wastes. Some of these may ultimately have been derived from crops and grain grown in the harvested fields thus simply completing a circuit, albeit with some losses, but wastes arising from the consumption of imported grain or hay collected from beyond the bounds of the system would represent real gains of nutrients.

If animal and human excreta or kitchen wastes were added as manures to the ancient fields of the study area, there can be little doubt that a nett gain of phosphorus could occur. Fixation of the phosphorus applied in agricultural fertilisers including FYM, a perennial agricultural problem, requires that farmers who wish to maintain maximum yields must continually add more phosphorus in fertilisers than will be removed in the subsequent cropping. As a result much intensively used farmland is continually gaining phosphorus. If very high fertiliser inputs are used, it is possible to saturate at least the plough layer of some soil types so that the soil no longer fixes, and in such cases maintenance dressings can be reduced to a level that supplies only the amount removed by cropping. Although this has been reported in Dutch arable farms (Henkens 1978: Tables 28, 29), most arable farms which use fertilisers probably only recover in their crops less than 50% of applied phosphorus (Frissel and Kolenbrander 1978:288-290).

However, in two circumstances it seems possible that little if any residue would be detectable. First, if only very small amounts of manure were applied, crop removal of phosphorus could exceed manurial additions. At Rothamsted, 1 t of manure containing straw and cattle excreta supplied 0.95 kg of phosphorus (Garner and Dyke 1969:31), a concentration that consultation with other sources (Salter and Schollenberger 1939, Hemingway 1961, Peperzak et al 1959, Marsh and Campling 1970) suggests is not atypical. From this, one can calculate that an FYM dressing of 4 t ha^{-1} would only just balance the losses induced by a wheat harvest that yielded 0.75 t ha^{-1} of grain (Table 2.12). Today FYM dressings of less than 20 t ha^{-1} are rare (Ministry of Agriculture, Fisheries and Food 1967) and dressings as high as 40 t ha^{-1} not uncommon, but although actual rates of fertiliser application reach these magnitudes, the effective rate per annum on arable and pasture land is usually much lower. Typically farmers apply all the available FYM to a part of their land each year and the long-term overall rate of application may often be less than 3 t $ha^{-1}year^{-1}$, as it is today in north and south Devon (1967:28-31). Fortunately, this low overall rate can be accompanied on modern farms by inorganic fertilisers, without which yields would fall dramatically, since there would simply be insufficient FYM to maintain current yields.

It does not seem likely that vastly greater quantities of FYM were available to earlier farmers. The amounts which might have been available to farmers in the study area can be estimated. Table 2.13 combines information from various sources in order to pinpoint the individual contributions of straw and excreta; the overall estimate of 11.9 t $year^{-1}$ of FYM from a milking cow is similar to the value calculated by Salter and Schollenberger (1939:Table 20), who also indicate that sheep would produce only half as much manure as a milking cow per unit of liveweight, but that sheep manure would supply about 50% more phosphorus per unit weight of dung. The concentration of phosphorus in the FYM shown in the Table is identical to that of the Rothamsted FYM (i.e. 0.95 kg t^{-1}).

Using the grazing population estimate introduced earlier (i.e. 140 cows in the 120 ha study area), and assuming that all the excreta produced during a period of 150 days in byres was utilised, it can be calculated that some 5.7 t ha^{-1} FYM supplying about 5.5 kg ha^{-1} phosphorus could be applied throughout the study area each year. Alternatively, a quarter of the fields could have received a dressing of about 23 t ha^{-1} each year; in the absence of inorganic fertilisers, the latter seems a more likely strategy. Note, however, that if FYM were applied in a rotation to all the fields, the overall rate of application can contribute only slightly more phosphorus than would be removed by a 1.0

Table 2.13 Estimates of manure production and the amount of phosphorus in faeces, straw and FYM.

	kg cow^{-1} day^{-1}	t cow^{-1} $year^{-1}$	kg cow^{-1} $year^{-1}$	t cow^{-1} 150 $days^{-1}$	kg cow^{-1} 150 $days^{-1}$
Fresh faeces (milking cow)	28.6	10.44		4.29	
Dry matter	4.0	1.46		0.60	
Phosphorus	0.028		10.22		4.2
Straw (air dry)	4.1	1.50		0.615	
Phosphorus	0.003		1.17		0.479
Faeces + straw		11.94		4.905	
containing phosphorus			11.39		4.679

150 days output from 140 milking cows		Rate of application if applied on: 120 ha	30 ha
FYM	696.7 t	5.7 t ha^{-1}	22.8 t ha^{-1}
Phosphorus	655.06 kg	5.5 kg ha^{-1}	21.8 kg ha^{-1}

t ha^{-1} grain harvest. If sheep formed a substantial element in the grazing population, it might well have been difficult to achieve even the very slow phosphorus enrichment that might have occurred with cattle. Of course, even slow enrichment would be impossible if it were assumed that a significant proportion of the feed consumed in winter byres was derived from hay and grain crops taken from the land which would receive manure.

Clearly, even using the optimistic manure production estimates advanced here (optimistic, because they assume that the grazing population of a pastoral farming system, which was estimated earlier, could be accommodated without reduction within a system that also included arable production), rotational manuring involving dressings not dissimilar to those encountered today will only lead to nutrient enrichment of land if large amounts of hay, grain or manure are procured from beyond the bounds of the agro-ecosystem. However, even without imports, a strategy that applied all the available manure on a relatively small proportion of the area, year after year, could supply substantially more phosphorus in FYM than would be removed even by continuous cropping of such areas. Only this sort of 'infield' manuring policy will lead to substantial land enrichment; nor need it involve the production of FYM, since 'day and night' transfers could be used to achieve much the same effect (see 2.3.1.2). Judging by the yields obtained on the No Treatment plots of the Broadbalk (Table 2.9), which are bare-fallowed every fourth year, 'outfield'-type cropping could have been a viable accompaniment to an infield strategy, even if no manures were available for such crops. Although Rothansted's soils are certainly more fertile than those in the study area are ever likely to have been, a change from three years' cropping out of four to perhaps one year's cropping in five or even ten years would go a long way to redressing the natural deficiencies of the soils in the study area. Certainly, pace Limbrey (1975:169), manuring cannot be regarded as an inevitable necessity for arable exploitation within permanent field systems; nor is crop rotation, though this would certainly contribute to the maintenance of yields by reducing the incidence of crop specific pests. If such outfield cropping occurred frequently or over a very long period of time, detectable losses of soil phosphorus might result.

It is also possible to envisage perhaps somewhat unlikely circumstances in which a surplus store of phosphorus accumulated at one time is totally removed by later cropping without the use of FYM, a second way in which the practice of manuring might leave little if any detectable residue. An example of this is provided by the experiment on the Exhaustion Land at Rothamsted (Johnston and Poulton 1977), where phosphorus added in FYM in the late 19th century is being slowly but steadily removed at present by continuous cropping of barley. The modern rate of removal on both the No Treatment plots and the ld FYM plots has been enhanced by the dressings of nitrogen, which have been added to all plots since 1941 (see Tables 2.10 and 2.11), but the higher yields on the Old FYM plots in 1917-1922 (last FYM in 1901) coupled with slightly higher concentrations of phosphorus in the present crops strongly suggest greater phosphorus uptake on the Old FYM plots even before the nitrogen treatment commenced. Unfortun tely, no records of crop yield or crop composition are available for the period 1923-1941. Johnston and Poulton (1977:64) stated that between 1949 and 1975, barley cropping had removed about 25% of the residual phosphorus that they estimated was still present in these soils in 1949. They thought that these residues might survive a further 70 or more years of cropping; if their prediction is fulfilled it will have taken a total of 150 years cropping to remove the effects of 26 dressings of FYM (each one of 35 t ha^{-1}). Including the smaller amount supplied as superphosphate, about 1260 kg P ha^{-1} was supplied by these treatments, which gives a mean loss rate of 8.4 kg P $ha^{-1}year^{-1}$; a higher loss rate than would have been observed without the additional treatments. Clearly small dressings of FYM might easily be removed by later exhaustion cropping.

Although it has been possible in this discussion to introduce quantitative data on the effects of various activities associated with arable cropping, it is, as argued earlier, pointless to attempt, at this stage, any estimate of overall transfers or balances within potentially complex agro-ecosystems. Firm predictions are therefore not possible. However, one can suggest that if a small proportion of land is found to have very much enhanced amounts of phosphorus, then there is a strong probability that some form of infield system of management has been employed. Manures spread more thinly will not leave substantial, perhaps not detectable, anomalies in the landscape. Lowered levels of phosphorus within a field from which soil samples exhibit the low level of variability which may be typical of cultivated land may indicate long-continued outfield cropping without manures.

2.3.3 Pastoral and arable land use

Although it was thought more convenient to detail the tr nsfers and changes of nutrients in pastoral and arable land in separate sections, the separate effects of some metapedogenetic changes which may be used to characterise arable and pastoral land use are more easily described and explained in a single discussion which allows direct comp rison. This section is devoted to such discussion and is presented in two parts. First, changes in the vertical distribution of soil phosphorus, including altered leaching and erosion rates are considered; secondly, the effect of various types of land use strategies on the soil organic matter are briefly reviewed.

2.3.3.1 The vertical distribution of soil phosphorus

Bakkevig (1980, 1981) has suggested that different types of ancient land use might be identified by non-quantitative evaluation of the vertical distribution of phosphorus in soil profiles. Fig. 2.10 reproduces some of the patterns which he thought gave credence to his speculations. These patterns do indicate that, even with the relatively crude field testing technique favoured by Bakkevig, in some soils it is possible to detect profiles whose phosphorus content has been changed by human activities. But there seems little in this work which, as yet, would justify a recognition of 'land use-specific' patterns of phosphorus distribution of the type he appears to be attempting to isolate. For example, the distribution of phosphorus in what seems to be modern intensively used pasture and in 'early tillage land', which he supposed might also have been affected by later, recent tillage, are essentially similar; they differ primarily only in the amount of phosphorus measureable using Bakkevig's field kit. In fact, there was no other clear evidence that tillage had affected the area concerned and attributing its pattern of phosphorus distribution to this activity was pure speculation, untempered by any adequate assessment of modern patterns or of the variability of such patterns in different soils.

In this author's opinion, the patterns illustrated by Bakkevig may conflate the effects of fertiliser applications, perhaps of varying age, both on grassland and on arable land and moreover probably include variation due to differences in the natural pedogenetic factors that have affected the profiles. Only if the separate effects of the state factors and metapedogenetic factors can be successfully identified in land affected by known agricultural practices can one hope to move towards credible inferences about past land use, and only then, if the transformations which may have occurred since the agricultural episode have been taken into account.

At the outset of this enquiry, it was hoped that the vertical distribution patterns of soil phosphorus would provide a key to ancient land use, not least because it was thought that the sampling density needed to establish the nature of such patterns would be lower than that needed to determine lateral patterns. In consequence, considerable effort was put into a thorough search and analysis of the literature which reported this type of information; there is certainly no shortage of published data, though arable land is much better served in this respect than permanent pasture land. However, it has to be admitted that this search for land use-specific patterns has to a large extent been a failure; one does not have to look far to understand why this is the case.

In the first instance there is the problem posed by the fact that the vast majority of modern analyses concern land which has received large and varied inputs of inorganic fertilisers of types unavailable to early farmers. This is the case with both arable and pastoral land. These studies, some of which are briefly discussed below are of limited relevance because it has been shown that there are considerable differences in the way in which phosphorus supplied in inorganic fertilisers and in dung or FYM reacts with the soil. There are of course some experimental studies limited to FYM additions, but even in these cases, the large amounts of manures supplied (often 35 t $ha^{-1} year^{-1}$), which are very generous, cast some doubt on their suitability for the extrapolation that is necessary in this context. There is also an acute shortage of studies which compare adjacent profiles affected by arable and pastoral activities. Most experimental agricultural stations specialise in either the one or the other; few investigate both. At Rothamsted, where plot 19 (FYM) of the Park Grass experiment and the nearby grazed portion of the Broadbalk Wilderness experiment provide, in conjunction with the classic arable experiments, a unique suite of soils in which to study these matter, there have been, so far, no investigations of phosphorus in either of the first two sites. The Grassland Research Institute at Hurley has compared soils under grazed grass and arable crops in a twenty year experiment (Garwood *et al* 1977), but this also provides no significant information about soil phosphorus. Nor are data from the 'control' plots of such experiments always ideal for the purposes served here because in most instances the experimenters have sought to compare the effect on crop yields and soils of cropping with or without a specific treatment or fertiliser; an uncropped control is rarely investigated. A precisely analogous problem exists with respect to grassland studies. Although the fate of phosphorus in FYM dressings has been traced, the separate effects of cropping and grazing are harder to evaluate, a task made no easier by the fact that natural processes of soil formation can exert an overriding influence on these patterns.

Variations in profile distribution in podzolised soils were noted earlier (2.2.2.2). Some of this variation is due to variation in sesquioxide and organic matter content, which affect the soil's propensity to fix phosphorus (see Williams 1959, Ozanne 1962, Fox and Kamprath 1971, Logan and McLean 1973) and are themselves affected by, for example, soil drainage (for examples of increased phosphorus mobility and losses in gleyed soils see Glentworth 1947, Glentworth and Dion 1949, Williams and Saunders 1956a, 1956b, Williams 1959, Runge and Riecken 1966). Soil texture and structure can also exert a profound influence on the vertical distribution of phosphorus (see Stephenson and Chapman 1931, Neller 1946, Spencer 1957, Fiskell and Spencer 1957, Ozanne et al 1961, Ozanne 1962, Bolton and Coulter 1966). The combination of pedogenetic and metapedogenetic factors produces an awesome variety of distribution patterns in different soils, a situation that undermines predictions even about the initial state of a soil at the moment agricultural activities are abandoned. Nevertheless some crude generalisations can be extracted from the available data.

One major difference between arable and virgin land, which might be found in nearly all circumstances, is a pattern of distribution imposed by the mechanical mixing associated with cultivation itself. Whereas in natural soils of podzolic type (and many other types) there is a more or less steady fall-off in phosphorus concentration (wt/wt) with depth down to at least the thickness of most plough layers (i.e. about 15 - 25 cm), samples from any point within the plough layer of regularly and recently cultivated land must be of more uniform composition. In many reported profiles this pattern cannot be clearly observed because in most instances the size of the sampling interval within plough layers is very large (often only a single sample is taken) due to the investigators' expectation of such a pattern; the effect is however apparent in some studies (e.g. McDonnell and Walsh

1957: Table 2 and Fig. 1). When cropping does not involve cultivation (i.e. direct drilling and 'dibbling'), and particularly if fertilisers or manures are applied to the undisturbed surface, this pattern will, of course, be absent.

If intensive grazing has any substantial effect on the vertical distribution of soil phosphorus, it is likely to be one which accentuates the natural pattern of surface concentration and subsurface extraction zones, though in some cases it might lead to increased rates of downward translocation. It was noted earlier (2.2.4) that, in land with a poor capacity to supply nutrients, grazing can improve the productivity of a soil-organism ecosystem because excretal returns speed up the cycling of nutrients. It is self-evident that this will only be the case in systems in which productivity is limited by a soil nutrient deficiency of some kind; the supply of phosphorus has often been allocated this role (see 2.2.2.1). In such cases, it is thought that most of the phosphorus returned in excreta in inorganic forms that are re·dily available to plants will rapidly be immobilised by the organic elements in the system. Initially unavailable organic forms may in time be released through mineralisation and thus continue to circulate. However at any one time, particularly in cold, wet, acid soils, a large proportion of the phosphorus return may remain locked up in organic forms within the litter and other organic surface layers. In such systems, dissolution of soil minerals may provide only a very limited proportion of the supply of plant nutrients. In systems where nutrient supply is not limiting or where deficiencies have been remedied, the biological element in the systems may exert a less tight hold over the available, soluble forms of phosphorus that are returned in excreta, which may, in consequence, be more readily leached from the surface layers. In this situation, increased supplies of excretal phosphorus could enhance the amount of phosphorus loss from surface layers.

Differences in the vertical distribution of soil phosphorus could also arise from variability in plant extraction patterns in arable and pastoral land, but it is difficult to make confident forecasts from the information available. The amount of phosphorus extracted by a plant at a specific depth varies not only as a function of the plant's rooting habits, but also with soil and climatic conditions (Russell 1973:520-554). Annual crops in unfertilised land may well be unable to tap nutrients to the same depths as perennial grasses in permanent pastures, but if manures and fertilisers are added to the former and not the latter, differences in rooting and extraction of nutrients might be decreased since fertilisers incorporated in the surface soil can increase the weight of roots, rooting depths and the uptake of nutrients from subsoils. Boggie and Knight (1958) investigated P^{32} uptake by plants in acid grassland in Aberdeenshire and pointed to the high proportion of absorption in the uppermost 10 cm of the profile, though certain plants - Agrostis tenuis, Holcus lanatus, Carex arenaria - made far more use of the subsoil phosphorus. These authors emphasised, however, that comparisons of their results with plant communities from other areas must take into account soil differences. It is evident from such studies that where agricultural activities cause a nett loss of nutrients (cropping without manures, areas suffering from loss by sheep transfer, etc.,), the loss will mainly affect the upper part of the soil profile.

The upper part of the profile is also most at risk from erosion and leaching losses of phosphorus. Arable land is more vulnerable to erosion losses, since the density of plant cover which intercepts rainfall is reduced; rain splash and run-off induced erosion will be maximised when cropping practices include a bare fallow. As one would expect, much data on erosion has been recovered from areas where it creates serious problems for farmers. The coarse sandy soils of the study area (see 3.3.2) allow rapid infiltration of rainfall where peat and iron-pans are absent, and catastrophic erosion of the type which removes the entire soil surface and thus truncates the soil profile is very unlikely to have occurred save on the steepest slopes at the fringes of the study area. However, land used constantly for arable as occurs in an 'infield' system may well, in time, suffer a disproportionate loss of finer particles, which could be deposited on lynchets (see 2.3.2.1); this will reduce the concentration of phosphorus and increase the proportion of coarser material in the soils left behind (see Neal 1944).

Although the evidence for phosphorus leaching losses from arable and grassland soils (reviewed by Cooke and Williams 1970, 1973, Cooke 1976) is neither as extensive or consistent as one would like it to be, there are some indications that, as is the case with most other soil nutrients, losses of phosphorus from arable land are greater than losses from permanent grassland. Data inconsistent with this generalisation include estimates based on samples from shallow tile drains beneath pasture, which may have been contaminated by excreta (Cooke and Williams 1970:257), and data from the Netherlands (Cooke and Williams 1973:22) where grassland losses are reported as higher than arable losses. In the latter case, one may suspect that high losses reflect very high phosphorus inputs in fertilisers or feeds; there is clear evidence that fertiliser phosphorus applied to grassland penetrates the soil more deeply than similar applications on arable land (Cooke and Williams 1973, Johnston 1976), though this evidence does not prove substantial loss from the soil profile as a whole. This is also the case with the evidence for movement of excretal phosphorus, which if it had not been intercepted by a shallow drainage system, might well have been trapped lower in the profile. However, it is noteworthy that Cooke and Williams (1970:268) suggested that 'cattle congregated near gateways and under shelter in bad weather drop so much excreta in small areas that there is a risk some may be washed into nearby drains or streams'.

This risk would be increased by the reduced infiltration capacity of the soils in stock camps, gateways etc., a result of the compaction, shearing and remoulding of the surface soil that is typical of heavily trampled soils. D.J.Briggs (1978) studied these features and also assessed the changes of nutrients in such areas. From his samples and experiments it is apparent that nutrient enhancement of camp soils may be a three-way process. As already noted (2.3.1.1), there is less nutrient removal due to grazing in these areas and they receive far higher inputs of dung than other parts of the pasture. However, higher bulk density at the expense of pore space reduces infiltration and thus leaching from the surface soil. On the other hand there is evidence (Campbell and Racz 1975) that where exceptionally large amounts of excretal phosphorus accumulate on the soil, as occurs in feedlots, a higher rate of loss by leaching may result, though, despite this, very large quantities of added phosphorus will persist in surface soils and subsoils.

What is quite clear, even from the relatively sparse data available, is that in general leaching loss rates in both arable and pastoral land are closely comparable with virgin soil-organism ecosystems' loss rates and are thus very low (see in particular, the most recent data from Saxmundham (Williams 1976: Table 12)). Any systematic <u>differences</u> between leaching rates under these different regimes, if they exist, are even smaller and therefore are unlikely to seriously affect the picture of past agricultural inputs and outputs that may be obtained by examining contemporary soils. Although loss rates are small, this does not mean that phosphorus, particularly additional phosphorus from manures and fertilisers, has not moved from surface soils into the subsoils. In this respect there are very substantial differences in the way in which <u>inorganic</u> phosphorus inputs affect arable and grassland.

In a survey of the evidence provided by long-term experiments at Rothamsted and Woburn Experimental Stations, Johnston (1976) showed that although phosphorus from inorganic fertilisers had penetrated below the plough layer on the Agdell and Barnfield plots, far deeper penetration was evident on Park Grass (permanent grass for haymaking since 1856). However, he also showed that on the arable plots to which FYM (containing both inorganic and organic forms of phosphorus) had been added, significantly more phosphorus had accumulated in the lower subsoils than on adjacent plots which had received only inorganic fertiliser phosphorus. These observations are consistent with the large amount of evidence which indicates that organic forms of phosphorus penetrate soil more readily than inorganic forms (Rolston et al 1975). Unfortunately, the FYM plot on Park Grass has not been analysed for changes in soil phosphorus, and so this data does not allow one to do more than speculate on the relative movement of phosphorus in arable and grassland that has received FYM or natural dung inputs.

If, as seems likely, some phosphorus movement on FYM treated land is associated with the organic phosphorus fraction in the form of microbial material (see Hannapel et al 1964), it may well be that the crucial element in phosphorus mobility is not necessarily the initial form of the input (i.e. inorganic or organic), but the avilability of carbon for microbial synthesis and the relationship between the amount of carbon and phosphorus in the system (see Kaila 1950, Dalal 1977: 97-100). Phosphorus added to organic-rich grassland soils and to arable soils where organic materials from FYM are abundant may well have similar mobility. Phosphorus movement on the Barnfield plot to which both FYM and inorganic phosphorus fertilisers had been added was greater than on plots which had received FYM alone, a result that can be explained by the mechanism postulated.

Although this consideration of the processes affecting soil phosphorus in arable and grassland soils indicates that under some circumstances the resultant profile distributions will differ significantly as a function of land use (e.g. the 'extremes' of permanently grazed grassland as opposed to cultivated land, regularly cropped without manures), there is little likelihood that such distributions will remain unaffected by subsequent pedogenesis. When it is possible to observe or infer the changes in soil phosphorus which have occurred over extended periods of time (see 2.2.2.2), large losses, which imply large movements, are evident. In order to predict the depth to which applied phosphorus might have penetrated after several millennia or to predict how long after abandonment it might be before surface soil phosphorus values fall to the same level as adj cent untreated, uncropped and ungrazed soils (if indeed this ever occurs) it would be necessary inter alia to make quantitative estimates of the rates of phosphorus movement, and these cannot be established safely from the currently available data. In fact, study of the liter ture reveals considerable divergences in such rates, even on quite similar soils.

One study, of the dissipation of slag dressings on permanent grassland in north Wales, appears to indicate that even substantial dressings supplying 98 kg P ha^{-1} had been entirely removed from the soil (sampled to a depth of 46 cm) within a decade (Robinson and Jones 1927). Although the most rigorous of the phosphorus extraction procedures used by these researchers (20 g soil, 70 ml of 20% HCl at 100^{o} C for 48 hr) may not have extracted all organic or inorg nic phosphorus in their samples, it is difficult to explain away this result, which appears to be at variance with so many other studies, as solely a failure of technique. Nor can one easily attribute such rapid dissolution and leaching to very coarse soil texture or exceptionally high rainfall; most of the profiles examined contained substantial amounts of clay and silt and only received some 890 - 1150 mm $year^{-1}$ of rain. Only one area reached the rainfall levels experienced in the study area on Dartmoor. Unlike Bolton and Coulter (1966), who found that most of the added phosphorus, which had been rapidly leached from the topsoils of sandy podzols in Dorset, had accumulated in the B horizon, Robinson and Jones (1927:101) saw no evidence for a 'downward wave of phosphate' and only very slight evidence for any precipitation of phosphorus, which they guessed might be occurring at depths lower than those sampled.

In contrast, Roy and Thomas (1951) estimated that 85.7 - 98.8% of the phosphorus applied in slag dressings to the Tree Field permanent pasture experiment in Northumberland over a period of fifty years had been retained in the upper 28 cm of the soil, a conclusion not at variance with both earlier (Hanley 1937) and later (Roscoe 1960) investigations on these soils and on many other types of soil (Midgley 1941, Dean 1949, Wild 1950, Hemwall 1957). Such conflicting examples of phosphorus movement or the lack of it undermine any attempt to use modern data to predict long-term patterns of phosphorus distribution that might have arisen from applications of FYM or kitchen debris or from land use-specific redistribution.

Similar difficulties are encountered when one attempts to predict the vertical pattern of particular soil phosphorus fractions or indeed the proportion taken by these fractions in the soil as a whole that might result from different land use. lant residues and FYM each contain inorganic and organic forms and some of the latter are relatively easily mineralised (Dalal 1977). Although some studies have shown that much of the variation in total organic phosphorus in agricultural soils can be explained as a product of land use history (Chater and ttingly 1980), reports of the effects of adding phosphorus to different soils reveal a wide variety of responses including both rises and falls in the amount of organic phosphorus (Dalal 1977:105). While cultivation, particularly of land newly-broken from grass or to which large quantities of FYM have been added, tends to increase the rate at which organic phosphorus is mineralised, the exhaustion cropping without manures or fertilisers on Hoosfield has had no effect on the amount, and little effect on the proportion of organic phosphorus in these plots (Chater and Mattingly 1980: Table 5).

On the other hand, land put down to grass tends to accumulate organic phosphorus at the expense of the inorganic fractions, a part of the general rise in organic matter content that attends this change of land use (see 2.3.3.2); in consequence it seems likely that, in most long-abandoned agricultural land, the proportion of organic phosphorus will mainly reflect the influence of present soil-forming factors, which may approximate a steady-state position if very long-term trends are ignored. This implies that, where phosphorus enrichment of land has persisted, the soils could contain more organic phosphorus; this might take the form either of larger amounts of organic matter or a greater concentration of phosphorus within the organic matter (lower C:Po ratios). Organic matter produced during or soon after an agricultural episode that has caused land enrichment may be thought to have a greater likelihood of enhanced phosphorus concentrations than that produced much later, when fixation will probably have reduced the supply of <u>available</u> phosphorus to levels similar to those in virgin land. Since the organic matter in B horizons contains a greater proportion of ancient organic matter (see 2.2.3), it may well be that land enriched in phosphorus by ancient agricultural activities will exhibit abnormally low C:Po ratios in the B horizon, while more recently created organic matter in the surface soil will have ratios closer or identical to those found in virgin land. In soil-organism ecosystems in which there has been a long-term decline in the available phosphorus supply, it might be possible to discern a relationship between the time of organic matter formation and its phosphorus concentration, a relationship that could be reflected in a vertical pattern of decline in the C:Po ratio. Such a pattern is generally present in soils (see 2.2.2.2), but could also be created by a process of degradation of older organic material which involved a preferential loss of other components (e.g. hydrogen, carbon, nitrogen). Clearly both processes could contribute to such patterning.

There are some special circumstances in which, irrespective of amount, even the proportion of organic phosphorus might not revert to the patterns typical of adjacent virgin land. Where pedological inertia or 'delayed metapedogenetic' factors maintain distinctive soils (see 2.3.3.2), the ratio of organic to inorganic phosphorus fractions, and vertical distribution patterns in general, may well be different, though these would not necessarily represent special instances of the preservation of metapedogenetic artifacts; they might merely indicate a divergent course during subsequent pedogenesis.

It is even more difficult to predict how agricultural activities may have altered the ratios and amounts of inorganic phosphorus fractions either in the short or long run. The possibility that relatively insoluble forms will be created by activities which involve burning has been pointed out above (see 2.2.4 and 2.3.2.2), but this is little more than speculation. One might also expect that initially the non-occluded fraction will be more substantially affected by agricultural activities than the occluded fraction though, at least in the longer term, some or all of the phosphorus added to the soil might revert to these sparingly soluble forms. Evidence that in podzolic soils in particular, substantial translocation of phosphorus may occur at an early stage in soil development (see 2.2.2.2), together with the possibility that major podzol features may be imposed (or reimposed) relatively rapidly (see 2.2.1), does not increase one's confidence that even if land use specific patterns in soil phosphorus fractions of this kind were once present they would necessarily survive today - a somewhat pessimistic conclusion that applies in large measure to all of the types of patterns discussed in this section. However, this conclusion does not mean that such patterns were not or are not present in the soils of the study area; it does mean that this author does not believe that their presence and nature can be reliably predicted from current knowledge.

In this situation, the best strategy, so far as these parts of the investigation are concerned, is to regard the Holne Moor studies as a hypothesis-generating venture rather than a hypothesis-testing one. Fractional compositions can be compared with the predicted natural patterns (see 2.2.5) and evidence of significant differences in vertical distributions in, for example, adjacent fields can be sought. If anomalies are apparent, their origin can then be assessed in the light of the information discussed here and earlier (see 2.2.2.2) and by reference to the analogous patterns observed in nearly modern f rmland (see 5.2.2.2).

2.3.3.2 Soil organic matter

Certain aspects of the processes of accumulation and destruction of organic matter in soils have already been introduced in sections 2.2.1 and 2.2.3. In this section, the way in which these processes are affected by agricultural activities must be considered; this involves recapitulation of some information noted earlier and a very brief review of the most recent relevant research. Since only relatively crude methods of measurement have been employed in this study, no attempt is made to include in this review the evidence which exists for changes in amino-acids, C:N ratios and other complex changes that could only have been detected if more extensive attention had been paid to this particular soil fraction.

It has long been known that climatic factors exert a substantial influence on the organic matter content of natural soils (Jenny 1941, 1961b). In particular there is much evidence that organic content rises with decreasing temperature and increasing moisture and falls in warmer, drier soils. Such variation principally reflects variation in the rate of organic matter decomposition rather than production. Both the rate of decomposition and production can be altered by management. When natural grassland or woodland soils are cultivated and cropped, organic matter levels fall due to destruction of accumulated reserves of organic matter and a reduction in the rate of organic matter additions (Russell 1973:316-317). Conversely, when cultivation ceases and a field is laid down to pasture or allowed to revert to wilderness, organic matter levels rise due to increased production and reduced rates of decomposition (Richardson 1938, Jenkinson 1971).

In some agro-ecosystems land is used continuously either for grazing or for hay or for arable cropping. This strategy of exclusive use produces large differences in the organic matter content of field soils; differences that can persist for considerable periods after a change of land use. Such patterns can be clearly observed on the Rothamsted Farm (Johnston et al 1981) and were also central to Johnston's (1973) comparisons of the effects of various ley-arable cropping systems (with or without grazing or FYM on the ley, etc.). Nitrogen analyses of the soils on two of the classic experiments at Rothamsted (Hoosfield and Broadbalk) also indicate that the addition of very large quantities of FYM (35 t $ha^{-1}year^{-1}$) can lead to large differences in the organic matter levels of old arable land despite continuous cultivation (Jenkinson and Johnston 1977, Jenkinson 1977). Although, after more than a hundred years, the rate of increase of organic matter in the FYM plots is now lower than in earlier years, a change that heralds the arrival of a steady-state equilibrium, it seems likely that, when the latter is finally established, organic matter levels on these plots will closely approach or even surpass the levels in the unmanured plots of ancient grassland within the Park Grass experiment (for Park Grass see Richardson 1938, Warren and Johnston 1964; for Broadbalk see also Johnston 1969a). However, as asserted earlier (see 2.1), it does not seem likely that the pattern of organic matter variation revealed by these and similar investigations elsewhere would persist in typical agricultural soils for more than one or two hundred years after cultivation ceased.

The best evidence that this is the case is to be found in a comparison of levels and rates of change in the organic matter contents of the various experiments cited in the preceding paragraph with similar data from the Broadbalk Wilderness experiment (Jenkinson 1971). This experiment, which includes a plot naturally colonised by trees and one in which trees and scrub have been excluded by regular stubbing (the stubbings were carted off), was laid out on old arable land some thirty years after the principal classic experiments commenced. Despite this, natural processes of organic matter accumulation have already raised the level of nitrogen in these abandoned soils to values equal to those of the FYM plots on Broadbalk (Jenkinson 1977:Fig. 1), which as noted above are themselves not far short of the values on Park Grass (total N in 1964 in the Wilderness soils: 0.2610% (Stubbed 'meadow'); 0.2549% (Woodland) and in 1 959 in Park Grass unmanured plots: 0.27, 0.28, and 0.28%). There is no indication and little likelihood that the Broadbalk Wilderness soils have yet reached a steady-state and even if, as one might suspect, the rate of increase is now falling, it is highly improbable that organic matter levels in these soils will not soon overhaul the levels found even in the ancient grassland.

Equifinality within a couple of hundred years of abandonment of arable or grassland soils assumes that the agricultural activities have left no lasting legacy of alteration to soil-forming factors affecting organic matter accumulation and that pedological inertia exerts no substantial influence. If, for example, ditched boundaries surrounding a field have greatly altered drainage and thus soil moisture levels, it could be that the new steady-state level established in an abandoned arabl e field would be significantly lower than that present in adjacent virgin land or in other fields whose drainage characteristics had remained more or less unaltered. In addition to the possibility of such 'delayed metapedogenetic' factors, differences between steady-state levels in virgin soils and abandoned farmland might also arise if the constellation of pedogenetic factors governing soil organic matter levels changes but the virgin soil fails to respond to the changes due to pedological inertia.

The latter effect may be of particular importance in soils like that of the study area, which today are mantled by thin surface peats whose high moisture retaining capacity may promote their survival even if the conditions necessary for their genesis no longer obtain. In these soils, a peat surface, once destroyed by cultivation, might not become re-established even though such surfaces persist in nearby virgin land. Pedological inertia in such soils may also be affected by the formation of iron-pans, often associated with the presence of a thin surface mat of 'mor' humus. Although, as Damman (1965) concluded, iron-pan formation in many soils probably follows the development of a surface peat, rather than vice-versa, there can be little doubt that, once in existence, such pans also act to maximise surface soil moisture and thus promote the survival and further growth of surface peats.

Even if peat-forming conditions do persist, leading to continued peat growth in virgin areas, pedological inertia might also cause lengthy delays in the re-establishment of peats; the transition from mineral to peat-covered soil, at least on sandy free-draining parent materials, could involve a long fight to overcome high threshold parameters.

As noted earlier (see 1.2.3), the effects of cultivation on soils of this type have been studied in detail in Ireland. These investigations demonstrated that the alteration to organic matter levels that accompanies arable cropping can be particularly easily observed in these former moorland soils where the initial organic content of the soil is very high and occurs as strong concentrations in certain horizons. The intensity and duration of cultivation could be estimated with considerable accuracy merely be noting changes of soil colour, which were found to be strongly correlated with organic content. Although equally rigorous and extensive study of the changes that occur after such soils are abandoned has not been reported, accounts of the changes seen in old arable and grassl^nd in east ancashire (see 1.2.3) strongly suggest that, at least in come circumstances, similar criteria (i.e. organic content and regrowth of surface peats) might be successfully used to assess the time that has elapsed since cultivated land has been allowed to revert to grass, moor and scrub. If peat does become re-established on an old arable soil, it may still be possible to distinguish such profiles from virgin profiles of generally similar appearance by measurement of peat depth. Unlike mineral soils, it cannot be assumed that peat-covered soils, even in a virgin state, establish a steady-state equilibrium with respect to soil organic matter (see 2.2.3); in consequence it is not difficult to envisage circumstances in which peat depth varies in part as a function of the time that has elapsed since an arable field was last tilled. Of course other, natural soil forming factors may not be uniformly distributed in the landscape and variation in peat depth or organic matter content due to such natural variation provides a potentially serious obstacle to the success of this investigative approach.

Natural variation may lead to both equifinality and indeterminancy. For example, organic matter levels in recently abandoned arable land with poor drainage might rapidly rise to equal (or even eventually surpass) the levels reached in freely-drained land abandoned at a much earlier date. Alternatively, land abandoned at the same moment might, today, have very different levels of organic matter if the drainage characteristics or aspect of the fields involved were sufficiently dissimilar. Clearly, interpretation of the contemporary pattern of organic matter content in the soils of ancient fields in terms of the nature and timing of agricultural activities presupposes a thorough assessment of the influence of other factors, particularly those which may be envisaged as affecting the climatic parameters of the soil system (e.g. drainage). Nor should one ignore the possibility that manuring or animal transfer of nutrients may have altered the productivity of the soils in different fields; from the point of view of organic matter accumulation, phosphorus enrichment may act as another 'delayed metapedogenetic' factor.

As noted earlier (see 2.2.2.1), the rate of organic matter production in several semi-natural soil-organism ecosystems may be limited by the availability of soil phosphorus; in consequence, if balancing changes to decomposition rates do not interfere, fields which have become enriched in nutrients may contain higher levels of organic matter. Jenkinson (1971), who studied organic matter accumulation in the Geescroft Wilderness experiment at Rothamsted, which included plots to which phosphorus fertilisers had been added, was unable to find any evidence of an enhanced rate of accumulation in such plots and therefore concluded that the availability of phosphorus was not a factor limiting production in the Geescroft soils. owever, this ma not be true of the soils of the study area; in what seems to be the only significant published reference to phosphorus in the soils developed on the granite plateaux of south-western Britain, Clayden (1971:112) noted that 'available phosphorus is usually low'. It is, therefore, certainly possible that nutrient enhancement of the ancient fields in the study area could be accompanied by higher levels of organic matter. The importance of this delayed metapedogenetic factor will be determined by the length of time during which phosphorus additions continue to enhance the supply of available phosphorus. If the rate of fixation in relatively unavailable forms is not fully proportional to the amount of phosphorus enrichment, one would expect that this process would le d to disproportionately high increases in organic matter production in heavily enriched areas and perhaps insignificant changes in lightly enriched areas. As noted earlier, primary candidates for such patt rning would be the sites of old animal camps.

Despite problems of interpretation (Jenkinson 1971:125-127), the Wilderness Experiments also demonstrate that the rise in organic matter as these soils reverted to wilderness was accompanied by a rise in organic phosphorus, though organic carbon, nitrogen and sulphur increased to a much greater extent. These increases in the organic soil fraction principally affected the upper 23 cm of the soil. Jenkinson also found that the rate of this accumulation was similar in both the wooded and the stubbed, meadow-like plots. This suggests that even substantial differences in plant succession on an abandoned field may have little or no effect on the subsequent pattern of soil organic matter accumulation. However, these soils have not yet reached a steady state and such differences could still appear.

Johnston's (1973) study of the organic matter in ley-arable cropping systems showed that rotational land use could lead to a wide variety of different organic matter steady states, many of them intermediate in character by comparison with grassland and continuously cropped land. Nutrient distributions and variability may also exhibit intermediate characters in land affected by these complex land use systems; such changes will be considered in the next section.

2.3.4 Convertible husbandry

As used here, the term 'convertible husbandry' covers a wide variety of complex land use strategies whose central and essential common element is that land used for one purpose at one time is later converted to one or several other uses. Rotation of crops in continuous arable cropping systems is thus included, but more important for the purposes of this discussion are those systems that combine the use of land as arable with its use as a grazing resource. In this category one may include more or less regular ley-arable systems that involve a grazed ley, which may be of variable length and either sown or unsown, and also the irregular and often infrequent cropping of areas that are primarily perceived as grazing land.

The possible effect on nutrient losses of both of the latter strategies has been considered earlier (see 2.3.1.2 and 2.3.2.2) and will not be discussed further. Nor is it necessary at this stage to comment further on the effects of changing the specific oomposition of the herds' grazing permanent pasture land. This section will be devoted to an assessment of how the characteristic patterns of nutrient distribution and variability in arable and pastoral land might be affected by farming systems that alternate such land use. The present shortage of information about lateral variability in soil characteristics (see 2.3.2.1; there do not seem to be any studies which can contribute data of direct relevance to the topic considered here) precludes all but a speculative and therefore short discussion of this issue.

Both the macro- and micro-scale patterns of nutrient distribution created by grazing animals will be affected by cultivation and cropping; two principal mechanisms can be postulated. First, there is the likelihood that plant uptake of phosphorus in crops will gradually reduce the differences between enriched and impoverished zones due to luxury uptake or higher yields in the nutrient-rich areas. The importance of these two forms of differential uptake may well vary as a result of other aspects of the cropping policy. If high yields were maintained throughout a field by heavy manuring, 'levelling down' might mainly occur due to luxury uptake; if manuring was not practiced or if only small dressings were applied and yields were low, levelling down might mainly result from higher yields in, for example, old camp areas. Manuring itself could, of course, increase nutrient values;

this could alter the relationship between nett values in diff rent zones, but would not in itself destroy the anomalies. t i impossible to make quantitative predictions bout the rate at which anomalies might be ironed out unless a whole series of assumptions ar made bout the frequency of cropping, the length of grazed leys, crop yields and nutrient transfer rates. While it is true that much inform tion relevant to these topics has been introduced and considered individually in earlier sections, synthesis of this dat produces an extremely wide variety of rates depending on the nature of one' initial a sumptions. Moreover one aspect is very difficult to predict save in qualitative terms. As noted earlier, even the immediate recovery of added phosphorus is very poor due to fixation; subsequent crops gener lly only benefit to a slight and rapidly diminishing degree. T us one would not expect markedly higher yields on the enriched zones, nor, since it is differences in yield that provide the most potent levelling mechanism, strongly marked differences in phosphorus uptake. In view of this, one can suggest that even in regular systems of ley-arable husbandry involving cropping as frequently as grazing this process will only alter micro- or macro-scale nutrient patterns very slowly, while the effects of rare and irregular cropping of an 'outfield' character are unlikely to be noticeable even if it were practiced over long periods.

The second, probably more important, change produced by the arable element in systems of convertible husbandry is caused by the homogenising effect of cultivation itself. This would quickly establish a plough layer of relatively uniform composition in which vertical distribution patterns seem unlikely to be distinguishable from those found in continuously cropped land and in which the differences in micro-scale lateral variability described earlier (see 2.3.1.1) could well become so blurred that this criterion could no longer be used even as a contributory indicator of grazing land use. Unlike the changes caused by crop uptake, the degree of change produced by ploughing should be directly and strongly linked to its frequency and duration; in particular, the resultant level of variability should reflect the relative intensity of arable vis-a-vis grazing activities within the system of husbandry, at least in those instances where grazing activities substantially increase variability. Although it seems unlikely that this process would be able to remove the sizeable anomalies presented by animal camps and other macro-scale nutrient zones, the boundaries of such features might become diffuse. nce again, it seems reasonable to suggest that rare outfield cropping in land otherwise regularly grazed would leave little trace in the form of altered patterns of the lateral distribution of nutrients.

Although there is insufficient information about the agricultural practices followed on the farm studied by Salmon (see 2.3.1.1) for her data to be used in support of these conclusions, her findings are not in conflict with them. No other data capable of confirming or denying them has been found.

It was noted above that when newly-introduced or re-introduced to a pasture both sheep and horses have been observed to establish spatial patterns of behaviour similar or identical to those which have been recorded in the particular paddock at some earlier time. It is also evident that, at least in part, the spatially-patterned behaviour which leads to nutrient redistribution is affected by environmental factors such as exposure, shelter and so on, and it may well be that in some instances continuity reflects such a linkage. Whatever the causal relationships may be, such evidence argues that continuity of transfer patterns may reasonably be expected despite the interposition of cropping in systems of alternate husbandry, though long-term transfer rates must be lower than those in permanent grassland. The rates, presumably, will be proportional to the frequency and duration of the grazed leys in such systems.

It is certainly possible to envisage circumstances in which farmers apply manures differentially because they have noticed that, due to nutrient redistribution by grazing animals, certain parts of a field regularly produce lower or higher yields. Contemporary ignorance of the magnitude of this nutrient redistribution suggests that such a scenario is improbable when land remains permanently under grass; nor, of course, would it arise if land were permanently cropped. But it might well arise on farms with regular ley husbandry where it could lead to equifinal nutrient distributions.

2.4 Models of agricultural transformations of pedogenesis in moorland soils

A major criticism that can be levelled against the few previous investigations of the soil within ancient abandoned farms and their enclosures is the absence of any serious attempt to predict the type of patterns of soil variables that one should expect to be present as a result of specific farming activities. Nor have many authors sought to assess the distorting effects of subsequent pedogenesis or the influence of later land use; yet reviews in this chapter show that both pedogenetic and metapedogenetic processes may have substantially altered nutrient values and their distribution, both lateral and vertical, even in areas where there has been only very low intensity agricultural activity ever since the early farms were abandoned.

Most of this chapter has consisted of an attempt to meet these criticisms by reviewing studies that allow one to predict (or at least improve interpretation of) the results of the soil investigations on Holne Moor. The review of pedogenetic factors has been deliberately restricted to aspects relevant to the particular, moorland location of this study area and so provides little guidance to those working on similar problems in other areas with different environmental parameters. This is not the case with the review of metapedogenetic factors, which is of much wider relevance. The form of these reviews bespeaks their model-building purpose and it is evident that many elements of the models, which must be tested by the empirical studies on Holne Moor, have already been presented and discussed - sometimes in considerable detail. It would therefore serve no useful purpose, nor is it the intention of this section to extensively repeat what has already been made plain. However these reviews have ranged over a very wide field of knowledge and so far no attempt has been made to summarise or integrate this material into more or less formal predictive models. It is such synthesis that must be attempted here.

Regrettably, there are too many areas where quantitative data is entirely absent (and many others where its applicability to other soil-organism ecosystems is questionable) to allow one to formulate precise quantitative models. In at least one instance (e.g. vertical distribution of soil phosphorus in profiles), this author has been forced to conclude that no satisfactory predictions are possible, though some further comment on this topic is offered below. Several ways of approaching the task of synthesis have been employed. It is possible to summarise much of the information about t e lat r l ai triLuti n of nutrients in enclosed land through cartogr.phy. This is tte ipt a first. Then, the ways in which tl e tot l store of nutrient in agro-ecosystems can be altered by various agricultur l activities 's t ul t d, and there follows a brief discussion of how these initial met pedog n c artifacts may have been affected by subse uent pedogene.is. inall, models of the pattern of morphological change that migt Le expected t arise if tillage has occurred in the study area s'nce the onset of pe t formation are discussed.

2.4.1 Changes in soil nutrients

Information about lateral redistribution of soil nutrients has been presented in sections 2.3.1.1 and 2.3.2.1. The patterns of nutrient transfers within agricultural land may be broadly divided into two classes - inter-field (or other areas such as droveways) and intra-field movements. The patterns of distribution arising from the latter may be further divided into macro- and micro-scale patterning. Figs. 2.11, 2.12 and 2.13 summarise the macro-scale patterns that can arise from the non-random nature of sheltering, feeding, idling, resting and excretal behaviour of grazing animals. The quality and quantity of evidence supporting the idea depicted here, that species may leave distinctive thumb prints in their pastures, varies from species to species. There is more and better evidence about sheep patt rns than cattle patterns and least information about horses. It would certainly be possible to redraw these maps in a manner that minimised their distinctive features while retaining conformity with the data on which they are based, an admission that recognises the probability of considerable equifinality. However, it is more useful to draw attention to those features that provide a possibility of making these distinctions than to further enumerate the problems which beset such an endeavour.

With sheep, the outstanding aspects are the severity of depletion and enrichment and the micro-scale pattern of low variability in grazed zones. In each case this contrasts with the cattle pattern of high variability, lower rates of transfer and less concentrated anomalies. Both these species tend to enrich boundary zones, in contrast t horses who may turn such areas into bare ground but are unlikely to sub tantially alter their nutrient status. Sheep and cattle also present a contrast to horses with respect to the effect on their behaviour of variation in stocking density and enclosure size. With the former, there is evidence that considerable variation in these parameters is of little import; only improbably high densities are likely to seriously disrupt these patterns. With horses, however, it is clear that very large enclosures (greater than about 5 ha) stocked at low densities (less than 2 horses ha^{-1}) may exhibit patterns quite unlike those shown here, which apply principally to smaller paddocks; the striking lawn and rough pattern gives way to night camps and, conjecturally, a pattern of micro-scale variability similar to that of cattle pastures. Even in smaller enclosures, lawns and roughs may not be established if horses share their pasture with sheep and/or cattle.

Prediction of the precise location of camps or what can be dubbed 'leeward transfer zones' requires a knowledge of the dominant winds, particularly during the cold, wet winter months, and assumes that social factors affecting aggregation, which have been clearly documented with sheep, have not influenced the pattern. If such knowledge is imperfect and an assumption of continuity in such weather patterns unacceptable, then the matter can be turned on its head; if camps can be located then the wind directions that may have governed their location might be inferred.

Although the problems of equifinality may rob species distinctions of some of their plausibility, there can be much less doubt of the distinction that can be made between all these pastoral patterns and the distribution of nutrients in arable land. Fig. 2.14 merely depicts the possible major zones in a cropped field; even the headlands need not necessarily be present. This brings out the main difficulty encountered in predicting macro-scale patterns arising from arable use, namely that since they do not arise from very basic natural patterns of behaviour, but instead represent human choices - a selection from a very wide range of farming tactics and strategies - it is only possible to speculate; predictions cannot really be justified. On a more positive note, arable land use can create a unique class of cultivation artifacts such as lynchets and ridges, which may form easily visible surface features and may also provide special nutrient patterns. An absence of major anomalies, save for those that might correspond with headlands, coupled to very low variability in the putative cropped area, are the main distinguishing features of cultivation land.

Information about natural, lateral patterns of nutrient and about lateral movements of nutrients that, through post-agricultural pedogenetic processes, could disturb the patterns imposed by metapedogenesis, is not abundant. Howev r, there ̄re ev r l ι ȝ in wh˙ch tl e problems posed by uncertainty about pedogeneticall imposed fe tur s maȷ be assessed. First, so long as there is no good r ι on to su pose that a field boundary was originally constructed, deliber t l or otherwise, along a natural soil boundary, one maȝ loo for the d ᵦree of correspondence between field boundaries and soil nutrient c anges of supposed metapedogenetic origin. If there is a possibilitȝ t t v n a close correspondence of this kind is merely fortuitous and may in f ct be a pedogenetic feature, then a distinction may still be able to be made if one can examine changes across the same landsc pe segment at a point where no field boundaries testify to partioned agricultur˙l management. Since gleying can increase phosphorus mobility (s e ?.?. .1), assessments of phosphorus movements in moorland soils, where s son l waterlogging is common, should also include field examination of soil features that can inform one about hydrological characteristics of t soil system. While it may be relatively easy to justify assumptions about the uniformity of climatic, biotic and parent m terial factors within small areas, an absence of significant variation in soil-w ter conditions requires verification.

Information and discussion of the changes one might expect in the total store of nutrients has been presented in sections ?.3.1.? and ?.3.?.2. Table 2.14 summarises some of the possible pattern of losses and gains to the soil within the fields of an agro-ecos stem. Particularly in the case of arable land, there c n be no clear predictions of overall change, but it is worth pointing to the gre ter likelihood of nett losses from such land. oth enhancement of natural proce ses (erosion and leaching) and the high rate of removal by cropping argue in this direction. By contrast, in pastoral land nett losses may be small; high losses in one area being largely matched by sizeable gains in other areas. No attempt has been made to include in this table all the many activities which may have affected the tot l store of nutri nt within the system. Among the more probable and sub tantial of these, one must include imports of hay, grain and turves, and exports of dairy products, wool, leather, carcasses and livestock; but neither the n tt change nor the spatial distribution of losses and g ins caused by such imports and exports can be predicted. However, it is possible to suggest that, aside from the anomalies created by grazing redistribution, only certain agricultural practices (infield-type manuring or c y and night grazing policies, the use of droveways, yards and byres) would

Table 2.14 Qualitative estimates of metapedogenetic changes to soil phosphorus

Agricultural activity		Sign of change	Micro-scale variability		Horizons Upper	Horizons Lower	Comments
Arable							
Deturf & remove		− − −	Reduced?	LOW	− − −	NC	
Denshiring & stubble burning		NC	NC		NC	NC	Po Pi; Pa Pf?
Cultivation			much reduced				" Losses" in arable land may be and often are losses from the system.
	Erosion	−	increased?		−	NC	
	Leaching	−	reduced		−	+	
	Cropping	− − −	reduced		− −	−	
Manuring & folding		+ + +	increased?		+ +	+	
Pastoral							
Sheep	Camps & boundary areas	+ + + +			+ + +	+	
	grazed areas	− − − − −	Reduced	LOW	− − − −	−	"Losses" in pastoral land may be mainly transfers within the system.
Cattle	Camps & boundary area	+ + +			+ +	+	
	Leeward pasture	+ +			+	+	
	Other grazed areas	− − −	Increased	HIGH	− −	−	
Horse	small enclosures						
	Lawns	− − − −	Reduced	INTERMEDIATE	− − −	−	
	Roughs	+ + +	Increased	HIGH	+ +	−	
	large enclosures						
	camps & shelter	+ + +			+ +	−	
	grazed areas	− − −	Increased?	HIGH?	− −	−	

NC = No change as a direct result; subsequent and consequent changes are not considered ⟶ Transfer paths.

lead to marked enrichment of particular fields or other parts of a pre-modern farming landscape.

Unlike lateral changes and patterns of soil phosphorus, there are many studies of leaching losses and/or the vertical redistribution of native or applied phosphorus that may be used to inform speculation as to the fate of changes in soil phosphorus associated with activities within ancient agro-ecosystems. It has long been known that anthropogenic changes to soil phosphorus can be identified many thousands of years later (see 1.2.3), but it is equally evident that this may not be the case in some organic or coarse-textured soils and that soil phosphorus can only be regarded as effectively immobile in the short run. There is some evidence that the phosphorus added to a soil has greater mobility than native phosphorus (see 2.3.3.1); where this is the case, modern analyses could underestimate the true extent and gradient of ancient changes. However, whereas in the short-term studies relevant to modern agro-ecosystems it is sometimes possible to make a clear-cut and meaningful distinction between native and applied phosphorus (e.g. through the use of P^{32}, (Larsen et al 1958, Ozanne 1962); in many other cases the distinction is conjectural), in longer-term studies such a distinction may have little value. Although at the time of application phosphorus in, for example, FYM may be present in forms that are unusually soluble, easily mineralised, more prone to leaching and so on, in time integration with the soil-organism ecosystem will largely remove such identifying features. Applied phosphorus not lost at an early stage will eventually behave in a similar way to native supplies. Exceptionally, if leaching is rapid, applied phosphorus might become positionally unavailable to shallow-rooted plant communities and so escape subsequent, extensive incorporation and thus transformation within the system. It could also be that very large inputs would continue to create unusual conditions in the soil phosphorus system for a significantly longer period than smaller inputs.

The attempt in Table 2.14 to indicate the changes to upper and lower soil horizons is therefore essentially speculative; nor does it take account of the longer-term changes that may flow from initial alterations to soil characteristics. It assumes that, as occurs in most soils, much phosphorus will at least initially be trapped in the upper horizons, but recognises some movement to B horizons even at an early stage. In podzol-type soils like those of the study are , it is reasonable to expect subsequent pedogenesis to have involved further translocation of phosphorus to sesquioxide and humus illuvial horizons, but the scale of such movements may have been reduced when a surface peat became established. This change in the soil system also forcibly reminds one of the strength of upward translocation in soils, which may act to offset loss of phosphorus from the surface soil. Although atmospheric input may contribute marginally to the phosphorus content of surface peats, it has been suggested (see 2.2.2.1) that such inputs will have been very small; in consequence one must suppose that most of the phosphorus in thin surface peats has been derived from the underlying mineral soil. This might lead one to expect a regular, predictable relationship between the amoumt of phosphorus in such peats and the amount in the underlying soils, but this may not always be the case, since upward transfer by plants may be better linked to available supplies than to total soil phosphorus.

Upward transfer could play an important role in the dissolution of land use specific vertical distribution patterns. Phosphorus enrichment concentrated in the upper few centimetres of a mineral soil might be almost wholly transferred to a growing surface peat horizon, whereas if enrichment were spread throughout the greater depth of a plough layer, a higher proportion might remain fixed within the mineral soil. Other factors such as subsurface gleying will also affect the relationship between nutrients in the peat and the mineral soil, but it is evident that investigations of pre-peat metapedogenesis could learn much from an examination of inter-horizon relationships of this kind.

A number of other speculations about the ways in which extra phosphorus may have altered the subsequent trajectory of soil processes have been advanced (see 2.3.3.2) and although one cannot truly predict in such instances, it is clear that there is much to be gained by an examination of the soil that includes such parameters as the organic matter content and, in particular, the concentration of phosphorus within the organic fraction of the soil, as well as inorganic and total phosphorus in the soil as a whole.

The largely speculative nature of the remarks made here about subsequent pedogenetic transformation of metapedogenetic artifacts is clearly unfortunate, because it does not enhance the credibility of later interpretations of the patterns found within ancient fields; too many assumptions about 'unknowns' would persist. Plausibility would be improved if the strength of these 'hypotheses' were first to be tested by examining soils where fewer and/or more reliable assumptions could be made. In some cases, this has been attempted and allows a brief reconsideration of models at a later stage (see 5.3).

2.4.2 Changes in profile morphology

Information about the way in which cultivation of moorland soils may alter their profile morphology (for the most part a reflection of changes in organic matter content and distribution) has been presented and discussed in sections 1.2.3 and 2.3.3.2. Such studies illustrate the breakdown and mixing of organic horizons and mineral soil as well as later re-establishment of surface peats. No research has been located that documents the effects on soils of the type of rare and irregular cropping of moorlands which H.S.A. Fox (1973) has shown occurred widely in south-western Britain during medieval and later periods, but it is not difficult to envisage such episodes creating distinctive, if less intensely disturbed, topsoils similar to those created by modern cultivation of moorlands. In south-western Britain, the role of cultivation has been recognised by the Soil Survey of England and Wales during the soil mapping of moorland areas, and cultivated and distinct topsoil 'phases' of various moorland soil series have been defined to cope with the patterns created by such anthropogenic intervention (Staines 1976:112-119). In fact, the same author has also speculated on the possibility that ploughing of medieval date may have led, through increased oxidation, to a thinning of surface peat on the soils of the St Austell granite in Cornwall (Staines 1975:66-67).

One can visualise a continuum of soils exhibiting features which testify to different levels of intensity of cultivation. At one extreme lie brown podzolic soils of the type Conry examined (see 1.2.3); these had been created by frequent cultivation over an extended period. At the other extreme, a year or two of outfield cropping might merely intermix the surface peat with the underlying mineral soil, though, if Denshiring preceded such cultivation, far more extensive, perhaps total, destruction of the peat could occur. In addition to the variety of forms that could arise from variation in the intensity of cultivation, any model that attempts to encompass and explain the patterns in abandoned land must also include variety introduced during the imposition or re-imposition of stagnopodzol features such as iron-pans, regrowth of peat and so on. Earlier discussion (see 2.3.3.2) has made clear that a number of post-agricultural trajectories may be expected due to the effects of pedological inertia and/or differences in natural soil forming factors. If subsequent pedogenesis were to be interrupted by further cropping episodes, very complex patterns of pedogenetic and meta-pedogenetic 'overprinting' might arise.

It is difficult to enumerate and probably impossible to disentangle in the field all the permutations that overprinting and variation in both cultivation intensity and subsequent pedogenetic trajectories could produce, but it is nevertheless worthwhile to consider how five basic patterns of modification might arise. In Fig. 2.15 the volution of a stagnopodzol from a brown podzolic soil and deviations from that evolutionary pathway due to metapedogenesis are illustrated diagrammatically. Pathway 1, that of a virgin soil, simply plots the emergence of increasingly differentiated horizons, the formation of an ironpan and the growth of a surface peat, which in this model is assumed to be a more or less continuous process though changes in growth rate are included. Pathways 2, 3 and 4 involve cultivation episodes of different intensity and/or age; in the first, Denshiring removes a shallow surface peat and regular, lengthy cultivation then creates a soil not unlike the brown podzolic soil that starts the sequence. Two possible subsequent pathways are illustrated. Pathway 2a postulates only minimal change to the ploughed soil; the addition of a litter layer and the development of a more humose surface soil being the principal features. Pathway 2b closely approximates that of the virgin soil, though peat development is much retarded. Such divergent pathways might reflect the operation of delayed metapedogenetic factors or differences in the duration or timing of post-agricultural pedogenesis.

Pathways 3 and 4 illustrate less intensive cultivation episodes. In Pathway 3 an early, short period of cultivation without prior Denshiring creates a plough soil, but in this case the soil remains humose, even peaty. On abandonment, pedogenesis similar to that of the virgin soil re-establishes a surface peat (Pathway 3a), leaving only an exceptionally organic-rich subsurface soil and a slightly shallower peat as characteristics indicating metapedogenesis. Note that if cultivation had been more prolonged, a soil similar to that created in Pathway 2 might have developed. Pathway 3b assumes that a second episode of cultivation disrupts the soil still further; this time very brief tillage reduces the thickness of the re-developing peat surface and incorporates some mineral material within it. Later pedogenesis merely consolidates this mineral-rich but organic surface horizon which is not augmented by substantial peat regrowth. The latter might reflect the timing or duration of pedogenesis; in this particular model, the absence of an iron-pan, whose development has been at least delayed, may be the crucial factor. A rather similar soil could arise in a much less complex way if a virgin soil was briefly cultivated at a similarly late date (Pathway 4). Note that only Pathways of this type (4 and 3b) would lead one to expect a surface organic horizon with a mineral content substantially higher than that of the virgin profile.

Many other changes must be envisaged as accompanying the morphological patterning illustrated here. Aside from the soils following Pathway 3, no differentiation has been made between the qualities of the upper mineral soils, yet large differences in organic content and bulk density are likely. Loss of organic matter and structural changes in plough layers may reduce their volume and, when abandoned, expansion will accompany the build-up of organic matter (Pathway 2). Surface mineral soils buried by peat growth may develop eluvial characters, which reduce their organic content and increase their density. The depth of ploughing may affect the subsequent positioning of horizon boundaries; iron-pan formation, in particular, may be affected in this way.

One cannot insist on the details of such models, but it is helpful to consider the general form of possible changes for this can guide one in framing suitable field observation routines and, to the extent that prediction on the basis of previous studies is involved, adds to the credibility of later interpretations of the patterns observed in the field.

3. AN INTRODUCTION TO THE ENQUIRIES ON HOLNE MOOR

'Dartmoor provides one of the finest opportunities in the British Isles for the study of soil development on a relatively uniform mantle of rock waste derived from granite' (Clayden and Manley 1964:117).

3.1 Introduction

This chapter provides an introduction to the physical geography, natural history and archaeology of Holne Moor and to the methodological strategies that have been employed during the investigations within the study area. Although it has been thought useful to indicate some of the literature which contains information about the wider geographical, archaeological and methodological context of these enquiries, there is no attempt to make a thorough critical review of these areas of knowledge.

While the studies and analysis both of literature, discussed in chapters 1 and 2, and of the soils of Holne Moor, reported in chapters 4 and 5, have an ultimate purpose of allowing the prehistorian or historian to make clearer and more detailed statements about past land use and thus further the general goal of reconstructing socio-economic patterns within extinct societies, it would be idle to suppose that the work reported in this thesis could traverse more than a very short distance along the lengthy road that such purposes demand. A proximate, more limited, primary objective was therefore set; namely the development and testing of new approaches to the study of ancient fields. Even a considerable measure of success in the pursuit of this objective could not necessarily be expected to yield substantial gains in knowledge about the wider economic systems which created the agricultural landscape that served as a testing ground in these studies. And, despite some measureable progress towards achieving these wider objectives, particularly with regard to the history of medieval land use, this has, in general, proved to be the case.

In consequence, a detailed review of Dartmoor's history and prehistory would constitute an unnecessary and lengthy diversion, even if it were limited to the little that is known about agricultural affairs, and despite the fact that some of this knowledge might be seen as casting light on the agricultural events which gave rise to the land boundary systems, fields and other archaeological features within the study area.

Nor is there a place in this thesis for examining the observations and data about the soils of Holne Moor, which have been collected for archaeological purposes, with a view to demonstrating their wider relevance either to an understanding of the physical geography and pedology of Dartmoor or to methodological aspects of soil science, except in so far as these wider perspectives are necessarily served as a consequence of attempting to fulfil the proximate objective noted above. So here too, only a selective and short appreciation of the literature is provided.

However, qualification of the type noted requires that two areas of knowledge be treated exceptionally: the pedology of the granite plateaux of south-western Britain and the archaeology of the study area itself. In these cases, the reviews do include a fuller coverage of the literature and/or more detailed discussion of the evidence.

The chapter is divided into two major sections: the first section concerns the physical environment and land use within the study area; the second section deals with fieldwork and laboratory strategies.

3.2 Environment and land use

Fig. 3.1 shows the location and extent of the Dartmoor study area which is centred on NGR SX 681713 (roughly 3°52'15" W Long, 50°31'30" N Lat) and lies within the Commons of Devonshire, some 3 km WNW of the village of Holne. It encompasses some 120 ha of presently unenclosed moorland and is defined on all sides by natural boundaries. The river Dart and its southern tributary streams have divided the lower plateau of Holne Moor into three broad spurs running roughly north-south. Today, enclosed land is confined to the gentle, sheltered, eastern slopes of the western (Combestone Farm) and eastern (the Stoke Farms) spurs while the central spur on which the study area is located is used as a rough grazing resource for Scottish Blackface sheep, a small herd of Galloway cattle and a dozen moorland ponies, all of which are owned by the aforementioned and other nearby farms. In addition to this low density grazing, the area is affected by recreational use and forms part of the catchment of the Venford reservoir, which drowned part of the Venford Brook valley in 1907.

In many ways the pattern of landscape and modern exploitation of Holne Moor provides a microcosm of contemporary Dartmoor, a region whose natural and cultural history has been repetitively described particularly over the past two centuries (for an extensive, near-exhaustive bibliography of the non-fictional literature of the region see Somers Cocks (1970b, 1974)). As today, in the past also, for Holne Moor like much of Dartmoor is littered with the now-abandoned works of man; it shared in the tin booms of late medieval and early modern times, was exploited by earlier medieval farmers from settlements analogous to those which survive on the surrounding spurs (Fleming and Ralph: in press), and earlier still was included within the southernmost part of a very large prehistoric field system, known as the Dartmeet parallel reave system (Fleming 1978b: Fig. 4). Although not without intra-regional diversity, Dartmoor nevertheless preserves a strong regional identity which ultimately stems from a physical environment which is unique in southern England and places severe constraints on the range of human opportunities. It is therefore sensible to consider these physical parameters before turning to the pattern of human response.

3.2.1 Physical environment

There are numerous summary and detailed accounts of the physical background of Dartmoor in both the 'classical' literature of the region (e.g. Harvey and Gordon 1953, Spooner and Russell 1967) and in works devoted more specifically to the physical environment (e.g. Simmons 1964a, Perkins and Ward 1970). Some of the information that is most relevant to pedological enquiry has been usefully summarised in a recent publication of the Soil Survey of England and Wales (Harrod et al 1976).

Geology, geomorphology and topography

With minor exceptions on the north-eastern periphery, the whole of the principal study area is underlain by a coarse-grained granite of late Carboniferous or early Permian age. The nearby margin of the granite laccolith is indicated on Fig. 3.1 which also shows that the outlying study areas at Rowbrook and at the Stoke Farms share this underlying geology (I.G.S. Sheet 338). The major physiographic features of much of Dartmoor have been attributed to a combination of early Pleistocene marine and Tertiary sub-aerial erosion (Brunsden and Gerrard 1970) and these authors indicate a mid-Tertiary age for an erosional surface corresponding in height with that of the lower plateau of Holne Moor (320-350 m a.s.l.). A lower terrace (275-300 m a.s.l.) is found in the north-eastern quadrant of the study area and this may be a remnant of a late-Tertiary surface. Both the river Dart and, in its lower stretches, the Venford Brook have made deep incisions in the mature landscape represented by the plateau surfaces, but the latter retain the gentle forms of this earlier landscape. Slopes on the plateau surfaces rarely exceed 4° and with few exceptions have either convex or linear forms. The latter tend to dominate the upper slopes leading out of the flat plateau top while the former are most clearly seen at the margins of the study area where they lead into the steep (7°-15°) slopes of the incised valleys. Gentle concave forms occur only at valley and stream heads.

The major portion of the study area consists therefore of a gently-domed plateau which measures some 1.1 km along its princi 1, almost flat, NNE-SSW axis and has a breadth of about 0.7 km. At no point in this study area is there a natural exposure of the underlying bedrock, but it can be observed at Combestone Tor, some 0.5 km WNW, and in quarries on the eastern margin of the study area which were cut during the construction of the Venford reservoir (Fig. 3.1). Although, at this site, haphazard piles of spoil obstruct a clear view of the uppermost stratigraphy, it can be seen that sound granite is overlain by several metres of solifluction deposits of the type named by Waters (1964) as the 'main head'. A 3-4 m deep excavation associated with construction of public conveniences some 50 m south-west of the quarry did not encounter bedrock or the soft, highly altered granite known as 'growan', but was entirely dug through the loamy, stony and much less weathered, head, which in this, the best exposure seen in the study area, showed only very slight evidence of stratification.

However, the pronounced horizontal platy structure visible some 1-2 m below the surface of these head deposits provides the best evidence from the study area for the thickness (about 1 m) of the indurated horizon which is a common feature at the base of Dartmoor soil profiles and often has developed at a point in the head where the stone content increases sharply and substantially. Despite controversy (e.g. Romans 1962), local soil surveyors (e.g. Clayden and Manley 1964, Harrod et al 1976) have followed Fitzpatrick's (1956) views and have attributed the indurated layer to processes associated with seasonal thawing of the solifluction deposits which mantle the bedrock over much of Dartmoor and throughout the study area. Pleistocene cold phase conditions have also contributed to the present characteristics of the soil parent materials of Dartmoor in the form of minor loessial additions (Clayden and Manley 1964, Harrod et al 1974) similar to those found over much of southern England (Perrin et al 1974).

A shallow valley, now much modified by tinning, indents the eastern margin of the plateau and its orientation (WNW) may have been influenced by the strike of an underlying mineral vein. Some 200 m to the south (see Fig. 3.2) a second vein is clearly indicated by a long tinning gulley and a line of discontinuous pits which extend westwards beyond the south-western extremity of the study area. These orientations are similar to those of the larger veins to the south, which have been mapped by the Geological Survey (I.G.S. Sheet 338). The lodes on Holne Moor appear to be the most northerly extensions of this southern 'emanative centre' (Dearman 1964) of mineralisation and contribute some additional variety to the suite of rock types that may have gone into the makeup of the solifluction sheet in this area.

No information has been located concerning the proportion of the various granite types that may have contributed to the soil parent materials on Holne Moor, but the relative uniformity of the rock analyses published by Brammall and Harwood (1923) suggest that only very minor variation in parent material chemistry would be produced even in the unlikely event that the proportions of rock types varied substantially within the study area. In particular, it can be pointed out that the phosphorus content of all of the typical granite types analysed by Harwood (including both the most common, 'blue' and 'giant' varieties) was very similar; all these samples had between 0.24 and 0.21% P_2O_5 (about 0.1%P). An earlier analysis of blue granite cited by Brammall and Harwood revealed 0.19% P_2O_5 and an 'extreme' granite type, composed essentially of coarsely-crystalline felspar and quartz contained only 0.16% P_2O_5. It is also worth noting that these analyses reveal that the Dartmoor granites are strongly acidic and extremely poor in bases (the range in typical rocks being: 70.23 - 75.09% SiO_2; 0.45 - 0.74% MgO; 0.66 - 1.56% CaO; 2.89 - 3.22% Na_2O; 3.78 - 5.38% K_2O).

No systematic characterisation of the rock fragments encountered in soil profiles of the study area has been made, but casual observations indicate the presence of granites showing considerable variation in crystal size. However, the extremes represented by very fine crystalline rocks and the truly 'giant' orthoclase crystals are rarely seen. There is only a little evidence for incorporation of decomposed material of 'growan' type (see 4.2.1.1); Waters' description (1964:90-99) corresponds closely to the evidence observed in the study area. He stated that 'the main head . . . comprises relatively sound crystal and and granite fragments . . . in a sandy clay or silty matrix. It is generally coarser below than above and . . . contains no decomposed feldspars, although it always contains the products of frost weathering of granite, whose impermeability and coherence may have been reduced by a certain amount of chemical weathering'. Variation in the coherence of rocks and minerals within soil profiles of the study area can be linked to the current cycle of pedogenesis (and is therefore discussed later; see 3.3.2), but is also affected by variation in rock type. Rocks showing intrusive quartz veining and what may be much-altered inclusions of 'country' rocks (zenoliths) have been observed and typically show little evidence of weathering. Waters' (1964) model for the cr tion of the main head deposit (there is no evidence in the study area for his 'upper' head, which Clayden and Manley (1964:120) also noted was 'often absent') nevertheless requires one to recognise the probability that it contains material that will have been affected by weathering processes, both chemical and physical during the later stages of the Pleistocene.

Soil profile evidence of surface instability will be discussed later (see 4.3.1), but it can be stated here that such evidence is confined to the steeper slopes at the peripheries of the study area, whose otherwise gentle topography seems unlikely to have undergone significant modification due to erosion and redeposition since active solifluction processes ceased at the end of the Pleistocene. If this is correct, one may conclude this discussion by pointing out that the geological and physiographic features of the study area conform to the criteria which, it has been suggested (see 2.1), are desirable in pedological studies of this character.

Climate

Although, to a first approximation, the size and topography of the study area permits an assumption of quasi-uniformity in the climatic parameters that have affected its soils, investigation of the trajectory of soil development requires one to assess the extent of changes in these parameters during the life of the systems studied. If, as the evidence discussed in this section suggests, the amplitude of climatic change within the Holocene has exceeded the range of variability observed during the period for which instrumental records are available, such observations may mainly be of interest as a means of introducing some sort of firm baseline and certainly cannot be viewed as establishing the 'climatic factor' for the systems. This present-day baseline is discussed first.

The contemporary climate of Holne Moor, like all of Dartmoor, is the product of a blending of the oceanic pattern of the south-western peninsula with the more rigorous conditions of an upland plateau. Perkins (1970) and Brunsden and Gerrard (1970) provide concise descriptions of the resultant wet, windy, but relatively mild weather. The highest areas on both North and South Dartmoor receive more than 2300 mm annual rainfall (1940-71 means) and few places on the granite massif record less than 1500 mm. There is a winter maxima, but summer rainfall is also frequent and heavy; early summer and autumn often provide the driest months. High humidity is characteristic and is associated with persistent low cloud and hill fog, which bl·nkets the central basin of Dartmoor for more than 70 days a year. Conditions on Holne Moor are not quite as bleak as those at Princetown, whose meteorological characteristics are usually cited in accounts of moorland weather.

It is for example, likely that the Holne rain-day annual average is lower than that of Princetown (214 rain-days year^{-1}), but substantially higher than that of lowland Devon (161 rain-days year^{-1}-see Brunsden and Gerrard 1970). There are in fact copious records of rainfall in the study area compiled by the South West Water Authority (S.W.W.A.) and its forerunner, the Devon River Authority; these cover more than half a century of daily records taken from four rain gauges whose locations are indicated in Fig. 3.1. The values recorded at the southern end of the reservoir ('Venford Reservoir - 363697' in the Hydrometric Reports of the S.W.W.A.) conform closely to the mean value for all four gauges and have therefore been selected here as the best available estimates of precipitation entering the soils of Holne Moor.

Annual average precipitation (1941-70) totalled 1773 mm, but there can be considerable variation around this mean value. In 195 , only 1118.2 mm was recorded whereas in 1974 precipitation rose to 2675.1 mm; nor is such variation rare. More than 2400 mm has been recorded in six years since 1941 and less than 1400 mm on eleven occasions since that time. Such variability also extends to monthly totals in all seasons; for example in December 1962, a mere 74.2 mm was recorded, but ten years later 436.9 mm fell in the same period. April is not a particularly wet month on Holne Moor, but in 1966 nearly 400 mm of rain fell; by contrast, April showers in 1938 brought only 7.1 mm and there were 27 rain-free days. The annual variability in particular is of interest for it demonstrates clearly that at least in recent times, the rainfall on Holne has varied from levels comparable with lowland stations in relatively dry areas of eastern England to levels not out of place on the higher peaks of the Atlantic seaboard - a fact to remember when assessing the nature of possible climatic patterns in the remote past.

There are no records of wind speed and direction or of temperatures on Holne Moor, nor any indication of days with snow cover and/or frost. However, after several years of fieldwork in the study area in all seasons, it is possible to state that at present the dominant winds have a westerly point. In summer most weather arrives from the south-west; in winter colder, north-westerlies are far more frequent.

Easterly and southerly winds are mainly encountered during rel tively rare anticyclonic intervals. As on the rest of Dartmoor, the present dominance of maritime air masses ensures that extremes of tem er ture are rare. Although local informants remember well the infrequent savage winters, it is doubtful if snow lies on Holne Moor for more than an average of about 10 days a year and while night ground frosts may occur from October to May, daytime frosts probably have a frequency of less than 60 days year^{-1} (these estimates are based on data from Princetown (Brunsden and Gerrard 1970:Table 3), where higher altitude must produce greater extremes of rainfall and temperature at least in winter).
The low annual range of mean monthly temperature in the south-western peninsula is associated in lowland regions with a relatively high winter minima. In consequence these areas enjoy an unusually lengthy period during which temperatures high enough for plant growth persist; parts of lowland Devon have almost uninterrupted growth the whole year round. However when depressed by altitude, a similarly 'flattened' temperature curve ensures a relatively short growing season on upland areas l ike Holne Moor - an unusually sharp contrast within a region. Mean monthly temperatures for Princetown (Perkins 1970:Table 2) suggest that on many parts of Dartmoor little growth occurs between November and April; on Holne Moor the 'keep' is often still poor at lambing time in April. As Perkins (1970) pointed out, the reduction of accumulated temperatures during summer months on Britain's western uplands considerably limits the growth and productivity of upland plants.

As with precipitation, there are marked inter-annual variations in seasonal temperatures and as Manley (1972:22?-230) showed, these have greater amplitude in upland regions. When south-western Britain has a good summer, Dartmoor weather may be little different from nearby lowlands; conversely, in poor years, Dartmoor's summers can be appalling. This too needs to be borne in mind when thinking about the nature of the climate in pre-modern times.

From the viewpoint of lowland Britain then, Holne Moor has experienced, during this century, what are perceived as cool and often wet summers and cold, wetter winters. The question now arises, how far are such conditions likely to be representative of climate during earlier periods in the Holocene? At the outset it must be admitted that at present direct evidence of earlier Holocene climate in south-western Britain is almost non-existent and unequivocal evidence from Britain as a whole still thin on the ground as a recent review (Simmons and Tooley 1981) makes clear. In particular, the latter publication highlighted the problem of distinguishing the effects on ecosystems of changes in natural parameters such as climate from those induced directly or indirectly by human activities.

J.A.Taylor's synthesis (1975) of earlier research on climatic changes figures prominently in the review and the s me source was wholly relied on by Staines (1979) in his recent discussion of Holocene environmental change on Dartmoor. However, contributors to the general review have shifted towards the idea that '. . . there seems to be much more in favour of increasing wetness immediately before and during the Neolithic period than there is to support the classical view of increased continentality' (Smith, A.G. 1981:203), whereas Staines followed the classic view without comment. Staines also suggested that Taylor's outline of climatic trends entitled one to think that over the past two thousand years '. . . conditions have changed relatively little, apart from the normal oscillations of weather' (Staines 1979:24); this view is not supported by the evidence discussed below, nor did Taylor discuss in any detail the changes of climate in historic times. Moreover, inasmuch as the historical period was considered by Taylor (it was included in several of his diagrams and charts), it must be noted that the early work by Lamb and his associates on the historical sequence, on which Taylor largely relied, has subsequently been heavily criticised. Ingram et al (1978:334) concluded that '. . . much of it can now be seen to have been based on the sands of unreliable data'.

When dealing with both historical and earlier periods one must also remain conscious of the typ e of circular argument that can arise between two or more disciplines and is well-illustrated by a statement of Pennington (1974) in her synthesis of British vegetational history. She thought that 'from the extent of upland settlement in England and Wales during the Bronze Age, particularly on Dartmoor and in the Lake District, it would seem that the climate may have been warmer and drier than that of today - that is, nearer to conditions resembling the Continental Sub-Boreal than to our present highly oceanic climate' (1974:79). Clearly any assessment of the relationship between climatic changes, agricultural activities and pedogenesis, on Dartmoor itself, must be particularly careful in its reliance on climatic reconstructions in which this sort of approach has contributed to conclusions.

Despite the caveats and problems outlined above, this author believes that it is possible to discern something of the general nature of climatic changes that are likely to have affected the study area and that these have been large enough to have had a profound effect on both natural and cultural phenomena. The main problems that cannot be fully resolved at this time concern the inter-action of changes in temperature and moisture (i.e. the difficulty of interpreting evidence of increased wetness when such changes may reflect alteration of either precipitation or evaporation) and the dating of such events. The latter continues to present considerable difficulties, despite the fact that some optimism about one's ability to discern the general pattern is predicated on the results from dated ice core studies, because although the latter provide substantial confirmation of patterns demonstrated from other types of evidence (Hammer et al 1980), there are indications of time-lag differences between Greenland climatic phenomena and that of other areas. Although this author has not undertaken an extensive evaluation of the now voluminous literature relevant to post-glacial climatic change, examination of the sources cited above together with other syntheses (e.g. Goudie 1977) and recent ice core studies (e.g. Herron et al 1981) suggests that a soundly-based consensus exists at least with respect to certain periods.

One may start by noting that the period for which extensive instrumental records are available is largely coeval with a period of warm, relatively benign climate. Thus the baseline of contemporary climate described above cannot be regarded, as Staines (1979) believed, as typical of the last two thousand years or indeed the last ten thousand years; it can, in fact be doubted whether the concept of 'typicality' is a useful one in this context. For the historical period, the general course of events, if not their exact timing, is perhaps best represented by the Northern Hemisphere temperature index of Hammer et al (1980). This subsumed three different types of proxy climatic records, which concur, at least in major events, both among themselves and with the volcanism-induced acidity record preserved in the Greenland ice cap, as well as with later ice melt features from the same source area (Herron et al 1981). The implication of all these studies is that for much of the 600 years prior to AD 1900 temperatures were lower than those of today, a period which includes the classic 'Little Ice Age', whose coldest depths between about AD 1550 and AD 1700 are clearly indicated. It is equally evident that this very cold period can be envisaged as the low point on a temperature oscillation; temperatures may have started to decline as early as ca. AD 1200, falling below those of today by the early 14th century. Although warmer spells are indicated in the first half of the 16th and 18th centuries, neither of these 'interstadials' appears to have been as warm as the present warm period. The timing of the glacial advances discussed by Goudie (1977) suggests that, as one might expect, ice advance generally occurs at some temporal remove from the date of the triggering event and that timing is also affected by purely local factors.

There also seems to be a general consensus that from about AD 1000 until the early 14th century temperatures were similar to and at times higher than those of the present; maximum warmth, significantly higher than the present, may have been limited to the 12th and early 13th centuries. Prior to AD 1000, agreement between the records is not as good, but there are indications of a cooler period from ca. AD 800 to AD 1000, when temperatures were almost certainly lower than today, and of a warmer period ca. AD 700-800, though it is unclear whether temperatures during this spell exceeded those of the present. The Northern Hemisphere temperature index runs only to AD 550, but the ice melt features in a Greenland core continue this sort of detailed record back to ca. 300 BC (Herron et al 1981). Although one cannot place much reliance on as yet unsupported data, this core indicates a possible fall from very warm summers prior to 300 BC to much colder conditions which appear to have lasted until ca. 100 BC. A subsequent period when temperatures may have been similar to those of the early period of medieval warmth (and thus similar to those of today) is terminated by a return to cold conditions at around AD 350 which continued till ca. AD 550. It is at present impossible to evaluate how far the timing or nature of these changes in Greenland's summers are applicable to north-west Europe. However, should other work confirm the pattern and extend its applicability, this could imply that very cold conditions, similar to those of the Little Ice Age, may have prevailed during both of these cold periods.

There seems to be a dearth of reliable information about changes in precipitation during the historical period. The degree of cold indicated by such events as the freezing of the sea at Marseilles in AD 1595 and AD 1638 (Goudie 1977:125) seems likely to have been accompanied by substantial continentality, which could imply that precipitation/evaporation ratios may not always have risen as temperatures fell. However, the marked drop in mean annual temperature indicated by the Greenland isotope data and these events was accompanied during the major part of the Little Ice Age by reduction in summer melting on the ice cap (Herron et al 1981:390) and a reduction of summer temperatures is also indicated by harvest problems (Goudie 1977:125). These data can be interpreted as indications of increased cyclonic activity in summer, which could imply considerable increases in the precipitation/evaporation ratio.

At present the fairly coherent picture of historical climatic change cannot be matched in the earlier, prehistoric period. Although there seems to be a broad acceptance of the picture of temperature optimum and decline (as, for example, presented by J.A.Taylor(1975)), that has been in vogue for more than a generation, it is a consensus based on remarkably little, hard, unequivocal evidence. Certain threshold changes do seem to be visible. Thus the timing of a very rapid rise in temperature in the earliest post-glacial seems firmly established; likewise Turner's review (1981) of the recurrence surface data strongly supports the traditional view that a rise in the precipitation/ evaporation ratio occurred during the early part of the first millennium bc. There are obvious discrepancies in the dating of this event, but these may mainly reflect differences in threshold achievement times rather than differences in the timing of the climatic shift responsible. Turner's estimate that wetter conditions occurred from ca. 850-450 bc seems to be justified by the dates available to her.

What such evidence does not reveal clearly is what this relative change meant in absolute terms. Although the rapidity of bog growth at sites like Tregaron (Turner 1964, 1965), which was nearly twenty times faster during the period between ca. 700 bc and ca. 400 bc than during the later period between ca. 400 bc and ca. 1200 ad, points strongly to a period of cool, very wet summers, it tells us little about winter conditions or about how this period compares with conditions during the worst of the Little Ice Age. Nor does the available recurrence surface data allow one to assess at what point, during what may have been either a stepwise or oscillatory deterioration from the earlier post-glacial temperature optimum, temperatures fell to and below those of our present climate.

After reviewing the evidence for Bronze Age climate, Tinsley (1981:211) was forced to conclude that 'the exact nature of moisture conditions in the Sub-Boreal is open to question' and the same can be said of temperatures. Unless one believes that under present climatic conditions, it would be impossible to survive as a farmer on Holne Moor (a view that would certainly be disputed by the author and the farmers at nearby Stoke and Rowbrook, whose farms embrace land no less hostile than that of the study area), there can be no justification for following the type of argument mentioned by Pennington as a m ans of overcoming the lack of adequate data. In the author's view, there is little to gainsay the proposition that during the later Sub-Boreal the climate of the study area could have been very similar to that of today.

Reviews of the climate during the Mesolithic (Simmons et al 1 81) and Neolithic (Smith, A.G. 1981) to a large extent follow the synthesis of J.A. Taylor (1975) with the exception noted earlier. Apparently no evidence has come to light in the past ten years to challenge the widely-held view that early post-glacial times were warmer and in the first stages drier than today; more oceanic, cyclonic conditions are thought to have become established after 5000 bc, and there are several indications of falling temperatures and/or increased precipitation/evaporation ratios by the middle and late fourth millennium bc. A.G. Smith (1981: 143) notes that there are indications of cyclical climatic fluctuations during the earlier Sub-Boreal, but it is clear that as yet the climatic record for this period lacks the resolution to define such changes with any precision.

This discussion can be concluded by noting that the climatic influence upon soil development in the study area has changed repeatedly during prehistoric and historic times; some of these changes in temperature and precipitation have almost certainly been large enough to significantly alter both rates of leaching and of production and decomposition of organic matter. In consequence, one is not entitled to assume that changes in soil processes, even ones which apparently involve a major shift in the pattern of soil development, merely indicate the passage of natural thresholds within a simple and inevitable pedogenetic trajectory; the very concept of a single, simple trajectory can be questioned. Nor is one justified in concluding, as Staines (1979:46) did, that man's activities must have played a significant role in the soil changes that are thought to have occurred.

Vegetation

Vegetation patterns and in particular their relationship with soil patterns are discussed in detail in section 4.3.2, so this section provides only a general description of the present vegetation and an assessment of the post-glacial history of vegetation in the study area.

If one follows Jenny's (1941, 1958) formulations, the biotic 'state' factor in pedogenesis, like the climatic factor, can be assumed to be identical for all profiles in the study area. This is not a denial of the considerable variety in plant communities within the study area, merely an assertion that all soils could have shared in the same potential range of vegetation both now and in the past. Nor does it deny the role of microclimatic and topographic variation in contributing to the present pattern of distribution of plants on Holne Moor, though such factors could only be expected to be of major significance on the more steeply sloping areas towards the peripheries of the study area. However, today and for lengthy periods in the past, the pattern of distribution has been affected by human activities both directly (e.g. moor burning, known locally as 'swaling') or indirectly (e.g. through responses to soils whose characteristics have been altered by metapedogenesis) and much of the present pattern of vegetation mainly reflects such factors.

The most comprehensive survey of Dartmoor vegetation is that of Ward et al (1972, see also Perkins and Ward 1970), who used air cover shot in 1969 and ground checks to produce a generalised vegetation map of all of Dartmoor. On their map, Holne Moor is shown as an area of 'Heath' surrounded by a fringe of 'Grassland-with-Bracken' and this is a good first approximation to the true pattern. An 'Air Photo/Soil Association Map' of Dartmoor produced at about the same time by Staines (1972) also includes Holne Moor, but the mapping units are less precise and the boundaries less accurate than those in the study by Ward et al (1972). Due to the effects of swaling, which made air photo interpretation of their 'Calluna-Molinia Moorland' vegetation category difficult, Ward et al (1972:512) included this category in either blanket bog or grassland or heath for mapping purposes and certainly in 1976, the plateau surface of Holne Moor was largely covered by plant communities of a type best described as Calluna-Molinia moorland, though if the association-analysis hierarchy of Ward et al (1972: Fig. 2) is employed, the rarity of deer-grass (Trichophorum caespitosum) would put the Holne vegetation into the 'drier' heath categories.

Three methods have been used to assess and map the Holne vegetation. First, the colour air cover used by Ward et al (1972) was examined; secondly, a vegetation survey employing visual estimates of abundance of a kind previously used on Dartmoor by Johns (1957) accompanied a large scale soil survey (see chapter 4) and was used for detailed mapping of limited areas. The general picture gained in these studies was then 'calibrated' and much improved by very detailed studies of the plant cover in seven 'representative' areas; this work was carried out, at the author's request by Dr S. Rogers of Seale-Hayne

Agricultural College, who has kindly made the results of her surveys available (see 4.3.2).

Fig. 3.2 shows the vegetation pattern in the study area in 1969 and indicates areas then affected by recent swaling; in fact few if any parts of the study area exhibit the uneven-aged communities of heather that might be taken as evidence that swaling had not occurred for a long time. Prior to 1969, swaling seems to have been practised extensively and was perhaps concentrated on the more gentle slopes on the eastern side of the plateau. Most of the patterns in this map, which was prepared from the colour air cover mentioned above, are also visible in the field today; in particular, one can easily identify the special patterns of plant communities in recently burnt areas and the generally older age of heather stands on the plateau ridge top. No extensive swaling has occurred since 1969 though a few small 'test' areas were burnt over in 1980.

Although variation in the representation of non-dominant species within the general category of Calluna-Molinia moorland may be affected by variation in, for example, soil moisture, peat depth and other soil characteristics (see Kent and Wathern 1980) as well as variations in the time since swaling and in grazing pressure, the information available does not allow assessment of the separate effects of these various factors. However, there is little indication that the major components of these communities (i.e. Calluna vulgaris, Molinia caerulea, Erica tetralix, E. cinerea and Agrostis setacea) are much affected in their distribution and abundance by the relatively minor variations in soil that occur within the areas covered by Calluna-Molinia moorland (see 4.3.2). A consequence of this is that, within the study area, vegetation patterns generally cannot be used as reliable proxies for soil patterns. Some 'islands' of grassland-with-bracken occurring within areas dominated by heather and purple moor grass constitute exceptions to this rule, since, in some but by no means all of these cases, their distribution can be seen to be linked to the presence of disturbed, usually better-drained soils on tinning piles, rabbit buries and ancient land boundaries.

Grassland-with-bracken communities of similar visual appearance (but in some cases very different composition) are far more extensively developed on the lower flanks of the plateau, but there does not seem to be a straightforward and direct linkage either with slope angle or altitude or a combination of these variables for both grassland-with-bracken and heath communities exist alongside each other on gentle and very steep slopes, and at higher and lower altitudes. As on the plate u surface, the distribution patterns have been affected by swaling and grazing pressures, but unlike the plateau surface, the distributions on the flanks are also strongly affected by soil variation, itself intimately linked to the pattern of medieval land use (see 4.3.2). In a closely similar environment (the Narrator catchment on south-west Dartmoor), Kent and Wathern (1980:168) observed that a relationship with altitude was 'a function not only of the direct effects of altitude on vegetation, but also of past and present land use practices which are themselves indirectly related to altitude'. Since this is also true of Holne Moor, detailed consideration of these patterns must be preceded by an account of medieval land use on Holne Moor and its effects on the soil (see 3.2.2 and 4.3).

Trees occur only sporadically in the study area and with a very few exceptions are limited to the most sheltered areas; for the most part these isolated trees are hawthorn (with occasional rowan) and typically they are found growing on old boundaries or in a few cases old tinning piles. It is tempting to see some of them as relicts or even direct survivors of ancient hedges on these boundaries. In addition to a plantation alongside the Venford reservoir, semi-natural woodland occurs on the northern periphery of the study area. Here the oak woodland of the Dart gorge reaches just over 300 m a.s.l. before succumbing to the combined pressures of swaling, grazing and exposure. Although the l atter cannot be seen as the only factor, it may well be the most important one; certainly the present woodland margin, which is found immediately below the sharp change of slope that terminates the plateau on the northern edge, suggests that exposure and in particular the effects of wind are determining the present location of the boundary.

The pattern of vegetation described above is really an historical one, since between the author's survey in 1976 and 1980, the heather beetle (Lochmaea suturalis) has ravaged parts of Dartmoor, including Holne Moor and areas once dominated by heather have been changed in places into almost pure swards of purple moor grass. This event serves well as an illustration of the rapid changes in vegetation that can occur in plant communities dominated by very few species and also reminds one that, even in times when man's influence is a fundamental factor in moorland ecosystems, natural parts of the system can still strongly reassert themselves.

There is at present no adequate history of the vegetation on Holne Moor. To remedy this, the author has, in collaboration with David Maguire of the University of Bristol, been processing soil pollen samples from buried and normal soil profiles in the study area. Unfortunately some of this work is incomplete and none of it has been published; in consequence, the results of these studies, some of which have been publicly presented (Association for Environmental Archaeology - Easter Meeting 1981), cannot be relied on in this thesis as the only or even the major source of information about the post-glacial development of vegetation in the study area. Nevertheless, some of the evidence gathered from Holne Moor is included in the account given here since despite the chronological problems associated with the interpretation of soil pollen spectra, this direct evidence forms a useful adjunct to the inferences which may be drawn from pollen studies on other parts of Dartmoor, whose utility and relevance are diminished both by dating problems and by the particular locations of the sampling sites.

Aside from the soil pollen studies of Staines (1972, 1979), which will not be considered here for reasons discussed in the next section, the most extensive published studies of Dartmoor vegetation history (Simmons 1962, 1964b, 1964c, see also 1961, 1963, 1969) are mainly based on pollen taken from high altitude blanket peats (e.g. Blacklane, Taw Head, Raybarrow Pool) or from lower sites (e.g. Taw Marsh, Postbridge, both at ca. 370 m a.s.l.), whose surrounding environments are today substantially different from Holne Moor. There is as yet no sound procedure for relating pollen catchments of such sites to the pollen production of lower, drier plateaux like the study area. In addition none of Simmons' peat profiles was radiometrically dated. Bearing in mind that his studies revealed some important differences between early post-glacial vegetation history on Dartmoor and that in other areas of England, it is difficult to regard Simmons' traditional zonation of the diagrams as more than an approximate indicator of the relationships between them. The absence of precise dates for vegetational events, when linked to equal imprecision about the dating of cultural events on Dartmoor requires one to look at Simmons' (1969) assessment of their interrelationship with considerable scepticism.

A more recent study of pollen deposition in south-west Dartmoor (Beckett 1981) has been radiometrically dated, but the main site studied lies in a sheltered valley (Blacka Brook, 270 m a.s.l.) and, moreover, much of the later vegetation history revealed by this and other nearby sites has been interpreted as reflecting local patterns of changing land use. Unless a similarity in the nature and timing of land use is assumed, these sites cannot also provide a history of vegetation and land use on Holne Moor. Such an assumption seems unwarranted. However, since the soil pollen studies from Holne Moor do not provide any indic· tion of the earliest post-glacial vegetation, Beckett's and Simmons' studies must force majeure be utilised as sources for that period.

From both a pedological and archaeological perspective the most important question about early vegetational history that needs answering is whether or not the study area was covered by woodland **at** any time in the early Holocene. Direct evidence of woodland in the form of stumps, trunks and twigs have only rarely been observed in the blanket peat of Dartmoor; few are known from sites above 365 m a.s.l. and none from sites above 395 m a.s.l. (Simmons 1964c, 1969). Worth (Spooner and Russell 1967:9) noted that 'bog-wood', mainly of birch and oak, had mostly been found 'in relatively sheltered places' and he concluded that the windswept plateaux of Dartmoor had never been covered by trees. Simmons (1964b) rightly questioned this view, but had to admit that the evidence remained equivocal. On the other hand, Brown (1977), who investigated pollen deposition on nearby Bodmin Moor, where bog-wood has also 'not been reported away from valley floors' (1977:299) concluded that, during the Holocene, trees had never flourished on the exposed uplands of south-western Britain. He thought that Simmons' pollen diagrams could be interpreted 'as indicating essentially open moorland, as on Bodmin Moor, with perhaps slightly greater open woodland cover' (1977:306); since he thought that such open landscapes were a product of the natural environmental conditions he was also able to conclude that 'deliberate clearance of woodland by later Mesolithic or Neolithic peoples cannot have been of any measurable extent and, indeed, would seem to have been unnecessary in view of the open landscape' (1977:307).

Despite recovery from a sheltered valley site, Beckett's pollen spectra, like those of Simmons and Brown never contain more than 50% tree pollen and values between 20% and 40% are more typical. A.G.Smith (1981:201) cited several studies of modern pollen rain which showed that 'only in an open landscape does the proportion of tree pollen fall below 50%', but pointed to the need for careful evaluation of the contribution of local non-tree pollen when using this statistic. Brown's conclusion appears to have been based on such an evaluation. In these circumstances, if one is not to interpret such values as evidence for a landscape dominated by non-arboreal vegetation, it is hard to know what values would provide acceptable evidence of such an occurrence.

One may envisage, therefore, that even during the climatic optimum, which period witnessed the maximum extension of woodland (Simmons 1964b), the grass and heather communities, which had become established at the opening of post-glacial times, continued to dominate on all the more exposed plateau areas of Dartmoor. Colonisation by trees will have been limited, as today, to valley bottoms and sheltered valley sides, which will have been covered by open oak woodlands with hazel and scattered birch and rowan. Both Simmons' and Beckett's pollen diagrams indicate that there was a subsequent decline in tree pollen though neither researcher believed that the landscape was substantially altered during Neolithic times. A reduction in woodland cover after ca. 5000 bc or later could reflect increasingly hostile conditions for tree establishment during a period of temperature decline and increased oceanicity.

How may these findings be linked to the evidence from Holne Moor itself? One would expect that, during the climatic optimum, woodland would have extended up out of the Dart gorge along each of the shallow valleys that surround the study area; open woodlands could well have colonised the lower, north-eastern plateau, the eastern slopes and southern parts of the plateau, which benefit most from the shelter provided by the higher land of Holne Ridge to the south. Both the density and extent of this woodland cover may well have been reduced sometime after ca. 5000 bc. This model of vegetation finds considerable support from the soil pollen information presently available from the study area. Sampling sites for this investigation are shown in Fig. 3.2; in the southernmost profile - a virgin soil profile, well beyond the anciently enclosed land - the following sequence is evident. A basal sample from the B_2 horizon, in which only a small amount of pollen was recovered, revealed grass, heather and tree pollen (ca. 30%). Above this, in the upper B_2 and lower B_1 horizon, tree pollen (mainly oak) increased to ca. 60% and both heather and grasses decline. At this time, the sampling site may well have stood near the borders of a woodland extending upslope from the Venford Brook valley to the south. In the upper B_1 and Ah/E horizons, tree pollen declines to between ca. 5% and less than 20%, initially in favour of grass pollen. In the highest sample from the mineral soil (Ah/E), heather increases, and this trend continues within the overlying Oh horizon.

A broadly similar sequence was found in two soil profiles in the north-east of the study area. However, in both profiles (one of which was buried beneath a boundary constructed ca. AD 1000 (see 3.2.2)) tree pollen is less abundant; in each case the basal s~m le contain the largest proportion of tree pollen (ca. 30%) and it decl'nes t reafter. This pattern would, then, accord with the notion th~t t e m st e posed, central and northern parts of the plateau may have c rried little or no woodland. It must be noted that all the soil pollen s ples from ol1 Moor, but particularly those from B horizons contain large amounts of Polypodium spores, whose ecological significance is at present uncle~r. Since they may derive either from epiphytic vegetative growth on trees or be part of the ground flora of an open landscape, and, in any case, may well be 'over-represented' due to differential surviv l, their presence has been ignored in the analysis offered here.

Something of the timing of the vegetational changes in the study area can also be inferred from the soil pollen spectra, particul rly those taken from buried soils. Two samples from a buried Ah horizon beneath the wall of a house which was constructed ca. 1250 bc (see 3.2.2) contained little tree pollen (ca. 12-15%) and were dominated by herbaceous species, mainly grasses. Since this house post-dates the initial construction of field boundaries on Holne Moor and lies within the field system, these pollen samples may both reflect a pollen rain altered by farming activities. There is support for this hypothesis, however, only from the uppermost sample; it contained far more of the species regarded as indicators of disturbed land (Maguire: personal communication). The lower sample can be seen as merely continuing a trend evident in the B horizon samples of this buried soil. Taken together, these show a regular fall in tree pollen (from 40% to 12%) and a rise in herbaceous pollen (from 10% to 40%) from lower B_2 to lower Ah. This fall could well be a correlate of the general decline in tree pollen evident in Simmons' diagrams.

What seems certain is that, in the study area, the extent and/or density of woodland declined substantially prior to the farming activities recorded by the field systems and associated settlement, which are thought to have been established at ca. 1300 bc. One can, at present, do little more than speculate on the cause of this decline.

The rise of heather pollen after a period of grassland dominance cannot be closely dated. This change is, however, clearly indic ted in the upper mineral horizon and continues in the Oh/Ah 'surface' horizon of the soil buried ca. AD 1000, but much higher values of this taxon occur in samples from the soil, which developed in the overlying bank, and in samples from sediments which accumulated in the adjacent boundary ditch (these profiles are described in section 5.2.1). From these data, one may only conclude that the increase in heather pollen significantly pre-dates the construction of this boundary in ca. AD 1000 and pre-dates, by a short period, the initial growth of a 'mor' humus horizon on the soils of the study area. It is also clear that the change post-dates ca. 1250 bc, since the soil buried beneath the hut wall contained very little heather pollen. Simmons' undated pollen diagrams are of little help here, while in Beckett's Blacka Brook profile, a depositional hiatus is followed by a rise in heather, which, if one accepts the relevant radiocarbon date of 2120 $\pm$ 70 bc (HAR-3379), must predate the same phenomenon on Holne Moor by 900 radiocarbon years and perhaps much more. However, this dating sample may span the hiatus for, on another of Beckett's profiles, the change occurs later and is bracketed by dates of 1450 $\pm$ 70 bc (HAR-3812) and 570$\pm$ 80 bc (HAR-3816). Clearly this change in vegetation may be linked to the climatic deterioration starting about 850 bc, but may not necessarily represent an immediate or direct response to this climatic change. An increase in heathland plants could be the result of a reduction in grazing pressure, itself a reflection of lessened agricultural exploitation of the uplands of Dartmoor during a period when the climate was much less hospitable than it is today. In the study area such an interregnum may have occurred between ca. 500 bc and ca. AD 1000 (see 3.2.2).

From the pollen spectra in the medieval bank and the undisturbed Oh horizon of the control profile in the south of the study area, one may safely infer that herbaceous plants similar to those of the study area today have been the dominant flora since before AD 1000, and there is some indication from these samples, like those of Beckett, that the proportion of heather has increased during the latter part of this period.

This discussion has shown that it is unlikely that the greater part of the study area was ever clothed by the sort of dense woodland that it is thought was typical of lowland Britain in the earlier Holocene. If woodland ever covered the entire study are, one is entitled to envisage a very thin open woodland with abundant ground flora. Parts of the plateau top may well have remained free of trees and such woodland as did occur may only have persisted for a relatively short period. Colonising birch may well have reached Holne Moor by ca. 7000 bc, but woodland decline may have set in as early as ca. 5000 bc. Whether by changing climatic stresses or human agency, this decline is certainly evident well before the principal prehistoric occupation of the study area in the later second millennium bc. These conclusions, like those concerning climatic change, are not in accord with the views advanced in the most recent review of the evidence for Dartmoor's vegetational history (Staines 1979) and challenge the premises of its argument that serious pedological and ecolo ical cl n es must have occurred as a result of prehistoric clearance of Dartmoor woodlands. Although variation in the composition and density of vegetation has certainly affected soil development in the study area during the post-glacial period, changes in the biotic factor in pedogenesis may have been far less important on upland plateaux like Holne Moor, than they are likely to have been in densely forested, lowland ecosystems.

Soils

The present and past soils of Holne Moor and their history form the principal subject of following chapters and this section provides an introduction to this subject by discussing previous studies of the soils that have developed on the granite uplands of south-western Britain; particular emphasis is paid to ideas about the genesis of characteristic features of these soils.

The description and discussion of Dartmoor soils provided by Clayden and Manley (1964), the first modern account to appear, still provides the best introduction to their general features and also summarises early work in the area (e.g. the accounts of Vancouver (1813), Worth (Spooner and Russell 1967)); Hornung (1970) relied substantially on this source. The soils of Dartmoor can be assigned to four broad groups: 'brown earths'; 'peaty gleyed podzols'; 'blanket bog and peaty gleys'; 'valley bog and peaty ground-water gleys'. Neither of the latter two types will be considered here, since they are either absent (blanket bog) or of very limited occurrence (valley bog) within the study area on Holne Moor. Using the more recent classification system of Avery (1973), all soils in the first two categories are assigned to the Major Group 'Podzolic Soils', with the 'brown earths' now falling within the Group of 'Brown podzolic soils' and the 'peaty gleyed podzols' within the Group of 'Stagnopodzols'.

In recent years, the pioneering work of Clayden (1964, 1971) in the Teign valley and its surrounds on the eastern side of Dartmoor has been extended by local soil surveyors, who have now mapped the southern (Harrod et al 1976) and western (Hogan 1977) extremities of the moorland massif. The northern fringes of nearby Bodmin Moor have also now been mapped (Staines 1976). In the course of these investigations, the surveyors have further subdivided the Groups and at present four main Soil Series (excluding the Gunnislake Series - a Brown earth (sensu stricto) of very limited distribution (Hogan 1977)) have been recognised and defined: the Moretonhampstead Series, which includes Typical brown podzolic soils and intergrades with Ferric podzols and was first described by Clayden (1964, 1971), but has been modified by Harrod et al (1976); the Moorgate Series, which includes Humic brown podzolic soils and intergrades with Ferri-humic podzols and was first described by Harrod et al (1976) - some of these profiles were originally assigned to the Moretonhampstead Series; a Hexworthy Series, which consists of Ironpan stagnopodzols and was first described by Clayden (1964); and a Rough Tor Series, which consists of Ferric stagnopodzols and was first described by Harrod et al (1976). The latter two soils are typically mapped as a single unit, since the presence or absence of an iron-pan is the primary distinguishing feature and in many areas on Dartmoor, including the study area, iron-pans are an intermittent fe· ture, which, in some places, disappear and reappear within less than a metre.

From this brief account of the current classification, it is apparent that a series of intergrading soils of podzolic type cover much of Dartmoor; the principal advances since Clayden's early mapping have been the recognition of the Rough Tor component of the main moorland soil and the recognition of greater complexity among the non-peaty soils. Even the present complex subdivision cannot cope with all the variants that have been observed; in particular, it is worth while drawing attention to a profile type described near Moorgate, North Bovey. This soil was originally assigned by Clayden (1971:110) to the Moretonhampstead Series, but has recently been reexamined (Hogan 1978:44-45) and is now regarded as a Ferri-humic podzol soil belonging to an, as yet, unnamed Series. It is clearly an intergrade lying somewhere between the Moorgate and Rough Tor soil types.

On a number of occasions, the soil surveyors have recognised that land use history has played an important part in the present differentiation of soils; in some cases, subdivision at the Series level has been seen to be due to land use, in other cases, Series have been further subdivided into Phases to cope with the complex pattern produced by metapedogenetic intervention. Thus, Harrod et al (1976:84) noted that in areas of Moretonhampstead soils, Moorgate soils were associated with 'areas of late reclamation', while Staines (1976:101) found that Moorgate soils within areas dominated by Moretonhampstead soils occurred mainly in a few places where he considered that 'enclosure and cultivation have not been completed'. Both surveyors noted Moretonhampstead soils with a lighter topsoil; Harrod et al (1976) defined a Brown topsoil Phase of the series and Staines (1976:99) noted that the browner colours were found on 'older enclosed land near the granite-slate contact zone'. This surveyor also defined a number of variants of the Hexworthy-Rough Tor complex to cope with the effects of cultivation of these soils; in addition to basic Cultivated Phases, he also recognised Distinct topsoil Phases in which 'dark coloured rather than black, humose or peaty surface horizons are associated with early enclosure' (1976:114). Even the stagnohumic gley soil of wetter areas (Princetown Series) needed a Humose topsoil Phase to cover those places where 'cultivation has mixed the peat surface horizon with the mineral soil below' (1976:118).

One may conclude that agricultural soils on Dartmoor include a pattern of variation very similar to the pattern which Conry and his associates (see 1.2.3) studied at the scale of individual fields. During large scale mapping, it is not at all easy to take full account of variations of this kind; they may at times mimic natural patterns (e.g. altitudinal change caused by climatic control of the land use pattern) or they may be grossly discordant. The picture is extremely complicated and, as Staines (1979:30) remarked, requires 'further detailed soil mapping', if it is to be better understood. Thus far, none of these local soil surveyors have indicated an awareness that soil variation beyond the bounds of present-day enclosures may also reflect land use history in now-abandoned land. However, although Harrod et al (1976:114) suggest that the broad division between Stagnopodzols and Brown podzolic soils is in part a function of climatic differences - a reflection of altitudinal differences - they also noted that the Typical Brown podzolic soils of the Moretonhampstead Series '. . . occupy cultivated areas on the lower ground of the main valley sides and granite margins'(1976:79, my emphasis). Clearly explanations of the pattern of soil development on Dartmoor must include assessment of metapedogenetic factors, which, particularly on the moorland fringes, may be of paramount importance.

To a large extent current classification of these soils rests on the presence or absence of features such as a peaty surface, an eluvial horizon or an iron-pan, all of which may be rapidly destroyed by cultivation, and on assessments of the pattern of sesquioxide release and movement. Differences between the vertical distribution of sesquioxides in the Stagnopodzols and the Brown podzolic soils were first considered by Clayden and Manley (1964; for later work on this aspect, which will not be considered in detail here, see Clayden 1970 (micromorphological analysis of an ochreous Moretonhampstead B horizon), Bascomb 1968 (pyrophosphate-extractable C, Fe and Al in the 'unnamed' profile noted above) and the comments of local soil surveyors (Harrod et al 1976, Staines 1976, Hogan 1978) on pyrophosphate analyses), who, on the basis of their analyses, fieldwork and knowledge of the postglacial climatic and vegetational sequence, advanced a model for the differentiation of these broad groups and for the timing of soil development on Dartmoor. This model reflected well the evidence available at that time and only one subsequent study provides any credible suggestion that it may not necessarily be as widely applicable as they believed.

In essence, Clayden and Manley (1964:129-135) suggested that the change to heath vegetation and cooler, wetter conditions after the end of the Bronze Age initiated changes in a progenitor 'brown earth'; while, in some areas, a surface layer of 'mor' humus formed, which subsequently led to ironpan formation and thus the Hexworthy Series visible today, in other areas these soil changes did not occur. They thought that 'the brown earths of today (i.e. the podzolic soils then allocated to the Moretonhampstead Series) may occupy more recently cleared woodland or may have been in continual agricultural use since forest clearance; they also occur generally in lower rainfall areas, where surface waterlogging is less likely to occur' (1964:134-135).

At that time no palaeosol or soil pollen studies were available to confirm or deny their ideas, nor were they fully aware of the pattern of occurrence of thick ochreous B horizons, which they thought were restricted to the areas of Brown podzolic soils. As a generalisation this view still encounters no serious conflict with later research, but it must be noted that ochreous B horizons of substantial thickness do occur (though less frequently) in Stagnopodzols (for examples see Hogan 1978:37-55) and that Staines (1972) noted a connection between B horizon colours and land use patterns. He stated that among profiles assigned to the Moretonhampstead Series (which at that time included Moorgate type profiles)'. . . soils with bright B horizon colours tend to be concentrated on the enclosed areas whilst the drab coloured B horizon soils are more typical of the moorland areas of SX 65' (1972:18).

There is still relatively little direct evidence for the nature of the hypothetical, 'common' progenitor soil of Dartmoor, but Staines' (1972) investigations of the soil in and under the stone wall of a Bronze

Table 3.1 The Chagford Palaeosol (Staines 1972)

Elevation: 425 m; Parent Material: Granite head; Slope: 5° Linear.

Ah 0-10 (1)	5 YR 2/2; gritty humose loam; slightly stony; moderate medium angular blocky; friable; high; common fine fibrous and woody; moist; merging to:-
A/E 10-16	7.5 YR 5/2-4; loam; slightly stony; structure indeterminate; friable; moderate; moist; narrow irregular to:-
Blfe 16-19	In places thick and layered, discontinuous iron concretions; generally very unevenly distributed.
B2bs 19-33	7.5 YR 5-6/6; loam; many coarse 7.5 YR 5/4; stony; moderate fine angular blocky and crumb; low; rare; moist; merging to:-
BCx 33-60	10 YR 5/5; gritty loam; extremely stony; structureless; firm to very firm; low; rare; moist.

(1) horizon depth in cm.

Age house on Chagford Common cast some light on soil history (see Table 3.1). The soil beneath the house wall of stone construction is unlikely to have remained unaffected by post-burial soil development; indeed Staines (1972:44-47, 98-99) suggested that the layer of unevenly distributed, discontinuous iron concretions, which lay at the same level as a normally developed iron-pan in the adjacent unburied soil, might have developed since the house was occupied. This seems the more likely since there was clear evidence that the normal iron-pan in the unburied soil had developed in and 'picked out' surfaces in what were thought to be roof turves that had collapsed into the house after it had been abandoned. A dark, humose Ah horizon was found beneath the house wall rather than a thin peat, but unfortunately Staines did not undertake any chemical analyses of this buried soil. Nevertheless, one can infer an absence of true peat prior to the construction of this house and this study also shows that iron-pan development post-dated its (unknown) time of abandonment.

Staines' (1972, 1979) studies of soil pollen distribution in these and other soil profiles on Dartmoor also strongly support Clayden and Manley's (1964) view that the Hexworthy iron-pans developed after the formation of a surface layer of peat. Staines (1972:50) argued to this conclusion from the absence of any evidence in the peat-covered profiles for a build-up of pollen above the pan, which he saw as evidence for the cessation of pollen movement prior to pan formation, a cessation due to the sealing of the surface by peat. The soil pollen distribution on Holne Moor fits this model and these soil pollen profiles also share several other patterns visible in Staines' profiles; in particular, the confinement of large quantities of heather pollen to the Oh and upper Ah/E horizons and the contrasting rarity of this taxon in soils buried by the walls of prehistoric houses. Since, as Staines (1979:39) later noted, 'pollen within the peat topsoils relates to the peat forming vegetation', one can hardly avoid the conclusion that the evidence supports a sequence of: first, an increase in Ericaceous vegetation; secondly, a build-up of surface peat and thirdly, the formation of iron-pans, yet curiously Staines earlier presented an ambiguous and equivocal argument concerning this sequence (1972:71-72) and later (1979) put forward a quite different sequence.

He suggested (Staines 1979:41) that, in response to woodland clearance, iron-pans developed during the Bronze Age under a vegetation cover of scrubby grassland and that peat topsoils and heathy vegetation came later as a response to worsening climatic conditions during the Iron Age. He seems to have been propelled towards this view, in part at least, because of the characteristics of palaeosols revealed beneath Bronze Age barrows on the St Austell granite (Miles 1975), which lies some 60 km south-west of Dartmoor. These palaeosols lacked a peat surface layer, but possessed iron-pans, though these were thought to be less coherent than those in the modern surface soils. Like the Chagford palaeosol, the characteristics of these soils and their overburdens were not investigated rigorously or reported in detail (a general description is provided by Staines (1975) and the pollen content is reported by Bayley (1975)) and, in consequence, there can be no certainty that the pans pre-date soil burial or that the soils had not been truncated. Moreover, if, as Brown (1977:297-299, 306-307) implied, the vegetation of Bodmin Moor, which lies mainly below 300 m a.s.l., was more open than that of Dartmoor, some 30 km east of Bodmin, due to greater exposure, is it not equally likely that vegetation history and, perhaps consequentially, soil development on the St Austell barrow site (263 m a.s.l.) may well have differed from or at least been out of phase with that of Dartmoor? None of the soil pollen samples examined by Bayley (1975) indicates that woodland ever grew on the barrow site. In fact, there is support for a difference in the timing of vegetational development in Staines' (1979:39) own comparison of pollen spectra from Dartmoor peats and soils with those from the St Austell buried soils.

Using the ratio of non-tree pollen to hazel pollen as an indicator of relative age, Staines (1979: Fig. 13) showed that soil pollen from all soil horizons on Dartmoor appears to have a younger age than the pollen in the buried soils, though he attributed this to better survival of p ollen beneath the barrows. In the case of B horizons (and less certainly his Eag horizons) this could be a factor, but pollen in the Ah or Ah/E horizons, which he attributed to the Bronze Age, in usually quite well-preserved as can be seen in his pollen diagrams.

Unlike Staines, this author is not willing to be seduced 'on grounds of similarity of climate and soil' into making 'a direct correlation' between what must be regarded as a questionable sequence of soil development on St Austell and that which may have occurred on Dartmoor. Several aspects of Staines' own useful research tend to refute the sequence of soil development that this correlation implies. It is notable that such refuting evidence (e.g. the Chagford study), which had earlier been presented in his thesis (Staines 1972) was omitted from his later review article (1979). Similarly the pollen evidence from only two sites (Fox Tor and Walkhampton) was omitted and again it is notable that both of these sites provide evidence that tends to refute

Staines' hypotheses about the degree of woodland development on Dartmoor. Fox Tor, a peat profile at 425 m a.s.l. had less than 30% arboreal pollen throughout, while Walkhampton, a soil profile at 365 m a.s.l., not only indicated open conditions throughout, but also contained high Polypodium values in upper horizons, which, because, at such a late date, they are unlikely to derive from epiphytic growth on the site, do not support Staines' interpretation of Polypodium spores as woodland indicators (see Staines 1979:32). (This apparently disingenuous approach to the presentation of data, as well as the fact that Staines' soil pollen studies added little to that which could be inferred more directly from the Holne Moor profiles themselves, led to the decision to omit his research results from the review of vegetation provided above. In this connection, it also needs to be pointed out that Staines' claim that cereal pollen and profile disturbance may have arisen from Bronze Age cultivations at Whittenknowle Rocks on western Dartmoor must be re-assessed when one reads that the soil profile involved lay not 'in close proximity to a group of hut circles' (Staines 1979:35) but in fact lay 'inside a hut circle' (Staines 1972:41)).

Three other enquiries have been considered to provide information about the nature and timing of soil development on Dartmoor. The first is conveniently encapsulated in Brown's (1977:307) statement that 'At Kes Tor, Dartmoor, Blackburn (in Fox 1954b) showed that Iron Age tillage took place after the growth of blanket peat had started'. This statement is both inaccurate and misleading. Blackburn (in Fox 1954b:62) offered no opinion about the age of the pollen beneath the Kes Tor lynchet and merely noted that from the pollen 'one can conclude that the vegetation was much as it is today'; it was Fox (1954b:35-37, see also 1954a: 96-99) herself, who argued a Sub-Atlantic age for this pollen assemblage, which in any case was not derived from blanket bog but from the thin peat of a stagnopodzol soil. The issues raised by this argument are not altogether trivial since the pollen assemblage is thought to provide useful, independent support for an Iron Age date for the settlement and fields at Kes Tor, a site which appears to refute Ralegh Radford's (1952:77) thesis that Dartmoor settlements were in general abandoned due to the climatic deterioration of the first millennium bc.

Apart from the pollen assemblage, which, dominated as it is by heather, grass and hazel, can only really be said to provide a date of sometime during or after the shift to Ericaceous vegetation, Fox's (1954b: 35-37) argument rests on two planks: the supposition that the ubiquitous eluvial horizon of the stagnopodzols at Kes Tor was created by cultivation and the supposition that the age of this cultivation can be reliably inferred from the stratigraphic position of stones which tumbled away from a house wall when it collapsed. The former supposition was noted and rejected earlier (see 1.2.3.), the latter is simply an assumption - 'it is most unlikely that the collapse of the hut was delayed for centuries' (Fox 1954b:35) - which was almost immediately restated as '. . . the fact that when the hut collapsed in antiquity . . .' (Fox 1954a:98, but my emphasis).

Silvester (1979:177-179) recently reviewed the archaeological material (pottery and iron slag) at Kes Tor and its interpretation. He concluded that it was more reasonable to assume that the iron-working dated to a later period, either very late prehistoric or medieval and was a re-use of a ruined house; he also pointed out that 'the pottery was hardly distinctive although sherds from round-shouldered bowls may support a date somewhere in the middle of the first millennium' (1979:177-178). Scraps of disintegrated, undatable pottery were also found at Kes Tor (Fox 1954b:30) and since the settlement seems merely to be a segment of a parallel reave system, whose construction dates, elsewhere, fall within a relatively brief span in the second half of the second millennium bc (see 3.2.2), it seems more than likely that Kes Tor was initially occupied in that period. If the lynchet, which post-dated Ericaceous vegetation and stagnopodzol peat growth, is another instance of late, perhaps medieval, re-occupation (and Fox (1954b:27) thought that eastern parts of the Kes Tor field system might have been modified in medieval times), a dating which would explain why the fields at Kes Tor appeared to Simmons to have been, somewhat exceptionally, 'reclaimed from the waste rather than hewn out of the forest' (Simmons 1964b:199), then one must envisage a long history for this moorland fringe site and reject a precise date for its evidence of the inception of peat growth on a stagnopodzol.

Eogan's (1964) investigation of a stone row at Cholwichtown on southern Dartmoor is the second study which provides evidence for the course and timing of stagnopodzol development. Eogan (1964:26) noted that the upper fill of the stone sockets was similar in consistency, colour and texture to the natural, undisturbed soil; the sockets could only be observed by first removing the Ah/E horizon, when the dark, soft earth of the socket fill showed clearly against the background of the orange subsoil (B horizon). Identical observations have been made during excavations at Holne Moor. He inferred that the leaching, which had created this soil pattern, post-dated the erection of the stones and there can be little doubt that this was the case. Although the dating of this and other rows is far from s tisfactory (Emmett 1979: 107), there is evidence that some at least pre-date the reave systems of the later second millennium bc, though others could be contemporary with, or even later than, these systems (see discussion in Fleming 1978b:109). However this may be, one may conclude that all of the major morphological characteristics of the Ah/E horizon could have been created by pedological processes operating since the construction at this site; this does not, of course, prove that the undisturbed soils on this site lacked such characteristics at the time of construction. Indeed, Simmons (1969:208) has argued that the evidence from this site supports the idea that the process of differentiation of Brown podzolic soils from the Stagnopodzols had begun by the time the row was built. This conclusion arose from Proudfoot's (1969) examination of soil samples taken from a socket where, it was thought, outspill from the row construction had sealed a small remnant of the old land surface.

Proudfoot (1969) noted that the thin (ca. 4 cm) lense of mineral soil sandwiched by humic layers was strongly leached, but that no iron-pan had formed on the buried surface below. From this, and from experience on other sites, he suggested that 'the outspill soil was already leached of its iron when the stone socket was dug' (1969:219). This conclusion can only be correct if Simmons' (1964d:34) assumption, that the outspill was deposited during row construction, is also correct; in this author's view the site stratigraphy does not necessarily support such an assumption. Eogan's (1964:Plate 7) drawing of the stratigraphy of the stone alignment shows that like many of the stone row sockets, the relevant socket did not contain a standing orthostat; instead a few stones lie in a 'fill' that does not show the development of a leached Ah/E horizon in its upper portion. On the basis of the leaching argument, Eogan (1964:26) suggested that if an orthostat had ever stood in the one empty socket (No. 58), which was 'sealed' by a normally developed Ah/E horizon, it must have been removed in antiquity. The clear implication is that he thought that all other sockets without orthostats had been disturbed when the orthostats were removed in more recent times. Eogan (1964:28-30) also regarded a large pit, whose outspill (Labelled 'upcast' in his Fig. 2) occupied an identical stratigraphic position to that of the outspill studied by Proudfoot, as a secondary disturbance, possibly of medieval age, though this pit digging clearly occurred after (though perhaps only immediately after) the robbing of an orthostat from a nearby socket (No. 5).

If the outspill arose during robbing rather than construction of the row, then Simmon's (1964d) pollen studies at the site can be seen as evidence that such robbing post-dates an increase in heathland vegetation, which here, as in the profiles discussed earlier, is evident in the pollen of the Ah/E horizon, and follows a small accumulation (2-3 cm) of 'mor' humus. All this evidence seems consistent with disturbance of the row either during or later than the last half of the first millennium bc, but perhaps a Dark Age or early medieval date is most probable. If orthostat removal occurred at any of these times, Proudfoot's evidence of prior leaching of the outspill, which in any case is not compelling, is no longer difficult to reconcile with Clayden and Manley's dating (Sub-Atlantic and later) of the leaching and iron-pan development of the Hexworthy Series.

Finally, one must turn to the extensive archaeological and environmental studies on and around Shaugh Moor on the south-western edge of Dartmoor (Wainwright et al 1979, Wainwright and Smith 1980, Smith et al 1981), where however soil development may not be perfectly comparable to other parts of Dartmoor due to local kaolinisation of the granitic soil parent materials (a qualification that may also apply to the Cholwichtown soils). The pedological data from these enquiries has been published in a series of Laboratory Reports (Keeley 1976, 1978, Keeley and Macphail 1979, Macphail 1980a, 1980b, 1981). This author took part in the initial survey of soils on Shaugh Moor, made several visits to the archaeological excavations and environmental sampling sites, and has also participated in two archaeological surveys on Shaugh Moor.

Arguing from what they perceived as a low density of prehistoric remains in the areas presently occupied by stagnopodzols and stagnohumic gley soils as well as their observations of soils beneath huts and enclosures (Keeley and Macphail 1979) and reaves (Macphail 1980a, 1980b, 1981), Keeley and Macphail (1979, 1981) suggested that, contrary to Clayden and Manley's model, the contemporary characteristics and distribution of soils on Shaugh Moor had developed by the Bronze Age. Their first argument is curious, since it flies in the face of evidence from both Shaugh Moor and almost all other parts of Dartmoor, where the relationship between prehistoric settlement and soils has been examined. As Clayden and Manley (1964:134) noted '. . . settlements are seldom found above 1500 ft. but tend to be found on slopes surrounding the hi h plateaux, now occupied by Molinia grassland and heath with soils of the Hexworthy series'. Similarly Staines (1979:41) thought that most settlements '. . . are on stagnopodzols of the Hexworthy and R ugh T r series whilst many also occur on the drier podzols'. On Shaugh Moor, the areas enclosed by 'pounds' or reave-bounded field systems possess what appears to be a continuum of soils, varying from Stagnohumic gleys to Stagnopodzols and from Ferri-humic podzols to Humic Brown podzolic soils, though the only substantial area where the latter (Moorgate Series) occur as a homogenous unit is found in the southern part of the surveyed area. A substantial part of this southern zone was enclosed in medieval times (Collis: forthcoming), while in the remaining area, west of Hawks Tor, destruction of the prehistoric field system is evident at precisely the point at which Keeley and Macphail (1979:4) noted that 'non-natural amelioration of soil conditions' may have occurred. Medieval or even much later casual cropping in this gorse-covered area seems probable and would rescue Keeley and Macphail (1981: 243) from their inability to explain why the most suitable area for cultivation was, as they put it '. . . empty of settlement but there is no soil evidence to suggest a reason for this'.

The evidence from soils beneath hut and enclosure walls is no more credible. Describing these, Keeley and Macphail (1979:2) stated that

> 'The grey colours of the upper soil and its lack of pollen seem to suggest that the Ah horizon of the buried soil has been removed, particularly as no buried peaty tops were observed. However, ignition tests indicated a loss of organic matter from the upper soil, suggesting that much of the organic matter in this horizon was oxidised, probably due to incomplete sealing of the soil under the loosely piled stone walls. The fact that the site had been flooded for a considerable period of time prior to excavation may also have affected the organic matter status of the soils'.

After suggesting that micromorphological characteristics of this Eag horizon (their classification) indicated that it had developed from an old Ah horizon by degradation and perhaps peat or turf removal, Keeley and Macphail (1979:3) continued

> '. . . it should be noted that there is no real difference in degree of degradation between buried soils and those in the surrounding area, except for slightly more intensive eluviation of the Eag horizon in soils with a contemporary peat cover. If the buried soils have lacked a peaty top since the Bronze Age, it is not surprising that present-day soils are slightly more degraded. Indeed, although the loose stone walls are unlikely to provide <u>perfect preservation</u> of the pre-settlement soil, there is no reason to assume that better soils existed in the Bronze Age. There are strong indications (Simmons, 1964a) that upland moor areas had by then been disforested' (my emphasis).

Later, Wainwright and Smith (1980:111) were to comment that these old soils 'had been imperfectly protected' - a considerable understatement, since they do not appear to have been protected in any significant degree. Almost the only inference one could make from these studies is that the pre-enclosure soils might have lacked a peat surface. However, later excavations on the Saddlesborough Reave on the plateau top, an area which today is mainly covered by stagnohumic gley soils, did reveal rather better-preserved palaeosols, and in this author's opinion it is this evidence alone that provides any justification for Keeley and Macphail's generalisation.

In this area, Macphail (1981) observed two soil types. In poorly-drained, almost flat areas, Humic gley podzols were found beneath a soil bank and surmounting reave (total thickness ca. 0.5 m); two of the five profiles of this type had very thin peat layers (3 and 6 cm) above a humose Ah and no iron pans were present. On slightly higher but more steeply sloping ground, a more typical 'stone with soil' reave, which may have provided somewhat less protection, covered a Humus-ironpan podzol with a dark Ah over a thin Eag and thin 'relatively firm' ironpan (see Table 3.2); this soil was not very different from the Chagford palaeosol (see Table 3.1).

As in that instance, the absence of quantitative analytical data for buried soils or overburdens, or even a clear description of the pedological character of the latter, make it difficult to assess whether all the present features of these soils pre-date their burial. However, it is clear that only a small amount of peat had accumulated on the wetter parts of Shaugh Moor before ca. 1400-1300 bc (for dating see Smith et al 1981), and equally clearly much more peat (14-16 cm) has accumulated since that time. The extent of pre-reave podzolization and iron-pan development is much harder to judge. In any case, there seems little reason to assume that the course and rate of pedological development on the plateau top and on its lower, drier slopes was similar.

When one puts these various studies together and introduces the possibility that variation in vegetational history, topography, microclimate and in some areas even the quality of parent materials practically guarantees that there will have been considerable differences in the timing of the development of the features found in the Stagnopodzol soils across an area the size of Dartmoor, two aspects stand out. First, that there is still very little firm, well-documented evidence for the timing and nature of soil development, in particular a severe lack of well-protected palaeosols of a variety of ages; and secondly, that there is still much to commend Clayden and Manley's generalised model as a framework to be tested by future research.

Table 3.2 The Saddlesborough Palaeosol (Macphail 1981)

Elevation: 282 m; Parent material: Granite head; Slope: 5-6° S.

Profile: AN; Soil subgroup: Humus-ironpan stagnopodzol.

Horizon, depth cm.	
Reave 47-0	Stone and soil overburden, shallow peaty top; contains fine sandy loam lens.
Old Ground Surface	
Ah 0-8	Black (5 YR 2.5/1) moderately weak sand; weak medium subangular blocky; common fine roots; humose; common very small stones; abrupt, irregular boundary.
Eag 8-11 (12)	Pinkish grey (5 YR 6/2) weak sand; weak medium subangular blocky; few fine roots; common very small stone; clear irregular boundary. (Under Reave extends deep into B(s)).
Bh 11 (12) - 14 (17)	Very dark grey to black (5 YR 3/1 - 2.5/1) weak loamy sand; weak medium subangular blocky; common very small stones; humose; sharp irregular boundary.
Bf 14 (17) - 14.5 (17.5)	Red (2.5 YR 5/8) relatively firm ironpan.
Bs 14.5 (17.5) - 22	Reddish yellow (5 YR 6/8) relatively firm loamy sand; massive; common very small stones; gradual irregular boundary.
B(s) 22 - 42+	Brown (7.5 YR 5/4) moderately weak loamy sand; coarse blocky; common very small stones; humic stain; gradual irregular boundary to B/C.

By contrast, the distribution and some of the characteristics of the contemporary soils of Dartmoor have now been investigated on a sufficient scale that the general pattern (summarised here in Fig. 3.3) is now clear. This framework can therefore be used as a basis for comparing the soils of the study area with those observed over the wider region.

3.2.2 Settlement and land use

The settlement and land use of Dartmoor, like its physical environment, has attracted a substantial literature. Among the more important general studies, which cover much of the period from prehistoric to modern times, one must include the compilation of Worth's many papers (Spooner and Russell 1967), a classic account of the Moor by Harvey and St Leger-Gordon (1953), wider regional histories by Hoskins and Finberg (1952) and Hoskins (1954, 1971) and the more general survey of Shorter et al (1969). There are also several recent multi-author works which provide introductory accounts of the area and its literature: Barlow (1969), Gill (1970), H.M.S.O. (1976), Devon County Council (1980).

When one turns to more detailed discussion of particular periods, the first aspect to note is that due to the belated recognition that a widespread system of land boundaries (reaves) on Dartmoor was constructed in prehistoric times (see Gawne and Somers Cocks 1968, Fleming and Collis 1973, Fleming 1978a, 1978b), there no longer exists any adequate synthesis of the social and economic prehistory of the region. Although the synthesis of A. Fox (1964, 1973) remains essential reading, her broad generalisations about the pattern of land use in later prehistoric times can now be seen to have been based on an inadequate understanding of the archaeological landscape of Dartmoor (Fleming 1978b:106; 1979a: 121) and must be put aside. Derivative works, such as those of Simmons (1969) and Hamond (1979, but note that this synthesis was based largely on a compilation completed in 1974), also, and for the same reason, lose much of their significance. The immense, but rewarding task of linking together the social and economic landscape revealed by the reaves and the dense distribution of settlement indicated by houses (Spooner and Russell 1967: Fig. 12, Fox 1954a: Fig. 1 and Appendix, Hamond 1979: Fig. 2), may be said to have started (Fleming 1978b, 1979a, 1980a, 1980b) but still has a long way to go. The new synthesis must overcome the fact that 'no remotely adequate study has been made of the distribution pattern and morphology of Dartmoor's prehistoric settlements . . .' (Fleming 1978b:108) and that until very recently not a single radiocarbon date for a Dartmoor settlement had been obtained. Fortunately the proximate objective defined above (see 3.1) would not be served to any significant degree by such a synthesis were it available.

Turning to later periods, one again seeks in vain for a detailed account of the history of Dartmoor as revealed by both documentary sources and archaeology. A discussion of some of the most useful literature, general texts and original articles, appears in the notes which accompany Somers Cocks' (1970a:76-99, 288-289) concise account of Saxon and early medieval settlement on the Moor; although not exhaustive, most of the principal writers who have taken the Moor as their subject appear in his notes, which only require updating. Some of the most important contributions since that time are those by Gawne (1970), Bonney (1971) and although Dartmoor itself was not the focus, there is much of value to be found in H.S.A. Fox's (1971, 1973, 1975) studies of fields, farming and enclosures in Devon and Cornwall. The publication by Beresford (1979) of Minter's lengthy excavations at a deserted early medieval settlement on the Moor is particularly important because of the paucity of previous studies of this kind. As Somers Cocks (1970a:82) remarked 'on much of what is today open moorland, apart from the highest and wettest regions, traces of agriculture and fields abound. These Dartmoor field-systems are only now beginning to receive the study they deserve . . .'. While something of the context of such moorland exploitation can be learnt from the general sources cited above, almost nothing is known of the agricultural strategies of now abandoned settlements on the higher moors.

This brief introduction to relevant literature must stand as proxy for a more extended account of the context of land use and settlement within the study area itself; in the succeeding pages there is room only for details of what is known from archaeological enquiry occasionally eked out by reference to wider sources.

Prehistoric

The results of over five years survey and excavation within the study area have not yet been the subject of a major report, though interim statements and other articles by Fleming (1977b, 1979b, 1980b), the director of the Dartmoor Reave Project, include interim site plans (1979b), selected portions of the field survey (1980b) and many photographs together with discussions of the excavated features. The information presented in this section includes such material but is also based on this author's own observations, free access to the field plans and section drawings and numerous, lengthy discussions of the sites with their excavator.

Fig. 3.4 shows the major prehistoric archaeological features of Holne Moor, which include a segment of the Dartmeet parallel reave system where the 'parallels' meet the 'terminal' (Venford) reave (for terminology and a general description of the Dartmeet system see Fleming (1978b)) at the southern end of this ca. 2000 ha field system, numerous prehistoric houses dispersed (often in pairs) among these fields and a stone row just beyond the south-western corner of the study area.

Traces of human activities prior to the establishment of the field systems are limited to the discovery of flint microliths during Fleming's excavations. On typological grounds, these (few) artifacts suggest a 'Mesolithic' presence in the area, whose date may be indicated by a radiocarbon date from charcoal in a palaeosol beneath a prehistoric house wall (4810 $\pm$ 240 bc - BM-1604), though this may simply date a natural fire. It can be argued but not proven that several ceremonial sites (barrows, cists, ring cairns etc.) on Holne Moor (including the stone row) also pre-date the field systems of the later second millennium and in zone B (Fig. 3.4) there are discontinuous segments of reave-like boundaries, which may represent abandoned and robbed boundaries pre-dating the layout of the main Dartmeet system, but excavations to test these propositions have not yet been undertaken.

Fig. 3.5 shows, on a larger scale, a part of the study area (zone A) in which Fleming has now completed several excavations, whose location is indicated. Only a strictly limited account of the information resulting from these investigations is presented here; the selection being governed solely by the criterion of relevance to the purposes of this thesis. Fleming has established that the principal prehistoric features in this area can be assigned to three archaeological phases - early (I), middle (II) and late (III). In phase I, he includes the construction of a timber house at site F and possibly the similarly-built house and other timber structures at site B together with ditches immediately south of the terminal reave (features in this area have not yet been fully explored), a hurdlework fence along the eastern boundary of fields A and B, a bank and slight, quarry ditch forming the western boundary of these fields, and a timber gate between bank and ditch boundaries at the north-east corner of field C. There seems to have been considerable heterogeneity in the forms of boundary construction during this early phase and there can be no certainty that, for example, the eastern boundary was of timber construction throughout the segment alongside fields A and B. Fleming argues that the presence of a timber gateway and a fence around some parts of these early fields suggests that their entire perimeter would have been more than symbolically marked, and therefore, that the bank on the western boundary of fields A and B must have been surmounted by either a hedge or a light wooden fence similar to that on the eastern boundary. However, despite careful investigation with such features in mind, it has not been possible to find evidence of either type of boundary. This is not really surprising, since post-occupation pedological development in these banks has been substantial (see 5.2.1.2), and, as at Cholwichtown, one would only expect to find such traces if, for example, heavy timbers had been sunk deep into the B horizon below the bank.

Charcoal found within the western bank has returned a date of 1320 ± 60 bc (BM-1609), which corresponds closely to the date for the construction of the Saddlesborough reave on Shaugh Moor (1390 ± 90 bc - HAR-4003); each of these dates is thought to indicate the time of construction of the first land boundaries in their respective area (Smith <u>et al</u> 1981). From evidence of timber replacements, Fleming estimates that phase I lasted 50 years or less.

The construction of stone-built houses, which post-date the timber ones on sites F and B, is assigned to phase II and was accompanied or soon followed by the construction of the stone-built reaves which covered the earlier farm boundaries and may well have extended the system of land enclosure in the area. In addition, a small circular, timber construction, which may be a second habitation unit but is thought more likely to be a storeroom, was built close to the main house on Site F. Construction of the main house wall on this site buried a part of the contemporary soil surface beneath <u>ca</u>. 0.5 m of wall 'fill' made up of soil materials. This palaeosol is described in section 5.2.1.2. Four radiocarbon dates are thought to relate to this phase of the prehistoric occupation of the study area: 1300 ± 50 bc, 1200 ± 80 bc, 1200 ± 80 bc, 1110 ± 50 bc (BM-1607-8, 1610-11).

In phase III, a smaller, stone-built house was constructed within the ruins of the main house on site F and a short stretch of reave, which divides field A from field B may also have been constructed at this time. Charcoal from beneath the wall of the new hut returned a date of 540 $\pm$ 110 bc (BM-1612). This date could relate to the new construction or to a late phase of activity falling within archaeological phase II.

In presenting this very brief outline of the settlement sequence on Holne Moor, it has been necessary to pass over and ignore many complexities and thus to imply a level of certainty about the precise relationship between events which cannot be sustained by the evidence. Such limitations must, however, be more properly discussed by Fleming, when the full report of his work appears. There does not seem to be any strong likelihood that future excavations will alter the basic sequence, though one may hope that further radiocarbon samples will establish more closely the relationship between events on sites F and B, and will reveal the length of abandonment that must precede the construction of the phase III hut on site F.

Evidence of land use within the fields surrounding these houses is extremely limited. Fleming argues that during the stone reave phase (II), the boundaries continued to present real obstacles to movement; a structure on site B may have utilised the terminal reave as a southern wall and more convincingly, he points to the height of the orthostats at each side of a gate (site E) as evidence for the likely height of the accompanying wall. If so, one must envisage either dead or live hedges, timber or turves inter-laced with or surmounting the stone reave base. Clearance stones laid against the revetted edges of reaves probably provide the least unambiguous evidence of prehistoric cultivation within these fields; some slight lynchetting may be evident at their edges, but the evidence is not compelling.

The western boundary bank of fields A and B could include a positive lynchet component but there is no evidence that this is the case. On the eastern side of this boundary and immediately adjacent to it, there are places where it seems probable that traces of a very shallow 'scoop' ditch have been correctly identified. However, in this author's opinion, its exact extent and depth may not always have been determined correctly due to the presence of a linear zone of gleyed sub-soil also adjacent to this boundary. This phenomenon may indicate altered patterns of soil drainage due to the construction of bank and reave. The picture is further complicated by the probability that negative lynchetting has also affected this area, but again there can be no certainty that this is the case. The eastern boundary of these fields may also be positively lynchetted and there are stratigraphic indications that such lynchetting could both pre- and post-date the stone reave construction of phase II. However, in this author's opinion the thickened Ah/E, which seems to pre-date phase II, may represent the remains of a small bank similar to that on the western boundary.

A limited investigation of this hypothesis was undertaken at an early stage of the excavations. 1.5 - 2 kg soil samples from the putative lynchet were taken from profiles 1 and 2 (see Fig. 3.6); two 'control' samples were taken from profile 3 and samples from another profile (4), which lay some 4 m west, inside field B, were also examined. In order to determine whether or not the 'lynchet' samples contained abnormal quantities of fine material, which could be expected within a positive lynchet (see 2.3.2.1), the oven-dried samples were sieved and the percentage (wt/wt) representation of fine earth (soil less than 2mm) and of particle size classes between 2 mm and 32 mm was calculated. Only one fragment larger than 32 mm was encountered and so the calculation of 'all material greater than 2 mm' as a percentage of 'all soil' does give a fair picture of the pattern in these samples (see Table 3.3). However, the sample size employed cannot have provided a fully representative sample of material larger than 16 mm and therefore Table 3.3 also includes the percentage representation of particle sizes 'greater than 2 mm but less than 16 mm' using 'all soil less than 16 mm' as a base.

This initial work with the soil fractions which are most resistant to subsequent pedological alteration showed that the thickened Ah/E did indeed have unusual soil properties, but not those which had been expected. Later work (see 3.3.2 and Table 3.6) has shown that the tendency for the percentage of stones to increase (usually quite regularly) with depth that is evident in profile 4 is invariably met on undisturbed soils in this area. Very few profiles have been encountered anywhere in the study area in which a surface horizon with similar amounts of stone to that of B horizons overlies a layer with lower stone content as occurs here in profiles 1 and 2. Although larger stones could have been thrown onto this field edge during cultivation, this practice cannot explain the rise in these much smaller stones, nor does it seem likely that ploughing or natural erosion processes would enhance these particular size fractions and so create the observed pattern. It is most economically explained as a residua from a bank whose mater al was derived from a ditch dug into the B horizon. Fleming did not observe such a ditch in the relevant excavation trenches, but these may not have been dug to the depth and/or extent necessary to prove or disprove its

Table 3.3 Stone content of soil samples from a section through a field bank/lynchet on archaeological site C (HM 77C 1-3), and from a nearby profile (HM 77C 4)(1)

Profile	Sample	HM 77C 1	Line of Reave	HM 77C 2	HM 77C 3	Sample	HM 77C 4
Ah/E	a	25.0 (24.1)		23.4 (23.4)	21.1 (18.8)	a	19.0 (18.5)
	b	15.2 (15.2)		18.4 (18.1)	17.9 (17.6)		
B_1	c			24.0 (19.8)		c	24.6 (24.3)
B_2	d			42.2 (36.4)		d	30.9 (20.4)
BCux	e			43.3 (39.1)		e	32.1 (28.0)

(1) Weight of all stones expressed as a percentage of the total weight of soil, and, in brackets, weight of 2 - 16 mm stones as a percentage of all soil less than 16 mm. See Fig.3.6 for section drawing showing location of sampling points.

presence. This author's soil section drawing (Fig. 3.6) and photographs show a ditch-like disturbed area immediately west of the reave.

Fleming's excavations on site F and the author's own ex mination of a palaeosol beneath the main house wall did show, however, that the depth at which B horizon quantities and patterns of stone can occur varies substantially over very short distances. This may merely reduce soil profile depths (this occurred close to and under the mein house, where in places the stoney, indurated fragipan was found at only 28-35 cm below the mineral soil surface (see 5.2.1.2) yet some 5 m further south, the same horizon was located at the more usual depth of 65-70 cm) or it may lead to dense patches of stone reaching up even into the Ah/E horizon itself. In such 'mounds', as in the BCux horizon, the stones are closely-packed with little fine soil as a matrix, and this phenomenon is here interpreted as 'tongues' of the basal, stonier head that have thrust through the finer head, which in most cases has a thickness of at least 45 cm. There seems to be no reason to believe that such stone patches are in any way artificial though their presence around and beneath the site F house may have led to the decision to build on this spot so as to take advantage of slightly drier conditions on what may have been a knoll in an otherwise flat landscape.

Evidence for the loss or discard of plant remains within the main house on site F cannot be regarded as evidence of plants grown in nearby fields, but do indicate the availability of species to the inhabitants of the site. Flotation of samples from sealed prehistoric contexts has produced 7 cereal grains (4 of barley, 1 of wheat and 2 of uncertain species), 17 'weed' seeds (including Ranunculus sp., Rosaceae sp. and Gramineae sp. - 14 seeds were unidentifiable) and 12 Vicia faba beans (all identifications by Dr Martin Jones of Durham University). These crops alone would have allowed a useful rotation to be practiced and other crops may also have been available. Quernstones from the house suggest that grain was ground on this site and the reasonable quantities of pottery confirm that its function was essentially domestic - a habitation unit. Neither bones nor artifacts indicative of animal husbandry have been recovered here or elsewhere in the excavations on Holne Moor, but slight hollow-ways alongside boundaries on site I may be products of animal behaviour and 'cobbling' close by the gateway in this north-eastern corner of field C could well represent a deliberate attempt to create a 'hard standing' at a point where poaching could have been a problem if the field was used by livestock, particularly during winter.

In conclusion one may point out that only in the excavated zone is it possible to speak of phase I; although in other parts of the study area, Fleming has noted alterations to the stone re ves, which suggest chronological depth, it is not possible at present to prove what seems most likely, namely that much or all of the stone reave system was laid out during a relatively brief period, or to assess whether this 'stone reave horizon' was everywhere (within the study area) preceded by a 'bank-ditch-fence' phase. As earlier discussion (see 1.2.1 and 1.2.2) of the difficulties of inferring land use from boundary and other archaeological evidence might have led one to expect, there is still much uncertainty as to the use of the prehistoric enclosures in the study area. If the small fields A and B were used for cropping (and the clearance stones make this at least probable), it left little trace in the form of lynchets, but there is no evidence of the use of a plough and if spade cultivation was employed in these small fields lynchetting might well have been minimised (see 2.3.2.1). There is only the slightest indication of animal husbandry (a barrier around the most likely area of cropping and the cobbling and gate in the adjacent field) despite the strong circumstantial evidence and elegant case that can be made (e.g. Fleming 1979a) for livestock having been an essential not to say dominant element in the economy of the reave builders.

All the pottery recovered in these excavations is thought to be similar to Trevisker style pottery as defined by ApSimon and Greenfield (1972) and so can be attributed to the principal occupation phases I and II, which present dates suggest last from <u>ca.</u> 1350-1150 bc. The significance of the stratigraphically pre-phase III date in the mid-first millennium bc is at present unclear. It could indicate late, aceramic, possibly seasonal re-occupation of the area; it is the only strong indication of human activities in the study area after the end of the second millennium bc. Although the present appearance of some prehistoric houses suggests that they may have been repaired and re-used in later times, the reality and dating of such putative re-occupations is unknown; they could have occurred during what is thought to be a colonisation of the area in immediately pre-Conquest times.

Medieval and early modern

Initial mapping of land boundaries in the study area by members of the Dartmoor Reave Project teams indicated that, in addition to the reave systems, there were later boundaries, which enclosed much of the eastern side of the plateau; some of the more prominent features of these later fields had been noted by other researchers (Gawne 1970:62, Somers Cocks 1970a:83). While gathering information for the soil and vegetation maps presented in this thesis, the author made a more thorough survey of these systems, which was used as a guide during later, accurate surveys carried out by teams under the joint supervision of the author and Andrew Fleming. The results of these joint investigations are being published elsewhere (Fleming and Ralph: in press) and so the account of medieval and early modern settlement and land use presented in this section will merely summarise the basic pattern and sequence as established and/or argued in the joint paper. As was the case with the earlier sequence, such brevity of description inevitably leads to the omission of qualifying remarks and thus tends to create a false impression of precision in chronology and sequence that neither author would endorse. In consequence, the words 'probably' and 'about' must often appear or be read into the description that follows, which assumes that those who wish to assess this aspect of the research on Holne Moor will consult the full text.

Fig. 3.7 shows the land enclosed during historic times, the relationship of these field systems to the earlier land divisions and the phasing and approximate chronology of this sequence of later settlement and land use. It is thought that an initial settlement phase in the 10th century or perhaps earlier enclosed four major land units - here referred to as Lobes - two of which contain sub-divided arable fields and three of which are now truncated to a lesser or greater degree by the reservoir construction, but had already been slighted prior to that time by extensive tinning in this submerged portion of the valley of the Venford Brook. The only settlement which survived such destruction and submergence lies beside the South Lobe, a mere metre or two from the steep edge of the tinners' gulley.

All the Lobes appear to have been cultivated at some moment in their history; in addition to the evidence of lynchetted sub-divided arable fields in the North Lobe and Central Lobe 1, small lynchets (ca. 30-50 cm) are visible on the southern and eastern boundaries of the South Lobe and only remnants of reaves survive within it. Similar lynchets occur on reave boundaries in the more steeply-sloping, northern part of Central Lobe 3; these may incorporate a prehistoric element. However, in the more gently-sloping southern part of this Lobe, intermittent grooves and very slight lynchets occur in an area where reaves have been largely eradicated; this may be interpreted as an 'invisible' ploughing episode in which cultivation has not been regul·rly confined within strict boundaries (see Bowen 1978:117). Central Lobe 3 is stratigraphically (and could therefore be slightly chronologically) later than the Lobes to the north and it could be that the differences in cultivation methods between this Lobe and those to the north are a reflection of later colonisation of the former.

The present outer boundaries of these Lobes, of a type known locally as 'corn-ditches', are thought to have reached their present form after the advent of Forest Law in early post-Conquest times (see Havinden and Wilkinson 1970:164), though some were modified later. One such unmodified boundary, on the south-western side of the North Lobe (Fig. 3.7) was sectioned by the author in order to assess soil characteristics at the time of the early medieval colonisation; the palaeosol beneath it is described in section 5.2.1.1. At the time of corn-ditch construction, a further small neck of land (South Link Close, which from its hollow-ways and gulleys seems earlier to have functioned as a drove between the South Lobe and Central Lobe 3) was enclosed. A similar but wetter and boggy drove between Central Lobe 1 and the North Lobe was closed-off during a later phase of enclosure expansion. The survey did not reveal signs of cultivation in either of these areas and this is also the case in two areas within the Lobes: the West Field in Central Lobe 1 and the Close in the North Lobe.

The survival of a relatively intact reave in the Close (elsewhere in this Lobe, reaves have been almost totally destroyed) suggests more positively, that cultivation may not have occurred here. From the appearance of cultivation artifacts and the pattern and stratigraphic relationships of boundaries, Fleming and Ralph (:forthcoming) suggest that cultivation of the Central Field and southern half of Central Lobe 1 may have been abandoned at an early date, perhaps at the time that Forest Law was established (probably late 11th century).

In the mid to late 13th century, it is likely that Forest Law ceased to apply to the purlieus of Dartmoor which seem to have been effectively defined by a perambulation of 1240. Royal requirements for boundary forms and stringent restrictions on land use seem to have been retained only within the central part of Dartmoor, which in 1239 had been transferred by the Crown to the Earl of Cornwall, who, through the perambulation a year later, established the bounds of his Chase (see Harvey and St Leger-Gordon 1953:153-159 and Spooner and Russell 1967:329-354). In the study area, which now lay within the Commons of Devonshire, these changes allowed new, very extensive land enclosures (see Fig. 3.7), which may have taken place in stages but which eventually led to the enclosure (using earth banks, which may have carried fences or hedges) of 48 ha of extra land, mainly within two huge enclosures separated by a droveway, which gave access to the southern enclosure and the open moor. (For comparison, the North Lobe had, earlier, only enclosed 12.2 ha). However, the newly-enclosed land does not appear to have been used as intensively as the land in the Lobes; archaeological evidence indicates that some of it was cultivated but probably only very briefly, during an episode of 'outfield cultivation'.

The field survey did not, in fact, reveal any clear traces of cultivation throughout the land enclosed by this major extension of boundaries, but Fleming's excavations, which lay within the Outer South Field (see Fig. 3.5) uncovered plough-marks which now have been shown to post-date the construction of the Inner South Field's western boundary bank and the scoop ditch on its western side. This boundary may be slightly earlier than that of the Outer South Field. (Initially, Fleming believed that these ploughmarks were prehistoric (see Fleming 1979b) and that the Inner South Field boundary marked the most westerly extension of medieval land use; although it still cannot be shown that <u>all</u> the plough-marks <u>must</u> post-date the medieval enclosures, they are all of similar appearance and stratigraphic position (V-shaped grooves in the top of the Ah/E horizon infilled with peat or sandy peat) and all do lie within the presently recognised bounds of medieval enclosure). The evidence available cannot prove that the plough-marks are not later than this episode of enclosure; it is merely economical to assume that enclosure and cultivation of the areas concerned was quasi-simultaneous.

Fleming has assessed the pattern and characteristics of these plough-marks and has concluded that they probably represent only a single deep-ploughing event, preceded, perhaps, by Denshiring, although traces of other marks at right-angles to the main series of plough marks have been observed on two of his sites. The cutting of the turf that precedes the beating and burning, could have been carried out by ploughs (Finberg 1951:93, see also Vancouver 1813: Chapters 5 and 7) or by hand, but, in either case, this operation seems unlikely to have created deep furrows in the mineral soil. Fleming also suggests that furrows on the headlands, which mark the edge of cultivation and lie at right angles to the plough-marks could be traces of later, shallower cultivations and that, if so, could indicate a minimum of three such cultivations. This author would not exclude the possibility that a plough team of two oxen, which Fleming thought was of a size consistent with the relationship of ploughmarks to prehistoric walls and a house, could have been used to deep-plough the land without prior Denshiring.

Detailed patterning of the plough-marks (they seem to fall into groups separated by baulks and there is inter-group variation in their spacing) led Fleming to suggest that co-aration may have been the practice in these large enclosures. This suggestion too, is entirely consistent with the picture of 'outfield cultivation' in the south-west of Britain as described and defined by H.S.A. Fox (1973), who demonstrated that there was evidence for long-term periodicity in the incidence of such cultivation in the region but that, even within the periods when it was common, it did not have the regular character apparent in some other parts of Britain; instead tillage seems to have occurred at irregular intervals, ranging from 15 to 100 years with, perhaps, 30 to 50 year intervals being most common. A few of the documents cited by H.S.A. Fox (1973:32) reveal that when the land was broken, it was sometimes tilled for two successive seasons. It is clear that, in Devon and Cornwall, the sporadic enclosure and tillage of large chunks of the 'waste' for a few 'bonus' crops was subordinate to their use as rough grazing land and was not part of an integrated farming system (1973: 34-38); none of the sources examined by Fox (personal communication) mention the use of manures or other soil additives during these episodes, which may be taken as further evidence of their essentially serendipitous nature.

It is possible that cultivation in the areas beyond the Lobes occurred not only in Fox's early period of outfield cultivation (13th to early 14th century) but also in a second rash of such activity in the 16th century; the archaeological evidence cannot confirm or deny such an event. It is notable that these periods of increased outfield cultivation correspond precisely with periods of more benign climate (see 3.2.1).

The next archaeologically-visible event on Holne Moor is stonework refurbishment of sections of the boundaries of the North Lobe, Central Lobe 3, South Link Close and part of the South Lobe. The southern half of this Lobe seems to have been abandoned and its corn-ditch deliberately despoiled so that livestock could pass freely through this zone. Extensive gulleying radiating away east and west of the gaps in this boundary (see Fig. 3.7) testify to such movements. Similar gulleys are found within the Lower South Field, where they radiate away from a gate in its north-eastern boundary, but the banks in this field were neither despoiled nor refurbished and such gulleying may simply indicate livestock use of the field.

The date of this refurbishment and the date of final abandonment cannot be precisely determined, but deep tinning gulleys and associated rabbit buries (see Fig. 3.7) slighted parts of all the land enclosed by refurbished boundaries (segments of the latter were utterly destroyed) except in the North Lobe. The absence of tinning in the North Lobe may merely reflect a lack of geologically relevant deposits, but the absence of rabbit buries may point to its continuing use either as an arable or pastoral resource during this period of tinning; rabbit buries were placed in the adjacent Lobe where tinning did not occur. This tinning most probably occurred between the early 15th and mid-17th century (Greeves: in lit. 1981), so a 14th century date for the refurbishment and a 15th or 16th century date for final abandonment of these farms seems probable.

At some time, almost certainly during the historic period, part of the wall of the main prehistoric house on site F was despoiled; boulders were dragged from a segment of the north side of the house and were set up in a horse-shoe shaped arc within the eastern half of the main house. This event post-dates a considerable accumulation of peat and may well have occurred during the later tinning and rabbit warrening; the extremely crude construction suggests a very brief period of use for this 'building' and that it may never have served as a house but merely as a 'shelter' of some kind.

Fleming and Ralph did not examine original documentary sources but were able to benefit from the advice and information possessed by local historians and other researchers (John Somers Cocks, Elizabeth Gawne, Tom Greeves, Hermon French, Harold Fox), whose considerable collective research among such sources has not revealed any specific references to the events described above, save perhaps in the case of the tin workings. Since documentary records do mention events (typically commoners' disputes) from the early 18th century onwards, it can be safely assumed that all intensive farming had ceased before that time. It is in fact far more likely that even the North Lobe, which was always cultivated in 'acre-strips', went out of arable use at least by the end of the 16th century, and it could well have lain abandoned more than a century earlier.

Historical records, such as they are, of the still extant farms close to the study area, evince no conflict with the archaeological evidence for the sequence of settlement summarised above. The farms on the Manors of Estocha or Stoche (Stoke) and Holla (Holne) were established before the Norman Conquest and are recorded in the local Domesday surveys (Page 1906:490), though other nearby farms only find mention in slightly later records: Comereston (Combestone) in 1333; Robroke (Rowbrook) in 1291 (Gover et al 1931). All of these settlements could be Saxon in origin.

Further evidence for the nature and dating of medieval and early modern land use in the study area is provided by investigations of the soils which are described and interpreted in chapter 4.

Recent and contemporary

After the abandonment of the farming settlements in the Venford Brook valley sometime in the late medieval or early modern period, agricultural exploitation of Holne Moor appears to have been limited to practices similar to those which characterise the area today. The nature and likely effects on the soil-organism ecosystem of the low density grazing, swaling and bracken cutting that is typical of contemporary or recent moorland exploitation have been considered earlier in section 2.2.4 and some details of the present complement of livestock and of recent swaling have also been mentioned (see 3.2 and 3.2.1). Only two matters remain to be considered. First, the contemporary pattern of sheep night camping areas and day resting areas must be described. The location of the camp areas has been included in Fig. 3.7, where it can be seen that, at present, there seem to be only two main camping zones within the study area. Both of these lie on the exposed plateau summit; the camp on the western boundary of the Outer South Field may not have been long established when first observed in 1978. Although heavy dung deposition along a stretch of about 60 m of this boundary (extending about 5-10 m either side) was observed again in 1980, there are as yet no signs of soil erosion or visible vegetational anomalies. This is not true of the second area lying close to the modern road. Here, a combination of pedestrian, vehicular and animal traffic plus sheep 'bedding' sites (hollows) has led to the removal of the peat surface and some mineral soil erosion in numerous small areas. Both heather and purple moor grass have been partially replaced by species of Agrostis, Festuca and Deschampsia. Although dense dung deposition is confined to an area similar in size (ca. 1000 m^{-2}) to that of the other camp, this oblong area (ca. 15 x 60 m) is merely the main focus of a wider zone used for day and night resting by sheep which extends all along the modern road but which is most heavily used in the sheltered area to the east of the camp. Similar areas, which sheep appear to use mainly during the day occur in the eastern parts of Central Lobe 1 (also near the modern car park), adjacent parts of the North Lobe and the areas disturbed by tinning in Central Lobe 3. An old sheep camp site can be seen to the west of the North Field. In this more steeply sloping area (ca. 5^{o}) there has been considerable erosion of peat around old sheep bedding sites leaving bare ground (peat surfaces and in some places mineral soil) with 'runs' of bleached quartz stones.

Secondly, it is necessary to consider the antiquity of swaling within the study area. The author has been unable to trace any authority which supports Simmons' (1964b:205) statement that 'The use of fire as an agent of clearance and for changing vegetation . . . passed into common rights during medieval times' and it may be that on Dartmoor, as in Scotland and northern England, the regular burning of heather dates largely to the period since 1800 (see Gimingham 1972: 187). The increase in heather pollen in the uppermost samples of Dartmoor pollen profiles could be a reflection of increasing use of fire as a tool in moorland grazing management.

Although tin mining occurred on Dartmoor as late as the early part of this century (Greeves 1980) and some workings near Combestone Farm were in use in the early 19th century (Greeves 1978), there is no evidence for such relatively recent extraction within the study area. Peat, however, may have continued to be extracted until recent times.

Peat has been cut within the Chase of Dartmoor since at least the late 14th century (Yates 1964:147) and continued to be cut until the first half of this century (Booker 1970:126, 129-131). It seems probable that even the relatively shallow but more conveniently located sources on the Commons were used at least as early and for just as long. Field evidence for this extraction is discussed later (4.3.1), but it can be noted that there is no sign of unvegetated trenches that would indicate very recent peat removal in the study area. The present inhabitants of the Stoke Farms do not use peat for fuel or other purposes.

The heavy rainfall on Holne Moor has also long been exploited. In addition to the reservoir constructed in 1907, two leats pass through the study area (Fig. 3.7). The higher one, called the Wheal Emma Leat, was constructed in 1859 to take water to the Brookwood Mine in the parish of Buckfastleigh (Greeves: personal communication), but is now dry throughout its length. A precise date for the construction of the lower leat, called the Holne Moor Leat, which flows from the west and is only wet as far as its intersection with the modern road at the apex of Central Lobe 1, has not been discovered. A leat from Holne Moor apparently served as a source of water (via the Michelcombe stream) for the woollen mills of Buckfast Abbey, but it is by no means certain that the present Holne Moor Leat ever served this purpose. If it did, this would of course imply a 16th century or earlier date for its construction. Today the flow from the Holne Moor Leat is diverted to the east by a pipeline across the valley, but the dry channel (not marked on the 1:25,000 O.S. Maps) continues south and this channel, like that of the Wheal Emma Leat, is clearly stratigraphically later than the major tinning gulley in the South Lobe and later than at least one major tinning episode in Central Lobe 3. The construction of these leats may have affected soil development in the soils downslope in several ways. Leats intercept and divert surface flow and in old leats where breaks occur may channel such flow into specific restricted areas, thus creating artificial 'flush' zones. Flowing leats with broken or weakened banks may do likewise and in any case lose water by seepage, thus adding to downslope sub-surface water flow. Clearly nett alteration to soil water is difficult to predict; one may guess that a reduction is the most likely outcome. If so, soils in areas below these leats may have been artificially drier than they would otherwise have been for over a hundred years and perhaps for several hundred years. If the Holne Moor Leat was constructed in the 16th century or earlier, such artificial conditions may have been operating for most of the time since the medieval farms were abandoned.

Recreational use of the study area is the remaining form of contemporary moorland exploitation and its ecological and pedological consequences (principally footpath and car park erosion) are of very restricted spatial extent. With these remarks then one can turn to a consideration of the strategies that have been used to investigate the nature and history of pedological development in the study area.

3.3 Fieldwork and laboratory strategies

The criteria for selection of a study area were introduced earlier (see 2.1) and the description of the physical geography, natural history and archaeology of Holne Moor (see 3.2) has shown that a study area on this plateau conforms to the requirements listed. Reasons for the selection of specific areas and features within the study area as prime targets for intensive sampling and analysis will be considered in chapter 5. This section provides an introduction to the overall strategies of mapping, sampling and analysis that have been applied in these studies.

Limitations of time, money and assistance (all field sampling and description and, with a minor exception, all laboratory preparation and analysis were carried out by the author alone) precluded the adoption of a program of work that would provide rigorous tests of all aspects of the models discussed earlier, and it was decided that in these circumstances the best course to adopt was one that would do most to hasten the day when such fully rigorous testing might be achieved. Steps along this path which seemed feasible included:

a) studies of the spatial distribution of soil characteristics observable in the field, which it was expected would provide a first, qualitative assessment of the way in which medieval farming had affected the soils of the study area, and would, in any case, provide an evaluation of the general pattern of soil types that was an indispensable precursor to all other sampling programs (see chapter 4).

b) studies of buried soils of prehistoric and medieval age, which would provide information about soil history and, in particular, long-term trends in soil phosphorus and organic matter accumulation (see 5.2.1).

c) studies of specific features of both the prehistoric and modern landscape that would help to establish both the nature and strength of pedogenetic transformations of metapedogenetic patterns and would, in particular, provide information about vertical and lateral patterns and movement of phosphorus (see 5.2.2).

d) studies of medieval and prehistoric enclosures on Holne Moor which could only be seen as a preliminary attempt to test the models advanced earlier (see 2.4), but which would allow one to judge whether further work along these lines was justified and, if it was, what <u>minimal</u> sampling strategies could be adopted with the hindsight provided by these preliminary enquiries (see 5.4).

Although from a spatial point of view, this program of investigation constitutes, by comparison with, say, Dimbleby's (1962) studies of moorland soil development, a highly intensive enquiry, it involved extremely extensive field and laboratory work and provides possibly the most comprehensive study of soil phosphorus in an area of 'wild' soils ever undertaken. Including observations made in the secondary sampling zones at the Rowbrook and Stoke farms (see Fig. 3.1), observations in small and large soil pits were made at nearly 500 locations. Detailed numerical information (see Appendix 1) was recorded at over 350 of these places and chemical analyses have been made of nearly 150 soil profiles, sampled, in most cases, to a depth of at least 40 cm below the mineral soil surface. These profiles generated *ca.* 675 samples and more limited sampling in some area, together with a small number of replication and other experimental studies raised the total number of soil samples analysed to *ca.* 900. Even using the relatively crude method of soil phosphorus 'fractionation', which was selected, each soil sample must be analysed twice, yielding a grand total of *ca.* 1800 phosphorus determinations (see Appendix 3). In addition, most of the samples for chemical analysis also underwent a limited physical analysis after preliminary laboratory preparation (see Appendix 2), and, in particular, soil bulk density was determined on *ca.* 300 samples in order that the weight of phosphorus within the fine earth fraction of standard volumes of soil could be calculated (see Appendices 2 and 4).

Although detailed accounts of the methods employed appear in the appendices, details of field sampling procedures used on specific features are described in the sections where the results of such investigations are presented (Chapter 5) and discussion and some overall description of methods of mapping, sampling and analysis are provided in the succeeding sections of this chapter. In addition, the sections devoted to laboratory analyses include presentation and discussion of the results of certain major, but preliminary, investigations of the pattern of bulk density and total phosphorus in the soils of Holne Moor.

3.3.1 Fieldwork

Much of the fieldwork was carried out between April and September, when weather conditions are more tolerable, practical help digging soil pits was available from volunteers otherwise working on the concurrent archaeological studies and when the pattern of vegetation is most easily recognised. Most of the soil sampling occurred during June, July and August over three successive seasons from 1977 to 1979. By sampling and analysing in stages, it was possible to utilise the results of one season's work to modify the approaches used in the following year, where experience had shown that such modification was feasible and desirable. In particular this approach enabled one to at least partially overcome the considerable problems posed by the absence of any previous studies whose findings could be used to reliably predict the density of sampling that would be required to characterise a population with sufficient accuracy to ensure that, where differences in soil characteristics exist, they would be identified.

There have, of course, been many studies of soil variability (Beckett and Webster 1971), but few of these looked at unenclosed 'wild' lands like those on Dartmoor or studied soil phosphorus; when soil phosphorus has been examined, variation in an extractable fraction of uncertain significance has usually been studied (e.g. Reed and Rigney 1946, 1947, Hemingway 1955, Ball and Williams 1968) and although research into soil variability and the efficiency of sampling strategies such as that by Ball and Williams (1968, 1971), Drees and Wilding (1973), Mausbach et al (1980) and particularly that of Reynolds (1975) provides some guidance, it does not allow one to predict either the optimum number or pattern of samples for any specific investigation in the study area. In consequence, it sometimes proved necessary to obtain additional samples from a particular area when analysis showed that the initial sampling had been too diffuse.

Examination of the literature of soil variability and the results of the first season's work also indicated that a useful contribution to the development of methods of assessing land use in ancient fields would include the testing of several sampling designs and methods and the strategies subsequently adopted attempted to include this goal. The spatial location of samples designed to assess a mean value for a population have usually included a randomising element (typically sampling locations were determined by using random numbers (from Tables) as Cartesian co-ordinates), though various simplifying tactics (transects, grid-layouts and other patterned lay-outs) have been employed in appropriate contexts and 'purposeful', non-random samples were taken from specific features of the farming landscape (gates, ditches, field corners, etc.) in order to test for patterns predicted in the models presented earlier (2.4).

Although a proportion of the data used to prepare soil and vegetation maps was recovered from soil sampling locations, the basic lattice for the mapping was established in a distinct operation and it is convenient to consider the mapping and sampling in separate discussions.

Mapping

Initially, the soils in an area encompassing, but slightly larger than, the land enclosed by the medieval farmers of Holne Moor was systematically surveyed by examination of 80 small soil pits set out within a rectangular grid of ca. 1.2 km x 1.0 km (see Fig. 3.8). To the south of the modern road, pits were dug at each corner of 100 m squares; to the north, 200 m squares were employed with an additional pit at the centre of each square. This differential density sampling was selected because of the extra complexity of enclosure in the southern part of the study area. All pits were dug to a depth which allowed a clear exposure of the B horizon soils excluding the indurated BCux horizon. Recording procedures at each location are described in Appendix 1. Similar records were made at 27 locations in zone A (see Fig. 3.9) during the first season's soil sampling program and more abbreviated records were made at a further 150 pits in this area during the second season's soil sampling. All these pits were examined to a depth of at least 40 cm below the mineral soil surface. In zone A, the location of sampling points was dictated by a stratified random sampling design, which used units of land defined by prehistoric and medieval land boundaries (see Fig. 3.9); locations within these units were chosen by random numbers used as Cartesian co-ordinates, but a location was held to have a diameter of 5 m and co-ordinates were rejected if they fell within this margin of a previously selected sampling point. Additional samples were taken from the edges and corners of fields as discussed below (see 5.4.3). Abbreviated records were also made in zone B (ca. 30 profiles) and zone C (8 profiles) though in the latter zone, 10 other profiles were examined during the first season's sampling and fuller records were made at that time. Sampling patterns within zones B and C are discussed below (see 5.4.1 and 5.4.2).

The position of sampling and mapping locations were found, in the field, by careful pacing from the nearest boundaries or other landscape features which had been mapped. In most cases positions were checked by reference to two such features and it is thought that the level of precision achieved probably justifies an assumption that the actual point sampled lay within 15 m of the planned location throughout the study area and within less than 5 m in zones A, B and C. In a few cases the locations dictated by the imposition of the mapping grid lay on boundaries, leats, tinning heaps or rabbit buries; in these cases a nearby location was substituted, though sometimes a pit was also dug in such features. Since the maps of subsoil, surface soils and vegetation that were eventually constructed (these are presented and discussed in Chapter 4) involve a further level of abstraction and make assumptions about the relationship between soil features and topography, these margins of error are of little consequence.

Visual estimates of land form and vegetation were also recorded at all mapping locations and most soil sampling pits, and this information together with selected soil variables was transferred to large scale maps. The subsoil and vegetation maps were constructed solely from the data base described above, except that, in assessing present vegetation boundary positions, the air photo cover, discussed earlier (see 3.2.1), was consulted, and, in zones A and B, the pattern of vegetation was mapped in the field, the position of boundaries and their relationship to land boundaries being assessed by careful pacing. The surface soil map benefited from further sampling; initial maps prepared from the data base described above indicated that some soil characters changed abruptly across certain land boundaries. This was clearly evident in zones A and C where the highest sampling density had been employed, and there were less certain indications that similar changes might be occurring at other boundaries. To check on such relationships, surface horizons were examined in a further 120 small soil pits (see Fig. 3.8), which were dug only to a depth sufficient to expose the upper surface of the B horizon. This 'purposeful' sampling program, in addition to allowing close definition of the location of substantial changes in surface soil characters, also provided an opportunity to test the homogeneity of soils within specific areas enclosed by land boundaries; in this manner, the reality or otherwise of the soil map units postulated from the results of the initial survey were critically assessed in the areas where such a reassessment was most crucial. This final mapping survey also served to fill gaps left by the initial grid survey; there had been no observations in a few areas surrounded by medieval boundaries and several pits were dug in each of these locations.

Sampling

The overwhelming majority of soil samples were taken from zones A, B and C, though some 30 profiles within or near a stone row lying just beyond the south-western corner of the mapped study area (see Fig. 3.8) and a further 10 profiles at each of the secondary sampling zones at nearby farms (see Fig. 3.1) were also sampled. The general principles of the spatial location of sampling in zone A have been mentioned above and precise details of sampling in other areas accompany the accounts of these investigations (Chapter 5).

Two basic types of sampling procedure were adopted. At 18 locations (see Figs. 3.8 and 3.9) large soil pits (1 x 2 m) were excavated to the depth of the BCux horizon and profile features were recorded using the methods and terminology of the Soil Survey of England and Wales (Hodgson 1976). Most, but not all of the soil variables listed by Hodgson were evaluated (see Appendix 1). The locations chosen for these pits ensured that information about the variability of soil morphology at this scale of observation was available for most of the major sampling zones and even the smaller sampling subdivisions of zone A. With several of these large pits the opportunity was taken to assess small scale chemical variability. Most samples were recovered from smaller pits (0.3 x 0.3 m), where, in general, the aim was to provide descriptions and representative, uncontaminated samples from all horizons above the BCux, save for the litter layers (see earlier discussion in section 2.2.2.1). Augering was considered and used experimentally (for B horizon sampling only) in four areas (see Appendix 1), but, in general, was felt to be an unsatisfactory alternative both for survey and sampling work; problems arose from contamination during auger withdrawal and from stoniness which often prevented adequate penetration. At times stoniness also affected the efficiency of small pit sampling, particularly of the lower B horizon. During the first season, attempts were made to recover lower B horizon samples spanning the entire depth to the surface of the BCux, but on many occasions this proved to be impossible without digging much larger pits. As a result, it was decided that, in the second season, sampling would be limited to the first 40 cm of the mineral soil, a depth that had been achieved or surpassed in most of the first season's sampling pits. This provided a lower B horizon sample, whose thickness varied with the depth of overlying Ah/E and upper B horizon layers, but which in most cases equalled or exceeded 10 cm. Problems of comparability and calculation arising from this decision to alter the lower B horizon sampling method are considered below and in Appendix 5.

Except at Stoke Farm and the stone row, where most B horizon samples were recovered from an arbitrary depth below the mineral soil surface, soil samples were generally taken from whole horizons rather than spits of arbitrary thickness; in most cases only one 'face' of a pit was sampled and in order to avoid contamination, an 0.5 - 1.0 cm sliver of soil, at the top and bottom of horizons, was excluded. This procedure was adopted since most samples were to be taken from stagnopodzols where large changes in iron and organic matter content occur at well-marked, sharp boundaries and create the strongly-differentiated horizons which are the conspicuous features of these soils in the field. Since one could anticipate that most of the soil phosphorus would be in an organic form and much of the secondary inorganic phosphorus associated with iron (see 2.2.2.2), it was thought that horizon sampling, which would be sensitive to changes in these associated soil fractions, would be far less likely than spit sampling to produce samples that had cut across and thus would blur the points in the profile at which substantial changes in phosphorus occurred. In quite a number of profiles, the colours and textures of upper and lower B horizons were very similar and/or changes in colour and texture occurred over a thick zone. In these cases, an arbitrary division was made; where a transition zone could be defined, the split was made at its mid-point and where this was not possible, the entire depth of the B horizon was sampled in segments of equal thickness. The number of such samples was adjusted to ensure that, in most cases, no sample spanned more than 15 cm. Similar procedures were also used when sampling less well-differentiated brown podzolic soils.

In addition to bulk samples of ca. 1 kg for general analyses (phosphorus, loss-on-ignition, stone and moisture content) samples of known volume for bulk density measurements and, in a few cases, extra large samples of ca. 2 - 3 kg for analyses of a larger stone component were taken during the first season's sampling. Kubiena tins designed and manufactured at Rothamsted for the purpose of recovering undisturbed soil samples for micromorphological analysis were used to obtain volume samples (and micromorphological samples, but this work is not reported here); the tins were pushed or gently tapped (using two pieces of wood) into the soil face and then cut out with spade, trowel and knife. In the peat and Ah/E horizons this procedure encountered few difficulties, and these were generally able to be overcome at a second attempt. The stonier B horizons presented more problems and in the first season relatively few volume samples were obtained from these horizons.

Although in some respects, the intensive, multiple-sampling of the first season must be regarded as the ideal field strategy, the sheer number and volume of samples produced by such procedures, which gave rise to problems in laboratory preparation and even the transportation of samples, forced the author to reconsider, and to seek ways of reducing the work load with minimal loss of information. The analyses of the first season's samples guided this reassessment. They showed that the bulk density of the soils in the study area was strongly correlated with their organic content and it was therefore decided to use this relationship, as previous researchers have done (Curtis and Post 1964, Saini 1966, Jeffrey 1970), to estimate bulk density from loss-on-ignition measurements. It was also found that the stone component of the soils as measured in the laboratory in 0.2 - 2.0 kg soil samples varied appreciably as a function of sample size and that even the largest samples were undoubtedly under-estimating total stone content of the soil. Since larger samples were ruled out as impractical, it was decided to standardise estimations of stone content using the amount present in the volume samples or, in some cases, equivalent, 'beakerful' samples (see discussion below), both of which had an oven-dry mass of <u>ca</u>. 0.15 - 0.25 kg.

With the exception of some critical profiles (e.g. the medieval palaeosol investigation), the second season's sampling was therefore modified in ways which took account of these findings. The large bulk samples for stone analysis were no longer needed and the bulk density sampling program was modified. Attention was concentrated on obtaining as many volume samples of the B horizons as could be taken and only a limited number of such samples from the peat horizon, where an adequate sample had already been obtained. For reasons discussed below, volume sampling of the Ah/E horizon continued to be attempted for all profiles. The volume samples were in future to be used also for general analyses and where they could not be obtained a bulk sample of at least 0.25 kg was to be taken. Where a horizon exceeded 10 cm in thickness, the volume sampling tin could not obtain a fully representative sample of the whole thickness of the horizon and in such cases an additional, bulk sample was taken for chemical analysis.

Radical changes in sampling procedures within a single project are obviously not desirable, so the new procedures adopted during the second and third season were chosen, not necessarily because they represented the best strategy for large scale sampling, but because they allowed a reduction in field and laboratory work-load without substantially altering the nature of the samples that would become available for chemical and other analyses. In general this strategy seems to have been successful; where differences in the results from first and second seasons' sampling have been identified, they seem to be artifacts of laboratory changes not sampling changes (see 3.3.2 and Appendix 5).

3.3.2 Laboratory work

Laboratory work spanned four winter seasons and was concluded in the spring of 1980. In this work, unlike the fieldwork program, an intensive series of tests prior to the first sampling season, enabled the author to adopt standardised laboratory procedures, which, as far as possible, were rigidly adhered to throughout the analytical program. Each season's samples were analysed during the subsequent winter, thus keeping storage times prior to analysis as similar as possible across all samples. Initial storage left the samples in field condition for up to three or four months, and, although a rigorous check on changes to samples during this storage has not been undertaken, the tests that were done (see Appendix 5) suggest that, under the dark, cool conditions utilised, these very acid soil samples underwent minimal post-sampling alteration.

Despite every effort, events nonetheless conspired to prevent absolutely even-handed laboratory processing. Two main problems occurred. Analysis of the first season's samples was interrupted by the withdrawal of essential facilities during a long industrial dispute. As a result, some of the first season's samples were not analysed until the second year, but the initial processing (oven-drying and sieving) was completed and, again, a small-scale test showed that the more prolonged storage (in the oven-dry condition) of the affected samples is unlikely to have had any appreciable effect on the subsequent analytical results (see Appendix 5). As a result of these difficulties, when an opportunity to move to another laboratory arose (at the conclusion of the second summer's sampling), it was taken up. This laboratory move resulted in further delays and created its own problems of comparability, but since, with one significant exception, all the new laboratory equipment was of the same specification, no significant change in the results of analysis was expected or detected (see Appendix 5). However, the one exception - a different type of oven for sample drying - did, initially, cause a problem, which, however, seems to have affected only one group of samples. The nature of this problem, the steps taken to analyse it and the chosen solution to it are also considered in Appendix 5.

Laboratory analysis of soil samples involved estimation of five main properties: soil bulk density; stone content; organic phosphorus; inorganic acid-extractable phosphorus; loss-on-ignition. In addition, pH, particle size, moisture content prior to oven-drying and total phosphorus was determined on a limited number of samples. Ideally, the total phosphorus content of all samples would have been determined, since this is the only way in which loss or gain of soil phosphorus can be proven beyond peradventure. However, in most soils, total phosphorus can only be determined by fusion in inert containers such as platinum crucibles (Muir 1952, see also Mattingly 1970), which were not available to the author. A very high proportion of total phosphorus can also be extracted by treatments which include HF and/or $HClO_4$, but with sandy soils the former involves tedious, lengthy treatments, quite unsuitable for large numbers of routine determinations, while the latter can only be used with safety if special facilities are employed and these were also unavailable to the author.

Since, in any case, it was felt that the most practical method for the purposes of archaeological research would be one which did not rely on rarely available facilities, several attempts were made to overcome these problems using alternative procedures. As a first step, twenty prepared samples were sent to Rothamsted Experimental Station, who had offered to determine total phosphorus (by fusion with Na_2CO_3) in a limited number of samples. Using these results as a standard, the efficacy of other methods was then tested on duplicate sub-samples (these tests and results are outlined in Appendix 3). A simple, rapid method (thus suitable for the large-scale routine analysis required on archaeological projects) involving oxidation with NaOBr (Dick and Tabatabai 1977) was tested first, but with Dartmoor soils, this method only recovered a similar proportion (ca. 70%) of total phosphorus to that which had been obtained by extractions from ignited samples using cold (ca 20° C) 2N H_2SO_4. Moreover, whereas the proportion extracted by acid showed systematic variation from horizon to horizon, which can be explained as the result of pedological processes in soils (see Chapter 5), these trends were less clearly monitored by the alkaline oxidation method. Further tests showed that pre-ignition of samples improved the proportion recovered by alkaline oxidation, particularly from the peat horizon, which suggests that organic phosphorus was not being quantitatively recovered in these organic-rich soils, but the total amount recovered still fell well short of the values given by fusion analysis.

Repetitive boiling to dryness with concentrated HCl was then tested (with and without the addition of magnesium acetate during pre-ignition of the samples), but this method (based on Beckwith and Little (1963), but omitting the $HClO_4$ stage) largely duplicated the recovery pattern obtained by cold 2N H_2SO_4 extractions of ignited samples. Finally, fusion with Na_2CO_3 in zirconium crucibles was assessed, though these tests are not reported in the Appendix, since the work was not followed to a rigorous conclusion. (Initially, higher total phosphorus values than those reported by Rothamsted were obtained; this may have been due to contamination of the crucibles in earlier experiments. Further testing was discontinued when repeated fusions led to surface damage of the crucibles).

The similarity of the proportion of total phosphorus recovered by hot, concentrated HCl and cold, dilute H_2SO_4 from ignited samples suggests that, in Dartmoor's soils, the inorganic phosphorus fraction not recovered by acid extractions (=Pf in the terminology of Floate (1962) and Walker (1965)) exists in (probably occluded) forms that are sharply differentiated from the acid-extractable inorganic forms (= Pa, which probably includes primary apatite as well as non-occluded and perhaps some occluded forms). To explore these aspects further and, in particular, to assess the genesis of the Pf fraction and the relationship between Pt and other phosphorus fractions, another 40 samples (in a selection which included samples from the buried soils and covered soils affected by different land use in medieval and prehistoric periods) were submitted to Rothamsted for fusion analyses. The results of this investigation are presented below and discussed further in sections 5.2.1 and 5.4.2.

Preparation and sampling

The principal concern during preparation and sub-sampling stages was to ensure that sub-samples submitted to physical and chemical analyses were representative of the samples taken in the field. Samples were returned from the study area in medium gauge polythene bags and were then placed in temporary storage in a dark, unheated chemicals store. During the relevant autumn and winter months, temperatures in this store probably ranged from ca. 3-13° C. Air moisture was not controlled but the samples were sealed by ties; the pattern of (high) moisture content of the samples when taken for analysis suggests that their moisture level may have remained close to that which obtained at the time of sampling (see Appendix 2).

The amount of soil recovered in the volume samples for bulk density estimates almost precisely filled, by coincidence, a 250 ml tall-form laboratory beaker and so it was decided to use this measure as the basic unit during laboratory preparations. Although larger, bulk samples were on occasion processed in their entirety, in most cases only a 'beakerful' sample was oven-dried for analyses. This sub-sampling of soil in field condition was accomplished with a medium-sized scoop. The sample in the bag was first stirred thoroughly and several scoopsful were then transferred to a beaker. Since, in field-moist condition little or no sorting of the soil occurred in the bags and thus nearly all the soil transferred was incorporated in peds or broken peds, little or no over- or under-representation of particular particle-size categories should have been produced by this procedure.

Initial tests had shown that oven-drying of such samples for 24 hrs at 105° C did not always reduce them to a state of unchanging weight (particularly wet peat samples), but it was thought (and later shown - see Appendix 5) that prolongation of drying would cause extra mineralisation of organic phosphorus and so interfere with later fractional analysis of soil phosphorus. Further tests showed that this dilemma could be resolved by allowing all samples to lose a proportion of their moisture during three days of air-drying prior to oven-drying, which was then capable of driving off all further moisture in 24 hrs, and this procedure was adopted. Only the volume samples collected during the first season, which were not used for chemical analysis, were oven-dried to a checked, unchanging weight. Moisture determinations were, of course, based on sample weight prior to the air-drying stage.

After drying, samples were weighed and separated into stone and fine earth (material with particle size less than 2mm) fractions by gentle crushing through a brass sieve (the low clay content of samples allowed such crushing with minimal damage or attrition of larger particles, though some weathered felspars did break up); at this stage the larger root and rhizome material was removed from samples (generally, only a small amount of such material was present, since it had been avoided in the field, and then, almost exclusively in Oh and Ah samples). No attempt was made to remove smaller root material from any samples (see 2.2.2.1). Subsequently the stone fraction was itself sieved, and from the residual fine earth fraction (weighing ca. 100 - 200 g depending on bulk density and stone content), a 15 - 25 g sub-sample was withdrawn using a steel sample divider (riffle box) which split samples into two equal halves. This sub-sample was then ground by hand using a porcelain mortar and pestle until all of it passed through a 250 micron sieve. The balance of fine earth and the ground sub-sample were then stored for analysis (in self-sealing polythene bags in the laboratory).

In some cases, for example where auger samples had been obtained, lesser amounts of soil were processed (and in one of these instances stone content was not measured) but all essential elements in the above procedures were adhered to for all samples throughout the program. (Samples affected by minor deviations in procedure are indicated in Appendix 2). The decision to grind all samples for chemical analysis, which may have increased the amount of acid-extractable phosphorus (Williams 1952) and certainly increased the laboratory workload, was taken in order to minimise differences between replicate sub-sample analyses arising from poor laboratory sub-sampling, which, as initial tests had shown, can be very substantial. Such minimisation was particularly important since regular duplicate analyses with a consequent two-fold reduction in the number of soil samples analysed was an unacceptable alternative. The replicate analyses that were infrequently included demonstrate the success of this strategy, since they reveal only very small analytical 'error' (Appendix 5). The decision to exclude from chemical analysis material of particle size greater than 2 mm was taken in order that the analyses be directly comparable with the bulk of reported analyses in Britain where such a procedure is normal practice. Since the stone fraction is unlikely to contain any significant quantity of secondary phosphorus, stone exclusion does not interfere with the goals of this investigation. The decision to process a 'beakerful' sample of soil was merely convenient, but this sub-sample was large enough to provide a representative sample of the fine earth in the bulk samples and moreover contributed to minimising differences which might otherwise have arisen as a result of the decision to alter field sampling procedures after the first season's sampling.

Physical analysis

Physical analyses were mainly undertaken in order that the results of chemical analyses could be expressed in terms of soil volume as well as weight, an essential prerequisite to the calculation of the weight of an element present in complete profiles (i.e. g m^{-2} to sampled depth). Since the stone fraction was not included in chemical analyses, which determined the concentration of, for example, total phosphorus per unit weight of fine earth (i.e. mg Pt kg^{-1} Fe), the main objective requires one to estimate the weight of fine earth per unit volume of soil (i.e. g Fe cm^{-3} Soil). This can only be achieved by establishing the weight of soil in an undisturbed volume sample (i.e. soil bulk density), which is then sieved to determine the fractional contribution of stones and fine earth.

As noted earlier, volume samples for soil bulk density (BD) measurements could not or were not obtained from all horizons at all locations; instead, in many cases (but not all - see below), the values for BD used in calculations involving volume of soil and its components have been derived from the loss-on-ignition (LOI) estimates of the organic content of samples. This procedure, which is based on the very strong relationship that has often been observed and would indeed be expected to exist between these two soil variables, has been adopted in many previous pedological and ecological studies. Some recently published pedological research (Harrison and Pearce 1979) even relied on a general equation for the relationship, which Jeffrey (1970) calculated from measurements on a large number of samples from a variety of soil types. However, other researchers (e.g. Floate 1962, Chapman 1979) have, more sensibly, relied on equations established from samples taken from the actual soils for which bulk density predictions were required; if predicted BD values are to be used to adjust the results of chemical analysis by weight (where precision may be measured in parts per million) it behoves one to take all possible steps to ensure the reliability of such predictions, and this is the course taken here.

The soil bulk density of just under 300 samples from the soils of the study area was calculated from the oven-dry weight of samples, which, in the undisturbed state, had a volume of just over 180 cm^{-3}. Procedures used for the measurement of loss-on-ignition are described below. The sample is nearly four times the size of that studied by Jeffrey (1970) and it reveals a number of patterns in the relationship between BD and LOI that were not apparent in that study. Scattergrams (Figs. 3.10 - 3.21) are used here to illustrate these relationships. The entire data set appears on Fig. 3.10, which shows that the general nature of the relationship in these samples is similar to that observed by Jeffrey (1970: Fig. 1) which was itself very similar to a data set published by Curtis and Post (1964: Fig. 2) a few years earlier. Although, as Jeffrey (1970: 297) pointed out, in the simple, two component system that is studied by ignition weight loss measurements, one would expect the reciprocal of BD to be proportional to the percentage by weight of the less dense component (and so LOI), neither he nor Curtis and Post (1964) chose to express the relationship in terms of a reciprocal transformation. Instead Jeffrey used a semi-log transformation (log ignition loss), while Curtis and Post employed log transforms of both variables in a quadratic equation. Jeffrey found that a semi-log regression produced a higher correlation coefficient than a regression based on reciprocal transformation of bulk density and suggested that the semi-log regression was, therefore, more appropriate 'as a convenient empirical means of predicting' bulk density (Jeffrey 1970: 297). However, use of the correlation coefficient as a criterion for choosing between different ways of statistically summarising the BD/LOI relationship has pitfalls. Saini (1966) employed no transformations and suggested that a linear regression, which had high 'r' values, could be used to predict BD from carbon estimates, but he did not publish scattergrams without which the utility of the equations is obscure. In preliminary statistical examination on subsets of the author's data, linear regression of untransformed data also produced high 'r' values, but the regression equations would nevertheless produce serious errors if used as predictors of BD.

In fact, the Holne Moor data sets produce high and very similar 'r' values with several of the transformations whose utility was explored (see Table 3.4). In the light of such results, it was decided that, with these data sets, there was no justification for moving away from the reciprocal transformation demanded by the nature of the system. Although, in general, the sample sets from different soil environments (Oh, Ah/E, B_1, etc.,) all conform well to the basic curvilinear pattern seen in Fig. 3.10, it was evident that such sample sets also showed systematic groupings within the pattern. The groupings, which are illustrated in Figs. 3.11 - 3.13, may well reflect the uneven influence of factors other than those envisaged in the simple two component model

Table 3.4 Soil bulk density (y) and loss-on-ignition (x) - coefficients of correlation for non-linear regression.[1]

Stone Row Sub-set

Transformations[2]	n	1	2	3	4
Oh samples	25	0.931	0.924	0.918	0.932
Ah/E samples	25	0.834	0.898	0.866	0.872

Zone A + Stone Row Sub-set

Oh + Ah/E samples	132	0.983	0.970	0.986	0.980

(2) Transformations used:

1. Reciprocal of soil bulk density
2. Square of soil bulk density, reciprocal of loss-on-ignition.
3. Log of loss-on-ignition (used by Jeffrey 1970)
4. Log of soil bulk density, log of loss-on-ignition.

(1) LOI values used in these calculations were expressed as % of OD fine earth; soil bulk density was expressed as gcm^{-3} soil.

of the relationship - variations in the density of the mineral and organic components themselves, differences in the arrangement of soil constituents, etc. Fig. 3.11 shows the regression lines produced by individual sub-sets from the surface soils (Oh and Ah) and the sub-surface upper mineral horizon of the stagnopodzols (Ah/E, but shown on these figures as AE). The two most striking aspects are: 1) the near identical regression lines of the peaty Oh and the 'mull-like' Ah horizon samples, despite the very different range of the values covered by such samples, which may be regarded as strong evidence for the dominant influence of the simple relationship envisaged in the two component model and thus further justification for the employment of a reciprocal transformation; and 2) the general similarity of the Ah/E curve, which, however, predicts slightly higher BD for a given LOI over most of the range. Such prediction accords with the field evidence, since the Ah/E typically shows little evidence of structural components and is usually a dense, massive horizon (soil descriptions are provided in section 4.2.1).

Fig. 3.12 allows comparison of the upper B horizon with the Ah and Ah/E. It is evident that the former usually has lower BD for a given LOI and that this tendency is most marked in samples with the highest LOI. This too accords with field evidence; the B horizons invariably have better-developed structural components - usually medium, sub-angular, blocky peds - and are much 'looser' than surface horizons. Fig. 3.13 shows that lower B horizon samples conform to the same tendency, samples with similar LOI to B_1 samples having even lower density; however, most B_2 samples have lower LOI than most B_1 samples and, at lower LOI values, the BD predicted by the B_1 and B_2 regression lines are very similar. This figure also shows the regression line produced by a small sample of 'special' soils.

It is apparent from the scattergram which shows the entire Holne Moor data set (Fig. 3.10), that samples taken from buried soils, their overburdens and from ditch silts (shown on these figures as 'Disturbed, buried'), tended to have lower BD for a given LOI than other mineral soil samples. Fig. 3.13 confirms that this is almost invariably the case; it seems that the tendencies evident in the B_1 sample set apply also to these buried/disturbed soils, despite generally lower LOI values. The latter could reflect reduced receipts of translocated organic matter with similar or higher organic matter decomposition rates. The generally lower BD may indicate preservation of relict structure (in the buried soils), a proposition discussed later (see

5.2.1) or may be the result of more complex alterations of structure produced by human disturbance of natural soil materials (ditch silts and overburdens).

Causality need not be pursued here, since the purpose of these investigations is prediction not explanation. What is important is that the various soil sub-sets exhibit systematic differences in the relationship of LOI and BD. All the individual regression equations are highly significant (see Table 3.5 and Figs. 3.14 - 3.19, which indicate the 95% confidence limits for the regression lines and for predictions made using these sample sets) and in each case a large and similar proportion of the variation in BD can be attributed to variation in LOI. In such circumstances, the use of a general equation, which would ignore such patterns, seems improper and therefore whenever it has been necessary to predict BD, the appropriate individual equation has been utilised.

The poorest correlation was found in the Ah/E horizon (Fig. 3.15) and these samples were, in consequence, examined further. Fig. 3.20 shows the contribution of samples from particular sampling zones to the total sample from this horizon (zone A = Fields, zone B = Droveway, zone C is included within Miscellaneous). The groupings evident here arise from differences in the range of LOI values in certain areas. While the soils of the area surrounding and within the stone row span a wide range of values, other zones seem to have a more restricted range; the Droveway area (zone B) mainly has higher values than the Fields (zone A), and samples from zone C tend to have higher LOI values than zone B. However, there is no indication of systematic differences between these zones with respect to the nature of the BD/LOI relationship. This may not be the case in the sub-zones within zone A (Fig. 3.21), where, with the exception of samples from bank/lynchets, all samples from fields A and B have lower BD than would be predicted by the overall Ah/E regression equation, while samples from field C and unit FG tend to have higher bulk density than the regression would predict. Samples from fields D and E are less aberrant. These patterns will be discussed later (see 5.4.3), but it must be noted here that the relatively poorer, overall correlation of Ah/E samples, and the evidence of spatial patterns, prompted an attempt to obtain volume samples from this horizon in as many locations as possible in order to minimise the use of this particular regression equation as a means of estimating BD.

Table 3.5 Soil bulk density (y) and loss-on-ignition (x) - non-linear regression equations and coefficients of correlation and determination.[1]

$$y = \frac{1}{a + bx}$$

Samples	n	a =	b =	r[2]	CD
Oh samples	86	0.6179049	0.0304212	0.9072	82.3
Ah/E samples	106	0.6076257	0.0271585	0.7869	61.9
Ah samples	24	0.5930464	0.0312339	0.8074	65.2
B_1 samples	39	0.5534842	0.0426421	0.8728	76.2
B_2 samples	26	0.4480727	0.0622231	0.8973	80.5
Disturbed and buried samples	12	0.6219073	0.0498253	0.8632	74.5
All samples	293	0.6246	0.03031	0.9823	96.5

(1) The regression lines produced by these equations are shown in Figs. 3.14 - 3.19, which also include lines showing the 95% confidence limits for the regression lines, and for predictions of soil bulk density; these latter limits were calculated from the equations given by Campbell (1974: 285). LOI values used in these calculations were expressed as % of oven-dried fine earth; soil bulk density was expressed as g cm^{-3} soil.

(2) All correlations are statistically significant with $P < 0.001$ in all cases.

After determining soil bulk density, it is necessary to evaluate the separate contribution to soil weight of the fine earth and stone fractions. Although samples from the Oh horizon of the stagnopodzols generally contained very few or no mineral particles larger than 2 mm, all such samples were nevertheless sieved prior to chemical analysis. However, with samples from this horizon the weight of stones retained during sieving was only measured in a limited number of cases (see Appendix 2); these measurements confirmed that most of the clearly visible mineral component in these peats (mainly bleached quartz grains) consisted of sand-sized or smaller particles and that stones contributed little to the weight of the samples. It was concluded that no significant error in understanding would arise if, in this horizon only, the weight of soil per unit volume (= soil bulk density) was taken to represent the weight of fine earth per unit volume. A few profiles were sampled in which a peaty surface horizon did contain substantial numbers of stones; samples from these horizons, which had loss-on-ignition values below 25%, were therefore treated in the same way as mineral soils.

Determination of 'true' values for the fractional composition of mineral soils is impractical (according to Shackley (1975: Table 3.1), at least 35 kg of sediment must be sieved to make an accurate estimate of the representation of 5 cm stones, while Avery and Bascomb (1974: Table 1) suggested that 30 kg would suffice to estimate the 6 cm stones in soils) and instead one must substitute some other measure, which, ideally, will not seriously underestimate total stone content, will be sensitive to 'real' variations in the amount of stones but will minimise fluctuations due to unrepresentative sampling of the larger stone fractions.

One can adopt the approach of the Soil Survey of England and Wales, who recommend visual estimates of the larger stones and simply omit unrepresentatively sampled stone fractions from their calculations by taking 'all soil minus such fractions' as the base for percentage calculations (Avery and Bascomb 1974: 2-5). This method was adopted for the 'bank/lynchet' investigation discussed above (see 3.2.2). However, the soil samples examined in that study were around ten times heavier than the 'beakerful' sample used for most of the other investigations in the study area and this larger size allowed meaningful estimation of all stone fractions up to, and including, stones of 16 mm. The limit for 'beakerful' samples may be nearer 8 mm and so records were kept of the representation of fractions up to this size - all larger stones were merely recorded as 'greater than 8 mm'. If, adopting the Soil Survey approach, one simply omits such larger stones from calculations, the total stone content of the soil is certainly underestimated and there is also a risk of underestimating the 'true' variability of the stone fraction. When the weight of stones between 2 and 8 mm is expressed as a percentage of 'all soil minus stones larger than 8 mm' both the apparent stone content and its variability are much lower than is revealed when the weight of all stones is expressed as a percentage of the weight of the entire soil sample.

In some soils the difference in apparent variability may be merely an artifact of the 'filtering out' of poorly sampled fractions, and, if this is the case, the Soil Survey method may well yield a satisfactory estimate of the 'true' variability. However, if there are differences in the variability of particular stone fractions, as seems to occur in the granite soils of the study area, 'true' variability may be underestimated. Examination of soil samples from Holne Moor showed that, while larger stones were generally made up of fragmented granite, many smaller stones consisted of individual crystals of felspar and quartz that had been weathered out of rock fragments but had suffered little further attrition. It seems likely that the incidence of smaller stone fractions is much influenced by the petrological characteristics of the rock, but that the representation of larger stone fractions may be mainly determined by fragmentation processes induced by frost and mass transport of the solifluction sheet. It was also apparent that the higher stone content of B horizons than Ah/E horizons mainly reflects larger numbers of granite fragments; the weight of the crystal component in samples of equal volume changes little above the BCux horizon, in which all stone fractions increase. In consequence, the crystal component forms a far higher proportion of the stones in samples from the uppermost Ah/E and E horizons. Presumably such patterns have arisen since the solifluction sheet stabilised at the end of the Pleistocene and are products of soil weathering processes during the current cycle of pedogenesis.

In the face of this evidence, the author concluded that it was not possible to assume and unlikely to be the case that, in all horizons, all stone fractions exhibited equal variability, and that it would be best, therefore, to estimate stone content as the weight of all stones expressed as a percentage of all soil. It is thought that, with the relatively small soil samples used in this study, this measure provides a better indication of both the total stone content of the soil and the way in which stone content varies between horizons. However, it has a serious drawback; estimates of the weight of fine earth per unit volume of soil are affected not only by 'real' variations in stone content but also by fluctuations due to unrepresentative sampling of stone fractions larger than 8 mm. Such inflation of apparent variability increases the difficulty of identifying statistically significant variation in soil chemical properties when these are expressed on a volume basis and so ways were sought to reduce the effects of unrepresentative sampling.

The abundance of stones in all the principal horizons of the soils of zone A is shown in Table 3.6. It is apparent that, using the chosen measure of stone content, individual samples span a very wide range of values in all horizons, and most particularly in the upper B horizon; it is equally clear that, when monitored by statistical summary of groups of samples, the apparent stone content varies relatively little between the various sub-zones, and this too is particularly evident in the upper B horizon. On the other hand, the mean values illustrate more clearly the differences between horizons and the generally higher stone content of B horizons. Large stones are more common in the lattter and one would expect that fluctuations in values caused by unrepresentative sampling of larger stones (and perhaps by the greater difficulty of obtaining volume samples in these horizons) would increase in magnitude and frequency as deeper depths are sampled. Although the statistics tabulated give some support to this hypothesis (note the increase in the standard error with depth and the wider range in values in the B horizons), the differences in the dispersion of values taken by samples from the upper and lower B horizon are minimal, despite a clear and substantial difference in stone content. This pattern could well be the result of the inability of samples of this size (ca. 180 cm^3) to provide an adequate measure of the larger stone fractions. It seems that with the particular particle size structure of these soils, such samples will rarely indicate an apparent stone content larger than 35%, although, particularly in the B horizons, the 'true' stone content may well exceed such values; one would expect this squeeze at the upper end of the range of values to affect the lower B horizon samples to the greatest extent and for it to be of little consequence among the Ah/E samples.

In the author's opinion the pattern of values in Table 3.6 strongly suggests that the best estimate of the 'true' stone content of the

Table 3.6 Stone content of soil samples from Zone A[1]

Ah/E

Sub-Zone	n	$\bar{x}$	Range	SD	SE	CV
A	5	12.59	8.26-18.95	4.67	2.09	37.1
B	7	13.49	10.75-16.23	2.00	0.76	14.9
C	15	17.54	10.07-25.47	5.31	1.37	30.3
D	5	16.15	12.42-19.04	2.95	1.32	18.3
E	9	16.40	10.17-25.23	4.12	1.37	25.1
FG	8	21.28	12.58-25.33	5.27	1.86	24.8
ALL Ah/E	49	16.72	8.26-25.47 = 17.21	4.97	0.71	29.7
B_1						
A	11	16.71	5.38-32.83	8.03	2.42	48.1
B	12	21.05	13.66-32.37	5.46	1.58	25.9
C	12	20.01	8.67-35.23	7.86	2.27	39.3
D	6	22.20	18.92-30.42	4.13	1.69	18.6
E	6	20.11	13.55-27.62	4.48	1.83	22.3
FKG	4	19.40	9.97-31.69	9.06	4.53	46.7
LM	5	19.77	14.53-25.15	4.93	2.20	24.9
RN	3	20.41	6.91-30.34	12.12	7.00	59.4
ALL B_1	59	19.80	5.38-35.23 = 29.85	6.68	0.87	33.7

(cont)

Table 3.6 (cont'd)

B_2

Sub-Zone	n	$\bar{x}$	Range	SD	SE	CV
A	4	25.64	17.53-30.91	5.70	2.85	22.2
B	4	28.79	21.32-35.45	6.03	3.02	20.9
C	11	27.07	15.98-38.27	7.31	2.17	26.6
D	5	33.02	25.70-43.09	6.49	2.90	19.7
E	5	23.05	18.27-32.19	5.63	2.52	24.4
FKG	1	24.74	-	-	-	-
LM	4	29.16	26.90-32.12	2.44	1.22	8.4
RN	2	23.66	22.88-24.43	1.10	0.78	4.6
ALL B_2	36	27.35	15.98-43.09 = 27.11	6.15	1.03	22.5
BCux	4	39.06	29.69-50.35 = 20.66	8.10	4.05	20.7

(1) Weight of all stones expressed as a percentage of the total weight of soil in equal volume samples; all Ah/E values are derived from volume samples taken in the field, but some B horizon values were derived from (equivalent volume) 'beakerful' samples (see text, section 3.3.2 and Appendix 2).

Table 3.7 Stone content of soil samples from zone C - B horizons [1]

North Field				North Lobe			
Horizon	n	$\bar{x}$	SD	Horizon	n	$\bar{x}$	SD
B_1	5	21.11	3.59	A/B or	4	23.37)	2.10)
					7	) 21.94	) 4.05
				B_1	3	20.04)	5.76)
B_2	6	21.56	4.30	B_2	4	30.36	7.96
$B_1 + B_2$	11	21.36	3.80	$A/B+B_1+B_2$	11	25.01	6.85
BCux	1	22.83	-	BCux	1	27.30	-
ALL B, A/B samples in zone C (excluding BCux)					22	23.18 [2]	5.72

Test for equality of variance of $B_1 + B_2$ samples (North Field group) and $A/B + B_1 + B_2$ samples (North Lobe group).

North Lobe $S_x^2 = 46.88$

North Field $S_y^2 = 14.45$

$$\frac{S_x^2}{S_y^2} = 3.245 \text{ with } 10, 10 \text{ df.}$$

$\therefore$ cannot reject null hypothesis of equal variance.

Test for equality of means of $B_1 + B_2$ samples (North Field Group) and $A/B + B_1 + B_2$ samples (North Lobe Group).

Student's t-test

t = 1.544 with 20 df.

$\therefore$ cannot reject null hypothesis of equal means.

(1) Weight of all stones expressed as a percentage of the total weight of soil.

(2) This mean value used in substitution for all individual sample data in zone C.

soil at any one location is not the individual sample value from that location but the mean value for the zone or sub-zone in which it lies. If this is correct, such mean values should be used in substitution for the individual sample values at least in the calculation of B horizon properties, where the distortion of volume estimates of soil chemical properties caused by unrepresentative sampling would otherwise be greatest, and this is the course that has, in general, been adopted in zone A and zone C. The individual Ah/E horizon sample values, however, were retained, not only because they were less likely to be unrepresentative, but also because there must be a possibility that the stone content of the upper mineral soil has been affected by land use (see 2.3.2.1) and to substitute a zonal value in this case would amount to denial of any such possibility. In the upper B horizon the sub-zonal values have been substituted, rather than the zonal value, since, in sub-zone A, low stone content in the Ah/E is matched by low stone content in the upper B horizon and this may not be coincidence. In all other sub-zones, upper B horizon mean values are so similar that it would matter little whether the zonal or sub-zonal values were employed in calculations. In the lower B horizon, where fewest samples were obtained and where the most serious distortion could occur, the zonal value has been used.

In zone C, where far fewer samples were available (Table 3.7), the trends apparent in the B horizons in zone A were far less evident and in this zone a single zonal value was substituted for all the individual B horizon sample values. Since there was a possibility that, in this case, even the B horizon stone content of the two sub-zones within zone C might differ as a result of land use practices (see 5.4.2), statistical tests of the differences in the variance and mean value of the samples from the sub-zones were performed. Since in neither case was it possible to reject a null hypothesis of equality, a single value based on the largest number of samples was used in calculations.

In other zones (zone B and the subsidiary sampling areas near the Stoke and Rowbrook farms), no substitution of values has been attempted. In these cases, either far fewer samples were available for estimating mean values and/or few of these were of the standard volume type recovered in the field zones A and C (see Appendix 2); moreover, in each of these areas, metapedogenetic distortions may be present (see 5.2.2.2 and 5.4.1) but could not be fully assessed.

The procedures adopted to deal with the difficult problem of obtaining a meaningful value for the stone fraction of the soil represent

Table 3.8 Particle size characteristics of soil samples from zone A and zone C (particle sizes in mm)

	% of fine earth (soil < 2.00) in size category indicated.						% of soil < 8.0	
	< 0.002	0.002/0.063	0.063/2.0 Hydrometer	0.063/0.25	0.25/0.5 Dry Sieving	0.5/2.0	2.0/8.00	
Oh	ND	ND	ND (1)	ND	ND	ND	ND	
AhE	2	33	65 (58)	14	10	34	11	Zone A
Bir	ND	ND	ND	ND	ND	ND	ND	Iron-pan
B_1	10	36	54 (50)	11	11	28	16	Stagnopodzol
B_2	8	38	54 (49)	12	11	26	19	(HM77F11 – sub-zone B)
BCux	3	27	70 (67)	13	12	42	37	
Oh	ND	ND	ND	ND	ND	ND	ND	
AhE	2	36	62 (55)	13	12	30	12	Zone A
Eg	5	45	50 (43)	12	8	23	11	Iron-pan
Bir	ND	ND	ND	ND	ND	ND	ND	Stagnopodzol
B_1	8	53	39 (40)	13	7	20	16	(HM77F5 – site F)
B_2	5	42	53 (47)	12	8	27	23	
BCux	3	32	65 (61)	15	12	34	26	
Oh	ND	ND	ND	ND	ND	ND	ND	Zone C
AhE	5	45	50 (45)	12	12	21	5	Iron-pan
Bir	ND	ND	ND	ND	ND	ND	ND	Stagnopodzol
B_1	13	34	53 (46)	10	12	24	15	(SP36 – North
B_2	10	50	40 (33)	7	8	18	20	Field)

(cont)

Table 3.8 (cont'd)

	% of fine earth (soil $<$ 2.00) in size category indicated.						% of soil $<$ 8.0	
	$<$0.002	0.002/0.063	0.063/2.0	0.063/0.25	0.25/0.5	0.5/2.0	2.0/8.00	
			Hydrometer		Dry Sieving			
Oh	ND	ND	ND	ND	ND	ND	ND	
AhE	7	40	53 (47)	12	13	22	10	Zone C
Bir	ND	ND	ND	ND	ND	ND	ND	Iron-Pan
B	13	45	42 (35)	8	9	18	19	Stagnopodzol
BCx	5	39	56 (52)	14	13	25	19	(GSP2 - North Field)
Ah_1	3	27	70 (64)	15	16	33	13	Zone C
Ah_2	3	28	69 (65)	13	15	37	13	Humic brown
B_1	8	38	54 (49)	11	13	25	15	podzolic soil
B_2	3	35	60 (57)	18	14	25	21	(SP32 North Lobe)
Ah	7	53	40 (2 8)	9	6	13	10	Zone C
AB	5	53	42 (35)	8	9	18	13	Humic brown
B	8	44	48 (43)	12	11	20	14	podzolic soil
BCx	8	40	52 (50)	15	12	23	19	(GSP3 - North Lobe)
Range	2-13	27-53	(28) 39-70 (67)	7-18	6-16	13-42	5-37	

(1) Figures in brackets represent Σ of sieved fractions.

a compromise; clearly they succeed in minimising the undesirable fluctuations caused by poor sampling, but, it must be admitted, that in doing this, they may seriously underestimate the 'true' variability of stone values in the B horizons. On the plus side, these procedures probably provide a far better estimate of the 'true' total stone content than other measures which could have been employed.

The particle size characteristics of the fine earth fraction itself were also analysed on a limited number of profiles including the buried palaeosols. The latter will be discussed below (see 5.?.1), but the data for other profiles are presented here (Table 3.8). These analyses do not reveal any information which was not already apparent from previous work on Dartmoor by the Soil Survey (for references see 3.2.1) and are only included here as an indication of the general nature of the soil's mineral fabric. These samples were treated with hydrogen peroxide (20%) to remove organic matter and with sodium hexametaphosphate to cause dissaggregation of fine particles; particle size was then determined using a standard hydrometer procedure. The principal characteristics shown by these analyses are: 1) the large contribution of coarse sand (generally 20 - 30%); 2) the small amount of clay-sized material (generally less than 10% - but note that it is not easy to remove all the organic matter from the organic-rich soils of Dartmoor and, in consequence, dissaggregation of small particles may have been less than totally successful, which would lead to underestimation of the clay fraction); 3) the substantial silt content (generally 30 - 45% and so usually larger than the coarse sand fraction), some of which may well be of aeolian origin. Profiles which may have had more than 60% silt in the Ah/E horizon were (infrequently) encountered during the field survey.

Chemical analysis

As indicated earlier, an attempt to find a rapid method capable of determining the total phosphorus content of soil samples from the study area was unsuccessful and so Pt has been determined only on a selected group of 60 samples. In searching for an alternative procedure several criteria were borne in mind. First, any method adopted should extract a high and predictable proportion of Pt; secondly, preferential consideration should be given to methods that extract chemically identifiable and/or ecologically significant P fractions and to those that have been extensively tested in the laboratory and/or have been widely used in pedological studies; thirdly, the method had to be rapid, relatively simple and demonstrably capable of identifying metapedogenetic alterations to P in the soils of the study area.

The soil fabric can be seriously attacked and much of the phosphorus released by any strong mineral acid or combination of acids and if the sample is pre-ignited most or all of the organic phosphorus can also be recovered during such extractions. Both the NaOBr oxidation and concentrated HCl extractions discussed above were of this type and all such procedures might well satisfy the first criterion. However, such methods do not allow the identification of any specific P fraction.

Fractional analysis using one of the several versions of the Chang and Jackson (1957) fractionation scheme was also considered, especially because the use of these procedures in archaeological studies of metapedogenesis was advocated by Eidt (1977), but was rejected here, primarily because of the lengthy processing that such fractional analyses involve. It would nevertheless have been advantageous to process a small number of samples in this manner, but this would have involved purchase of special equipment, whose very brief use could hardly justify the outlay. When considering the utility of fractionation schemes of this type, it was also borne in mind that essentially they monitor variation in inorganic phosphorus and provide no information about organic phosphorus (except that subtraction of the sum of inorganic fractions from Pt determined by fusion may be the most accurate way of determining Po - see Williams et al 1970), which dominates in the study area's soils. Nor do such methods necessarily provide as accurate a picture of the inorganic fractions as was once believed (there have been many critical studies of these schemes, e.g. Khin and Leeper (1960), Smith, A.N. (1969), Conesa (1969), Bromfield (1970)).

The method that has been adopted, which is one of the several ignition methods that have been developed for determining organic phosphorus by difference, is thought to fulfil all of the criteria outlined and, moreover, because it includes an ignition step, this method allows simultaneous measurement of the organic content of the sample. The method is essentially the same as that apparently first proposed and tested by Odynsky (1936) but used with modifications in many subsequent studies (e.g. Mattson et al 1950b, Saunders and Williams 1955, Williams et al 1960). In combination with determinations of Pt, the method provides the limited fractionation used by Floate (1962, 1965) and Walker (1965) during pedological enquiries that have been discussed in section 2.2.2.2. Evidence for its efficacy as an identifier of metapedogenetic alteration of soil phosphorus will be presented in section 5.2.2; evidence for the relationship between Pt and the P fractions determined by this method (details of analytical procedures appear in Appendix 3), will be considered in this section after it has been outlined and its limitations discussed.

Ignition methods for determining Po utilise acid extraction (in this study 2N H_2SO_4) of duplicate samples, one of which is ignited before extraction. The extra phosphorus extracted from the ignited sample is assumed to be Po. The methods thus involve the determination of two fractions - acid-soluble inorganic phosphorus (Pa) and acid-soluble phosphorus after ignition (Pao or Pa + Po). The difference between Pao and Pt indicates the magnitude of the residual Pf fraction which, from an ecological viewpoint, consists of relatively inert forms of phosphorus. There have been many reviews, studies and comparisons of the extraction and ignition methods for determining Po - see Commonwealth Agricultural Bureau S 1410R (1971) and, for aspects relevant to this particular method, see Saunders and Williams (1955), Dormaar and Webster (1964), McKercher and Anderson (1968), Williams et al (1970). No method provides an infallibly accurate measure of Po, though, as noted above, sequential fractionation combined with Pt determinations may provide values that closely approximate this ideal; however, such a procedure is far too lengthy for routine determinations. For highly-weathered soils, there is a strong case to be made for the employment of an extraction method, while on weakly-weathered post-glacial soils, the more rapid and simpler ignition methods may be as efficaceous. Both types of method were found wanting in studies at Rothamsted (Jenkinson 1971) and at present the station uses the mean value produced by an extraction method (Mehta et al 1954) and an ignition method (Saunders and Williams 1955), which is similar to that used in this study, for its estimations of Po (Chater and Mattingly 1980).

In soils of 'secondary weathering' (see 2.2.2.2) like those of the study area, it is possible that ignition methods over-estimate Po due to increases in the solubility of the inorganic phosphorus fractions during sample ignition (McKercher and Anderson 1968), but decreases in solubility have also been reported (Bornemisza and Igue 1967, Williams et al 1970). On the other hand, volatilisation losses are also possible (Dormaar and Webster 1964) and these would lead to under-estimation of Po. The data presented by Adams et al (1973:

Fig. 1), who studied the effect of variation in ignition temperature on the results of subsequent inorganic fractional analysis of a strongly-weathered granite soil, suggest that ignition temperatures substantially below 600° C may lead to incomplete mineralisation of Po, while Saunders and Williams' data (1955: Table 7) suggests that with mineral soils, volatilisation losses do not interfere at temperatures below 650° C. The pure peat samples (lacking sesquioxides and iron and aluminium phosphates) studied by Dormaar and Webster (1964), which suffered from some volatilisation loss at temperatures above 400° C, appear to be atypical. The temperature used in these studies (575° C) may therefore have affected the solubility of inorganic phosphorus but is not likely to have produced significant volatilisation losses. Only much more extensive testing of the method with samples from the study area could establish more precisely just how good an estimate of Po is provided by the ignition method used in this study and this could not be attempted in the time available. In many ways reliance on this procedure is analogous to reliance on LOI as an estimator of organic matter content; in both cases no satisfactory absolute standards are available and although one knows that some inaccuracy is almost certainly present, the employment of such methods for certain types of study (particularly those in which large numbers of samples must be examined) seems to be justified.

As noted above, total phosphorus was determined on 60 samples from the study area. One of these analyses has been discarded due to the over-large difference between duplicate analyses, but 59 are available for assessment of the relationship between Pt, Pao, Po, Pa and Pf. These samples were not selected randomly: 20 samples came from the two buried soils and their overburdens; 4 complete profiles in zone C were selected so that the differences between the soil in the western field of the North Lobe and adjacent areas in the North Field could be more rigorously assessed; and most of the rest of the samples were used to monitor Oh and Ah/E horizons in zone A, where virgin land could be compared with land enclosed by reaves and medieval boundaries. Pt analyses of samples from the palaeosols and zone C are considered separately and in detail later (see 5.2.1 and 5.4.2); however, it is useful at this stage to use some of these results to provide an overall picture of phosphorus patterns in the stagnopodzol soils that dominate the study area.

Figs. 3.22 and 3.23 illustrate the vertical distribution patterns of the various phosphorus fractions calculated in several different ways and are based on mean values for the horizons derived from between 2 and 11 samples of each horizon (buried soils, their overburdens and samples from the soil in the North Lobe have been excluded as atypical). Presentation of the concentration by weight (Fig. 3.22) shows that Pt, Po and Pao each exhibit a similar podzolic-type distribution with marked minima in the Ah/E and a less clear horizon of accumulation (B_1), which is largely accounted for by the Po fraction. The difficultly-soluble Pf fraction rises steadily with depth and has no minimum in the Ah/E; indeed, it is in this horizon that Pf accounts for the largest proportion of the inorganic phosphorus. In contrast, the readily-soluble Pa fraction is at its highest in the Oh horizon, falls to very low values in the Ah/E and rises only gradually to a secondary maxima in the basal, indurated horizon; there is little evidence of Pa accumulation in this composite profile, but the larger sample considered later demonstrates that this is not always the case. Calculation on a volume basis (Fig. 3.23) alters this picture in several ways. The apparent strength of phosphorus accumulation in the Oh horizon is much reduced and, although the values in the Ah/E and B_1 horizons still indicate loss and accumulation, the strength of this pattern is also much reduced. Both Pf and Pa reach their proportional and absolute maximum in the BCux horizon and the increase in Pa in this horizon and in the B_2 helps to maintain the value of Pao despite the falling value of Po. About half the phosphorus in the BCux is found in the Pf fraction, but this fraction only accounts for ca. 30% of the phosphorus in the overlying mineral horizons and 10 - 15% in the Oh, a three-fold division of the profile distribution, which was less apparent from the pattern of values for concentration by weight.

In assessing the extent to which Pao and its constituent fractions provide an adequate understanding of soil phosphorus in the study area, the levels and distribution of the residual Pf fraction are crucial. Fig. 3.24 shows the values of this fraction for all 59 samples in which it has been determined. Although, in some horizons, the number of samples is too low for statistical assessment, the substantial difference in the contribution of this fraction to Oh and BCux horizons and the intermediate quality of the other mineral horizons is apparent. However, the incidence of samples with 'high' Pf values (greater than 200 mg kg^{-1}Fe) is somewhat erratic and there is some indication of bimodality. Aside from samples from iron-pans, which have a modal value between 175 and 200 mg kg^{-1}Fe, there is a distinct lack of samples with values in this range from both Ah/E and

B horizons. It can be suggested that samples from the BCux and from B horizons in the North Lobe soil may have been drawn from a distinct population with a higher mean Pf value, a suggestion that will be considered below and in section 5.4.2.

Table 3.9 shows the values of Pt, Pao and Pf for samples from the most adequately sampled horizon, the Ah/E; it indicates that 'high' and 'low' Pf value samples are not found preferentially in any one zone or sub-zone and that, despite considerable variation between individual samples (particularly those with high Pt values), the amount of Pf (as a proportion of Pt) is similar in both high and low Pt 'groups' of samples. However, it is noteworthy that, if the three samples which contribute to the putative higher mode are ignored, the absolute amount of Pf in both high and low Pt groups is very similar; almost all the extra phosphorus in the high Pt group appearing in the Pao fraction. Pt/Pao relationships can be pursued further by means of scattergrams and regression analysis.

A scattergram (Fig. 3.25), which includes all samples together with the linear regression line they generate (regression equations and 'r' values for this and immediately following regressions are listed in Table 3.10), indicates that, taking the entire sample into account, there is a very strong positive correlation between Pt and Pao despite the erratic incidence of samples with exceptionally high Pf. The latter samples have been excluded (exclusions are listed in Table 3.10) from the two scattergrams (Figs. 3.26 and 3.27) which illustrate the relationships within individual horizons. Fig. 3.26 shows that, despite their considerable differences in Pf content, the groups of samples from the peat surface soil and from the ironpans generate regression lines with near identical slope values. Interestingly, these regression lines encompass all the samples shown in Fig. 3.27 ('A' and 'B' horizon samples), though the regression lines generated by the A and B horizon samples themselves have slightly different slope values. Correlations within individual horizons are statistically significant and remain so even if the excluded samples (which tend to alter slope values) are included (though in some such cases the 'r' values are only significant at the 0.01 level.

If the bimodality in Pf values evident in Fig. 3.24 is not merely a product of inadequate sampling or poor analysis, th n the central tendencies of the two populations may be correctly characterised in Fig. 3.28, where the regression lines of the set of excluded samples and a set comprising all the horizon groups (from which 'high'

Table 3.9 Pt, Pao and Pf (mg kg^{-1} Fe) in Ah/E samples from stagnopodzols on Holne Moor.

	Pt	Pao	Pf	$\frac{Pao}{Pt}$.100	Zone	Sub-zone	Comment
1	340	256	84	75.3	C		
2	355	186	169	52.4	A	FG	Virgin Land
3	360	269	91	74.7	C		Buried soil horizon
4	365	250	115	68.5	C		Buried soil (turf)
5	365	237	128	64.9	A	B	Overburden soil, house wall, site F.
6	365	189	176	51.8	A	FG	Virgin land
7	380	244	136	64.2	A	A	Reave field in medieval outfield
8	410	320	90	78.0	A	A	Reave field in medieval outfield
9	410	262	148	63.9	A	B	Reave field in medieval outfield
10	420	193	<u>227</u>	46.0	A	FG	Virgin land
11	460	353	107	76.7	C		Buried soil (redeposited)
12	470	260	<u>210</u>	55.3	C		
13	505	332	173	65.7	A	B	Adjacent to house wall, site F.
14	510	281	<u>229</u>	55.1	A	A	Reave field in medieval outfield.

(cont)

Table 3.9 (cont'd)

	Pt		Pao		Pf		$\frac{Pao}{Pt}.100$		
Group	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	n
1-7	361.4	12.1	233.0	32.6	128.4	35.4	64.5	9.5	7
8-14	455.0	42.9	2 85.9	54.3	169.1	56.5	63.0	11.8	7
D(1)	93.6		52.9		40.7				
1-6	358.3	9.3	231.2	35.4	127.2	38.6	64.6	10.4	6
7-9, 11, 13.	433.0	49.4	302.2	46.9	130.8	32.9	69.7	7.0	5
D(1)	74.7		71.0		3.6				

(1) D denotes difference between $\bar{x}$ of groups. The three 'high' Pf samples (underlined) have been excluded from the second statistical summary.

Table 3.10 Pt (x) and Pao (y) - linear regression equations and coefficients of correlation[1]

Group	n	y =	r[2]
1. All samples	59	1.024395x - 164.29299	0.9581
2. Oh + bOh-Ah	10	0.9841067x - 75.82244	0.9916
3. Ah, Ah/E, A/B	16	0.897414x - 88.999819	0.9550
4. Bir	6	0.9719928x - 160.09634	0.9943
5. Other B's	11	1.0882826x - 187.7152	0.9822
2-5	43	1.0547443x - 161.24551	0.9850
6. High Pf group incl. all BCux	12	1.0167544x - 246.39075	0.9798

(1) All values for variables used in these calculations were expressed as mg P kg^{-1}Fe.

(2) All correlations are statistically significant with $P < 0.001$ in all cases.

List of samples excluded from calculations for equations 2 - 5 in Table 3.10

A. 2 overburden (E horizon) samples and 2 buried (Ah horizon) samples beneath them.

B. 12 samples with > 200 mg Pf kg^{-1}Fe = 'High' Pf group.

Horizon	n	Pf values (mg Pf kg^{-1}Fe)	Comment
Oh	none		
AhE	3	227, 229, 210	—
Ah	1	205	North Lobe brown podzolic soil
A/B	1	202	North Lobe brown podzolic soil
B_1	none		
B_2	2	243, 227	North Lobe brown podzolic soil
Bir	1	299	Stone row P enriched sample
BCux	4	239, 231, 279, 250	All BCux samples

Pf samples have been excluded) are, for comparison, shown together. The slope values for these sets and the set of all samples are closely similar (Table 3.10).

A full interpretation of the patterns introduced here would be premature; several of the individual studies in Chapter 5 shed further light on Pt/Pao/Pf relationships, while these and other studies throughout the study area provide a very much larger sample of Pa and Po values that must be considered before the pattern of these fractions can be fully understood. At this stage one may, however, conclude that there is a sufficiently strong linkage between Pao and Pt to justify the view that variation in the former can be taken as evidence of variation in the latter and that, although individual samples do not always conform, when groups of samples are considered, one may be reasonably confident that reliance on Pao measurements will not mislead.

The highly significant correlation between Pao and Pt is largely due to the contribution of the Po component and this fraction is itself closely correlated with Pt in the sample as a whole and in all horizons except the BCux, where Po usually forms less than 25% of Pt. Fig. 3.29 illustrates this relationship and Table 3.11 shows the relevant regression equations. All samples are shown on the scattergram but, as in some of the previous calculations, samples with more than 200 mgPf kg^{-1} Fe have been ignored in calculations for the regression line. In addition, Bir samples, whose organic content varies far more than other sets of horizon samples due to variation in the depth of pan formation have been excluded, as have buried surface soil samples. The latter do not fall far from the main cluster of values and their inclusion would not have significantly affected the regression statistics, but their separation from the main cluster may well be 'real' and exist as a result of changes to the soil organic fraction caused by processes unique to the buried soil environment (see 5.2.1).

Although Po is the main component, the Pa fraction also contributes to the correlation between Pao and Pt and is itself significantly correlated with Pt (Table 3.12); in fact it is the only inorganic fraction that is closely linked with Pt and then only if the sample as a whole is considered. Calculation of the regression of Pa on Pt using sample sets from individual horizons showed that significant correlation of this fraction and Pt only occurred among the Ah samples and this correlation was only significant at the 0.05 level. Analogous calculations with the Pf fraction and with Pi, total inorganic phosphorus (Pt minus Po), showed no significant correlations, although as with Pa,

Table 3.11 Pt (x) and Po (y) - Linear regression equations and coefficients of correlation[1]

Group	n	y =	r[2]
1. Oh	8	1.0513x-287.7244	0.9762
2. Ah, A/B	7	0.7431x-84.0811	0.9914
3. Ah/E, BAh/E, E	13	0.7968x-73.7335	0.8435
4. Other B's	11	0.9073x-170.4643	0.9366
1 - 4	39	0.8233x-106.8351	0.9734
5. Bir	6	0.5105x-63.1558	0.9228

1. All values for variables used in these calculations were expressed as mgP kg^{-1}Fe.
2. All correlations are statistically significant with $P < 0.001$ in all equations except 5 where $P < 0.01$.

List of samples excluded from calculations for equations 1-4 in Table 3.11

A. Buried Samples

2 bOh-Ah samples excluded from (1).

2 bAh samples excluded from (2).

B. High Pf samples (see also Table 3.10, list of exclusions)

3 AhE samples excluded from (3)

2 B_2 samples excluded from (4)

1 Bir sample excluded from (5)

4 BCux samples excluded.

Table 3.12 Pt (x) and Pa, Pf or P i (y) – coefficients of correlation and determination for linear regression[1]

Sample Group	All samples		All samples excluding Oh and bOh-Ah samples		All samples excluding 'High' Pf group samples		All samples excluding Oh, bOh-Ah and 'High' Pf group samples	
n	59		49		47		37	
	r	CD	r	CD	r	CD	r	CD
Pt:Pf	–0.0794 NS	0.6	0.3252 ǂ	12.0	–.02281 NS	ND	0.2272 NS	ND
Pt:Pi	0.4157 ǂǂ	17.3	0.6113 ǂǂǂ	ND	0.5305 ǂǂǂ	ND	0.7050 ǂǂǂ	49.7
Pt:Pa	0.6610 ǂǂǂ	43.7	0.6737 ǂǂǂ	ND	0.7544 ǂǂǂ	ND	0.7697 ǂǂǂ	59.2

ND = Not calculated

Statistical significance

ǂǂǂ = $P < 0.001$

ǂǂ = $P < 0.01$

ǂ = $P < 0.05$

NS = Not statistically significant.

(1) All values for variables used in these calculations were expressed as mg P kg^{-1} Fe.

when larger sample sets are considered (Table 3.12) some correlation is apparent. Since Pf is very poorly linked to Pt, the significant correlation between Pi and Pt is largely a function of the contribution of the Pa fraction. These results are not unexpected; the inorganic phosphorus fractions form a relatively small proportion of Pt in all but the BCux horizon and there are too few samples from this level for meaningful statistical analysis.

As noted above, the chosen procedures for the determination of phosphorus fractions include an ignition step that allows measurement of the loss of weight from a sample due to ignition. In earlier discussion (see 2.2.3) it was suggested that, in these particular soils, estimations of organic matter content based on loss-on-ignition procedures provided an acceptable alternative to the more tedious and time-consuming methods involving the determination of organic carbon. Both high (850°C) and low (375°C) temperatures and varying duration (0.5 to 16 h) of ignition can be used to obtain useful estimates of organic matter content, though low temperatures minimise the interfering effect of carbonate and clay water losses (Ball 1964). Preliminary tests (see Appendix 3) demonstrated that ignition at temperatures above 400° C did not lead to any marked increase in LOI values in samples from Oh, Ah/E and Bs horizons and it was therefore concluded that the ignition step in the phosphorus extraction procedure (575° C for 2 h) was suitable for LOI estimation. This procedure is not merely convenient; it means that Pao and LOI are determined on the same sub-sample and therefore subsequent estimates of the concentration of P in the organic soil fraction are unaffected by differences that would arise from separate analyses of sub-samples.

An opportunity arose, at a later stage, to assess the relationship between these LOI estimates and total carbon and nitrogen measurements using, respectively, a high frequency induction furnace procedure and a slightly modified semi-micro Kjeldahl procedure. Beavis (M.Sc. Thesis 1981), who examined amino-acid patterns in samples supplied by this author, also determined total C and N as part of his investigation. Full details of this work appear in the cited thesis and are not discussed here. Fig. 3.30 demonstrates that the relationship between LOI and total C in these samples is similar to that observed by Ball (1964), who used a much larger sample to compare organic C (Tinsley's method) with low and high temperature LOI. Fig. 3.31 indicates a similar linkage between LOI and total N. Regression equations for these relationships are given in Table 3.13; the

Table 3.13 Loss-on-ignition (y), and carbon and nitrogen (x) - linear and non-linear regression equations and coefficients of correlation.[1]

Linear regression

Variables	n	y =	$r^{(2)}$
C : LOI	17	$2.5395x + 1.4600$	0.983
N : LOI	17	$47.4041x + 1.4544$	0.941

Semi-log regression (log loss-on-ignition)

Variables	n	y =	r
C : LOI	17	$(1.1534)(5.6652)^x$	0.981
N : LOI	17	$(16.2165)(5.4943)^x$	0.984

(1) Carbon and nitrogen determinations by Beavis (1981), LOI estimates by author; all values for variables used in these calculations were expressed as % of oven dry fine earth.

(2) All correlations are statistically significant with $P < 0.001$ in all cases.

correlations are highly significant despite the small number of samples and one is entitled to conclude that, in these soils, the organic matter estimates based on LOI are not substantially different from those that could be derived from C and N measurements. The significance of the predicted weight loss of just under 1.5% in samples with nil carbon is discussed later in this section.

During the first season's fieldwork, soil acidity was estimated by means of a portable pH meter at each of the large soil pits (see Fig. 3.32). Although these measurements provided a useful indication of the strongly acid character of all the soil types encountered in zone C and the sub-zones of zone A, the minimal variation in pH from zone to zone, even among soils exhibiting large morphological differences (zone C - see 4.2 and 5.4.2), convinced the author that, as expected, measurement of soil pH in the field or laboratory would not prove in general to be a useful tool in this type of investigation. In consequence, systematic, routine analysis of this soil property was not undertaken. However, it was thought to be a valuable characteristic to record during assessments of modern, limed fields (see 5.2.2.2) and buried palaeosols (see 5.2.1) and in these cases soil pH was determined. These analyses were performed in the laboratory and thus benefited from more precise determination of soil and water quantities, but, it must be noted, the use of oven-dried samples of fine earth (unground) in these studies led to a substantial depression of pH, particularly in samples from surface or near-surface soils; these analyses are not therefore comparable with those shown in Fig. 3.32. As was the case with particle size measurements, the pH analyses shown in Fig. 3.32 do not reveal any information that was not already apparent from previous studies of Dartmoor's soils by the Soil Survey of England and Wales.

Calculation and expression of results

Laboratory evaluation of the quantity of solid materials typically involves measurement of mass, since this property can be very easily, accurately and rapidly measured. In consequence, the initial, 'laboratory' values for soil variables must usually be expressed in terms of weight, either concentration by weight (e.g. mg kg^{-1}) or absolute weight in an entire sample. In soil chemical analysis, it is also customary to evaluate the composition of the fine earth fraction rather than the soil as a whole and therefore the results of most analyses must initially be expressed in terms of fine earth (e.g. mg kg^{-1}Fe). However, if, as in this study, the thickness, soil bulk density and stone content of a horizon have been measured, it is also possible and often more appropriate and informative to express the results of chemical and physical analyses on a volume basis. Two formulations are commonly used; the first provides an estimate of the weight of an element in a specific horizon or to a specific soil depth per unit area (e.g. kg ha^{-1} in plough soil or g m^{-2} in profile to sampled depth), while the other ignores the thickness of horizons and simply expresses the weight of an element per unit volume of soil (e.g. μg cm^{-3}Soil) - usually within a single horizon.

Unless the elemental composition of stones has been determined, neither of these formulations are strictly correct; in both cases, one is actually calculating the weight of the element <u>in the fine earth fraction</u> within a specified soil volume and it is in this sense that these formulations are used here. It must also be noted that in this study the calculation of the weight of an element in a single horizon (all calculation formulae are given in Appendix 4) is accomplished by simple multiplication of the concentration of the element (mg kg^{-1}Fe) by the weight of fine earth per unit volume (g cm^{-3}Soil) and by the thickness (cm) of the horizon. Profile weights represent the sum of several such calculations. The point is laboured since this practice differs from that of some researchers (e.g. Floate 1962), who have chosen to calculate profile weight of elements using a definition of 'bulk density' that excludes the <u>volume</u> of stones within volume soil samples. This procedure raises the apparent values for profile weights or concentrations by volume <u>of soil</u>, and the latter, as used, for example, by Harrison (1979) appear to be, strictly speaking, estimates of the weight of an element within <u>a</u> volume of fine earth (which varies with stone content) rather than per <u>unit</u> volume of soil as labelled in the article cited. This may well be a useful measure in ecological studies but is not used here.

Each of the volume basis formulations described above serve to overcome the problems posed by differences in soil density; concentration by volume is unaffected by small, perhaps insignificant, variations in soil horizon thickness and is a useful measure for inter- and intra-profile <u>horizon</u> comparisons, whereas estimates of total weight of an element to a standard profile depth are useful for <u>profile</u> comparisons. However, even equal volume comparisons between profiles may not always represent the best approach; when differences in the overall density of profiles exist (for example, where unequal accumulation of soil organic matter has led to differences in the amount of soil expansion), comparisons using the weight of ignited fine earth as a base (e.g. mg kg^{-1}IFe) may be more useful (see Jenkinson 1971) and can be calculated using the loss-on-ignition values recorded for estimating soil organic matter levels.

The fraction lost on ignition may itself serve as a base in some calculations; in this study, where carbon has not been measured, the most commonly used measure of the changing proportion of Po in the soil organic matter, the C:Po ratio, cannot be used. Instead, the weight of Po per unit weight lost on ignition has been used to assess such changes (mg Po kg^{-1}LOI) and the relationship between this measure and the C:Po ratio is shown in Fig. 3.33, where the C:Po ratios are based on Beavis' (1981) carbon estimates and this author's Po estimates. At first sight a linear relationship seems plausible, but further examination of the pattern within individual stagnopodzol profiles (Fig. 3.34) suggests that a curvilinear relationship may in fact be present. As C:Po ratios fall to low levels in B horizons a disproportionate rise in the apparent weight of Po per unit LOI occurs and, in contrast, as C:Po ratios rise to very high levels in the surface horizons, the corresponding fall in Po per unit LOI is less than proportional to the rise in the C:Po ratio. Fig. 3.35 shows linear and non-linear (C:Po ratio expressed as a reciprocal) regression lines for the stagnopodzol sample set; both regressions are highly significant. The brown podzolic soil samples do not copy the relatively simple pattern of inter-horizon variation evident in the stagnopodzols, but the relationship between C:Po ratio and the weight of Po per unit LOI in these samples is much the same.

It would be premature to evaluate the pattern of Po in the organic matter of the Holne Moor soils before considering the much larger samples discussed in Chapter 5, but it is necessary to consider briefly why the relationship between these two methods for evaluating the changes in the concentration of Po in the organic matter, perhaps, neither linear, nor as tight as one might have expected. In the first place, one has to recognise that by combining three measurements, one of which (Po) is itself derived from two other measurements (Pao and Pa) and thus particularly prone to analytical error, the level of uncertainty in the values used is substantially higher than the level of uncertainty for any one of these measurements. Nor is there any reason to think that changes in either carbon or LOI values accurately reflect the 'real' changes in the organic matter content of soil samples since the carbon content of organic matter varies and the loss of weight during ignition can include loss from components other than organic matter (Ball 1964, Howard 1966).

The linear regressions of LOI on C and N suggest that a sample with nil organic matter might nevertheless show a weight loss of just under 1.5% (see Figs. 3.30 and 3.31 and Table 3.13). This may be taken as an indication of the extent to which LOI values overestimate the organic matter content of samples; it implies that the values for the apparent concentration of Po in the organic matter estimated as mg Po kg^{-1} LOI will generally be lower than the 'true' values. However, unless LOI values overestimate organic matter content more substantially at one or both of the extremes than in the central range of values, the imperfections of LOI alone cannot be held responsible for the departure from linearity seen in Fig. 3.34. In fact, Howard's (1966) studies do suggest that LOI values for the organic-rich Oh and Ah/E horizon samples could be less seriously affected by LOI 'error' than the values for B horizon samples, where losses of 'bound' water probably form a higher proportion of total weight losses. Adjustment of sample values to allow for this would, however, increase the departure from linearity, since Po per unit 'adjusted LOI' values in B horizon samples would increase more, proportionately, than the values for surface samples.

Like C:N ratios, C:Po ratios narrow with depth in stagnopodzols (see 2.2.2.2), but, since the proportion of C in the organic matter may rise with depth in 'mor' soils (see Howard 1966: Table 3), the decline in the C:Po ratio may not be proportional to the increase in the concentration of Po in the soil organic matter as a whole; if C values could be 'adjusted' such that they provided a constant proportion of the organic matter, C:Po ratios in the B horizon would be even lower, thus reducing the curvilinear element in Fig. 3.34.

It is also possible that Po values (kg mg^{-1}Fe) for, in particular, B horizon samples have been inflated by increases in the solubility of Pi during the ignition of samples; this, of course, will not affect the relationship between the two methods for estimating changes in the concentration of Po in the organic matter, but it would lead to overestimation of the concentration of Po in both cases. One may conclude by noting that the methods used in this study may overestimate Po, particularly in B horizon samples, but that the effect of this on the estimated concentrations of Po in the organic matter expressed as mg Po kg^{-1}LOI will to an unknown extent be offset by the overestimation of organic matter due to 'error' in the LOI values for the same samples. In consequence, the overall pattern of change from horizon to horizon may not be seriously distorted. The failure of this method of calculation to produce values that exhibit a close linear correlation with C:Po ratio values probably reflects real differences in the decline with depth of the values of the individual elements present in the organic matter and does not, necessarily, indicate that the method provides a less valuable measure than the C:Po ratio.

In presenting the results of chemical analyses in graphs, bar charts, histograms and scattergrams, all of the calculation bases discussed - weight, volume, ignited fine earth and the LOI fraction have been utilised on one occasion or another; for the most part, a volume basis has been adopted and so large fractions (e.g. LOI) are expressed as mg cm^{-3} or kg m^{-2} and smaller fractions (e.g. P) as ug cm^{-3} or g m^{-2}. In calculating the latter for profiles as a whole, the changes to sampling procedure after the first season and the failure to adopt a standard metrical depth during that season's sampling has made it necessary to depart from a strict adherence to normal methods of calculation in some instances. In general, the calculations assume that all sampling has been carried out to a precise depth of 40 cm below the mineral soil surface (as indeed occurred in the second and third season's work), but in fact, as noted above, during the first season, samples of the lower B horizon were taken, where possible, from the full depth of the horizon and in quite a number of cases this exceeded 40 cm. However, in some profiles the BCux, which is practically impenetrable in small exposures, lay at less than 40 cm and in some instances (in all three seasons) stoniness in the lower B horizon precluded sampling to its full depth and/or to the standard depth of 40 cm.

The standard depth of 40 cm was adopted, both for later sampling and in calculations, for two reasons. First, it lay close to the modal depth that had been sampled during the first season; secondly, it normally would include a very large proportion of the lower B horizon, but exclude the last, most stony, few centimetres and was thus a practical sampling proposition. The effect of calculating to a standard depth when samples may have exceeded or not reached that depth is not thought to have led to any serious distortion of the data. In zone C it was possible to compare similarly-sized data sets from the first and second season's sampling and this exercise (see Appendix 5) supports this view. In so far as some distortion must be present, it should be noted that no one zone or sub-zone suffers significantly worse than another, since the profiles affected are found in all zones, and the principle result of this 'data adjustment' may well have been a general increase in the apparent variability of some soil fractions.

Some fractions will have been affected more than others; the main changes which occur in the lower B horizon and affect these analyses are a reduction in organic content and an increase in acid-soluble phosphorus. Thus, the inclusion of a sample which reached below 40 cm may have led to slight underestimation of Po and LOI and slight overestimation of Pa, while shallow sampling will have had an opposite effect. The Pao fraction and, where known, Pt, which change relatively little within the lower B horizon, will have been least affected. When considering the import of such adjustments, it must also be borne in mind that in most cases, the difference between true and calculated sampling depth is only a few centimetres and that since this adjustment has been made on only one of the four or five sampled horizons, which must be summed to produce values for 'whole' profiles, the nett under- or overestimation will be a very small proportion of the total value. In some cases, but for quite different reasons, the figures for the thickness of peat horizons have also been adjusted, but these changes will be discussed at a later stage (see 5.4.3).

Uncertainty, sampling, probability and error

The relationship between the composition of soils and the values recorded for specific soil properties after laboratory analyses of samples from them is affected by many factors: simple mistakes (misread instruments, faulty computation); analytical error (imprecision of instruments and methods of analysis) and, more important than either of these, the difficulty of obtaining a truly representative sample of a soil.

The nature of the sampling problem can be illustrated by the data in Table 3.14, where the results of analyses from 11 samples from a single soil profile appear. In some respects this profile represents a 'worst-case' situation since sizeable morphological variation matched by apparently congruent chemical variation occurs in each of the three upper horizons and, although many of the profiles sampled

Table 3.14 Phosphorus and loss-on-ignition analyses of samples from profile GSP6 (zone A - sub-zone E)(1)

Samples	Sample depths (cm)	LOI (%)	Po	Pa	Pao	Pao	Po	Po
			mg kg^{-1} Fe			$mgkg^{-1}$ IFe	$mgkg^{-1}$ LOI	$\frac{Po}{Pao}$.100
Oh (excluding mineral lense)	+9 to 0	31.4	365	103	468	682	1162	78
Oh - mineral lense	+5 to +2	13.4	206	44	250	289	1537	82
Ah/E (including 'E' mottles)	0 to 7, 8, 14	6.6	154	14	168	180	2333	92
E mottles, in places a layer at base of Ah/E	7 to 13 (maximum)	4.6	122	10	132	138	2681	92
Bhs (where iron-pan absent)	8 to 22	12.9	356	178	534	613	2760	67
Bh (above iron-pan)	14 to 20, 26	13.7	484	44	528	612	3533	92
Iron-pan	at 20, 26	21.1	405	358	763	967	1919	53
Bs (below iron-pan)	20, 26 to 29	10.7	339	242	581	651	3168	58
B_2 (below iron-pan)	29 to 48	4.7	183	131	314	329	3894	58
B_2 (where iron-pan absent)	22 to 35	6.4	245	158	403	431	3828	61
BCux (sampled 48-61 cm)	35, 48 +	3.6	112	138	250	259	3111	45

(1) Note that this profile used to illustrate variability in samples from a single soil exposure is not typical of its zone or sub-zone; it passesses unusually low surface, and high subsurface values.

included at least one of the morphological variants illustrated here (and/or others not shown here), relatively few had such a combination of features. The chemical variation in the lower B horizon was not matched by clear morphological variation; two samples were taken from this horizon in order to test the proposition that its properties might have been affected by the partial development of an overlying iron-pan. A similar profile was sampled in zone C and, in that case also, a sample from the B_2 below an iron-pan had a lower LOI value than an adjacent sample not overlain by a pan. The small 'data adjustment' applied to this horizon in some profiles fades into insignificance as a source of 'error' beside such 'invisible' chemical variation.

The data in Table 3.14 monitor two scales of variability within a very small area, micro-variability within horizons and macro-variability between horizons. In the context of assessment of chemical variation in larger areas, the profile measurements may be envisaged as point estimates, which must be repeated at several locations to establish the extent of variability at a third and larger scale. The general approach to field sampling has already been discussed, but the author's sampling policy with respect to visible micro-variability must be outlined. In general, any continuous layer, visible in the field, was sampled as a separate unit, whereas an attempt was made to incorporate a representative portion of any discontinuous features, such as mottles, within the general sample of the horizon in which they featured. Exceptionally, mineral lenses within the Oh horizon (as opposed to the more generally incorporated mineral component) were avoided during sampling; such features were only common in one or two areas (see Chapter 4).

Usually this policy was not difficult to follow consistently but borderline cases did occur; when E, Eg or Bh 'mottles' at the base of the Ah/E horizon were so strongly developed that they constituted a layer across more than half the four 'faces' of the soil pit, they were treated as a separate layer. The typically discontinuous iron-pans were treated in a similar fashion. If a pan was sampled, then other samples from the B horizons were extracted above and below those portions of the profile in which the pan was present.

In addition to the uncertainty about the significance of values that arises from the need to sample structured, heterogenous materials, an uncertainty which can be expressed as a statistical probability, one must also consider the uncertainty produced by analytical error and simple mistakes. There is no way of estimating the probability of mistakes in calculation, misreading of instruments and so on, but it is not difficult to spot any large errors of this type and such cases will almost certainly have been noticed and the necessary computational or analytical procedures repeated. When, as in these studies, samples of similar character (i.e. from the same soil horizon) are analysed in the same batches, grossly inconsistent or atypical values are immediately apparent. Comparisons can also be made with adjacent samples from the same profile, which in most cases will have been analysed in two other batches. Computation, which was all performed on a programmable hand calculator, can and did include 'self-checking' routines. Although some mistakes may, and considering the amount of computation perhaps must, have gone unnoticed, the low magnitude that will have made them 'invisible' ensures that their correction would be unlikely to affect conclusions reached as a result of the original computations.

Usually analytical error is reduced to a minimum by routine analysis of replicates. With so many samples, this course was impractical, but sufficient replicates were run to allow the imprecision of instruments and methods to be evaluated (see Appendix 5). The level of precision is high enough to justify the view that most of the apparent difference between samples from different horizons and profiles arises from the heterogeneity of the sampled material and only a small proportion can be attributed to analytical error.

4. THE SOILS AND VEGETATION OF HOLNE MOOR - THE FIELD SURVEY

'COINCIDENCE You weren't paying attention to the other half of what was going on. - The Hipcrime Vocab by Chad. C. Mulligan.' (Brunner 1978:39).

4.1 Introduction

Information about the vegetation and field characteristics of soil profiles was gathered, using the techniques described earlier (see 3.3.1 and Appendix 1), throughout the 120 ha study area with several purposes in mind. First, such observations would assist in the selection of suitable areas for intensive study - the smaller zones and subzones, which would be intensively sampled for chemical analysis - and, when summarised, would provide evidence of general characteristics and patterns against which one could judge the significance of variations in soil and vegetation within such smaller areas. Secondly, the observations would be used in the preparation of large-scale soil and vegetation maps which would be needed for assessments of the way in which the distribution of vegetation and soil morphological characteristics related to land units defined by boundaries of various ages. This chapter reports the results of this extensive survey in two parts which reflect these purposes. In the first part, the soils are described and classified, and soil distribution maps are presented. In the second part, the relationship between soil and medieval land use is described and discussed. A concluding section offers some observations and speculations concerning the linkage between soils, vegetation and land use.

4.2 Soil description, classification and distribution

With a minor but interesting exception, all the soils in the study area exhibit characteristics fully in accord with those described in previous studies of Dartmoor soils and may be encompassed, from the point of view of general soil classification, within the spectrum of soil variation spanned by the variants described and discussed earlier (see 3.2.1 and Fig. 3.3). The dominant soils of all parts of the study area lying outside the Lobes and smaller medieval enclosures are Stagnopodzols of the Hexworthy and Rough Tor Series; within the enclosures most soils are of podzol or podzolic type and include examples similar to the Moorgate Series, the Moretonhampstead Series and the Ferri-humic podzol described at North Bovey.

In this section, the principal characteristics of the horizons found in these soils will be briefly described; subsequently, a subjective classification of the variants seen in the study area will be introduced; finally, the distribution of soil map units will be introduced and discussed.

4.2.1 Soil description

Many of the morphological characteristics visible in the subsoil horizons are common to both Stagnopodzols and Brown podzolic soils throughout the study area; in contrast, near-surface and surface soil types tend to have a more restricted spatial distribution. It is, therefore, convenient to consider these groups of soils in separate discussions. The terminology, format and vocabulary used in these descriptions follows those recommended by the Soil Survey of England and Wales (Hodgson 1976).

4.2.1.1 Sub-soils

None of the soils observed in the study contained a horizon so little altered by soil processes that it could be designated a C horizon and, in view of the non-sedentary origin of the materials in which Dartmoor's soils have developed (see 3.2.1), it can also be doubted whether the deepest horizon generally recognised (BC or BCux) necessarily provides a true analogue for the parent material of the overlying horizons. At a depth of between 30 to 80 cms (but usually about 45 to 50 cm) below the mineral soil surface, a very marked increase in stone content occurs over a span of a few centimetres, a point of change often but not always accompanied by changes in structure, fine earth texture, deposition of translocated materials and colour. It would be difficult and tedious to prove, but the author suspects that whereas the stones in the immediately overlying B horizons may provide between 25 and 45% of the soil weight, this percentage may rise to over 75 in the BCux horizon, a difference which seems unlikely to reflect differences in soil weathering since the solifluction sheet achieved stability.

BCux horizon

Brown to yellowish brown (7.5 - 10 YR 5/4) gravelly sandy loam or loamy sand (abundant coarse sand); very to extremely stony with very small to large sub-angular and angular granite fragments; moderately to strongly developed, medium to coarse platy (slightly lenticular) ped structures (firm but brittle); 0.5 - 2% very fine macropores; very rare, very fine roots in shallower examples.

This horizon has only been adequately observed in the 18 larger soil pits, but in each case the visible characteristics were closely similar and it seems that this horizon is very homogenous throughout the study area and its close environs. In some pits, stones become abundant or extremely abundant a few centimetres above the point at which platy structure becomes evident, but, in most cases, these changes coincide. This indurated horizon sometimes contains manganese accumulations (rare), often has silt (with some clay) coatings on stones and peds (frequently most prominent on their lower sides) and ubiquitously provides evidence of iron deposition in the form of fine to medium, distinct, clear, common, yellowish red (5 YR 5/8) to dark red (2.5 YR 3/6) mottles or a similarly coloured often well-developed 2 - 4 mm very hard iron-pan. In a few profiles, this 'basal' iron-pan is physically continuous with pans at higher levels in the soil, but this seems to be rare. Where a basal pan is present as a carpet over the indurated horizon, the latter is often darker and redder in colour (7.5 YR 4/4) over the first 2 - 5 cm immediately below the pan.

Lower B horizon - Bs, Bs_2, B(g) - Typical thickness 12 - 20 cm

Most commonly brown (7.5 YR 4/4) but also yellowish brown (10 YR 5/4) and, more rarely, strong brown (7.5 YR 4/6) sandy silt loam or sandy loam; moderately or very stony with very small to large sub-angular granite fragments; weakly-developed coarse compound sub-angular blocks with moderately-developed fine to medium sub-angular blocky ped structures (weak); 0.5 - 2% fine and very fine macropores; few, very fine and fine roots only.

This horizon has been observed in several hundreds of profiles and like the BCux is in general remarkably similar over wide areas. Clear evidence of coatings (cutans) occurs very rarely, and in most such cases consists of a very thin, dark brown (5 - 7.5 YR 3/2) or black (5 YR 2.5/1) coating along a limited number of vertical fissures. In a very few instances clay-silt coatings occur towards the base of the horizon and equally infrequently one encounters an iron-pan. The most important variations in this horizon indicate differences in the amount of organic matter - coarse, distinct, diffuse, dark brown (7.5 YR 3/2-4) mottles (referred to here as 'organic mottles'), which may be few, common or many (but the latter is rare) - or differences in the incidence of signs of seasonal water-logging or weak gleying. No strongly gleyed horizons were observed in the study area, but they may be presumed to be present beneath deep (0.3 - 1.0 m) peats which are found in shallow valleys in two parts of the study area. The signs taken to indicate weak gleying include fine to medium, distinct and sometimes prominent, clear or sharp, strong brown (7.5 YR 4-5/6) or even yellowish red (5 YR 5/8) mottles and a tendency for more yellow (10 YR) or greyer and lighter matrix colours (10 YR 4/2-3). Variation of this type produces profiles in which the lower (and sometimes also the upper) B horizon may be dominated by lighter 'gley' colours with darker and redder mottles (relatively strong gleying) and, at the other extreme, profiles dominated by the darker, brown colours in which lighter 'gley' mottles occur (relatively weak gleying). Although organic mottles are often seen in profiles without signs of gleying, they appear to be most common in the profiles showing the strongest signs of seasonal water-logging. When a basal iron-pan is present, signs of gleying are often found in the first few centimetres of soil above the pan, even though the rest of the lower B horizon appears to be free-draining.

Upper B horizon - Bs, Bh, Bhs, B(g), Bir - Typical thickness 12-18 cm

The upper part of the B horizon shows far greater variety of form than the horizons below but frequently includes many of the elements that occur in the lower B horizon; indeed in a number of profiles, particularly the more strongly gleyed ones, there is little justification for division on the basis of field characteristics. In general, however, the yellower colours (10 YR) are rarer and many profiles have darker upper B horizons. What occurs as a patchy organic mottle in the lower B horizon is found as a dominant matrix colour (7.5 YR 3/4), intermixed with coarse, distinct, diffuse brown (7.5 YR 4/4 - frequent) or strong brown (7.5 YR 4-5/6 - rarer) mottles. As in the lower horizon, mottle colours and dominant matrix colours may be reversed.

Usually the upper B horizon consists of sandy silt loam (but less silty, more clay-rich examples occur) and is moderately stony (though it can be slightly stony or very stony) with mainly very small to medium sub-angular granite fragments; weakly-developed compound coarse sub-angular blocks and moderately-developed fine to medium sub-angular blocky ped structures (weak); 0.5 - 2% very fine macropores only; where a pan is absent, very fine and fine roots can be common but there are few medium or coarse roots.

One of the most distinctive characteristics of the upper B horizon is its 'speckled' appearance caused by the presence of common or few, strong brown to reddish yellow (5 - 7.5 YR 5 - 6/8), very fine to medium, distinct or prominent, clear mottles. In many cases, but not all, these mottles appear to be centred on disintegrating granite fragments; they occur also in the basal portion of the overlying Ah/E horizon or E horizon (but only much more rarely) and in the lower B horizon, where, in profiles with signs of gleying, they can be as common in the lower as in the upper B horizon. Where other evidence of seasonal water-logging is absent, speckling is more rarely encountered. The partial association of these mottles with weathering granite suggests that, at least in part, these iron concentrations may represent very localised redistribution of iron, but these centres may also act as a focus of deposition for iron moving more generally in the soil water. Speckling appears to be most common in the zones between the plateau flats (where many profiles show signs of sub-soil gleying) and the lower slopes (where iron-pans are common and the sub-soils are free-draining). In this intermediate zone, iron-pans are seen infrequently (and are usually poorly-developed) and although speckling and iron-panning are not mutually exclusive, they do appear to some extent to represent alternative modes of iron accumulation. Rudeforth (1963: 22 and Fig. 1) observed similar mottling in analogous landscape positions in stagnopodzols in Mid-Wales and it does seem that speckling of this type is strongly associated with intermittent water-logging. Since speckling seems to be most abundant not where water-logging conditions occur over prolonged periods but at the fringes of such areas, this particular process of iron redistribution may be linked, perhaps, to more frequent and higher amplitude fluctuations of the redox potential in such areas.

An upper B horizon zone with characteristics of the type described above occurs in the majority of profiles. In many profiles, however, additional features are present, which in some cases require one to recognise a sub-division of the upper B horizon. The presence of iron-pans has already been noted; in all but a very small number of cases, a pan, if present, is located at the boundary between the Ah/E or E horizon and the upper B horizon. Typically the pans do not vary very substantially in depth or thread their way through the B horizons. They exhibit wide differences in their degree of development, varying from very hard pans similar to the basal pan described above, which are never more than a few millimetres thick, to softer, more diffuse zones, which may be up to 2 cm thick. Both 'types' and all intermediate examples act as a barrier to water and roots, though, as one would expect, the diffuse pans are least effective; they are also least common. The most common type is a dusky red (2.5 YR 2.5/2 - upper half) to darkred (2.5 YR 3-4/6 - lower half) pan of 1 - 3 mm, which in a few places may be hard (and in these instances is dark but iridescent) but is mainly very soft (these are referred to here as 'incipient' pans). On occasion, circular pockets and tubes (some of which may be old root channels - see below) may be surrounded by pans, but such features are not common.

Several of the generalisations made above do not seem to apply to pan development on an archaeological site within zone A (site F). Although pans are infrequent in the surrounding prehistoric fields (but speckling is common), a fairly continuous, well-developed pan occurs across the area which lies between two prehistoric houses. In this area, the pan is, in places, connected to a basal pan and this occurs both in areas where the BCux and basal pan are at an unusually shallow depth and in other places where the soil depth is greater. Fairhurst and Taylor (1970 - 1971) also noted differences in pan development on an archaeological site (in their case, within a house) and, although the variability in pan development is so great that the pattern on site F could simply reflect an unusual (for its area) but natural phenomenon, it is also possible that especially strong pan development has occurred as a result of the special land use in this area.

Like the basal pan, these 'upper' pans are sometimes accompanied by changes in a thin zone below the pan. With the upper pan, this takes the form of a diffuse strong brown (7.5 YR 4-5/6) or even yellowish red (5 YR 5/8) zone of intense iron accumulation, which is rarely more than 5 cm thick. Again, Rudeforth (1963:22 and Fig. 2) also noted the intermittent nature of such diffuse zones below pans; in some areas, he was able to discern a relationship between its presence and landform. No such correlation was observed in the study area, where, in any case, this feature was rather rare.

Another important feature, which is found at the boundary of the B and Ah/E or Eg horizons in some profiles is a thin, highly-developed Bh. Many profiles contain more organic matter in the upper B horizon than in the immediately overlying horizon, but in some cases, the differences are far more marked. This tends to occur in two situations; first, it sometimes occurs where an iron-pan is present (though if the pan is well-developed, a thin Eg is more commonly encountered immediately above); secondly, it often accompanies the weakly-gleyed B horizons of profiles on the plateau flats and is also found sporadically in profiles on the fringes of the flatter areas that show no signs of poor drainage. In the case of the apparently 'iron-pan induced' Bh, the layer is rarely thicker than 5 cm and when thinner and less-developed is not easily distinguished from the overlying Ah/E horizon. The colour of ignited samples suggests that in some instances iron may also be accumulating in this layer, but this seems to be atypical. Whereas this type of Bh is only an infrequent accompaniment to an iron-pan, it is usually found at the top of the weakly-gleyed, plateau flat B horizons and often attains a thickness of 5-10 cm in these circumstances. Here too, it is not always easy to distinguish from the overlying Ah/E, but its higher organic content can be 'felt' during 'hand-texturing' in the field and it is often slightly redder (5 YR 3/3) than the Ah/E horizon.

Two other features deserve mention at this juncture; the first have been dubbed 'old root channels' by this author, although it is recognised that their origin is obscure. This term has been applied to tubular channels with diameters of 2-5 cm, which occur in both upper and lower B horizons. Although they are usually partially infilled by dark reddish brown soil (5 YR 3/2) with an appearance and texture similar to that of the Bh horizons discussed above, a large proportion of the channel space remains empty. In a few cases, iron appears to have accumulated on their walls. Unfortunately, variation in their frequency of occurrence across the study area cannot be properly judged from the information gathered by the author; only the 18 larger pits provide a sufficient exposure of the B horizon for this purpose. They were not present in all such pits.

The second feature of note has been dubbed the 'grey stone' phenomenon; usually restricted to depths elsewhere occupied by upper B horizon features (but occasionally found in Ah/E and lower B horizons), this phenomenon consists of pockets and zones, sometimes amounting to whole horizons (as defined earlier for the purposes of sampling; see 3.3.2) in which large and very large, usually soft but intact rock fragments of grey appearance are embedded in a thoroughly leached grey to greyish brown (10 YR 5/1-3) matrix. In most cases the matrix does not extend far from the rock fragments but merely surrounds them with a halo. Sometimes these zones are found beneath iron-pans but in no case has an iron-pan or strong iron accumulation been observed below such a zone. The texture of the matrix is gritty, with much sand (usually coarse) and very little clay. Although in certain respects these zones exhibit features similar to those found in the classic E horizons of podzols, this phenomenon should not, in the author's opinion, simply be seen as evidence of patchy development of this type. E and Eg horizons and mottling are encountered in the study area (see 4.2.1.2) but differ from grey stone zones in several respects. The latter occur infrequently and very sporadically (never recorded in two adjacent sampling points), whereas the former are common in specific landscape segments; in most cases grey stone zones take the form of an abnormal pocket in an otherwise 'normal' profile, while E features, even when they are so little-developed that they do not amount to a horizon, tend to appear intermittently across all the faces of a soil pit. Moreover, Eg horizons are invariably found at a single level in the soil (base of Ah/E, usually above an iron-pan) whereas grey stone zones occur at a variety of depths. Finally, the peculiar weathering that has produced soft rock fragments has not been seen in E or Eg horizons.

The author suspects that textural variation in the parent material may be responsible for these zones of high leaching and severe weathering; perhaps these zones are residua of rare inclusions of more severely pre-weathered material within the solifluction sheet; if so, they constitute the only evidence that this has occurred.

Before considering the characteristics of the surface and near-surface soils, where the division between Stagnopodzols and other soils is clearly apparent one must consider the extent to which such divisions are evident in the sub-soils. The limited variation in the field characteristics of the BCux and lower B horizon does not appear to bear any relation to the differences in surface and near-surface horizons that are used to define the major soil variants - Stagnopodzols and Brown podzolic soils. However, the division within the Stagnopodzols between Hexworthy Series (thin iron-pan with free-drainage below) and the Rough Tor Series (no iron-pan, imperfect drainage, drabber B horizon colours) is clearly evident in the sub-soil characteristics of the study area. Note that this classification has no place for the not infrequent profiles which lack an iron-pan but show no sign of weak gleying in the sub-soils. If this division between Series is based on sub-soil drainage characteristics, then it must be recognised that the Hexworthy (free-drainage) Series includes many profiles without iron-pans. It is in the upper B horizon that some differences between Stagnopodzols and the only Brown podzolic soil of the study area are seen. Generally, the latter includes a Bs horizon similar to that of the Stagnopodzols, but in some profiles there is a zone wherein the Bs grades into (in part by inter-fingering with) the Ah above (A/B horizon); this is never observed in a Stagnopodzol profile.

4.2.1.2 Surface and near-surface soils

The soils of the study area can be divided into two basic groups - mineral soils and those which include a surface cover of peat. With the former, only a single horizon has been recognised above the B or A/B horizon - an Ah horizon - though this horizon has often been arbitrarily subdivided for sampling purposes (when this has been done the upper sample has been labelled Ah_1, the lower one, Ah_2; these labels carry no other implications). The peat-covered soils are more complex; in addition to the extremely organic Oh horizon, which itself may require subdivision in some instances, these soils always include either one or two mineral horizons between the uppermost B horizon and the Oh; an Ah/E horizon is always present; an Eg horizon sometimes accompanies it.

Ah/E, E, Eg - Typical thicknesses: Ah/E 7 - 12 cm; Eg 3 - 6 cm

Ah/E - dark reddish brown (5 YR 2.5 - 3/2) but varies from black (5 YR 2.5/1) to dark brown (7.5 YR 3/2) gravelly, sandy loam or sandy silt loam; slightly or moderately stony with mainly very small to small angular and sub-angular quartz and felspar, plus small to medium sub-angular granite fragments; apedal, massive (weak); 0.5% very fine macropores; many, very fine and few coarse and medium roots (mainly in upper 5 cm) plus many very fine (often dead) roots concentrated immediately above the iron-pan, when this is present at the base of the horizon.

Found throughout the study area, this humus-stained eluvial layer is remarkably uniform. The grey colours of ignited samples and the high proportion of quartz gravel testify to iron loss and severe weathering, despite its dark, 'earthy' appearance. The variation in colour testifies to changing organic matter content but this is always high enough for the horizon to be classified as a humose mineral soil. Although in many cases there is little apparent change in the characteristics of the horizon throughout its thickness, where iron-pans or gleyed B horizons are found below it, lighter coloured mottles tend to occur in the lowest 5 cm and, particularly when a strong, relatively impermeable, pan is present, the mottles may coalesce to form a continuous Eg horizon. The latter is rarely thicker than 5 cm and a seam of 1 - 2 cm is more common. What constitutes a light mottle varies with the darkness of the matrix; strongly-developed mottles may differ by two colour value points (i.e. 7.5 YR 5/2 mottles in a matrix colour of 5 YR 2.5/1) but this is rare. It has been noted earlier that, where iron-pans or gleyed sub-soils are present, a thin Bh commonly develops at the base of the Ah/E. This is an alternative pattern of development often seen together with an Eg within a single exposure; the Eg occupying downturns in the pan, with the Bh elsewhere. In profiles with gleyed sub-soils, a thin Eg may be present just above the Bh (thus giving a stratigraphy of Ah/E - Eg - Bh); such profiles are seen most frequently on the highest plateau flats.

Somewhat similar in appearance, but probably indicating a different process, are the coarse, faint to distinct, diffuse light-coloured mottles which occur in all types of profiles and may be found in any part of the Ah/E horizon; these have been dubbed 'E mottles' since there seems to be no evidence that gleying plays a part in their formation. Such spots are here regarded as simply the most strongly leached portions of the Ah/E horizon. Unlike Eg mottles, E mottling is relatively rare and, except in the unusual circumstances provided by constructed features (such as reaves, soil-filled house walls - see 5.2.1.2), which raise soil materials above the level of the surrounding soils, never coalesce to form a true E horizon.

Oh - Typical thickness 8 - 13 cm (excluding L and F layers)

Black (N 2/0, 5 YR 2.5/1, 10 YR 2/1) amorphous peat with a highly variable content of bleached quartz sand and finer mineral material; usually stoneless; apedal and greasy when wet, compound medium to coarse angular to sub-angular blocks and fine to medium angular blocky peds when dry (very strong to rigid); 0.1% very fine macropores; many very fine and fine roots; few medium and coarse roots (except when bracken rhizomes are present, when they can be common). This is the principal rooting horizon; few rhizomes penetrate the mineral soil below and when they do, they are usually found only in the upper 5 cm of the mineral soil.

The thickness and organic content of this peaty layer vary substantially but systematically within the study area; values for LOI range from ca. 90% to ca. 25% in samples that retain a peaty appearance; the depth of peat accumulations varies from profiles covered by little more than a thickened litter layer to a maximum of about 20 cm. Generally, these two variables covary such that deep peats typically have high LOI values and shallower ones, low LOI values; however, not a few exceptions occur and, within the lower range of thicknesses (6 - 10 cm) LOI values can vary from ca. 75% to ca. 25%. The pattern of variation is more fully described below (see 4.3.1.1).

In certain areas, thin lenses of mineral material are a common and prominent feature of the Oh horizon. They rarely exceed a thickness of 5 cm; in a few instances they are composed of material indistinguishable from that of the Ah/E horizon below, but in most cases they consist of a 1 - 2 cm seam of bleached quartz (mainly coarse sand and very small stones) sandwiched between two or more layers of peat.

In most profiles the boundary between the Oh and the Ah/E is sharp and the overlying peat exhibits little change in mineral content throughout its depth. However, in some profiles the Oh horizon can be subdivided into layers with varying mineral content; the simplest case of this type (and the most common one) consists of a thin (2 - 5 cm) basal layer of peat which contains more mineral material. Profiles with this pattern occur sporadically throughout the study area. Far more complex patterns have been encountered; in some cases, the uppermost peat layer contains the most mineral material, in others, variation in the mineral content of peat is accompanied by mineral lenses of the type described above and by peat lenses within the Ah/E. These multilayer profiles are not common and have a restricted spatial distribution which will be discussed below (see 4.3.1). Another phenomenon, also with a restricted spatial distribution, and with a superficial similarity to Oh 'layering', is represented by what are referred to here as 'black-topped Ah/E' profiles.

The change from mineral to organic soil, although sharp, is not always marked by a concordant change in colour; in many profiles, the upper 2 - 5 cm of the Ah/E is slightly darker than the main body of the horizon but in some cases, this more stained portion can be as dark as the overlying organic soil. Although, as one would expect, it is sometimes difficult to distinguish this phenomenon from profiles with a thin basal layer of high mineral content peat, in most cases, there is a clear difference between a mineral rich peat and a heavily stained mineral soil and the special spatial distribution of the examples allocated to the black-topped Ah/E group supports the distinction (see 4.3.1).

Ah - Typical thickness 17 - 20 cm (excluding L and F layers)

Dark brown (7.5 YR 3/2), sometimes dark reddish brown (5 YR 3/2), humose, sandy silt loam; slightly to moderately stony with mainly very small to medium angular and sub-angular quartz, felspar and granite fragments; weakly-developed compound coarse granular to sub-angular blocks and very weakly-developed fine to medium granular to sub-angular blocky peds (weak); 0.1 - 0.5% very fine and fine macropores; many very fine and fine roots; many bracken rhizomes (which in these non-peaty soils can extend to a depth of ca. 35 cm, but are found mainly in the upper 25 cm); boundary to Bs below usually sharp or abrupt and smooth, but sometimes only clear or even gradual and wavy or irregular (in these latter circumstances an A/B horizon has been sampled from the intermediate zone).

This Humic brown podzolic surface soil occurs only in areas which bear clear field evidence of medieval cultivation; the combination of a generally smooth-based horizon with some irregularities and a mull-like appearance despite a level of acidity similar to that found in adjacent stagnopodzol mineral soils suggests that the appelation Ap would not be inappropriate for this soil, but this has been avoided to prevent confusion with not dissimilar horizons in nearby recently cultivated land. The colour of ignited samples from this horizon is similar to those from Bs horizons below and indicates that much iron is still retained in this surface soil.

The surface (Oh, Ah) and near-surface (Ah/E, Eg) horizons described above are found in the vast majority of soil profiles encountered in the study area, including all typical Stagnopodzols, Ferri-humic podzols and Humic brown podzolic soils. However, three of the smallest medieval enclosures have a surface soil which cannot be accommodated within these categories; although in several respects intermediate in character to the horizons described, it has some features quite unlike any other soils observed in the study area or previously reported on Dartmoor. In the first place, it seems to be free from the coarse gritty texture of all other Dartmoor soils (caused by the abundance of coarse sand and very small stones) and in the field was classed as a very humose silty loam; the very high organic matter content may have served to mask some of the coarser sands, but this soil does appear to be largely free of stones as well. Secondly, unlike the Stagnopodzols, the transition from what is clearly a mineral soil in the basal portion to what is nearly a peat in the upper portion occurs as a very gradual change; no clear division can be made within the ca. 15 - 20 cm depth of this dark reddish brown (5 YR 2.5-3/2) soil. Unfortunately, this soil does not occur within any of the intensively studied zones (A, B or C) and, as yet, no laboratory investigations have been undertaken. The distribution and possible origin of this peculiar soil type, which will be referred to as an Oh/Ah horizon, is discussed below (see 4.3.1.2).

4.2.2 Soil classification

The horizon nomenclature used to subdivide the foregoing soil descriptions has already imposed one form of classification on the observations of soil characteristics. It is customary to follow this by allocating whole profiles to soil 'Major Groups', 'Groups' and 'Series'; in some cases, the Dartmoor classification into Series mainly reflects the differences in surface soils (e.g. Moorgate Series with a humose Ah, Rough Tor Series with a peaty Oh), but in other cases the division proceeds from sub-soil variation (e.g. Hexworthy Series with iron-pan and no sub-soil gleying, Rough Tor Series without pan but with some sub-soil gleying) - but note that this division is not used for mapping purposes (all the Stagnopodzols have been mapped as a single Hexworthy-Rough Tor mapping unit).

The dense and detailed surveys in the study area confirm the largely disparate nature of the patterns of variation in surface soils and sub-soils and make it possible to draw up separate maps for each of these categories; this procedure allows one to employ more refined mapping units, better suited to the objectives outlined earlier. The units of classification used below reflect not only the covariance of soil characters as recorded at individual profiles but also take account of the spatial grouping of individual or covarying variables. This follows from the technique employed, which involved the mapping of individual variables prior to the recognition of classification units. Information about selected groups of variables (in the form of codes and symbols) was transferred to baseline maps drawn at two scales; one covered the entire study area, the other was limited to zone A, where the highest density of observations had been made. The detailed patterns found in the latter area (and to a lesser extent those visible in the other densely sampled zones - B and C) were then used to guide the interpretation of the more widely scattered information produced by the general survey.

4.2.2.1 Sub-soils

The observations of sub-soil characteristics appear to provide samples from a continuum rather than a series of discrete populations. The subdivision of this continuum into four basic 'types' creates artificial disjunctions, but the recognition and use of a lower hierarchy of 'variants' tends to mediate between the types.

I Deep valley peat soils with (presumably) strongly gleyed sub-soils

Although small areas with deep (0.5 - 1.5 m) peat have been located by augering and their spatial extent estimated from the distribution of their distinctive vegetation, these areas have not been further investigated.

II Weak gley soils

These soils show clear signs of weak gleying often in both upper and lower B horizons; Eg mottling is frequently seen in their Ah/E horizon; thin Eg and Bh horizons are common but iron-pans are absent.

III Freely-drained soils

These soils show no signs of gleying in their sub-soil; Eg mottling is rare and Eg and Bh horizons are absent; iron-pans are rare and, when present are typically of the 'incipient' kind.

IVa and IVb Iron-pan soils

These are the soils in which iron-pans are common; there are no signs of gleying in the sub-soil horizons but, in type IVa, an Eg horizon or Eg mottling is common; type IVb, which occurs mainly on the lower (often steeper) slopes of the plateau, lacks these signs of near-surface drainage impedance; Bh horizons are absent from both sub-types.

Most of the soils of the study area can be accommodated within these four 'types' (many of them within types III and IV), but the addition of three 'variants', which transcend the boundaries of 'types' makes allowance for those characteristics which occur irregularly among more than one soil type.

Va Intermittent thin Bh

This feature, a basic component in soil type II, also occurs in soil types III and IVb; in both types it is found as a very thin seam at the base of the Ah/E (in type IVb, it lies immediately above the pan).

Vb Intermittent weak sub-soil gleying

In these profiles there is evidence for gleying but it is usually confined to one of the two B horizons (upper or lower); less-developed mottling and generally brighter B horizon matrix colours suggest less persistent waterlogging than occurs in profiles of type II. This variant occurs mainly in soil types III and IVa.

Vc Rare iron-pans

In areas with an Ah surface soil (Humic brown podzolic soils), a very small number of profiles have a smooth iron-pan at the base of the Ah. This variant is found only in soils of type III.

4.2.2.2 Surface and near-surface soils

The pattern of variation in the surface and, to a lesser extent, the near-surface soils seems to differ from that of the sub-soils; observations in these horizons appear to provide samples from a series of inter-grading but discrete populations rather than a continuum. Except in one area, this was not clearly apparent from the observations made during the initial survey but became increasingly evident during the high density survey of zone A. Once again the surveys in zone B and, in particular, zone C also helped to define the nature of variation within the study area as a whole, but the additional surveying of surface soils only at 120 places (40 locations in the large North and South Fields - the outfields, 80 in the Lobes and smaller medieval enclosures) was crucial to the assessment of the pattern outside zones A, B and C. This aspect is stressed for two reasons; first, to emphasise that the observations summarised in the classification offered below represent the end result of a cumulative process, which allowed and involved repeated testing of initially, hesitantly-identified patterns over a period of several years. Secondly, to emphasise the poor likelihood of confident recognition of such patterns during routine, relatively low density soil surveying. While an experienced surveyor might guess that such patterns were present, only high density survey is capable of closely defining the patterns.

The classification used here is based mainly upon variation in the organic content and depth (or absence) of both the surface peat and, to a lesser extent, the underlying Ah/E horizon. Estimates of the organic matter content of soils outside zones A, B and C are based solely on field inspection; within these zones both laboratory measurements (LOI) and the field estimates made during the first sampling season have been utilised. Field assessment of the organic content of the Ah/E horizon relied mainly on differences in colour and only very substantial differences were regarded as significant and used in the classification. Colour variation also contributed to the assessment of Oh horizon samples, but in the case of these peaty samples, the change in textural qualities caused by the (visible) incorporation of mineral soil was, in many cases, a better guide. (At the end of the first season, a comparison was made between the LOI and field estimates of the organic content of Oh horizons in zones A and C; this provided both a 'control' over the estimates made in other areas during that season and provided a means of improving estimates made in subsequent seasons. Field estimates were placed in four, 'estimated LOI' classes - 39% or less, 40 - 49%, 50 - 59%, 60% or more - at 36 locations for which LOI measurements were available. In 21 locations, the Oh sample had been placed firmly within a single class and 15 of these estimates were correct (71%). In another 15 locations, a wider estimate, spanning part or all of two classes had been made and only 2 of these estimates were wrong (87% success). All wrong estimates placed the samples in a class adjacent to the class indicated by the laboratory measurement). Bearing in mind that later estimations benefited from this appraisal, it seems probable that at least three-quarters of the field estimates will have placed samples in the correct class and most of the balance will have been placed in an adjacent class.

The pattern of variation in peat depth is considered in greater detail in section 4.3.1.1, where a statistical analysis of the peat depth data from zone A is presented. (In that analysis and in the following descriptive notes and Table, the peat 'depths' or 'thicknesses' cited include the thickness of any litter (L) or partially decomposed litter (F) horizons found on the surface of the Oh horizons; this procedure has the advantage of simplicity and, more important, overcomes the considerable practical problem of precise identification of the F - Oh boundary; it also avoids the conceptual difficulties that would be associated with a decision to exclude such layers. Since the depth of litter layers (L + F) on Oh horizons varies very little throughout the study area (4 - 6 cm in almost all cases), their inclusion should not affect assessment of the differences between soils).

The differences between the surface soil 'types' are most easily appreciated in a tabulation of the characteristic features of each unit (see Table 4.1), a format that facilitates direct comparisons; additional comments on each soil type appear below.

S - I

These are the undisturbed, natural Stagnopodzol soils of the study area; peat depths range from 15 to 20 cm (the latter mainly found on the wetter soils with type II sub-soils) with a mean value around 17 cm; these peats rarely have a LOI value lower than 50% and more frequently fall between 65 and 80%.

S - Ia

These soils differ from soil S - I only in respect of peat depths, which are shallower, and the amount of mineral material incorporated in the peats, which is usually greater. The thickness and organic content of the Ah/E horizon seems to be identical in S - I and S - Ia soils; although typically 7 - 12 cm, much thinner (4 cm) and thicker (21 cm) Ah/E horizons have been recorded.

S - Ib

This soil has an Oh horizon similar to those of some soils classed in type S - Ia, but differs in Ah/E horizon characteristics and possibly in upper B horizon characteristics as well. The sub-peat mineral soil is darker, more peaty and of much looser consistency (apedal - of single grain type rather than massive). Its friable character seems to be the product of a much higher organic content than is usually found at this level; too few sub-soil observations have been recorded for the upper B horizon pattern to be stated with confidence, but there are indications of an unusually high organic content at this level as well (a 'thin Bh' is rare below this soil, but the upper B has extensive organic mottles and a very dark matrix - 5 - 7.5 YR 3/2).

All S - I series soils can be classed either as Iron-pan or Ferri-humic Stagnopodzols.

Table 4.1 Field characteristics and classification of surface and near-surface soils on Holne Moor.

Soil type	S - I	S - Ia	S - Ib	S - II	S - IV	S - III	S - V
Main areas	Virgin land and corner profiles	Outfields	South Lobe	Lower South Field. The Close in the North Lobe	North Lobe Parts of Central Lobe 1	Central Lobe 3 and parts of Central Lobe 1	Central Lobe 1
Litter depth	0-5 (4, 7)	0-5	0-5	0-4	0-3	0-4	0-4
Horizon	Oh	Oh	Oh	Oh/Ah	Ah	Oh(-Ah)	Oh
Depth[1]	5-17 (15, 20)	5-13 (11, 15)	5-11 (10, 13)	4-19 (15, 23)	3-22 (20,23)	4-7 (5, 9)	4-7 (5, 9)
Colour	N 2/0	N2/0 (5 YR 2.5/1)	N 2/0- 5 YR 2.5/1	5 YR 2.5/2	7.5 YR 3/2(5 YR 3/2)	5 YR 2.5/1	N2/0-5 YR 2.5/1
Est. LOI (%)[2]	50-80	30-80	40	30	10-15	25-30	35-40
	Sharp Boundary	Sharp Boundary	Sharp Boundary	Loamy grades to	Mull-like	Gritty grades to	Sharp boundary
Horizon	Ah/E	Ah/E	Ah/E (Ah)	Ah	A/B	Ah/E	Ah/E
Depth	18-28 (26,30)	13-22 (19, 24)	11-22 (21, 25)	-	horizon	7-18 (17,23)	7-22 (20, 23)
Colour	5 YR 3/2	5 YR 3/2	5 YR 2.5-3/1	5 YR 3/2	sometimes	5 YR 2.5/2	7.5 YR 3/2 (5 YR 3/2)
Est. LOI (%)	7 - 10	7 - 10	15 - 20	15	present	12 - 17	8 - 12
Eg horizon or mottles	Rare/common	Rare/common	Rare/common	Rare	None	Rare/Rare	Rare/common
Iron pan depth	" 28(26,45)	" 22(19,36)	" 22 Possibly Bh better developed	Rare	Very rare (19)	Common (18)	Common (22)
B Cux (depth)	55	to		65	45 -	50	55 - 65

(1) All depths given are from surface of litter layer (cm). (2) All LOI estimates are field estimates.

S - II

This is the soil which has the anomalous loamy-textured Oh/Ah horizon; this is tentatively placed in the Major Group of Man-made soils, though as discussed later 'Animal-affected' might provide a better label.

S - IV

These are the soils which lack a peat surface; instead the mull-like, mineral Ah horizon is present. On the basis of field characteristics alone, these soils can be assigned to the Humic brown podzolic soil sub-group, though many profiles are more similar, in appearance, to profiles assigned to the Moretonhampstead Series than the Moorgate Series. The few profiles in which iron-pans occur at the base of the Ah may be regarded as Iron-pan podzols and no doubt intergrades of Ferric podzol type are also present.

S - III

This soil appears to be an intergrade between S - IV and the Stagnopodzols; the surface soil is much more humose than the Ah of S - IV (and is here labelled as an Oh horizon) but it blends gradually into the underlying horizon, which generally has a higher organic matter content than typical Ah/E horizons. This soil finds its nearest counterparts among profiles assigned to the Moorgate Series of Humic brown podzolic soils, but in some areas an iron-pan is frequently present at the base of the Ah/E and these profiles must be classed as Iron-pan podzols or even Iron-pan stagnopodzols.

S - V

This soil is even more similar to the Stagnopodzols than S - III; the surface soil is clearly a (very thin) peat and the transition to the underlying Ah/E occurs at a sharp boundary. However, the Ah/E is is unusually thick and is often as light in colour as the Ah horizon of S - IV. This soil is in most respects similar to the Ferri-humic podzol described at North Bovey (see 3.2.1), but differs in the frequent presence of an iron-pan.

It is evident that none of the soil classes used in this study exactly match the soil types recognised on Dartmoor by the Soil Survey; nor, without evidence for iron and aluminium distributions, is it possible to establish the exact relationship between the soils of Holne Moor and those classified elsewhere. However, as a whole, the soils observed on Holne Moor do fit into the universe of soils observed elsewhere on Dartmoor and Fig. 4.1, attempts to portray the soil units used in this study within that wider context.

Certain profile variants - multi-layer peats, peats with mineral lenses, black-topped Ah/E soils - have not been taken into account in this scheme of classification; they occur only within S - I series soils and will be considered separately in discussion below (see 4.3.1).

4.2.3 Soil distribution

In this section, the distribution of the soil types defined above is presented; the general pattern of variation in the sub-soils of the study area is considered and particular note is taken of the patterns within the smaller intensively sampled zones and sub-zones. Although the surface soil distributions are also introduced at this stage, they are only considered briefly in this section since, in the author's view, an adequate explanation of these distributions must include a consideration of the effects of medieval land use and this is discussed in the subsequent section.

4.2.3.1 Sub-soils

The pattern of sub-soil variation evident in the initial plotting of individual and grouped variables did not appear to correlate in any respect with the pattern of prehistoric or medieval enclosure with the exception of soils in the North Lobe and eastern segments of Central Lobe 1. However, the pattern of sub-soils did appear to be consistently related to the plateau landforms and so the interpolation incorporated in Fig. 4.2, which summarises these observations, made extensive use of the assumption that sub-soil and landform 'boundaries' or 'transition zones' were in fact concordant.

Although the distribution map provides a uniquely detailed assessment of sub-soil variation in a Dartmoor soil, none of the patterns is surprising and, for the most part, this survey does not greatly assist the primary purposes of this study. In consequence, the general pattern is, here, only considered briefly.

The soils with signs of weak sub-soil gleying (II and Vb) are found in three positions in the landscape: on the flat plateau summits in both the north and south of the study are; in areas fringing the valley bogs (where soils of type I are present) in the extreme south-west and north-east of the study area; and in a zone lying athwart the long, gentle eastern slope of the southern half of the plateau. In the latter area, the distribution of weakly-gleyed subsoils is largely coeval with an area of relatively well-developed iron-pans with Eg horizons sub-soil type IVa). In general, strong iron-pan development is restricted to the more steeply sloping areas and in particular to zones well below the plateau crests. As gradients increase, signs of sub-soil gleying become rarer and eventually signs of surface waterlogging also disappear (sub-soil IVb). The presence of thin Bh horizons in soils without signs of water-logging (sub-soil type Va) also seems to be simply related to landform. Throughout the study area, these soils are found in the areas with very low gradients (2 - 3^{o}), which form a fringe surrounding the plateau centre. Apparently anomalous zones on the eastern slopes - at the mouth of the South Channel and the areas to the north - occur just above a secondary but important increase in slope gradient and so, are, in fact, in positions broadly analogous to those on the central fringes of the plateau. Apart from the gleyed sub-soil zones and the fringe areas with Bh development, a large portion of the plateau summit has free-draining soils without extensive iron-pan development (sub-soil III) or signs of gleying in the Ah/E horizon.

The only places in which sub-soil characteristics can clearly be seen to have been influenced by medieval land enclosure and farming occur in the north-east of the study area, where the southern boundary of the North Lobe and the western boundary of the Wedge field (in Central Lobe 1) each coincide with a sharp change from sub-soil type IVa (and in places IVb) outside the enclosures to type III within them. These changes are paralleled by changes in the surface soils (see Fig. 4.3 - these enclosures alone are dominated by surface soil S - IV) and it is most convenient to consider all the soil transformation across these boundaries in a single discussion at a later stage (see 5.4.2). At this point one should, however, note that the valley bog in the North Channel has overridden the North Lobe corn-ditch at one place (the boundary is partly buried by peat) and in winter surface water also flows through breaks in this boundary (some of these breaks may be original field gates). Small areas of sub-soil type II occur just beyond these breaks and it is in the areas adjacent to this that iron-pans, smoothly marking the base of the Ah surface soil, are found in a few profiles (sub-soil type Vb).

Iron-pans also occur in some parts of each of the other medieval, Lobe enclosures. There is no indication that panning has developed more frequently inside such enclosures than elsewhere; the pattern of occurrence seems entirely explicable as the result of variation in slope forms and gradients. An easterly fringe of soils of type III coincides with a flattening of slope just outside the bounds of the reservoir enclosure fence. In one respect, however, iron-pans within the Lobes may differ from those outside; whereas the latter undulate in depth along a band perhaps 10 - 15 cm in thickness (and only rarely plunge more wildly), pans within the Lobes rarely show any significant irregularity and are found at very similar depths throughout these enclosures (see Table 4.1). A sufficient number of observations of such pans have been made in the Central Lobes (1 and 3) for one to feel that this pattern is not simply a fluke of small pit sampling and may well represent a case of preferential pan development at the base of an old plough soil analogous to those noted earlier (see 1.2.3).

Sub-soil patterns within zones B and C require only brief mention here; the latter zone was selected for intensive investigations because of the very substantial changes in sub-soil and surface soil that occur across the boundary that bisects the zone - from a Stagnopodzol to a Humic brown podzolic soil. Although the _ca._ 5^{o} slope, whose dip parallels the direction of the boundary, creates some complications in assessing soils in this area, no other place along the North Lobe boundary offers such a good opportunity to make this comparison. On the other hand, sampling of the probably 13th century droveway to investigate the effects on soils of early animal traffic, required as much soil uniformity as could be attained, and the positioning of zone B in the centre of what is an almost completely flat area without significant sub-soil variation, is thought to have come very close to achieving the ideal level of soil homogeneity.

The requirements for zone A were more complicated (they are discussed further at a later stage (see 5.4.3) and it is clear that in this larger zone, sub-soil changes must be considered as a factor complicating any explanation of differences between land units (sub-zones) within the zone. The magnitude of the difference in soil drainage between the western parts, which cover the plateau summit, and the eastern parts, which extend down the uppermost plateau slopes (gradients of around 2 - 4^{o}), should not, however, be exaggerated. As noted earlier, none of the sub-soil features on the plateau indicate more than weak gleying and the differences between these soils and the free-draining soils of type III on the eastern slopes give rise to no more than a prima facie case for expecting the sub-soil pattern to be matched by consonant but minor differences in other measured soil variables.

4.2.3.2 Surface and near-surface soils

As explained above, an understanding of the pattern of surface soil variation on Holne Moor arose cumulatively over a period of several years. Plotting of the relatively thinly-scattered initial survey data suggested to the author that, with the exception of the changes apparent in zone C, all the variation in surface peat depths and other qualities might be encompassed within the general catena model (see 2.2.1) which envisaged organic horizons thinning on the lower slopes and even fading out altogether on the steepest slopes as a result of entirely natural differences in soil development processes on the plateau summits and on its steeper slopes. However, by the end of the first season's sampling in zone A, it was apparent that changes in peat quality and depth sometimes occurred at land boundaries and this realisation prompted both more intensive examination of the initial survey data and the development of an alternative model to explain the pattern of surface soil change known at that time. A later, much refined version of this alternative model has been presented in section 2.4.2.

Both the original and the new model could predict thinning of organic horizons in certain areas, but only the new model gave any reason to expect that many significant changes in surface soil type would occur at land boundaries and that the surface soil within any one 'enclosure' would usually be highly homogenous. To test for the presence of such patterns and to define better the qualities of surface soil in areas not monitored in the first survey, an additional high density survey was then undertaken; this survey mainly concentrated on the soils in an around the medieval enclosures in the eastern part of the study area. However, a large amount of information including peat depths and quality was acquired during the second season's large scale sampling in zone A and this has served to clarify the pattern in the western parts of the study area where both unenclosed, 'virgin' land and what were later to be interpreted as medieval 'outfields' could be compared.

The observations during all these investigations are summarised in Fig. 4.3 in which it can be seen that the distribution of surface soil types defined earlier is in fact intimately linked to the pattern of medieval enclosure. So much is this the case that very little evidence of the pattern of soils which would have existed if Holne Moor had not been farmed in medieval times can now be discerned. Areas with more or less undisturbed Stagnopodzols (surface soil S - I) can be found on northern, southern and western extremities of the study area, but aside from parts of the South and North Channels, there are few soils on the eastern side of the plateau, which have not been substantially affected by metapedogenetic factors. The sub-divided fields of the North Lobe and similarly partitioned land in Central Lobe 1 contain the Humic brown podzolic soil (S - IV), while soil S - III, which proved to be a very homogenous mapping unit, is found in most of the land lying between the South Lobe and the northern half of Central Lobe 1; the South Lobe itself is the only area with the anomalously organic-rich and friable Ah/E horizon (soil S - Ib). Soil S - V is essentially confined to the north-western quarter of Central Lobe 1 and soil S - II appears in the remaining small enclosures - the Close (in the North Lobe), Lower South Field and the 'funnel' enclosure to the west of Central Lobe 3. In the latter enclosure, it is found only sporadically among soils highly disturbed by tinning activities, while to the west of the reave, which bisects the Close, some S - II profiles are markedly more peaty and thus approach the typical Stagnopodzol soils.

In Fig. 4.3, soil type S - Ia has been subdivided for mapping purposes into three variants, which, it is believed, correspond to differences in the timing and nature of soil disturbance during medieval outfield cultivation. This will be discussed further after the pattern of soil changes in zone A has been documented and considered, but, since it can be seen that, within the North and South (Inner and Outer) Fields, changes in surface soil type Ia mainly occur at prehistoric boundaries, the attribution of these patterns to medieval farming activities requires some explanation. The case for a medieval date is in fact clear-cut. First, there is evidence from studies of palaeosols (see section 5.2.1 and 4.3.1) both that peat was not present when the reaves were built and that much of the peat growth on Holne Moor occurred after *ca*. AD 1000; secondly, in zone A, plough marks, which post-date the medieval boundary of the Inner South Field lie sealed by the disturbed peats of soil type S - Ia; finally, soils of the latter type are confined to areas enclosed by the boundaries of the medieval outfields.

Clearly the models advanced in section 2.4.2 do offer a way of explaining the genesis of this kind of soil distribution, and the relationship between model and observations (i.e. between land use and soil variation) must and can now be considered.

4.3 Modern soils and medieval land use

It is evident that on Holne Moor there is a pattern of soils in several ways analogous to that studied in Ireland by Conry and his associates (see 1.2.3 and 2.3.3.2). In that study, destruction of organic surface horizons and decreasing organic matter content was linked to the 'intensity' and duration of relatively recent moorland reclamation. However the much longer history of farming on Holne Moor and its earlier abandonment require and allow a more complex explanation for the creation of the present character of the surface soils. The contemporary characteristics reflect not only the intensity of man's intervention but also the degree to which natural processes have managed to reassert themselves and reimpose 'normal' features on the altered profiles. Moreover, at the time when medieval farming started, the soils on Holne Moor were significantly different from the virgin soil of today. These aspects have been included in the models of metapedogenesis present in section 2.4.2, which, initially, were drawn up with the knowledge provided by analogous previous studies but, it must be admitted, were later revised in the light of the evidence obtained in the study area.

This section, then, is devoted to arguments (backed where necessary by further detailed evidence), which, in the author's view, explicate the existence and nature of strong linkages between specific soil patterns and land use practices. The section is divided into three parts; in the first, introductory part, there is a discussion of the origin of certain types of atypical profiles, whose characteristics could not be anticipated in the general models presented earlier; in the second part, detailed evidence of soil characteristics in zone A is presented and land use in this area and analogous parts of the study area is considered. Finally, the concluding section discusses the soils of the more intensively farmed land inside the Lobes and smaller medieval enclosures and advances *post hoc* models to explain specific details of the pattern.

4.3.1 Land use and soil variation

The models in section 2.4.2 foresaw that cultivation could lead to the destruction or reduction in depth of organic surface soils and/or to their intermixture with underlying mineral soils, but did not consider the many other ways in which somewhat similar soils might be created. Natural processes can create surface soils whose characteristics mimic those which are attributed by the models to the process of ploughing, and several other activities within the study area may have done likewise. Some of these sources of soil disturbance - peat cutting, poaching and erosion resulting from intense animal traffic, tinning and the construction of rabbit buries - were briefly mentioned in the introduction to section 2.2.4 but their role as factors contributing to the variability in surface soil characteristics must now be considered.

The best examples of thoroughly mixed sandy peat surface soils of entirely natural origin are found on the very steep slopes (ca. 8 - 15°) of the Dart Gorge on the northern edge of the study area; there can be little doubt that such soils are a product of continual surface erosion. In a few profiles one can observe a succession of relatively pure peat layers separated by thin mineral lenses, but this testimony to more periodic surface instability is more commonly encountered on somewhat shallower slopes (ca. 6 - 8°) in the extreme south-west of the study area. Although in this area (labelled segment II in discussion below), the soil profiles testify clearly to past instability there is little evidence that surfaces of this gradient are presently unstable, and in many cases a thick (12 - 19 cm) layer of relatively pure peat (50% or more LOI) now overlies the uppermost mineral lense. It seems probable that surface soil instability on such slopes was greater during the earliest phases of peat growth and that the present peat cover and vegetation confer considerable resistance to soil erosion. Features of this kind are also present on the flat and very gently sloping areas (1 - 5°, but generally less than ca. 3°) that are more typical of the study area, but in many of these cases, nearby evidence of tinning (e.g. spoil heaps and grubbing holes) or animal erosion (e.g. deep (15 - 45 cm) gullies radiating away from gates or breaks in the medieval boundaries) strongly indicts non-natural forces as contributors to or the sole cause of instability or artificial, built stratigraphy.

Tinning disturbances are most clearly evident in Central Lobe 3, the funnel-shaped enclosure on its western boundary and in the South Lobe. In each of these areas multi-layer profiles (see 4.2.1.2) are commonly encountered beside the workings but also in locations that show little superficial evidence of having been disturbed. Fleming's most recent excavations on site B (see Fig. 3.5 - this excavation lies in the area labelled segment X in discussion below), also revealed tinning spoil and holes, which, covered by 16 - 17 cm of peat, formed inconspicuous surface features, and boundary ditches, which could not be detected before excavation.

The construction of very low, inconspicuous rabbit buries also contributes to soil disturbance mainly in areas close to the tin workings. Medieval hedgebanks were shovelled away to make these slight mounds some of which are still occupied by rabbits. In all cases pits dug into these mounds reveal that a surface soil of type S - IV has now developed in these soil materials and this is also true of many of the larger tinner's spoil heaps. The stratigraphy of the bury in the South Lobe was accidently examined during the initial survey (prior to the time when these buries were recognised) and it is now clear that the bury builders buried but did not seriously disturb the S - Ib surface soil of the area. A very similar buried soil was found beneath the tin heaps, which line the deep tinner's gulley in the South Lobe. Although from the point of view of surface soil survey, these activities produce noise that needs to be filtered out, they also produce signals of considerable importance.

Table 4.2 brings together a number of observations of variously-aged buried soils (the first two palaeosols on the list are reported in detail in section 5.2.1) within the study area. Although it would be desirable and possible to expand this list (when it might provide a useful local relative chronology for the wall-building, tinning and rabbiting episodes on Holne Moor), this compilation from survey and excavation records already gives some indication of the chronology of peat growth. In particular, it can be seen that, even in areas where the surface soils may have been affected by cultivation, peat depth may have doubled during the medieval period and much of this increase may post-date the tinning activity near site B, which is unlikely to be earlier than the 11th or 12th century.

Although tinning activities and consequential soil disturbance may be more widespread than surface signs betray, there is much evidence to suggest that the mineral lenses in peat, which occur very frequently in soils to the west of the South Lobe, result from surface instability caused by regular animal movements along preferred tracks in medieval and early post-medieval times (see Fig. 4.3). In the western half of this Lobe and in areas to the west and north (i.e. the mouth of the South Channel), deep ruts (sometimes amalgamating to form narrow hollow-

Table 4.2 Depths of peat buried by walls, tinning spoil and rabbit buries on Holne Moor.

Estimated date of Burial	Depth of[1] Peat (cm)	Estimated LOI (%) of Peat	Burial Agency	Location	Soil type of overburden
Prehistoric[2]					
ca. 1300 bc	Nil	N/A	Wall of prehistoric house	Site F, Zone A	S–I series, but with very deep E horizon.
Medieval and Post-Medieval					
Late 10th century[3]	5–6	*ca.* 25%	Corn-ditch	North Lobe Zone C	S–IV
Probably *ca* 11–12th but could be as late as 15th–16th century (4)	8–9	ND	Small tinners' spoil heap	Site B Zone A	S–I series with 16 – 17 cm subsequent peat growth.
Late 13th (4)	4–9	ND	Hedgebank	Inner South field Zone A	S–IV or S–III
Probably 15th or 16th but could be as late as mid 17th century	4–10	*ca.* 30%	Low rabbit bury	South Lobe	S–IV
"	11	*ca.* 40%	Large tinners' spoil heap	"	S–IV but S–III soils have been observed on some spoil heaps in this area.

(1) Observed values are given here; no allowance has been made for compression or decomposition (see section 5.2.1.1)

(2) See section 5.2.1.2. (3) See section 5.2.1.1. (4) Information provided by A.Fleming (personal communication)

ways) provide very clear field evidence of these movements (and indeed of their changing pattern through time - see Fleming and Ralph: in press). In view of the nature of the soil disturbances observed on an old sheep camp (see 3.2.2), it is difficult to avoid the conclusion that the common appearance of mineral lenses in the peats from these areas is a product of animal-induced erosion. In the field, ruts become progressively less prominent features as one moves westwards onto the flatter ground some 300 m west of the South Lobe, but the full extent of the areas affected can be easily traced on colour air photographs, where these features remain prominent, and is equally evident in the continuing high frequency of mineral lense profiles. Modern low density grazing by sheep and a small herd of Galloway's (the latter are only frequently seen in this southern part of the study area) together with horses and hikers have produced a small area of tracks and erosion on the slopes of a stream lying immediately south of the study area; if this provides a good analogue for the circumstances in which mineral lense profiles can be created, one is tempted to suggest that far heavier animal traffic occurred in medieval times, though this view must be tempered by the probability that the shallower peats of that era were more vulnerable to destruction than the modern peat surface.

In some cases, mineral lenses may be a product of peat cutting activities; it is not hard to envisage suitable patterns of erosion and renewed peat growth in old peat cut depressions. However, peats with mineral lenses quite often have a similar depth of peat to nearby 'normal' profiles and investigations at locations where a sharp 'edge' clearly indicated old peat workings suggest that in most cases peat cut profiles exhibit one of two patterns. Either a very thin (<u>ca</u>. 5 cm layer of peat plus 5 cm of litter layers) but often pure (high LOI) peat layer is present, which may be residual or due to new peat growth (it was customary to replace turves in the trenches after peat cutting), or an even thinner, highly disturbed band of sandy peat, topped by a litter layer, lines the floor of the old workings (suggesting that intentionally or otherwise, the peat cutter bit into the mineral soil and mixed it with the basal peat). The former pattern seems to be more common on the wetter plateau summit areas, where surviving uncut profiles indicate that natural peat depths were slightly greater (see 4.3.1.1), and this suggests that the difference in pattern may merely reflect the difficulty of avoiding cutting into the mineral soil when shallow peats were exploited. Since peat growth may also be more rapid in the wetter, summit soils, it is difficult to argue that the pattern should be interpreted as an indication of variation in the age of the workings, though such variation may well contribute to the pattern.

In contrast to the atypical soil features which have been taken to indicate soil disturbance, the 'black-topped' Ah/E profiles (see 4.2.1.2) may only be present in land that has lain undisturbed at least throughout historic times. Of 14 examples recorded in zone A, 12 were located beyond the outermost bounds of the land enclosed by medieval farmers and, perhaps of equal importance, 9 of these 12 occurred on the flat, wetter areas to the west of the enclosures and only three were found in the gently sloping, virgin land to the south of the Outer South Field. This extra humus-staining is perhaps most simply explained as a normal but intermittent characteristic of wetter soils with deeper peat cover; such deeper peats may never have been present in the enclosed land (see 4.3.1.1). If this interpretation is correct, this feature may in some circumstances provide a useful clue for those investigating ancient land use, though the phenomenon should not be regarded as evidence for the preservation of an 'old land surface' beneath the peat. In view of its limited occurrence in the study area, it has not been relied on in this study.

It is evident from this discussion that ploughing is only one of several land use practices that may lead to alteration of the natural characteristics of the peat surface and that, in steeper, areas natural processes can themselves produce patterns which mimic those created by various forms of human interference; clearly this makes it much more difficult confidently to identify the specific effects of cultivation. However, since it is quite impracticable to excavate for ploughmarks over more than a minute proportion of the study area, very considerable efforts have been made to overcome and allow for these interfering factors and so establish the basic patterns which can reveal the amount and type of cropping that took place in the outfield enclosures.

4.3.1.1 Virgin land and the outfields

In order to establish the pattern of land use within the outfield enclosures as a whole, the most densely sampled portion - zone A - will be examined first. Fig. 4.4 shows the spatial subdivisions of zone A (segments I - XIV) which have been used in the analysis described below; the original sampling 'sub-zones' and the location of profiles in this sampling zone have been described above (see 3.3.1 and Fig. 3.9). Although the 'segment' and 'sub-zone' divisions mostly coincide with each other (and with areas enclosed by medieval and prehistoric boundaries), they are not identical. The original sampling strategy in this area was designed to allow any parcel of enclosed land, irrespective of the age or ages of the boundaries surrounding it, to be compared to any other parcel or to the land beyond the enclosures; the small sub-units could then be joined together in varying combinations to allow analysis of the differences between the actual land management units indicated by the boundaries of any one period. Initially, the author expected that a simple three-way comparison of the Inner South Field, the Outer South Field and virgin land would be appropriate for the analysis of the medieval landscape, but it very soon became apparent that this expectation was naive; it underestimated the complexity of the pattern of medieval land use and ignored significant variation, linked to changing land forms, in the virgin areas.

Two criteria were used to select a more appropriate combination of analytical units. The areas outside the medieval enclosures, which had been sampled in 4 sub-zones separated by a prehistoric boundary and an unfinished medieval boundary, were re-assessed as landform units. The gently sloping area of sub-zone F and the almost flat land of sub-zone J were retained as segments I and IV, but sub-zones G and K were abandoned and profiles in these areas were re-allocated to segments II and III, which partition reflected the moderate slopes of the former compared to the flat land in the latter and ignored the unfinished boundary that partially bisects the area.

The integrity of the original sampling sub-zones was maintained during the initial analysis of the enclosed land. However, at a later stage, sub-zone E was split into two new segments (V and X) when it became apparent that differences in peat quality in the western and eastern halves of this area matched those in the adjacent sub-zones north of the terminal reave (see Fig. 4.4). All sub-zones were relabelled simply to provide a uniform nomenclature.

Ploughmarks have been observed in all of the segments in which excavations have been conducted (VI - XI, see Fig. 4.4); their pattern and uniform appearance has led Fleming to suggest that they may have been formed during a single ploughing (see 3.2.2). However, the evidence of variation in surface soil characteristics suggests a much more complex history of medieval land use, which at times employed some of the prehistoric reaves as outfield boundaries and even ignored the Inner South Field hedgebank. In consequence, it is pointless to compare segments combined together on the basis of the medieval land boundaries and instead the units of comparison must arise from the analysis itself.

Table 4.3 and Figs. 4.5 - 4.7 summarise the information available from all segments in zone A. Assessment of land use was based upon two properties of the surface peat, its depth and an estimate of its organic matter content. The latter took account of both laboratory LOI measurements and field estimates and is therefore subject to a level of uncertainty similar to that of the field estimates made during the general soil mapping. For this reason, and in order to overcome the problems created by the several forms of soil disturbance described in section 4.3.1 (which were found to have affected the soils in many segments; see Table 4.3), more attention was paid, when summarising these observations, to the frequency distribution of values than to any apparent 'average' value. It can be seen in Table 4.3 that with one exception, the segments beyond the bounds of the enclosures are characterised by relatively homogenous peats with high LOI values. Frequent lower values in segment I are here attributed to peat cutting, tinning and animal disturbances (for which there is abundant field evidence), since this segment also includes many apparently undisturbed profiles with high LOI peats. This interpretation, which excludes cultivation as a source of disturbance in this area is supported by the peat depth analysis presented below.

Using the criterion of organic matter content, the segments within the enclosed land fall into two broad groups which form two coherent spatial units separated along a single line by two prehistoric boundaries. To the east, segments XI - XIV are all characterised by peats which appear to have been intermixed in varying degrees with the mineral soil. With the exception of 'corner' and 'edge' samples (discussed below), all profiles in these segments have peats with low LOI values; in segments XI and XII, a very homogenous surface soil is present and some samples contain so much mineral material that they can barely be classed as peat. To the west, segments V - X form the second group composed of areas with apparently undisturbed peats yielding much higher LOI values, which are often not dissimilar to values from virgin land samples. Each of the broad groups can, perhaps with less certainty, be divided in two on the basis of slighter differences in organic matter content; these four groupings are used

Table 4.3 Surface soil characteristics in Zone A.

Segment	Total number profiles	Landscape Element	Estimated LOI Range	Estimated LOI Mode	Homogeneity in unit	Plough Marks	Other Disturbances (1)	Peat Cutting
I	25	Gentle slopes on plateau flanks	30-80	45	Low	ND	T, A	Yes, Bimodal
II	12	Higher, steeper slopes	50-80	60	High	ND	E	Very rare
III	13	Flat plateau	40-80	75	High	ND	R	Yes, all profiles
IV	15	" "	60-80	75	High	ND	T	Yes, Bimodal
Corners	26	Flat plateau & gentle slopes	55-80	65	High	ND	-	Yes, Bimodal
V	7	Flat plateau	50-90	70	High	ND	T, D(?), A	Yes,
VI	19	Flat plateau				✓	T	Bimodal
VII	16	Gentle slope	40-70	55	Intermediate	✓	T, D,	Not
VIII	15	on				✓	D	demonstrable
IX	16	Plateau				✓	T, D	Probable
X	19	Flanks				✓	T, D, A	
XI	23	"	20-40	30	Very High	✓	T, A	Yes,
XII	11					ND	T, A	Bimodal
XIII	8	"	25-50	40	Intermediate	ND	T	Yes,
XIV	11					ND	T	Bimodal
All	210							

(cont)

Table 4.3 (cont'd)

Segment	Peat depth: incl. L.F; uncut profiles (2) Range	$\bar{x}$	SD	n	Corner and edge samples	Enclosure Medieval	Enclosure Prehistoric	Excavation	Sampling sub-zones	Descriptive and Anovar units
I	14-21	16.50	1.90	16	NA	-	-	-	F	
II	14-19	16.58	1.56	12	NA	-	-	-	K, G	Virgin
III	6-13	10.27	2.20	11	8, 7 by gate	✓incomplete	-	-	K, G	Land
IV	16-20	18.75	1.89	4	16, 17, 23	-	✓	-	J	
Corners	15-23	17.68	1.81	22	NA	✓	✓	✓	NA	Corners
V	15-16	15.50	0.71	11	18	✓	-	-	E	Deep Undisturbed
VI	13-17	14.78	1.56		17, 19, 19, 20	✓	✓	✓	C	
VII	10-17	13.50	1.99	44	16, 18	✓	✓	✓	B	Shallow Peats
VIII	11-16	13.67	1.44		16, 17	✓	✓	✓	A	
IX	12-16	13.22	1.30		15, 15, 16	✓	✓	✓	L	
X	12-16	13.67	1.50		16	✓	-	✓	E	
XI	11-19	13.79	2.52	20	18, 19	✓	✓	✓	D	Shallow
XII	13-15	13.33	0.82		18, 19	✓	✓	-	R	Mixed
XIII	13-17	15.43	1.40	10	17, 18	✓	✓	-	M	Deep Peats
XIV	14-17	15.67	1.53			✓	✓	-	N	
All				150						

ND = No data NA = Not applicable - = None

1. A = Animals, T = Tinning R = recent erosion by old gate
   E = Natural slope erosion D = Ditches (prehistoric & medieval)

2. Corner, edge and disturbed samples were excluded from calculation of these segment $\bar{x}$ values (see text, section 4.3.1.1); segment III values are for peat cut profiles.

in Table 4.3 and in the analysis of peat depths presented below (see also Fig. 4.7).

During the analysis, it became apparent that samples from the corners and edges of enclosures often differed from the random samples taken from the main body of the field; in the eastern, 'mixed peat' segments, they had anomalously high LOI values and, as shown below, the corners and edges of all segments seem to have a greater depth of peat (see also Table 4.3).

Figs. 4.5 and 4.6 show all peat depth measurements taken in zone A; these measurements include the thickness of litter layers for reasons discussed earlier. In addition to the random samples, 'corner' and 'edge' samples (the non-random sampling tactics employed in zone A are discussed in section 5.4.3) from segments in enclosed land have been included in the histograms for the relevant segments, but also appear in a separate histogram in Fig. 4.5. The 210 profiles examined in zone A reveal a complex pattern of variation intimately linked to historic land use in the area. In the author's opinion, only segment II, which lies furthest from the enclosures, can be regarded as a sample from an area where little or no human disturbance is evident; peat depths in this area range from 14 - 19 cm (mean value 16.6 cm).

Most samples from the corners and edges of enclosures (the majority of these samples were taken from corners) fall within the range of values seen in segment II, but four samples are much thinner, and make up a separate mode at 8 cm (if allowance is made for the litter layers on these samples, the true peat depth is about 3 cm). It can be argued that, with the exception of segments II and III, all segments in zone A have a bi-modal distribution of peat depth values similar to that seen in the corner samples. This is most clearly evident in areas outside the enclosed land; if all 65 samples from this area are considered, two strong modes appear at 16 and 10 cm. In segment III, only one (disturbed) sample appears at the higher mode, and it can be suggested that all the other samples from this segment are drawn from the population which has a modal depth of 10 cm.

It is not difficult to interpret this pattern; peat has been cut on Dartmoor for hundreds of years (see 3.2.2) and most of the samples contributing to the lower mode had already been noted in the field as having been affected by this activity. The spatial pattern of low mode samples also supports this interpretation; segment III, where all profiles appear to have been peat cut, lies on flat plateau land where peat accumulations may well have been among the deepest in the study area (aside from the valley bog peats, which are not represented in the zone A samples). In the adjacent, nearly flat land of segment IV, peat cutting was almost as thorough. Out of the 15 profiles examined here, 8 appear to have been peat cut (these lay in one coherent group on the flattest eastern side of the segment); 3 uncut profiles were found at corners and edges (see Table 4.3) and only four profiles from central parts of this area appear to be intact. Their mean depth of 18.8 cm, over 2 cm deeper than the mean depth on the sloping area of segment II, supports the idea that these plateau top areas once had slightly deeper peats.

In order to make an estimate of the mean depth of peat that would have been present if peat cutting and the several other forms of disturbance discussed earlier (see 4.3.1) had not taken place, it is necessary to ignore such 'abnormal' samples. In Figs. 4.5 and 4.6, shading and dots have been used to indicate the samples which field evidence and this analysis suggest fall into this category. It must be admitted that within the enclosed land, it becomes increasingly difficult to identify peat cut profiles, since, in these areas, the total range of values and the 'uncut' modal value of the segments tends to be lower. In fact, in two segments (VII and VIII) peat cutting cannot be reliably demonstrated (without the evidence from other areas as a clue, the minor mode in their combined distribution would unquestionably have to be dismissed as a product of inadequate sampling of a normal distribution); in these two segments, only corner, edge and disturbed samples have been regarded as 'abnormal'. In other segments peat cut profiles have also been excluded from calculations of mean peat depth (Table 4.3); exceptionally, the mean of <u>cut</u> profiles is given for segment III.

Plotting of these mean values on a map (Fig. 4.7) reveals a clear and coherent pattern of variation in peat depth, which matches the pattern of the 4 segment groups tentatively established on the basis of organic matter content. To assess whether the apparent differences between these 4 groups, the corner and edge group, and the virgin land segments were statistically significant, two analyses of variance were performed (with and without the samples from segment III). The results of these analyses are shown in Table 4.4, in which it can be seen that the exclusion or inclusion of segment III has a barely perceptible effect on the significance levels. Either analysis provides strong support for the recognition of the 4 enclosed land groups as distinct entities and confirms that the mean depth of peat in the enclosed land is significantly lower than the mean depth in the virgin lands.

Table 4.4 Anovar analysis of peat depth values in zone A[1]

Groups used:

Segments I (n = 16), II (n = 12), III (n = 11), IV (n = 4), Corners (n = 22), V + VI (n = 11), VII + VIII + IX + X (n = 44), XI + XII (n = 20), XIII + XIV (n = 10).

Including Segment III - 9 groups, n = 150	Excluding Segment III - 8 groups, n = 139
F = 26.3805+++ (8, 141, df)	F = 19.5845+++ (7, 131 df)

Contrasts - Virgin land and corners

	F =		F =	
I v II	0.0153	NS	0.0159	NS
I v IV	5.1966	+	5.4224	+
II v IV	4.5176	o	4.7139	o
I v corners	4.1501	o	4.3305	o
II v corners	3.0055	NS	3.1361	NS
I, II v corners	5.1911	+	5.4167	+
I, II, IV v corners	3.1604	NS	3.2977	NS

Virgin land and Enclosed land

I, II, IV v <u>All</u> enclosed land segments	60.4788 +++	63.1070 +++
I, II, IV v <u>Shallow</u> peat segments (VII to X, XI + XII)	72.2817 +++	75.4228 +++
I, II, IV v <u>Deep</u> peat segments (V + VI, XIII + XIV)	10.7007 ++	11.1657 ++

(cont)

Table 4.4 (cont'd)

Corners and Enclosed land

	F =	F =
Corners v All Segments	77.4590 ≠≠≠	80.8251 ≠≠≠
Corners v Shallow peat segments	89.1164 ≠≠≠	92.9891 ≠≠≠
Corners v Deep peat segments	21.3916 ≠≠≠	22.3212 ≠≠≠

Enclosed land - Undisturbed Peat Groups

Deep (V + VI) v Shallow (VII to X)	5.4255 ≠	5.6613 ≠

Enclosed land - Mixed Peat Groups

Deep (XIII + XIV) v Shallow (XI + XII)	7.3191 ≠≠	7.6371 ≠≠

Segment III v all other segments taken individually	$>$ 25 ≠≠≠	-

(1) Anovar calculated as described by Campbell (1974: 177-205)

Statistical significance levels

$p < 0.001$ ≠≠≠
$p < 0.01$ ≠≠
$p < 0.025$ ≠
$p < 0.05$ o
$p > 0.05$ NS

Differences among the various virgin land segments and the 'corner' group are for the most part barely significant, but one can note some support for the idea that plateau top peats were slightly deeper than those on the gentle slopes of the flanks (contrast I v IV). It is also important that there are only very small differences between the mean depth of peat in the corners and edges of enclosures and that of the virgin land segments lying outside.

The frequent survival of apparently undisturbed, natural peats at field margins is not particularly surprising. Headland areas - and these samples were taken from pits sited ca. 0.75 - 1.0 m away from the edge of boundaries - often retain virgin characters (see 2.3.2.1). Most of the ploughmarks in these fields stopped 1 - 2 m short of the boundaries and at this point, Fleming's excavation section drawings show a marked increase in peat depth, which continues across the headland up to the boundary itself. Clearly most 'corner' and 'edge' samples will have been taken from the unploughed and relatively undisturbed headlands. The mean depth of the 'corner' group samples is slightly deeper than that of the samples from sloping segments of virgin land (segments I and II); this may merely reflect the many disturbances in segment I and the steeper gradients in segment II. However, it is also possible that in the soils adjacent to boundaries, nutrient enrichment has led to an increase in organic matter production rates and/or impedance of surface water run-off has led to a decrease in the rate of decomposition; either or both processes could produce slightly higher nett rates of accumulation.

Taken together, the evidence from virgin land and the corner group of samples strongly suggests that a mantle of peat of about 16 - 18 cm depth would today clothe all of zone A if man had not intervened. During the final mapping survey, an attempt was made to locate undisturbed profiles close to reaves and other boundaries in other parts of the study area, in order to assess whether a similar depth might also have been present on the more extensively altered eastern slopes. Profiles with more than 16 cm of peat were in fact found in such 'protected' locations within the mouth of the South Channel, in the north-east corner of the Unfinished Field, in the North Channel (though since this profile lay at the edge of the valley bog area, it may not have been typical) and, perhaps most important of all, in the Close of the North Lobe. As noted above, although S - II soils are present in this small field, some profiles to the west of the reave are not markedly different from the stagnopodzols; one such profile had 19 cm of peat (estimated 50% LOI). So it would seem that even on this lower altitude shoulder of the study area, the notional 'natural' cover of peat would not have been significantly different from that found in zone A. Sandy peats are even present on the uppermost slopes of the Dart Gorge and no natural area of non-peat brown podzolic soils is known in the study area.

It is now possible to consider the history of cultivation which led to the peat disturbance and/or loss in the fields of zone A. At the outset, it must be stressed that the available evidence allows more than a single interpretation; the models offered here comprise 'minimal' explanations that seem to be most plausible. The soil trajectories - Pathways - of the contemporary soils will be considered in the light of the model Pathways advanced earlier (see section 2.4.2).

Despite the apparent lack of disturbance to the peat surface of segments V - X, the ploughmarks and the shallowness of the peat indicate tillage. This pattern is most economically explained as an instance of soils that have developed along Pathway 2b. The peat visible today has developed since tillage ceased; the original peat cover having been destroyed either by Denshiring or cultivation itself. Segments V and VI have deeper peat than segments VII - X; this might reflect earlier abandonment of the most exposed land where poor drainage could also have reduced yields, but poor drainage in these segments may itself explain the pattern. Perhaps earlier abandonment and a faster rate of peat accumulation are responsible for the present differences.

The peat in segments XI - XIV is also shallow but in addition has clearly been intermixed with the underlying mineral soil. Here too ploughmarks confirm that tillage took place. This pattern suggests that Denshiring did not occur in these segments and that cultivation was too brief to destroy more than a part of the pre-existing peat surface. These soils may well be the product of a single, relatively late and brief episode of cultivation as envisaged in Pathway 4 of the models. Although it is more than likely that some organic matter has accumulated on these soils since tillage was abandoned, there is no sign of a new, relatively pure layer of peat surmounting the mineral rich peat. Another line of evidence also suggests that the tillage in these segments post-dates the construction of the medieval boundaries in zone A by some considerable time.

It is notable that although reaves serve to outline coherent spatial units within which the soil is homogenous, the hedgebank of the

Inner South Field runs right through areas with homogenous soils. If the similarity of soils either side of this boundary can be taken to indicate a similar history of cropping, then this may be an indication that the boundary was being ignored during the cropping episode recorded in the present surface soil characteristics.

The peat in segments XI and XII is shallower, has more mineral material incorporated within it and is more homogenous than the peat in segments XIII and XIV. All these characteristics point to a more intense disturbance of the soil and this could be the result of slightly more prolonged cultivation. However, it might merely reflect deeper and more thorough ploughing when the land was broken. Using Fleming's estimates of the depth of the ploughmark grooves in the Ah/E, it is possible to assess how much mineral material should have become incorporated in the peat surface during the episode that produced the ploughmarks but, unfortunately, to predict how this event will be reflected in the contemporary organic matter content of the soil, requires information that is not available. An estimate of the original peat depth could be made (8 cm might be reasonable); its organic content could be estimated (perhaps 50% LOI in these early shallower peats); but, at present, the amount of oxidation during cultivation cannot even be 'guesstimated' and, until a more precise age for the cultivation is known, it is also impossible to make a useful estimate of the amount of organic matter that has accumulated since cultivation ceased. It seems probable that the Ah/E-derived mineral material would not have been substantially different from that found in this horizon today and this is perhaps the only secure assumption one can make; the ploughmark evidence itself is not easy to interpret.

By ignoring the problems of oxidation and subsequent accumulation (or by assuming that they cancel each other out) and, by assuming various different plough groove depths, pre-existing peat depths and LOI values, one can make estimates of the organic matter content of the post-cultivation surface soil ranging from ca. 30 - 60% LOI; several combinations produce estimates of about 40 - 45%. Although they produce results with the right order of magnitude, such calculations cannot safely be used to improve the interpretation of the differences among segments XI - XIV. However, they do raise questions about the relationship between the tillage indicated by the ploughmarks and the tillage indicated by soil disturbance which have not yet been considered.

Fleming (personal communication) has not found any significant systematic differences between ploughmarks beneath 'mixed' peats and those beneath 'pure' peats; nor has he found any certain evidence that two or more discordant 'sets' of ploughmarks are present. In the absence of any other evidence, it would be economic, though it would not be necessary, to presume that all the ploughmarks date to a single ploughing event. However, the tillage which produced the mixed peats must have scored or otherwise eroded the mineral soil surface and again it is economic to assume that the ploughmarks and the soil disturbance record the same event. If both these hypotheses are correct, then inevitably one must conclude that both areas came under tillage siumultaneously, but that more prolonged tillage or Denshiring occurred in the areas now covered by undisturbed peats. One is also forced to conclude that some 13 - 15 cm of peat could subsequently blanket these areas without leaving any trace of a 're-growth' layer on the mixed peat areas, which should also have somewhat deeper peats. The latter conflicts with the observations and the former seems unlikely.

The second hypothesis cannot easily be rejected for it is difficult to imagine a second ploughing episode which incorporated large amounts of mineral soil in the peat but left no traces in the form of at least a few discordant ploughmarks. It is much simpler to reject the notion that all the marks are from a single episode and to conclude that the mixed peat areas were cultivated substantially later than the areas with undisturbed peat. The first episode could well coincide with the construction of the outfield boundaries, probably in the late 13th century, while a second episode in the early 16th century would accord with evidence for both long term periodicity in outfield cultivation in Devon and a spell of warmer weather (see 3.2.1 and 3.2.2).

The minimal destruction of the peat during the second episode testifies to its brevity and the absence of any clear signs of either medieval lynchets or ridge and furrow in these fields, despite some ploughmark evidence for cultivation in 'bundles' separated by baulks, suggests that the first episode may also have been very short. If so, what must have been a near total destruction of the peat surface during the first episode may well have been accomplished not be cultivation but by preliminary Denshiring, and the employment of different techniques in adjacent areas is perhaps less surprising if one allows a gap of some eight generations to lie between these events within the outfield; it is also possible that tinners were responsible for the second cultivations and they may have been little versed in the techniques (and/or had little time for the niceties) of creating a proper seed bed.

The survival of ploughmarks attributed here to the second episode of cultivation is not hard to explain; strong acidity and the consequent rarity of earthworms guarantee a lengthy life for any deformation of the mineral soil so long as it is protected from rain and wind erosion by a cover of surface peat. The survival of similar marks in an area in which most of the peat had been destroyed is more surprising. Certainly ploughing may have left a humose surface soil but one must still envisage a very rapid 'sealing' of this surface by the formation of a new layer of 'mor' humus. This may well imply that the first episode of outfield cultivation stopped during (or immediately before) a period of particularly wet and cool weather which, aided by the poor drainage qualities of the dense Ah/E horizon, could have led to extensive waterlogging and rapid peat accumulation.

The complexity of the evidence in zone A illustrates the amount of information that may be locked up in the soil but at the same time signals that one should be wary of offering too fine an interpretation of the more thinly scattered data in other parts of the huge outfield enclosures. Although, during the final mapping survey, investigations in the outfield areas concentrated on assessing the relationship between reaves and soil boundaries, the problems presented by peat cutting and other disturbances could not be fully resolved. In consequence it must be stressed that the picture of land use in the North Field and parts of the South Fields lying outside zone A is not as reliable as one would like it to be, and is only offered as a tentative model that demands further fieldwork for its validation.

Variation in the quality of surface peats has been mapped (Fig. 4.3) using a three-fold division of S - Ia soils; the two most densely hatched areas have 'mixed' peat soils, the most dense corresponding to soils similar to those observed in segments XI and XII. Undisturbed but relatively shallow peats like those in segments V - X are mapped using the least dense hatching. Evidence of peat cutting is frequently encountered in the central parts of the North Field (plateau summit area) and on its eastern margins (the North Channel mouth, where wetter soils occur), a distribution pattern that can reasonably be linked to the original availability of deeper peats; peat cutting seems to be rarest in the areas immediately west of the Lobes such as the Unfinished Field, the Inner South Field and corresponding areas in the North Field. There is no indication in these distributions that peat was quarried extensively or perhaps at all for use as a soil amendment within the more intensively used land in the Lobes.

It appears that the use of the North Field, the Inner South Field and the Unfinished Field may have followed a very similar pattern to that in zone A, though the most western part of the North Field does not seem to have been put under the plough since peat started to form, sometime prior to ca. AD 1000. An extensive area of 'mixed' peat lying between the medieval droveway and the modern road may not solely (or perhaps even dominantly) reflect cultivation; this area has been churned up by travellers crossing through the study area, whose coaches, sledges, carts and animals have left many ruts and gullies. It is noticeable that one does not see a simple pattern of increasingly intensive outfield use as one approaches the Lobes. The most easterly part of the Outer South Field has a soil similar to that in segments V and VI, while the area to the west of the North Channel seems never to have been cultivated. The omission of the latter area could reflect its wet soil conditions, but it is argued below (see 4.3.1.2) that this area could well be wetter today than it was in the past, and certainly this explanation cannot apply to the minimal use of the area west of the South Channel. Fleming and Ralph (in press) have argued that, with the exception of the Inner South Field and the Unfinished Field, the outfield enclosures and cropping may have been undertaken as a joint project involving all the Holne and Stoke commoners, not just the local farmers of the Venford Brook valley. The 'distancing' of outfield cropping areas from the enclosed land of the Lobes might well reflect a distinction between the land used by commoners (and perhaps tinners) from that under the control of the local farmers.

4.3.1.2 The Lobes and smaller medieval enclosures

Interpretation of the pattern of soil variation within the Lobes and associated smaller enclosures is in some ways a much more straightforward task than interpretation of the outfield soils. Most soil boundaries coincide with internal or external medieval field divisions (see Fig. 4.3) and these sharp and often substantial changes can be confidently identified. Several enclosures feature unambiguous cultivation artifacts, which indicate much more prolonged cultivation than took place in the outfields and complement the soil evidence of tillage. The depth of the Ah horizon in soil S - IV and of the iron-pans in soils S - III and V (Table 4.1) may indicate that these cultivations affected the upper 18 - 20 cm of the mineral soil.

Aside from soils S - II and S - Ib, which will be considered later, the Lobe soils may be regarded as products of soil development along trajectories similar to Pathway 2 of the models advanced earlier (see 2.4.2); S - IV provides an example of Pathway 2a and a detailed study of the differences between this soil in the North Lobe and adjacent stagnopodzols (S - Ia) in the North Field is presented later (see 5.4.2). Soils S - III and V appear to represent two stages in the reversion of soils of S - IV type along Pathways of type 2b. Already a much more humose surface characterises the S - III soil, but emergent stagnopodzol features have developed further in soil S - V, which now features a very thin but true peat surface. It betrays its origins by the consistent presence of an unusually thick Ah/E horizon whose field appearance with the exception of structure is closely similar to the appearance of the Ah horizon of zoil S - IV. The pattern of distribution of these soil types supports the 'genetic' relationships that can be inferred from the soil characteristics observed in the field; the variation in organic matter accumulation being of particular importance.

Changes to soil organic matter, which accompany various farming strategies and which occur when farming land is allowed to revert to wilderness have been outlined in section 2.3.3.2. It is clear that when the land in the Lobes was abandoned, the soils of various enclosures may well have differed as a result of variation in pedogenetic and metapedogenetic factors. However there is very little chance that the present pattern of variation bears any close, direct relationship to the ancient metapedogenetic patterns, since all such patterns will have been eclipsed by the general rise in organic matter following the cessation of cultivation. Differences in the amount of organic matter that has accumulated together with other indicators of reversion in the contemporary soils could reflect large differences in the time that has elapsed since tillage ceased, but one must also consider whether variation in the natural factors affecting soil formation and/or 'delayed' metapedogenetic factors can explain the present pattern.

Although the soil parent material is common to all enclosures, it is possible but unlikely that significant inequalities in nutrient supply produced by ancient metapedogenesis survive in the contemporary soils. Studies of soil S - IV (in zone C) demonstrate that inequalities in total soil phosphorus are present (see 5.4.2), but there is no evidence that the phosphorus supplying power of the soil has been changed, and in general the quantitative studies of phosphorus and organic matter reported in chapter 5 indicate that metapedogenetic enrichment of soil phosphorus has not been accompanied by increases in the accumulation of soil organic matter.

Although very slight changes of aspect along the eastern slopes of the plateau may create minor differences in micro-climate, it would be difficult to argue that differences in organic matter accumulation in, for example, the South Lobe and the adjacent enclosure (South Link Close) stem from such factors since no landform change occurs across the boundary which separates them. The correspondance of soil and field boundaries in fact confounds most attempts to explain the patterns in terms of natural factors.

This is not the case with vegetation; in several places soil, vegetation and field boundaries coincide. The contemporary soil - vegetation relationship is complex and may well include feed-back loops, but it is argued below (4.3.2) that, although modified in certain respects by present land use practices, the current distribution of vegetation should be explained as merely part of the long term adjustment of an entire soil - organism ecosystem that has yet to return to equilibrium; it is not surprising to find 'vegetational reversion' accompanying soil reversion but the former offers little in the way of an explanation for the latter.

The quality of land drainage within the Lobes is affected by topographic variation within and between these enclosures, but is also influenced by the presence of delayed metapedogenetic factors. The Lobe boundaries include deep external ditches which must divert surface water flow away from the Lobe soils and may have a similar if lesser effect on sub-surface flow. This diversion of water, which affects all the Lobes, might merely increase the time needed for stagnopodzol features to re-emerge in the Lobe soils but, to the extent that the ditches may be regarded as permanent landscape features, it could also amount to a permanent alteration to the balance of soil-forming processes that will indefinitely delay a reversion to soils similar to those in virgin and outfield land.

The strength of such diversion is spectacularly evident in the north-eastern part of the study area. Here, the deep lane that skirts and diverts water away from the land in Central Lobe 1 and the long corn-ditched southern boundary of the North Lobe, which almost reaches the plateau summit, act together to funnel water down into the North Channel, where it can be shown that the wetness of soils has substantially increased since these boundaries were constructed. The consequent build-up of a deep peat bog has not only partially buried a prehistoric boundary, which must have been built in drier conditions, but has also in places overridden the medieval corn-ditch itself. Where breaks in the latter allow some of the concentrated flow to spill into the North Lobe, small patches of S - V type soils with iron-pans and exceptionally deep peat have formed; the ubiquitous lynchets of this Lobe continue uninterrupted into these areas and so complete a chain of evidence that points incontrovertibly to the presence and nature of soil transformations that have occurred during post-medieval times.

The leats could also reduce the flow of water to soils on the slopes below them; with one exception no differences in the soils either side of leats have been observed, though this may merely reflect the relatively recent construction of such channels. The exceptional area lies in the North Lobe, where leakage of water from the only leat still in use has created very small artificial flush areas in a couple of spots immediately adjacent to the leat.

The diversion of water by leats and corn-ditches is a factor affecting all the Lobes and, although it must certainly be taken into account in any explanation of the soil development processes in these enclosures, for a better understanding of the contemporary soil distribution, one must look also to the natural pattern of soil drainage imposed by topographic variation. Much of the North Lobe encompasses convex, well-drained shedding slopes which have S - IV soils but in central parts of the Lobe, straighter (even slightly convex) slopes occur in the very gentle valley that separates the steep western half of the Lobe from the lower plateau; in these damper receiving regions, soils of type S - III occur intermittently. Similar S - III profiles with their more humose surface are found throughout South Link Close, Central Lobe 3 and over most of the southern half of Central Lobe 1. In these areas, however, they occupy shedding slopes little different from those occupied by S - IV soils in the North Lobe; in a few places, the slopes are even steeper. The leats and, more important, the corn-ditches around these enclosures are much like those around the North Lobe; the boundary on the southern side of Central Lobe 1, in particular, provides an almost perfect analogue of the relationships present on the south-western side of the North Lobe. The greater extent of stagnopodzol reversion in these areas must, then, be due to some other factor, and one may reasonably postulate that cultivation stopped earlier in Central Lobe 3, South Link Close and the southern half of Central

Lobe 1 than in the North Lobe.

The Central Field in the northern half of Central Lobe 1 consists of a long, slightly convex slope which would have shared at least some of the dampness of the adjacent North Channel were it not for the diversion of water by the North Lane. Despite this, if drainage was the main factor determining soil type in this receiving area, one would expect either S - III soils or a mosaic of S - III and IV soils by analogy with the similar situation in the damper parts of the neighbouring North Lobe. In fact, this is the only large area dominated by S - V soils which have a thin but well-differentiated peat surface. In this area too, one may invoke early abandonment of tillage as the factor responsible for a greater degree of reversion than is apparent in the North Lobe. A thicker peat cover occurs on the slightly convex slopes of the West Field and adjacent areas in the southern half of Central Lobe 1; since the underlying mineral soil is also darker than that of the soils in the Central Field, this area has been mapped as having S - III soils with deep er than normal peat. However, taken together these characteristics indicate a soil distinguishable from virgin stagnopodzols only by the still relatively shallow depth and high mineral content of its peat; these profiles cannot be readily distinguished from some outfield stagnopodzols (S - Ia soils). Since, if there is any significant difference in drainage between the West and Central Fields, it is that the former is better drained, one may argue for a particularly early end to cultivation of this land.

Finally, one must consider the eastern parts of this Lobe. The East and Wedge Fields occupy nearly flat land, stretching from the end of the reciving slopes of the Central Field down to the lower slopes of the Venford Brook valley, which at this point have been truncated by the large reservoir builders' quarry. It is a landscape position analogous to the South-eastern Field of the North Lobe and, like that area, is dominated by S - IV soils, though S - III profiles occur (rarely) in the Wedge Field. The western boundary of the latter includes a small (and now heavily silted-up) ditch, which may play some part in the soil change that occurs at this internal boundary, but it seems unlikely that these fields have enjoyed a significantly different history of land use from those of the North Lobe. Across the modern road in the southern half of the Lobe, S - IV soils are also found in a small area extending south of the Wedge Field. However in this zone, works associated with an earlier road including drainage ditches and spoil heaps, as well as a narrow hollowway and gulleying have disturbed the surface soils and changed local drainage to such an extent that the contemporary soils testify only to these disturbances.

Fig. 4.8 recapitulates and formalises the arguments and inferences made above concerning the land use history of the North and Central Lobes. One of the aspects brought out in this chart is the difficulty of making more precise statements about the relative timing of cultivation. Even in Central Lobe 1, where several changes of soil occur, the change in land form across the Lobe does not allow one to assess, for example, whether the southern half of the Lobe went out of cultivation earlier, later or at the same time as the Central Field. Within the northern half, however, it is possible to suggest a sequence of tillage abandonment that is entirely consistent with the archaeological evidence for cultivation. The most sizeable lynchets occur in the East and Wedge Fields, which the soil evidence suggests were the last areas to be tilled; on the other hand no evidence of lynchetting has been recorded in the West Field, where deep peat can be linked to early abandonment. The similarity of these soils to S - Ia soils may in fact indicate a similarity in land use; it is certainly possible that no cropping occurred here during the earliest history of the Lobe aand that the present shallow, mixed peat is due entirely to a brief, later period of cultivation.

This brings out a more general limitation on inference that must be borne in mind when assessing the ability of soil characteristics to record land use events. In any area of these Lobes, cultivation might have been abandoned for long periods only to be renewed at some later date. If the latter episode was more than the most brief event, it could well detroy all trace of the long period of fallow. For example, it cannot be excluded that for a period all land in the valley was abandoned and that the present characteristics derive from a later reoccupation. However, the limited sequence of final abandonment that has been suggested would still be valid. Clearly, it is in the context of intensive study of other archaeological evidence (cultivation artifacts, boundary relationships, etc.) that soil evidence can sustain the most powerful inferences.

In the South Lobe, archaeological evidence of cultivation (lynchetting) is only encountered at the eastern and southern boundaries and is in no way comparable to the sizeable lynchets of the North Lobe. The soil here is the peculiar stagnopodzol variant S - Ib, whose Ah/E (or Ah) sub-surface mineral horizon is in many ways analogous to the surface soil in the most intensively disturbed parts of the outfield (e.g. segments XI and XII of zone A). Archaeological and soil evidence thus concur and indicate a relatively brief period of cropping. However, the highly organic mineral soil horizon is now overlain by a substantial layer of peat, whose relatively high mineral content may indicate further casual cropping of much later date. If this is the case, soil S - Ib represents an example of a soil that has developed along Pathway 3b of the models advanced earlier (see 2.4.2). The later cropping may well have occurred at the time when the boundaries around the northern half of the Lobe were refurbished (probably 14th century), for clear signs of a cropping episode are evident in air photographs, but these signs are confined to the northern segment. However, the air photographs also show the extensive animal gulleying that has occurred in this Lobe and which is particularly frequent in the southern segment; it may be that at much the same time as casual cropping was affecting the soil in the northern half of the Lobe, very heavy animal traffic was incorporating similar amounts of mineral material in the soil of the southern segment, though this may have occurred at a much later date.

It is difficult to avoid the conclusion that intensive pastoral use of land is in some manner responsible for the special characteristics of the remaining soil type S - II. And here too it is the strong linkage of soil and archaeological evidence that allows this inference. This soil is found in the Close - the only part of the North Lobe which lacks cultivation artifacts; it is found in the Lower South Field, which also lacks cultivation artifacts and in addition has deep gulleys fanning out immediately west of the gate from Central Lobe 1; finally it occurs sporadically in the funnel-shaped enclosure west of Central Lobe 3 which leads into the Central Lane. It is inconceivable that this area was ever used for cultivation.

The soil pattern in the Close, which is divided in two by a reave, is particularly interesting. To the east of this prehistoric boundary, the deep organic horizon that is the hallmark of this soil is markedly more mineral-rich than it is in the western half of the enclosure. Moreover, the transition from soil S - II in the Close to soil S - IV in the adjacent, sub-divided arable field (the North-eastern Field) is, unlike most soil boundaries in the Lobes, difficult to pin down. There does not seem to be a wide transition zone - most profiles can be assigned to one or the other soil - but the position of the fairly sharp boundary does not simply occur along a straight North-South line. The edge of the area used as sub-divided arable, in this one instance, is not marked by a clear field boundary and it is conceivable that the margin of cultivation in this field varied from time to time. The southern end of the reave terminates at a transverse orthostat some 1 - 2 m north of the southern boundary of the Close; this could be a late modification of the prehistoric boundary that left a gate between the two halves of the Close. It seems possible that early cultivations included all land east of the reave and that at a later date the Close was extended; a hedge might have been set to provide a new eastern boundary.

Without laboratory studies, it is only possible to offer some brief, highly speculative remarks on the likely mechanisms that could account for this deep, loamy organic soil. If the small enclosures in which it occurs were used to impound animals, one would expect 'poaching' and nutrient enrichment by transfer from grazing areas (see 2.3.1.1); the former could explain the incorporation of small amounts of mineral material, while the latter, by enhancing the amount of biological activity in the soil (particularly the earthworm populations), might explain why in this soil, unlike the stagnopodzols, there is a gradual transition from Oh/Ah to Ah/E horizon. Greater earthworm activity could also be responsible for the very low stone content, though in part at least this could merely reflect the fact that much of the horizon is derived from a surface peat.

It has been argued that to a very substantial extent the surface soil characteristics within the study area can be explained as the products of metapedogenesis as modified by subsequent pedogenesis. By considering the form taken by these products - artifacts - together with the field archaeological evidence, which has been presented in detail elsewhere (Fleming and Ralph: in press) , it has been possible to infer the nature of the metapedogenetic factors responsible (brief outfield tillage, more long-lived arable land use, intensive pastoral land use). The products of subsequent pedogenesis have been used to suggest a relative chronology of events, which is entirely consistent with the field archaeological evidence and the tentative but absolute chronology proposed by Fleming and Ralph. All these aspects are summarised in Fig. 4.9, which shows the nature and dating of land use in each of the major medieval enclosures and has been taken with minor modifications from the cited article.

Several of the more detailed, quantitative soil investigations reported in Chapter 5 provide additional information about the medieval farming of Holne Moor, and assessment of the wider implications of this soil survey appears in Chapter 6.

4.3.2 Vegetation, soils and land use

A general description of the vegetation in the study area together with a map prepared from air photographs taken in 1969 has been presented earlier (see 3.2.1 and Fig. 3.2). In this section further information about the vegetation obtained by the author during ground surveys in 1966 and 1978, and by Dr S Rogers of Seale-Hayne Agricultural College, Newton Abbot, in 1978 will be presented in support of a discussion, whose principal purpose is explication of the apparent relationships between contemporary soils, vegetation and both the ancient and modern land use of Holne Moor.

The author has no formal botanical training and does not pretend that the ground surveys add materially to the broad picture that can be garnered from expert examination of the 1969 air cover. In fact for the general positioning of vegetation boundaries and in particular the presence and location of small patches of bracken-grass communities, the vegetation map based on air cover is more useful than the map presented here (Fig. 4.10), which for the most part is based on discontinuous data and so lacks fine detail. However, only ground survey revealed some of the slight but significant vegetation differences within the medieval enclosures and, where detailed mapping of vegetation boundaries was undertaken, allowed one to assess the amount of movement of boundaries after an interval of eight years. The small scale but more expert studies of Dr S Rogers also provided new information (Table 4.5) , but detailed analysis and interpretation of this data cannot be offered in this thesis.

Comparison of the soil maps (Figs. 4.2 and 4.3) with the vegetation maps (Figs. 3.2 and 4.10) and with the land use map (Fig. 4.9) reveals that, although in most parts of the study area a strong case can be made for linking the plant distributions to soil characteristics, there are several exceptions to this generalisation, not all of them clearly explicable as recent by-products of swaling. At the two extremes are the Stagnopodzols (S - I and Ia), which in most areas are dominated by heather and purple moor grass, and the Humic brown podzolic soils (S - IV), which are usually covered by 'bracken-infested' grassland. Table 4.5 includes a sample from the latter (Map reference 1, in zone C) and all the other analyses, except for Map reference 6, provide examples of the heath communities found on the Stagnopodzols. Much of the variation among the heath communities appears to reflect differences in the timing and perhaps intensity of moor burning.

Table 4.5 Botanical analyses by Dr.S.Rogers, Seal-Hayne College, of selected areas on Holne Moor[1]

Zone	C		A		A		B		C		B		A	
Sub-zone			C		N								E	
Segment			VI		XIII								X	
Enclosure	North Lobe		Outer South		Inner South		North Field		North Field		Outer South		Outer South	
Vegetation Map[2] reference	1		6		7		4		2		3		5	
Viola riviniana	1.0)													
Oxalis acetosella	2.0)													
Lolium pereme	2.0)	17.0												
Agrostis canina	3.0)													
Holcus lanatus	9.0)													
Agrostis tenuis	55.0)		26.0)											
Anthoxanthum odoratum	31.0)		4.0)											
Festuca ovina	4.0)	113.0	19.0)	73.0										
Luzula campestre	5.0)		2.0)											
Galium saxatile	18.0)		12.0)											
Vaccinium myrtillus	1.0)		13.0)		3.0)		1.0)		3.0)		)		4.0)	
Agrostis setacea	2.0)	39.0	9.0)	48.0	15.0)	37.0	31.0)	46.0	38.0)	63.5	48.5)	52.5	61.0)	67.0
Potentilla erecta	9.0)		4.0)		2.0)		2.0)		3.0)		2.0)		2.0)	
Hypnum cupressiforme	27.0)		22.0)		17.0)		12.0)		19.5)		2.0)		)	

(cont)

Table 4.5 (cont'd (i))

Zone	C	A	A	B	C	B	A
Sub-zone		C	N				E
Segment		VI	XIII				X
Enclosure	North Lobe	Outer South	Inner South	North Field	North Field	Outer South	Outer South
Vegetation Map reference(2)	1	6	7	4	2	3	5
Carex pilulifera		7.0) 58.0					
Deschampsia flexuosa		51.0)				0.5	
Nardus stricta			10.0	2.0		5.0	17.0
Molinia caerulea			99.0	44.5	134.0	77.5	143.0
Calluna vulgaris			74.0	199.0	173.0	207.5	137.0
Erica tetralix			10.0	27.5	15.0	28.5	28.0
Erica cinerea				2.0	2.0	3.5	40.0
Carex bineruis				1.5	2.0	8.0	1.0
Ulex galli			10.0		14.0	2.0	14.0
Sieglingia decumbens				0.5			
Polygala					1.0		2.0
Trichophorum caespitosum						0.5	

(cont)

Table 4.5 (cont'd (ii))

Zone	C	A	A	B	C	B	A
Sub-zone		C	N				E
Segment		VI	XIII				X
Enclosure	North Lobe	Outer South	Inner South	North Field	North Field	Outer South	Outer South
Vegetation Map reference (2)	1	6	7	4	2	3	5
Pteridium aquilinum (fronds/m^2)	30.2	38.6					
% of C. vulgaris alive			9.5	ND	32.9	ND	ND
% cover by litter	179.0	161.0	187.0	96.0	242.0	127.0	224.0
% cover by plants	171.0	179.0	245.0	328.5	396.0	403.0	451.0
Points sampled	100	100	100	200	100	200	100
SOIL TYPE	S - IV	←		S - Ia stagnopodzols			→
Number of species	15	12	9	12	11	12	12
Number of species with > 20.0% cover	3 + P. aquilinum	3 + P. aquilinum	2	4	3	4	4

(1) Values given are for percentage cover of species listed, except for Pteridium aquilinum where the values are for fronds m^{-2}.

(2) See fig. 4.10 for sampling locations indicated by these reference numbers.

The 'intermediate' soils (S - III and V) have 'intermediate' communities; unfortunately, no detailed studies have been undertaken in these areas. Soil S - III generally carries bracken-grass communities but, unlike those associated with soil S - IV, these communities include a low density but regular presence of heather and there are patches, sometimes large, in which heather is much more strongly represented. The latter does not appear to be linked to any appreciable variation in soil qualities and may also be a pattern imposed by old moor burns. Heather is even more common on the more peaty S - V soils and in these areas one also finds purple moor grass, which in places may be the dominant plant.

As might be expected, the deep organic soil S - II generally supports plant communities similar to those on the Stagnopodzols but, particularly in the Close, fine grasses are also important elements in the vegetation. In the North Lobe, heather is now largely restricted to the Close; the larger areas of heather visible in the 1969 air photographs, which seem to have arisen after moor burning, have mainly been recolonised by bracken and grasses. An exception is provided by the small patch of S - V soils, which carry a plant community almost identical to those on the Stagnopodzols in the adjacent North Channel.

However there are some surprises. The South Lobe, which has a Stagnopodzol soil (S - Ib), has large areas of grass with bracken; heather is mainly restricted to small islands in the northern half of the Lobe. Bracken-infested grassland is also abundant in zone A of the Outer South Field and, in this case, the area affected seems to have increased slightly since 1969. Neither the present nor the earlier distribution seem to be linked to variation in the qualities of surface soils or sub-soils and it is particularly surprising to find that some of the most dense bracken stands occur in areas where weak sub-soil gleying is very common. This bracken-grass community is superficially very similar to communities in the North Lobe, but there are in fact several important differences (see Table 4.5; compare Map references 1 and 6). In zone A, the flora includes an abundance of Deschampsia flexuosa and both Festuca ovina and Vaccinium myrtillus are common; the latter species are rare in the North Lobe and the former is extremely rare. Instead, the vegetation of the Lobe soils includes several grasses, which do not seem to occur elsewhere, and in particular has an abundance of Anthoxanthum odoratum. These differences may only reflect the very substantial differences in soil quality (S - Ia v S - IV) in these areas, but it seems possible that they could have arisen as a more direct result of differences in land use. Perhaps some of these species are in a sense 'relict species'.

More detailed, expert investigation of the vegetation in the study area will be needed to explain fully both the way in which it responds to soil variation and the reason for apparently 'exceptional' areas, but one or two speculative comments are in order. First, it seems that, in the outfield and virgin areas with Stagnopodzol soils, the bracken-grass communities are found mainly in or close to areas with disturbed soils and that colonisation along the medieval boundaries (and, to a lesser extent, the prehistoric boundaries) is an important element in the present distribution pattern. The larger areas (like that in zone A) cannot be fully explained in this fashion. It is worth noting that there is not the slightest evidence that the Stagnopodzols beneath such bracken stands, which must be at least 15 years old and probably much older, are changing into brown podzolic soils; in fact none of the observations provide support for the barely credible hypothesis proposed by Jarvis and Duncan (1976, 1977). In zone C, a sharp change from bracken-infested grassland to Calluna-Molinia moorland coincides with an equally sharp soil boundary but is most economically explained as an instance where pre-existing soil differences (of metapedogenetic origin) are reflected in contemporary vegetation patterns; in several other areas, the sharper bracken boundaries appear to reflect fire effects and certainly are not always concordant with soil boundaries (see, for example, the boundaries immediately west and south of Central Lobe 3, which coincide with leats that seem to have acted as firebreaks).

Secondly, it can be suggested that the general 'matching' of soils and vegetation arises not from deterministic relationships within the soil-organism ecosystem but from a continuous process of soil-vegetation interaction during a period in which metapedogenetically-imposed features have been gradually eroded. The pattern in Central Lobe 1 is particularly instructive in this respect. In the northern half of this Lobe, there are three soil types, which, although they mimic a natural catenary sequence, have been attributed above to differences in the age of abandonment of tillage. Although other factors provide 'noise' (e.g. disturbed soils colonised by bracken alongside the modern road and possibly fire-induced patches where heather grows more densely), ground survey shows very clearly that each soil type tends to be dominated by a different vegetational community. The East and Wedge Fields (S - IV) are mainly grassy with some bracken; the Central Field (S - V) has far more heather and purple moor grass replaces the finer grasses; the West Field (deep peat variant of S - III) is an area of Calluna-Molinia moorland. In such cases, close study of the vegetation would yield patterns similar to the pattern of soil distribution but exceptional areas like the South Lobe and zone A prevent one from generally using vegetation as an accurate guide to soil-type. Nor in general will study restricted to air photographs provide enough detail for the sort of interpretations offered here; in many cases the patterns evident in the air cover can only be properly understood with the hindsight provided by high density ground survey of both soil and vegetation.

Finally it must be pointed out that, although a fire-grazing interaction may be responsible for the minor differences in the representation of species within areas of Calluna-Molinia moorland, there is no evidence that the major division between the latter and the areas where fine grasses are common has arisen or is sustained by the present very low density grazing by sheep, cattle and horses. None of these herbivores has established regular night camps in the grassland areas during the past five years, nor in general do such areas seem to receive extra attention during grazing. Two factors may be responsible for this apparent lack of interest in what might seem to be a particularly important grazing resource. First, there is the very dense bracken cover that for much of the year prevents easy access to the ground flora of herbs and grasses and no doubt markedly reduces the productivity of the latter. For a brief period during the spring renewed growth of grasses precedes the re-establishment of the bracken cover and it is noticeable that during this time, which coincides with lambing, the sheep do tend to concentrate on these grasslands. However, they may be as much propelled there by the lack of good grazing elsewhere at that time of year as attracted there by the frequently still very poor keep that it offers. This brings one to the second factor. For it is only in late winter and spring that the grazing resources of the study area seem to come under severe pressure. It can be doubted whether, during much of the summer and autumn, the present stock remove more than a small proportion of the available herbage; thus when grassland access is most difficult there is least pressure to utilise such resources.

The short-lived spring utilisation of the grasslands does not seem likely to produce a large enough increase in the rate of nutrient cycling for this factor to become an important element in an explanation of present vegetation patterns as was postulated in somewhat similar circumstances for fields within the Narrator catchment on the western edge of Dartmoor (Kent and Wathern 1980: 171). Inter-habitat transfer of nutrients might have a similar effect but, it has been argued earlier (see 2.2.4) that in itself differential use of habitat-types does not necessarily create inter-habitat transfers; certainly in this instance such transfers, if they occur, must be very small. One may conclude that, although many details of the present character and distribution of plant communities undoubtedly arise from modern land use practices - swaling and grazing, the major variations in vegetation mainly reflect the qualities of the underlying soils, and so indirectly reflect the long-forgotten activities of medieval farmers; there is no indication in these surveys that prehistoric farming has left a legacy of this type.

5. THE SOILS OF HOLNE MOOR - INVESTIGATIONS OF PHOSPHORUS AND ORGANIC MATTER

> 'At this site (Byrsted Heath) the author (Professor G. Hatt) collected several samples of soil both from the old fields and from the virgin heath, and found confirmation of the observation of Dr O. Arrhenius that soil which has been cultivated in former times contains a greater proportion of phosphoric acid than uncultivated soil. This hint is one which is perhaps worth following up in our efforts to trace Neolithic or Bronze Age cultivations on our western moors.' (Curwen 1932:396).

5.1 Introduction

As had been anticipated, the field survey by itself, although capable of revealing a considerable amount of information about the medieval land use of the study area, did not provide any information about prehistoric land use. Nor could the field survey techniques yield more than a small amount of quantitative and so more rigorous evaluation. The investigations of soil phosphorus and organic matter reported in this chapter attempt to move beyond these limitations. The specific objectives and the methods used during these quantitative studies are presented here in four stages. First, there are what are termed here 'the contributory studies'. These provide information about natural trends and patterns of phosphorus and organic matter in the soils of Holne Moor (section 5.2.1, which considers the results of studies of buried palaeosols) and about the way in which these may be affected by human activities (section 5.2.2, which considers information provided by studies of the soils in houses, a ceremonial monument and the fields of nearby farms). Some aspects of the models of pedogenesis and metapedogenesis described in chapter 2 are then reconsidered in the light of these preliminary studies (section 5.3). In a third section, the results of investigations in prehistoric and medieval agricultural enclosures are presented (section 5.4) and this is followed by an assessment of the relationship between these results and the expectations generated by the models.

5.2 The contributory studies

In framing a research strategy which would maximise benefit and minimise cost (in the broadest sense), one sought out locations and features which could yield information that would be not only of direct relevance to the proximate objectives of the studies that form the core of this thesis but would also be of interest to the general archaeological enquiries on Holne Moor and, to a lesser extent, other studies elsewhere. This is particularly the case with the preliminary studies reported in this section.

The palaeosols described in the first part of this section were examined and sampled in order to obtain information about the morphological, physical and chemical properties of soils buried in medieval and prehistoric times - matters of central importance to this thesis - but the opportunity was also taken to extract samples for pollen analysis, which have been of use to the author (a brief account of their pollen content has been included in section 3.2.1) and to others interested in the nature and timing of the development of vegetation on Dartmoor. Similarly, and perhaps to an even greater extent, the investigations of soils in prehistoric houses, a ceremonial monument and in the modern fields of farms near the study area, which are described in the second half of this section, were designed not only to answer the specific questions discussed below but to reveal aspects which cannot, for reasons of relevance and space, be properly considered here.

These studies therefore appear, to a lesser or greater extent, in a truncated form; in some cases, most or all of the available data from a particular study is presented and truncation mainly affects the extent to which this data is fully explored in discussion and interpretation. In other cases, only a part, sometimes a small proportion, of the available data has been used. (It should also be noted that studies of the amino-acids in the buried palaeosols and nearby surface soils, which were undertaken by Beavis (1981) using sub-samples provided by the author, have only been briefly considered here, and that parallel but as yet incomplete micromorphological studies by the author (in collaboration with P. Fisher) only receive even more fleeting mention).

The presentation of data produced by studies included in this chapter has sometimes been abbreviated in another fashion. A series of essentially separate but related and similar sets of data offer an opportunity to examine, in each and every data set, some specific variable or relationship between variables that may be relevant to questions posed by the models presented earlier. Where it is useful to demonstrate that all the data sets share some property, this opportunity has been taken up. However, in other cases, this course of action would lead to laborious reiteration of data and the conclusions that stem from them. In consequence, although in most cases the same series of numerical manipulations and analyses have in fact been undertaken, the presentation is selective. In general, such selection was based on differences in the size and/or context of sample sets, which made one or more sets more suitable than another for the investigation of a specific issue.

In discussing and interpreting the results of the mainly small scale studies considered in this section, it has often been necessary to make comparisons with larger data sets, which have primarily been studied for other purposes. In these cases, only the relevant part of such data sets appears in this section, the rest appearing in the appropriate later section. Consequent repetition of some data has been regarded as a lesser evil than constant reference to the later sections of the chapter.

5.2.1 Palaeosols

For some three thousand years the construction of land boundaries and houses, and the extraction of tin from Holne Moor has led to the burial of soils on a substantial scale. Some of the field characteristics of these buried palaeosols have been examined at a number of locations during the course of the archaeological excavations and the soil survey and some aspects of these soils have already been mentioned (see 4.3.1 and Table 4.2). Two buried profiles were selected for more intensive study; one lay beneath the early medieval boundary that bisects zone C; the other was buried during the late second millennium bc by the construction of a house in zone A.

Vreeken (1975) has suggested that, at least theoretically, the investigation of such palaeosols, which collectively comprise what he would term a 'pre-incisive chronosequence', offers a better opportunity to trace the sequential development of soils than examination of post-incisive or time-transgressive chronosequences, which nevertheless have formed the subject of most pedological investigations of palaeosols (see also Yaalon 1971); however, he also noted that relatively few pre-incisive sequences had been studied and that, in such studies, post-burial alteration sometimes created interpretative dilemmas that might never be solved satisfactorily. Valentine and Dalrymple (1976) offered a more comprehensive review of studies of buried palaeosols but they too stressed the problems posed by post-burial alterations; they noted that these could involve both the destruction of original features and/or the imposition of new ones, and that such changes might often hinder the 'recognition' or 'identification' of a palaeosol. Their discussion of the problems of recognising or identifying palaeosols seems to have been primarily addressed to those studying soils which had been buried by natural processes (e.g. by a blanket of loess) and indeed it might be thought that the study of soils beneath man-created landscape features would be relatively free of such problems; unfortunately this is not the case.

Recognition or identification of a palaeosol cannot merely involve establishing the stratigraphy of an exposure and so locating the position of a buried surface, which can be (but is not always) an easy task when the surface has been buried by an archaeological feature, but must also include distinguishing between relict (i.e. fossil), diagenetic and pedometamorphic (i.e. the products of pedogenetic processes operating on a soil after burial) features. It is also important to establish whether at the time of burial the soil was intact or had in some way been truncated. Gerasimov (1971:20) concluded that 'the main task in the study of buried soils is to define the degree of preservation or "protection" of the paleosol', and that this task was often underestimated. Yaalon too thought that there was 'an urgent need for studies on the rate of alteration and preservation of pedological features in palaeosols' (1971:35). It was noted earlier that these aspects had received scant attention during previous studies of buried palaeosols in south-west Britain (see 3.2.1) and that as a result it was difficult to judge whether, for example, an iron-pan in a buried palaeosol was a relict or pedometamorphic feature. Although in the case of the better-known British investigations of palaeosols under burial mounds (Dimbleby 1962), deeper burial may make <u>diagenetic</u> processes a more likely source of alteration than a continuance of pedogenetic processes, identification of truly relict features still remains a problem. Unlike analogous research in America (e.g. Parsons 1962) and Russia (e.g. Madanov <u>et al</u> 1968), Dimbleby relied very heavily on the morphological features of the buried soils to support his hypotheses about soil history, an approach that Gerasimov (1971:20) has suggested 'often leads to superficial and false conclusions'.

From this very brief survey of the problems associated with studies of buried palaeosols, one could conclude that the best strategy for investigation of long term changes in soils would be to examine and compare palaeosols of similar age beneath both deep and shallow overburdens. However, on Holne Moor this would only be possible with soils buried in late or post-medieval times to which period one must attribute most or all of the larger tinners' spoil heaps. To understand the progress of soil development in earlier periods and, more specifically, to assess the qualities of the soils, which existed at or close to the moment when they came under human management in both prehistoric and early medieval times (see 2.1 and Fig. 2.1), it was necessary to investigate soils beneath walls, despite the likelihood that they would prove to have been substantially altered due to the shallowness of the protecting overburden (ca. 0.5 m). It was felt that at a minimum such studies might establish the extent to which one could rely on the evidence provided in similar studies where little or no attempt had been made to assess post-burial changes. Moreover, since sampling beneath walls allowed the investigation of palaeosols within zones A and C where the characteristics of many contemporary soils were being investigated, this tactic would at least ensure that unusually extensive sets of data would be available for comparisons.

5.2.1.1 An early medieval palaeosol

The field survey revealed that the greatest difference between soils either side of a land boundary occurred along the southern boundary of the North Lobe; differences in both sub-soils and surface soils were evident (see 4.2.3 and Figs. 4.2 and 4.3), and these soils have been studied in detail in zone C (see 5.4.2). A major question which could not easily be resolved from study of the contemporary soils alone concerned the extent to which their differences should be exclusively attributed to metapedogenetic processes operating within the North Lobe soils or alternatively might in part at least (and perhaps solely) be due to continued pedogenesis in the North Field at a time when the Lobe soils had been 'removed' from the pedogenetic system. An investigation of the soil beneath the boundary within zone C offered the best way of resolving this question and could at the same time provide a general picture of the stage of soil development reached by the soils on Holne Moor at around AD 1000. It was hoped that this buried soil would be an example of a soil of type S_3 (see 2.1 and Fig. 2.1) and this appears to be the case.

Fig. 5.1 shows the position of the two (1.5 x 2.0 - 2.5 m) trenches which provided both partial sections of the ditch and bank that form the boundary and an exposure of the soil profile beneath it; the location of the soil profiles in zone C that have been used as a comparative sample can also be seen. Fig. 5.2 illustrates the major features revealed by this excavation which, at times, used hand trowelling to ensure that the surface of the buried soil would be properly observed prior to its destruction. Analyses of samples from the ditch sediments are not reported here since they provide only a small amount of information relevant to the issues discussed below.

Morphological features

Although some of the original wall and bank material has fallen back into the ditch (layer 9 appears to be a collapse layer, which sealed earlier sediments and caused a shift in the axis of silting), the remaining volume of soil in the bank corresponds closely to the volume of the present ditch and it is therefore economic to presume that the latter provided all the material for the bank. If this is correct, it is unlikely that there has been serious erosion of the 'ramp', which forms the north side of the boundary and covered the old land surface, though the wall itself must once have stood somewhat higher. The preservation in the lower half of the overburden of chunks and patches of redeposited Oh-Ah, Ah/E, Bsh and Bs_2 soil materials (including some intact 'clods' and 'turves'), clearly identifiable in the field from their still contrasting colours and textures, provides further evidence that the bank was made up of material excavated from the ditch (rather than, for example, being made up of turves alone). This matter is of some importance since, if little erosion has occurred, it can be presumed that the new shallow (ca. 0.25 m) soil profile, which has developed in the upper part of the overburden and whose field appearance is similar to soil profiles in the adjacent sub-divided arable land (soils of type S - IV), representa the result of about a thousand years of soil development.

Equally important, the apparently well-preserved character of the lower overburden, which extends to the pollen and stone content, and to some extent the chemical qualities of the materials, may be regarded as evidence that the underlying profile may also have undergone minimal alteration of at least its morphological qualities. Taken at its face value, the buried soil appears to be what one would expect of a type S_3 soil on Holne Moor, namely an earlier, less-developed variant of a stagnopodzol. The principal morphological differences between it and the Iron-pan stagnopodzols in the adjacent area of the North Field are the shallower depth and higher mineral content of the Oh-Ah surface horizon, the absence of an iron-pan and the slightly more diffuse boundary between the Ah/E and Bs_1 horizons.

With a depth of 6-7 cms, the buried Oh-Ah horizon is about half as thick as the Oh horizons of nearby profiles and only just over a third of the depth of the organic accumulation which it is thought would have covered almost all parts of the study area if natural processes had not been interrupted by man (see 4.3.1.1). Post-burial alteration of this buried organic surface is considered at a later stage. The absence of an iron-pan and, related to this, the relatively diffuse lower boundary of the Ah/E horizon does not appear to be an accident of sampling; every profile examined in adjacent areas of the North Field (9 pits) possessed a thin iron-pan, and the configuration of the iron-pan in the ditch section also suggests that its formation post-dates the cutting of the ditch and the burial of a soil, which was already covered by a significant accumulation of 'mor' humus.

Finally it is worth noting that the depths and thicknesses of the soil horizons of the palaeosol and of the Iron-pan stagnopodzol at the southern end of the ditch trench are very similar and, in this respect, both differ from the soils in the North Lobe, where the upper horizons appear to have extended their depth at the expense of the lower B horizon; this change can be seen to occur about halfway along the bank section and appears to be related to the depth of the overburden. If this is correct, this difference between S - IV and S - I series soils may largely be attributable to the absence of a sealing cover of organic accumulation and could mainly have developed during the long period since the field was abandoned.

Quantitative investigations

Particle size characteristics of the overburden and the buried soil are listed in Table 5.1, which can be compared with similar data for nearby Iron-pan stagnopodzols and Humic brown podzolic soils shown in Table 3.8. Such comparison shows that for the most part the horizons within the buried soil and the overburden materials are sufficiently similar to analogous horizons within the contemporary soils for one to suppose that the slight differences, which are present, arise from natural variability and the imprecision of these measurements. The high stone and coarse sand content of the newly developed Ah horizon samples and the substantial variation in the particle size characteristics of the samples from the underlying overburden are consistent with the mixed origin of these materials and taken together suggest that the upper part of the overburden may have been derived largely from B horizon (and even BCux horizon) parts of the adjacent ditch. To this extent, but only to this extent, there is a reversed stratigraphy; unfortunately, one certainly cannot assume that collectively the overburden materials, whose maximum thickness is similar to that of nearby profiles, can be regarded as equivalent to the material once present in a 'complete' soil profile.

The pH values recorded for samples from the overburden, the palaeosol and nearby profiles are shown in Fig. 5.3, where contemporary Iron-pan stagnopodzols have been matched to the buried stagnopodzol and contemporary Humic brown podzolic soils to the overburden (a presentation format followed in some other diagrams illustrating these soils). Again it is clear that the 'new' and 'ancient' soils are not very different from their modern counterparts, although the low pH of the surface sample from the overburden produces a much stronger gradient of change in that profile than is typical of the North Lobe soils. It can be noted that the redeposited Oh-Ah material in the overburden causes a hiccup in the rise in pH with depth but the pH of this sample is nevertheless somewhat higher than that of equivalent material in the buried soil and in the contemporary soils. The underlying redeposited Bs_2 material, which lies at a similar depth below the surface to that of the Bs_2 horizons in undisturbed contemporary soils, does not seem to have been altered by its incorporation in the overburden at thie level. The pH of the Oh-Ah horizon of the buried soil is very slightly lower, and the underlying Ah/E horizon samples somewhat higher, than is typical of contemporary soils, a combination of differences that results in a reversal of the trend in pH found in the modern soils, where the eluvial mineral horizon is usually more acid than the organic surface. The values for the B horizons of the buried soil are in line with those from contemporary soils.

If one assumes that the small differences mentioned are 'real' and are not merely an artifact of sampling (which seems reasonable, for, although there is only a small amount of comparative information, it is for the most part very consistent), it is worth considering their genesis. The present overburden profile seems to have developed in B horizon materials excavated ca. AD 1000 and in view of this, the low pH of its surface horizon is somewhat surprising; although partially 'pre-weathered' the new 'parent materials' must have been less weathered and leached than surface and near surface soil materials. It could be that soil materials placed in a superincumbent position in the landscape suffer greater leaching and, consequently, more rapid weathering than undisturbed soils. If this is the case, the process has not yet had a substantial effect on this particular profile and certainly one cannot make much of the small difference observed here. However, the postulated process is much more clearly evident in the older overburden discussed in the next section (see 5.2.1.2).

The differences in the pH of the upper horizons of the buried and contemporary stagnopodzols could reflect the results of subsequent pedogenesis in the latter or pedametamorphic change in the former - the classic and often insoluble conundrum presented by studies of buried soils - and unfortunately, in this instance, it does not seem to be possible to rule out either of these mechanisms. From the character of the change in pH with depth in the Humic brown podzolic soils, one could argue that a steady rise in pH with depth might well have been present in an ancestral variant of today's stagnopodzols - the process of differentiation of Oh and Ah/E horizons being less advanced. On the other hand, the termination of biological upward translocation of bases to the organic surface soil, and later downward translocation of bases from the Oh-Ah horizon itself and from the overlying mineral soil, could also explain the present pattern and would be consistent with the anomalously high pH of the redeposited Oh-Ah lense in the overburden. Evidence for loss of acid-soluble inorganic phosphorus (described below) from the buried Oh-Ah soil is also consistent with an attribution of the present pattern to pedametamorphism and so the author inclines to the view that a relict pattern of pH has not survived at least in these surface samples from the buried soil. Despite this, it is evident that in general the pattern of pH values supports the morphological indications of a relatively well-preserved palaeosol.

The concentration of organic matter by weight and by volume in the palaeosol and its overburden are shown in Figs. 5.4 and 5.5, where the equivalent mean values for six of the podzolic profiles in the North Lobe and four of the stagnopodzol profiles in the North Field are shown for purposes of comparison (these particular profiles provide the least metapedogenetically altered samples from the surrounding land - see 5.4.2). Either presentation in fact provides a similar overall picture, but the volume estimations are particularly useful in a situation where the amount of fine earth in the soil varies erratically due to the disturbed origin of the parent materials. In general, the patterns in the buried and new soils are once again quite similar to the patterns in their modern counterparts, and this is also true when one considers the overall accumulation of organic matter in these profiles (shown in Figs. 5.6 and 5.7). The main differences concern the surface samples. In both the overburden and the palaeosol, these have less organic matter than the soils with which they have been compared, but note that in the overburden, the lower organic matter content of the upper part of the Ah horizon is counterbalanced by a higher value in the lower part of this horizon; the total accumulation of organic matter in the new profile (and in the overburden as a whole) is not significantly different from that within equivalent depths in the North Lobe soils. However, the values for samples from the lower part of the overburden clearly reflect the sundry origins of these redeposited materials (e.g. the high value of the Oh-Ah lense), and the similarity of the total accumulation in the overburden and the North Lobe profiles arises not from a simple equality in the dynamics of accumulation but from a complex balance between current production and decomposition, and the survival of inherited organic matter. Uncertainty even about the initial quantities (as well as qualities) of soil from the various horizons that were used to build the bank, make it unprofitable to investigate post-burial alteration processes in the overburden; a much better opportunity is provided by the buried soil itself.

Figs. 5.6 and 5.7 show that the total organic matter content of the modern stagnopodzols is markedly higher than that of the buried soil and that this difference can mainly be attributed to the large amount of organic matter now present in the peat surface of the modern soils. However, the profiles examined in the North Field also contain more organic matter in their mineral horizons ($\bar{x}$ 29.05 kg m^{-2}) than is present in the analogous portion of the buried soil (26.55 kg m^{-2}).

These differences could reflect the state of the soils on Holne Moor prior to the burial of the palaeosol but it seems more likely that, in part, they are the result of post-burial loss of organic matter. The extent of post-burial losses in the mineral soil horizons will be considered first.

Fig. 5.5 shows that the concentration of organic matter in the buried Ah/E horizon (76.1 mg cm^{-3}) is substantially lower than that in its modern counterparts (108.2 mg cm^{-3}). It can also be seen that the thickness of this buried horizon is some 4 cm greater than the mean thickness of this horizon (7.5 cm) in the nearby profiles; in consequence, the total accumulation of organic matter in these horizons is much the same (buried Ah/E - 8.75 kg m^{-2}; modern Ah/E - 8.25 kg m^{-2}), a situation that increases the difficulty of drawing up balance sheets that allow a meaningful comparison of the buried and modern soils. There is far too much variation in the thickness of this horizon among the contemporary soils (see sections 4.2.1.2 and 4.2.2.2) for one to argue that the extra thickness of the buried soil is necessarily, in any sense, a consequence of burial and so the analysis offered here attempts to circumvent the problems presented by variations in horizon thicknesses that, for these purposes, may have no significance.

If at the time of burial the concentration of organic matter in the Ah/E horizon was similar to that in the modern soils and the present lower value is the result of post-burial decomposition and perhaps translocation of organic matter, and if this loss of 32.1 mg cm^{-3} was not accompanied by changes in soil structure (e.g. compression effects), it can be argued that the soil bulk density of the buried horizon should be only very slightly lower than that of the modern Ah/E horizons, but very much lower than the present organic content of the horizon would lead one to expect. In 1979, the palaeosol and an adjacent profile (HM 79 Q), which was selected because it had an Ah/E horizon of similar thickness (13.5 cm), were sampled for the specific purpose of testing these propositions. Each Ah/E horizon was volume sampled in two layers and the standard measurements and analyses were performed; the results, shown in Table 5.2, are fully in accord with the propositions advanced. Despite the lower concentration of organic matter in the buried soil, its bulk density is nearly identical to that of the comparative sample which is, in all respects, typical of the profiles in the surrounding part of the North Field. This experiment confirmed a pattern that had been noted in several earlier samples, some of which came from undisturbed buried soils (including the B horizon of this palaeosol) and others which were obtained from disturbed materials including ditch silts and overburdens (see 3.3.2), and supports the view that, prior to burial, the concentration of organic matter in the Ah/E horizon was probably closely similar to that in the modern soils. If so, the buried horizon would initially have contained about 12.44 kg m^{-2} of organic matter and must subsequently have lost some 3.69 kg m^{-2} or 30% of its initial content. This loss may only have involved in situ decomposition but it could also have included translocation to the B horizons; such movements would be consistent with the phosphorus distribution pattern (described below) and could be responsible for the slight differences in the distribution of organic matter in the B horizons of the buried soil compared to the modern soils (see Figs. 5.4 and 5.5 and discussion below).

At present, the buried B horizons together contain 17.80 kg m^{-2}, some 3.0 kg m^{-2} less than their modern counterparts, but this is largely a result of the unusual depth of the Ah/E, which, since all calculations are to a standard depth of 40 cm below the mineral soil surface, reduces the sampled depth of the B horizons by 4 cm. The overall concentration of organic matter in these horizons (62.4 mg cm^{-3}) is only very slightly lower than that in the modern soil (64.0 mg cm^{-3}). If the latter figure is used to calculate an 'initial state' for the B horizons (the procedure used for the Ah/E horizon) a value of 18.24 kg m^{-2} is produced; this value is only 0.44 kg m^{-2} higher than the measured present content of the buried B horizons and, on the face of it, suggests a much lower rate of organic matter loss from these horizons (2.4% of their initial content). However, this is nett loss and the total loss could well have been substantially higher, if, as suggested above, the apparent loss from the Ah/E included losses by translocation. Due to differences in sampling depths, it is difficult to argue convincingly for the existence of a real difference in the distribution of organic matter within the B horizons, but it is possible that less sluggish movement of soil water in the modern soils has shifted the point of maximum accumulation to a slightly greater depth in these soils than has occurred in the buried soil. If total losses in the B horizon were greater, then, of course, this implies that loss due to decomposition in the Ah/E horizon has been somewhat lower than the estimated nett loss.

In the argument offered here, it has been assumed that the B horizons, like the Ah/E horizon initially had a concentration of organic matter similar to that of their modern counterparts; this could be incorrect and certainly cannot be reliably demonstrated. The stoniness of the B horizons makes it difficult to rely on individual measurements of soil bulk density and although the measurements obtained (Table 5.3) are, in each case, lower than would be expected from their present organic content - suggesting some loss of organic matter - one may only regard this as consistent with the view adopted here; they cannot adequately confirm it. If the organic matter content of the stagno-podzol mineral horizons has remained virtually unchanged for the last thousand years due to a steady state balance of input and decomposition rates - as seems probable, then the nett post-burial loss of organic matter from the mineral horizons can be estimated as some 4.13 kg m^{-2} or just over 13% of their initial content.

It would, of course, be quite wrong to assume a similar steady state for the overlying accumulation of organic matter. Direct and certain evidence of an accumulation of peat since AD 1000 has already been presented (see 4.3.1), and this evidence of continued peat growth since the palaeosol was buried undermines quantitative analysis of the type that has been employed to assess changes in the mineral horizons. In consequence, it is more difficult to judge which if any of the present features of the buried Oh-Ah horizon are relict. In the field, this horizon has the same appearance and structural qualities as nearby Oh horizons and was quite unlike even the most humose mineral soils that have been observed during these studies. Its stone content (see Appendix 2, Table A2.1) is, like even the more mineral-rich peats, extremely low - much lower than the most humose mineral soils. A comparison of its measured bulk density with that predicted by its present concentration of organic matter (Table 5.4) suggests that, unlike the mineral soil, this organic layer may well have been slightly compressed by the weight of the overburden.

The present concentration of organic matter at 192.0 mg cm^{-3} is some 40.9 mg cm^{-3} less than that of the contemporary Oh horizons, a difference similar to but slightly higher than the equivalent difference in the Ah/E horizon (32.1 mg cm^{-3}). However, the buried Oh-Ah possesses less than half the amount of organic matter found in the modern Oh (horizons (12.48 kg m^{-2} as opposed to 27.99 kg m^{-2}), a very much more substantial contrast than that indicated by the difference in concentration values and further confirmation, if it were needed, that organic matter has indeed accumulated on the contemporary surface soils since the palaeosol was buried. Since neither the modern nor the buried soil can reasonably be presumed to provide an unchanged reference point, an infinite array of quantitative evaluations could be pursued. Interpretation of the apparent 'reduction' (of 40.9 mg cm^{-3}) in the concentration of organic matter illustrates this point. This present difference arises as a nett result of an unknown balance between both the effects of compression and degradation of the organic matter in the buried soil and simultaneous unknown changes in the contemporary Oh horizons; it certainly cannot be used to calculate a true weight loss in the buried soil.

Since, in this instance, there is no unique solution to the conundrum, it is only possible to evaluate the initial state of the buried soil by making additional assumptions. Table 5.5 sets out the likely characteristics of the surface soil in AD 1000 on the assumption that organic matter has been lost from the buried Oh-Ah soil either in the same proportion as it appears to have been lost from the Ah/E horizon or some 50% greater. In addition, alternative assumptions as to the quantity of ignited fine earth have been included because it seems possible that the present quantity of mineral material in the buried Oh-Ah may have been increased by infiltration of mineral particles from the overlying overburden. The amount of ignited fine earth in the Oh horizons of the North Field stagnopodzols is itself higher than would be found in a virgin soil - these profiles (soil type S - Ia) lie in an outfield area and have probably been cultivated (see 5.4.2).

None of the losses assumed here is as high as those suggested by Mattingly and Williams (1962) or Gardiner and Walsh (1966) but in each of these cases the soils studied were mineral soils of very different character to the stagnopodzols on Holne Moor and had been buried for a longer period. In addition, Mattingly and Williams' estimate that ca. 75% of the organic matter in a calcareous Roman soil had been lost was based on an assumed initial organic matter content for the buried soil that was substantially higher than any of the modern 'control' soils they had investigated and, as they pointed out, assumed that the soil had not been extensively cultivated prior to burial. Gardiner and Walsh provided a description of the Neolithic soil at Newgrange which, in this author's view, suggests that their buried soil may have been truncated prior to burial and, therefore, that it may have been a mistake to suppose that a modern Ah horizon provided an appropriate unit of comparison.

Cultivation and truncation may also have affected the soil on Holne Moor; though no plough marks were seen, the former cannot be ruled out. The results of phosphorus analysis, however, strongly support the view that the soil was at least intact (see below).

The similarity of the estimated loss of organic matter per unit volume in model 1b (Table 5.5) to the estimated loss in the Ah/E horizon (30.3 mg cm^{-3} and 32.1 mg cm^{-3}) is notable and commends this particular model to the author. This model implies a nett loss rate of 5.26 g m^{-2} $year^{-1}$ in the Oh-Ah, which can be compared to an estimated nett loss rate in the Ah/E of 3.69 g m^{-2} $year^{-1}$; both calculations assume burial 1000 years ago. On the same assumptions, the entire profile to a depth of 40 cm below the mineral surface has lost 9.40 kg m^{-2} or rougly 19% of its initial content of 48.43 kg m^{-2} at a loss rate of 9.40 g m^{-2} $year^{-1}$. A balance sheet incorporating these assumptions is provided in Table 5.6.

The amount and distribution of phosphorus in the overburden and the buried soil are shown in Figs. 5.8 - 5.23. These diagrams make use of four types of presentation: Figs. 5.8 - 5.10 show the total weight of P fractions (g m^{-2}) in the profiles and the cumulative weight at specific sampling depths; Figs. 5.11 - 5.16 show the concentration of P fractions by volume of soil (µg cm^{-3}) in each horizon; Figs. 5.17 - 5.22 show the concentration of P fractions by weight of ignited fine earth (mg kg^{-1}) in each horizon; Fig. 5.23 shows the concentration of Po by weight of organic matter (mg kg^{-1}) in each horizon. In each case the data is accompanied by equivalent values from nearby profiles in the North Field; for Pt or Pt-dependent values (Pf, Pi) only two profiles are available for comparisons, but, as in the case of LOI values (and for the same reasons), Pao, Pa and the derived Po values are shown alongside the mean values for four of the eight North Field stagno-podzol profiles. The brown podzolic soils in the North Lobe provided a useful sample against which to compare pH and LOI values in the over-burden; however, this procedure cannot be used for phosphorus comparisons, since the phosphorus values in the North Lobe soils, unlike the overburden, were altered during the agricultural use of this field (see 5.4.2). The diagrams showing concentration values include an 'adjusted' value for the buried Oh-Ah horizon; this adjusted value assumes that, before burial, this horizon had the organic matter content, mineral soil content, thickness and soil bulk density calculated for model 1b presented above (see Table 5.5) but the phosphorus content (g m^{-2}) that it possesses today. In the author's view, this procedure provides a more realistic soil matrix in which to 'place' the phosphorus and thus allows a more realistic assessment of post-burial change.

Each method of presentation has advantages and disadvantages. Figs. 5.8 - 5.10 show very clearly that the total amount of phosphorus (calculated to the standard depth of 40 cm) in the buried soil is almost identical to that in nearby stagnopodzols. Equally evident is an apparent deficiency of phosphorus in the overburden; however, the latter also has less fine earth (see Fig. 5.6), which in turn reflects to a small extent, a higher than usual stone content, and to a much larger extent, the very low soil bulk density of the overburden. The brown podzolic soils of the North Lobe also typically have lower soil bulk density than the equivalent mineral horisons of the stagnopodzols (for discussion of this difference see section 5.4.2) and the low density of the new podzolic soil in the overburden may reflect the same factors. However, in addition, the redeposited materials in the lower part of the overburden have an unusually low density which may be due to structural differences arising from their disturbed origin. The deficiency of phosphorus in the overburden is therefore 'apparent' but not necessarily 'real' and cannot be seen as evidence for a leaching of phosphorus from the overburden into the buried soil. On the other hand, such movements cannot be ruled out merely because the total weight of phosphorus in the buried soil is very similar to the mean weight in nearby profiles.

The four profiles used for Pao comparisons provide a range of present-day values from 145.5 to 178.6 g Pao m^{-2} (compared to 160.7 in the buried soil) while the two 'Pt profiles' have 201.7 and 215.8 g Pt m^{-2} (compared to 203.4), a level of natural variability which could 'conceal' phosphorus additions of 10 - 15 g m^{-2} and which, therefore, make it unprofitable to pursue a precise balance sheet. The best indication that, at most, only small movements of phosphorus can have occurred lies in the similarity of the values for the overall concentration of Pt (mg kg^{-1} IFe) in the overburden (563), the palaeosol (567) and the Pt profiles (559 and 665). If, for example, the overall concentration in the palaeosol had risen from 559 to 567 since burial, this would imply an addition of only 2.7 g Pt m^{-2} to the profile. Minimal movement within, and out of, the lowest parts of the overburden can also be inferred from the similarity of the concentrations of Pao, Po, Pi and Pt (mg kg^{-1} IFe) in the redeposited materials and in the comparable horizons of contemporary undisturbed soils (see Figs. 5.18 - 5.21); for this comparison the concentration by volume (ug cm^{-3}) values provide a misleading picture (these values are depressed by the 'artificially' high volume occupied by these materials).

However, the concentration by volume values (Figs. 5.11 - 5.16) do provide the best illustration of the pattern of vertical distribution of phosphorus within the buried soil because they redress the distorting effect of low density organic horizons. In addition, if it can be assumed that the volume of the buried mineral soil has remained unchanged (as argued above), and if allowance is made for the estimated change in the volume of the organic surface horizon, then these figures also allow a meaningful comparison of the patterns of vertical distribution in the buried and contemporary soils. The general form of the distributions shown in these diagrams are typical of podzol soils (see section 2.2.2.2) and the most striking feature is the relatively high concentration of Pt in the upper part of the B horizon of the buried soil by comparison with its modern counterparts. There seems to be a corresponding, but not equal, deficiency of phosphorus in the underlying B_2 horizon and this suggests that, at least in part, the pattern has arisen not from an abnormally high input of phosphorus, but from an unusually high retention within the B_1 horizon. Once again, differences in horizon thicknesses, and thus sampling depths, hinder precise comparison of profiles but it seems that only a relatively small amount of extra phosphorus has entered the B horizons of the buried soil. The total thickness of B horizons sampled in one of the Pt profiles (GSP 2) is nearly identical to that of the buried soil; it contains 136.1 g Pt m^{-2} at a concentration of 473.2 $\mu g\ cm^{-3}$, which can be compared to the 137.6 g Pt m^{-2} at a concentration of 482.7 $\mu g\ cm^{-3}$ in the buried soil. The other Pt profile was only sampled to a depth of 31 cm, but it has a substantially lower concentration of 423.0 μg Pt cm^{-3}, a value that suggests that, taken together, the buried B horizons may have a slightly higher phosphorus content than their modern counterparts. If so, the data in Table 5.7 may indicate the order of magnitude of the excess; taken at face value, these indicate that there is some 4.1 g Pt m^{-2} more phosphorus in the mineral horizons of the buried soil as a whole and there is certainly no indication in the concentration values that this has been retained in the Ah/E horizon.

The concentration values in Figs. 5.11 - 5.16 and the data in Table 5.7 both indicate an important difference between the fractional composition of the phosphorus in the palaeosol and the contemporary soil. The tabulated data show that, taking the mineral soil as a whole, there is little difference in the split between organic and inorganic phosphorus but that there is a large difference in the fractional composition of the latter; a far higher proportion of the inorganic phosphorus is in an acid-soluble form (Pa). The diagrams show that a sharp rise in Pa in the B_1 of the buried soil contributes to the very high Pt value in this horizon, but the distribution of this fraction is mainly notable for its steady rise with depth, which commences with unusually low values in the buried Oh-Ah horizon, passes through a much slighter deficiency in the Ah/E horizon and reaches consistently higher values in the B horizons. In contrast, the adjusted value for Pf in the organic horizon is similar to that in the contemporary soils but the Pf values in the mineral horizons are consistently lower. As a result, there is only a small difference in the concentration of total inorganic phosphorus (Pi) in the B horizons of the buried and contemporary soils but there is substantially less Pi (and Pa) in the upper horizons of the buried profile. This evidence, therefore provides further support for the view that some phosphorus may have moved into the B horizons.

There is no difficulty in locating a 'surplus' of acid-soluble inorganic phosphorus in the buried B horizons. They presently contain about 9.8 g m^{-2} more Pa than the equivalent zone in the contemporary soils and, to correspond with this, there is some 7.1 g m^{-2} less of this fraction in the buried Oh-Ah and Ah/E combined than occurs in the equivalent combination in the contemporary soils. Moreover, due to the exceptional thickness of the Ah/E horizon in the buried soil, these figures should be regarded as minimal (under- and over-) estimates. Note, however, that the phosphorus characteristics of the buried Ah/E horizon are not substantially different from those of the modern soils and, although its present state may reflect a balance of inputs (from the Oh-Ah) and outputs (to the B horizons) that conceals the processes of post-burial alteration which have affected it, one must nonetheless conclude that it is mainly losses from the Oh-Ah horizon that could provide a source of at least some of the surplus Pa in the B horizons.

The apparent Pa surplus of more than 9.8 g m^{-2} exceeds the apparent nett deficit in the overlying horizons (7.1 g m^{-2}) and even the mean Pa content of the modern Oh horizons (9.0 g m^{-2}); there are several ways in which this apparent discrepancy could be explained. First, the surface (and sub-soils) of the palaeosol may, at the time of burial, have contained more Pa than is present in the modern soils; this possibility will be considered further below. Secondly, it has already been suggested that a large amount of organic matter has been lost from the upper horizons of the buried soil, particularly from the Oh-Ah horizon, and that this loss may have involved both <u>in situ</u> degradation and translocation of organic matter. Decomposition of the organic matter must have involved mineralisation of Po, which would be released as Pa and could then have been leached into the mineral horizons. Translocation losses of organic matter would lead to a gain of Po in the mineral soil. The data in Table 5.7 are entirely consistent with this model of events, though in view of the uncertainty which exists about the significance of the Po - Pa division relied on in these studies (see Appendix 5), one cannot demand too close an accounting of the specific contribution of these fractions. (There can be no doubt that some of the phosphorus recorded here as Pa must have been present in the field sample in a relatively easily mineralised form of Po; if other procedures had been adopted at least part of the Pa gains and losses would have been recorded as Po gains and losses).

The lower amount of Po in the buried Oh-Ah (21.5 g m^{-2}) compared to that in the modern Oh horizon (29.1 g m^{-2}) and the lower concentration of Po per unit weight of ignited fine earth (Fig. 5.20), whether one takes the 'real' value or the adjusted value, might also be regarded as evidence for Po losses. However, these differences may mainly reflect continued accumulation of Po in the modern peat since the palaeosol was buried. A better picture of the pre-burial qualities of the Oh-Ah can be gained by examining the concentration of Po by volume - after allowance has been made for the loss of volume which accompanied the decomposition of organic matter and mineralisation of Po in this horizon. The adjusted value of 260.8 µg cm^{-3} is in fact not dissimilar to the equivalent modern value of 243.9 µg cm^{-3} and one would have to make a considerably larger adjustment (i.e. assume a much greater loss of volume) to obtain a value substantially lower than the modern value. There is little indication that the present Po content of this horizon has been enriched by leaching from the overburden and if, as seems certain, Po has been lost due to mineralisation and translocation, then one is forced to conclude that at the time it was buried, this soil had a substantially higher concentration of Po than is typical of its modern counterparts.

The possibility that, a thousand years ago, the concentration of Po and Pa in the organic surface soil was somewhat higher than it is today, is not inconsistent with the other major difference in the buried soil - the much lower content of Pf.

It was noted earlier (see 2.2.2.2) that the fractional composition of soil phosphorus could be expected to alter during the course of soil development; at a certain stage (see Figs. 2.2 and 2.3), the insoluble fractions (Pf) start to increase at the expense of other fractions. It appears that the soils of Holne Moor may have reached this stage either before or within the last thousand years; only 21% of the total phosphorus in the buried soil occurs as Pf, but this fraction accounts for 29% of the phosphorus in the overburden, 27% in the North Field's Iron-pan stagnopodzols and 28% in the North Lobe's Humic brown podzolic soils. Pf may have started to accumulate before or after AD 1000 (this change is discussed in more detail below), but in either case, it seems likely that today's soils have a lesser capacity to supply phosphorus to other components of the ecosystem than the soils of early medieval times. It has been suggested earlier (see 2.3.3.1) that such a change in the availability of phosphorus might be reflected in a change in the concentration of phosphorus within the soil organic matter, and, specifically, that organic matter produced during the earlier phases of soil history, when phosphorus was more abundantly available, should contain a higher concentration of phosphorus.

Fig. 5.23 shows that the phosphorus content of the organic matter in the buried soil is consistently higher than that of the modern soils and, in particular, the new overburden soil; only the little-altered redeposited materials in the lower part of the overburden have values similar to those in the buried soil. As noted earlier (see 2.3.3.1), the increase in values with depth within the buried soil may also be attributable to differences in the age of the organic matter, but both this pattern and the generally higher values in the buried soil may mainly (or even only) reflect the way in which decomposition processes, which clearly have had a substantial effect on the amount of organic matter in the buried soil, may have changed its chemical composition. Since several of the contributory studies provide further information about the factors which determine these values, interpretations of the vertical distribution of these values will be discussed later (see 5.3).

If the phosphorus characteristics of the soil have changed in the way that has been suggested, a quantitative 'reconstruction' of the initial state of the buried soil and dependent calculations of nett mineralisation losses are no longer possible. Nor, in view of the higher variability of soil phosphorus compared to organic matter, is it worthwhile to attempt a speculative model of the type attempted earlier. However, one should note that higher Pa and Po concentrations would have made the soils of medieval times a somewhat better agricultural resource than the present soils of Holne Moor.

This investigation of a relatively well-preserved palaeosol allows one to draw several other general conclusions. In both buried and modern soils, Pf and Pa reach their highest values in the lowest horizons; typically, the least-weathered, BCux horizon has very much higher values of both of these fractions (see Figs. 5.11, 5.15, 5.17 and 5.22 and Table 5.8). At this level, the concentration of Pf (and the proportion of Pt within this fraction) are much the same in the buried and the unburied soils. In contrast, there is considerably more Pa in the buried BCux sample. Although not conclusive, this pattern does suggest that the soils developed in the Dartmoor solifluction sheet are soils of 'secondary weathering' (see 2.2.2.2 and Fig. 2.2) in which the parent material for the current cycle of pedogenesis contained large quantities of both occluded phosphorus and apatite; an original 50:50 split between these fractions seems possible. The higher value of Pa in the protected BCux horizon could reflect less severe weathering of apatite in the coarse sands, which form the bulk of the soil in this basal horizon, and, in addition, suggest that, although part of the Pa surplus in higher horizons must be non-occluded secondary inorganic phosphorus of pedogenetic and pedametamorphic origin, some of the surplus may be due to more extensive survival of apatite - a relict feature of the buried soil.

It is also evident that the model of phosphorus changes in such a soil outlined earlier (see 2.2.2.2) is consistent with the data presented above; the relatively low values of Pf and high values of Pa in the palaeosol are attributed by this model to a process of dissolution of Pf during the earlier stages of pedogenesis. In an addendum to this model, it was suggested that even in profiles that had passed this stage (i.e. in profiles in which, taking the soil as a whole, Pf was now accumulating), dissolution of Pf might continue in the most strongly weathered uppermost parts of the profile with Pf accumulating in the lower horizons. The pattern of vertical distribution of Pf in the strongly weathered upper part of the overburden is consistent with this hypothesis, as is the pattern in the buried soil, where some Pf may have accumulated in the B_1 horizon. If this is correct, the shift to Pf accumulation may pre-date, perhaps by a small margin, the burial of this soil. In the stagnopodzols, the variability of Pf in the two profiles examined makes interpretation hazardous, but it is clear that little Pf is present in the largely organic surface soil, though there is a very high concentration of this fraction in the Ah/E horizon of one profile.

The similarity of the concentration of Pf (mg kg^{-1} IFe) in the new profile developed in the upper part of the overburden and in the stagnopodzols, despite the disturbance to normal weathering processes that affected the soil materials in the former, suggests that, in many respects, this new soil is now as 'mature' as the surrounding undisturbed soils. A faster weathering rate in these loosely-packed soil materials may be responsible for this apparent precocity and this evidence ties in with the low pH of the surface of this soil; it is only in its relatively shallow depth, that this profile reveals its youthful origin.

Finally, there is little evidence in this study for nett leaching losses of phosphorus and likewise, little evidence for nett additions of phosphorus due to rainfall input. Indeed, the similarity of total phosphorus concentrations (mg kg^{-1}IFe) in overburden, palaeosol and modern soils suggests that inputs and outputs of phosphorus from these materials must have been very small indeed. It is hard to imagine these differently exposed materials maintaining their equality in the face of substantial inputs and outputs even if these were of equal magnitude.

5.2.1.2 A prehistoric palaeosol

Fleming's excavations in zone A and the field survey showed that few prehistoric features provide the degree of protection needed to preserve even a recognisable palaeosol beneath them. Stone-built reaves certainly alter the character of the soils which continue to develop beneath them, but such soils do not provide a useful source of information about the prehistoric soil. Likewise, soil profiles revealed by sectioning of reaves which incorporate a bank of soil material, do possess anomalous features but, even in these cases, it is impossible to identify the level of the old land surface. Sometimes a slightly thicker Ah/E horizon constitutes the only visible evidence of soil addition to the profile. In other cases, an unusually well-developed E horizon has formed in the bank materials and a thin Bh horizon is present towards the base of the bank. In part, the new Bh may incorporate the old surface soil, but the present field characteristics do not clearly betray such a dual identity.

The most well-protected prehistoric land surface that has been located was found beneath the wall of the large prehistoric house on site F, which lies in sub-zone B of zone A (see Fig. 3.5). The palaeosol beneath this wall, which was built ca. 1250 bc (see 3.3.2), was examined by the author during the course of Fleming's total excavation of the house and its surrounds in 1977-8. It was hoped that the buried soil would be an example of a soil of type s_{tl} (see 2.1 and Fig. 2.1), but Fleming's excavation later showed that the present stone house had been preceded by a wooden house; consequently one cannot assume that this palaeosol was a virgin soil at the time of burial.

Fig. 5.24 schematically illustrates the nature of the trench which revealed the palaeosol; hand excavation techniques were used to remove all the deposits in order that morphological traces of the original character of the overburden and the buried surface could be sought. Fig. 5.25 shows the major features revealed in this excavation. Before discussing these features in detail, it must be pointed out that the depth of the Oh horizon shown in the section drawing of the west face of the trench is a conjectural reconstruction. Unfortunately, the excavator deturfed this area prior to the author's arrival on site. The lower half of the peat cover outside the wall was still present but all peat had been removed from the surface of the wall. The peat depth has been reconstructed from a) the peat 'tide line' visible on the orthostats and b) the surviving, complete profile on the north side of the trench; it is unlikely that this reconstruction is seriously in error. Sampling was more seriously affected; only the lower peat could be sampled from the comparative profile (HM77F 5) and this may not have been fully representative of the entire depth of peat. To obtain an estimate of the qualities of the peat which had once grown on the overburden surface, a sample of the Oh horizon that mantled the orthostats in the north face of the trench was taken. Clearly these samples are not ideal, but in view of the other limitations on the scope of this investigation, which are discussed below and which resulted from the nature of the buried profile itself, these imperfections are of less consequence than might at first sight appear to be the case.

Morphological features

It can be seen that the old land surface was buried beneath abbut 0.50 m of overburden materials; the latter do not seem to have been obtained from a quarry ditch. A ditch was present on the north side of this house and it may have provided the wall fill on that side; however on the south side of the hut, Fleming did not find a ditch and he supposes that the fill was obtained from relatively shallow scopps taken from the nearby soil. The overburden may once have been slightly deeper; a 'skirt' of soil rises up against the outer edge of the orthostats of the wall and may indicate some erosion of the wall fill or some superincumbent structure. Whatever its precise original depth, the overburden is now twice as thick as typical reave banks on Holne Moor; Unfortunately, even this depth has proved to be too shallow to prevent pedomatamorphic processes (of a type broadly similar to those affecting the soils beneath reave banks) from producing major changes in the overburden and the underlying buried soil.

In Fig. 5.25 the major stratigraphic and pedogenetic units recognised in the field are numbered - horizon nomenclature has been omitted; instead two schemes of nomenclature are shown in Fig. 5.26, which succinctly draws attention to the problems of interpreting this profile. Most of the wall fill materials now have the characteristics of eluvial horizons (for simplicity, designated here as E_1 and E_2 - their features do not fully match the standard units, Eag and Eg) forming part of an abnormally-developed stagno-podzol in which the buried soil has been incorporated as the illuvial component. The approximate location of the buried surface can be inferred from the level of the mineral soil surface in the adjacent profile, a level which, as can be seen in Fig. 5.25, roughly coincides with the surface of the horizon marked b Ah in model A and Bhs in model B. This coincidence may indicate that the location of the horizon boundary has in some degree been determined by the stratigraphic division occurring at this level. However, recognition of this relict division, which was less clearly evident in the field than the section drawing implies, does not allow one to presume that the position and nature of other pedogenetic horizons in the profile are, in any meaningful sense, relict characteristics.

The present field characteristics of the overburden provide few clues as to the nature of the materials used as wall 'fill'; a typical Ah/E horizon has developed in the uppermost portion and is underlain by a very thin, soft and intermittent line of iron deposition. (This feature, which was almost invisible in the field - a mere smear of iron, was later examined in thin section under a petrological microscope; although extremely thin, it appears as a coherent band rather than a diffuse accumulation). All the fill material below this iron-pan has relatively light colours and a low content of organic matter and clay. The sharp E_1 - E_2 division shown in Fig. 5.25 was clearly visible in the field, E_2 being substantially greyer than E_1 (this difference was also evident in the ignited colour of these materials; E_2, like the Ah/E, was grey, whereas E_1 was a very pale pinkish brown). In addition, the E_2 material possessed structural units separated by organic-rich cutans; no precise analogue for this pattern had been observed during the field survey. In the lowest part of the E_2, some granite fragments exhibited 'speckling' (see 4.2.1.1).

Although it is possible that all the features described have been created by pedometamorphic alteration of the fill materials since their emplacement, the differences between E_1 and E_2 might in part reflect initial differences. For example, if the 'parent material' of the E_1 horizon was obtained from deeper levels - A/B or B_1 horizons - than the parent material of the E_2, subsequent weathering and eluvial movement may only have accentuated or diminished the initial contrast between such materials. The irregular and sharp boundaries of the E_1 (with both the Ah/E and the E_2) might indicate initial divisions in the fill materials. The special structural qualities of the E_2 might also reflect the initial state of these materials, though nothing in their field appearance allows the inference that these materials are the degraded remnants of turves.

The horizons below the overburden have a character and sequence similar to that of the Humic brown podzolic soils (S - IV) of the North Lobe, though the uppermost horizon (b Ah or Bhs) is thinner and in most places slightly darker than the modern Ah horizons and the thin, soft intermittent iron-pan that runs along part of the base of this horizon is very rare in S - IV soils. In several respects, the characteristics of this buried soil match those recorded for other Dartmoor palaeosols (see Tables 3.1 and 3.2 and section 3.2.1), particularly the Chagford palaeosol described by Staines (1972). As in the Chagford palaeosol, the iron-pan is almost certainly a post-burial feature; partial dissolution of a pre-existing pan cannot be ruled out, but seems unlikely in view of the late or post-medieval age of pan development in zone C (see 5.2.1.1) and the clearly post-burial age of the overburden pan. The boundary between the E2 and the b Ah (or Bhs) is abrupt rather than sharp and includes both small and larger scale irregularities; the latter might reflect damage to the soil surface during construction of the orthostatic wall, while the former may be an indication that the location of the boundary has not wholly been determined by the position of the pre-existing stratigraphic division; many other factors may be influencing the position of an accumulation of translocated organic matter. No traces of an Oh horizon could be found at the surface of the buried soil but, in itself, this observation is of limited value; if an Oh-Ah horizon similar to that beneath the medieval bank (or, more plausibly, a somewhat thinner one) was once present but has suffered similar degradation over an even longer period, one might well fail to recognise the final residua. Alternatively, such an horizon could have been deliberately removed or in some other manner destroyed prior to the construction of the stone house. Finally, it must be noted that the buried soil profile is substantially shallower than any other profile seen in zone A; the extremely stony BCux horizon is encountered some 20 - 30 cm higher in this trench and this impairs the utility of comparisons with all but the adjacent profile, which fortunately, shares this extreme shallowness.

It is evident that none of the present characteristics of the buried soil should necessarily be regarded as relict features and this may also be true of all the other prehistoric palaeosols observed on Dartmoor. This is particularly regrettable since a well-preserved palaeosol with morphological characters similar to those observed here would make a highly acceptable second millennium bc 'prototype' for the modern stagnopodzols. However, although the buried soil conforms well with the predictions of the most plausible model of pedogenesis on Dartmoor (see 3.2.1), this model can be neither confirmed or refuted until relict features can be distinguished from pedametamorphic ones.

Quantitative investigations

Particle size characteristics of the overburden, buried soil and comparable nearby profiles are listed in Table 5.9; the stone content is also shown diagrammatically in Fig. 5.27, which includes similar data for the medieval palaeosol described in section 5.2.1.1.

The relatively low stone content of the overburden as a whole supports the suggestion that the wall fill was obtained by fairly shallow excavation of surrounding soils and the tendency for higher stone content in the upper parts of the overburden may also be interpreted as evidence for the presence of an element of reversed stratigraphy. These data, therefore, support the idea that some of the present morphological differences among the fill materials may reflect initial differences. Both the pattern of stone content and the representation of finer particles confirm the stratigraphic and pedogenetic divisions recognised in the field. As one would expect, the samples from the putative buried surface soil (5c and 5) have the lowest stone content and are in this respect almost identical to samples from nearby Ah/E horizons. It is also notable that sample 5c, which was taken from what was thought to be the best-protected part of the b Ah, and each of the other samples from the buried horizons beneath it, share a relatively high content of fine sand and in this respect differ from the overburden materials and the nearby profiles. Some of the values for clay content seem suspect; in particular, sample 7 from the buried soil is much lower than was estimated in the field, where little difference was noted between samples 5, 5c, 7 and 8. In view of these uncertainties, these data cannot be used to support any complex hypotheses about the nature of alterations to the overburden or buried profile, though it is worth noting that the field evidence suggested a much stronger contrast between the clay content of the buried soil and the overburden.

The pH values recorded for samples from the overburden, the buried soil and the adjacent Iron-pan stagnopodzol are shown in Fig. 5.28. The general level of values and the pattern of change with depth in the stagnopodzol are similar to those recorded for the stagnopodzols in zone C (see Fig. 5.3). Values in the upper samples from the overburden also lie within the range found in those soils; only the value for the basal sample (the E_2 horizon, which had an identical value to that of the E_1 horizon) is 'out of step'; its relatively lower value could reflect greater weathering of the E_2 material prior to burial. However, the buried profile is unusual; all samples had a higher pH than their equivalents in the adjacent stagnopodzol and in the upper part of the profile this difference is quite marked. The pH values in the medieval palaeosol (see Fig. 5.3), which are insignificantly different from those of the modern stagnopodzols of zone C, are only very slightly higher than those of the adjacent stagnopodzol and are substantially lower than those of the prehistoric palaeosol. At first sight these comparisons might appear to indicate that reduced weathering in the longest buried soil has minimised leaching losses of bases and that the higher pH could be a relict feature. In part, this might be true; however the differences among the BCux samples are slight and if this basal horizon is in a similarly-weathered state in all the profiles, it is unlikely that the pre-burial qualities of the overlying horizons in the palaeosol have been more substantially preserved. A more likely explanation for the pattern lies in considering the nature of the changes throughout both overburden and buried soil. In marked contrast to the pattern in the medieval overburden and buried soil (see Fig. 5.3), where each of these component parts had their own 'pH profile', the pH values here show no disjunction at the overburden - buried soil interface. Taken as a whole, the pattern is therefore essentially similar to that seen in undisturbed soils; the relatively high values of the upper part of the buried soil reflect their position and status as B horizons within the complete profile (as in model B). These values are also absolutely higher than most stagnopodzol B horizons in the study area, but the difference is very slight and B horizons in the Humic brown podzolic soils of the North Lobe, which have a higher content of organic matter than the stagnopodzols (see 5.4.2), have a range of pH values which span those recorded in the buried soil. This suggests that the high values may in part be due to retention of cations (some of which may have been leached from the overburden) by the large quantity of organic matter in these horizons. It may be that burial has reduced the rate at which cations have been leached from the buried soil but the present pH values may mainly reflect its subsequent pedametamorphic incorporation within a much deeper profile.

The concentration of organic matter (by weight and by volume) and the cumulative total weight to specific sampled depths in the overburden, buried soil and the adjacent profile (with and without the contribution of the Oh horizons) are shown in Figs. 5.29 - 5.32. Each of these indicators of the organic matter status of the profiles confirm the relatively low organic matter content of the overburden compared to the adjacent soil profile. The LOI (% wt) values of the E_1 (5.2%) and the E_2 (3.2%) can only be matched by values recorded for E horizons in podzols on Vag Hill (see 5.2.2.2). If, as the stone content indicates, these materials were obtained from surface and near-surface soils, then a very large proportion of their initial organic matter content has been lost by decomposition and/or translocation.

The buried soil also has a much lower organic matter content than the adjacent stagnopodzol, though this difference stems solely from the contribution of the Oh horizon of the latter; the total weight of organic matter in the mineral horizons is nearly identical (palaeosol: 27.89 kg m^{-2}; stagnopodzol mineral soil: 27.54 kg m^{-2}). However, in the face of the evidence for large losses of organic matter from the medieval palaeosol and from the overburden of this profile, it would be absurd to suppose that this equality is due to survival of a relict pattern. The similarity of the concentration of organic matter in the lower horizons of the buried soil and equivalent samples from the adjacent soil can be explained as a function of their contemporary pedological equivalence but this explanation cannot apply to the upper horizons where, although the total accumulation is similar, there are marked differences in the distribution of organic matter.

Since no other profile in the study area has an eluvial zone with the qualities and depth of that which has developed above the buried soil, there are no precise analogues for the upper horizons of the buried soil and certainly the concentration of organic matter in the two upper layers (5c: 105.0 mg cm^{-3}; 7: 87.9 mg cm^{-3}) is much higher than the concentration in the Bs_1 horizon of the adjacent soil (73.2 mg cm^{-3}). This does not necessarily indicate that ancient organic matter has survived to inflate the contents of these horizons, since all of their present content may be illuvial; a considerable number of the contemporary stagnopodzols have illuvial horizons with similar concentrations of organic matter (see Table 5.10). On the other hand, investigation of the amino-acids in samples from these upper horizons (Beavis 1981) may indicate that some relict organic matter is present, but the evidence is ambiguous. Beavis used several measures to assess the relationship between samples (e.g. hierarchical cluster analysis, principle co-ordinate analysis) and he employed both raw and log-transformed data. In nearly all cases, these analyses allowed a clear distinction to be made between the samples from the modern surface soils and their sub-soils and in one analysis (1981: Fig. IV.22), a sample from the buried soil horizon (5) was grouped with two samples (Ah and A/B) from the Humic brown podzolic soil in the North Lobe (SP 2). However, several other analyses placed the same sample among the samples from B horizons taken from both stagnopodzols and podzolic soils. It seems, therefore, that the ambiguity encapsulated in the two models presented above (Fig. 5.26) may also apply to the amino-acid content of the organic matter.

The dual identity of the profile formed in the overburden and buried soil precludes meaningful analysis of post-burial losses of organic matter; nor is it possible to say anything of the initial vertical distribution. Some indication of the losses that must have occurred can be gained by comparing the present organic matter contents (both absolute weight and concentration values) of this soil with other soils in the study area (Table 5.11). No other soil has as little organic matter and even the combined weight in overburden and palaeosol (i.e. the contents of a notional 80 cm profile) only slightly exceeds the weight in the 40 cm stagnopodzol profiles in the North Field. The equivalent combination of the medieval palaeosol and its overburden has some 9.81 kg m^{-2} (or 16%) more organic matter.

It is not particularly surprising that relict morphological features of a palaeosol should prove difficult to identify some three thousand years after its burial; nor could one reasonably expect an overburden of only half a metre to prevent wholesale alteration of the original organic matter and soil reaction properties after such a length of time. It was, however, more disappointing to find that similar depredation had affected the phosphorus characteristics of the soil, though with the hindsight now provided by the evidence of alteration of phosphorus patterns in the medieval palaeosol, this too could have been anticipated. It is not that there is an identical pattern of alteration in both palaeosols - far from it. Whereas in the medieval soil, the buried surface has suffered large losses of organic matter accompanied by much smaller phosphorus losses but does not seem to have been much altered by receipt of translocated materials from the overburden, the latter process has occurred on a substantial scale in the prehistoric soil; in consequence, interpretation of the present phosphorus patterns in this soil, particularly the contents of the b Ah (or Bhs) horizon encounters the same ambiguities as were present in the interpretation of the organic matter content. This aspect is conveniently and clearly illustrated by the data in Table 5.12, which allows a comparison of the values of phosphorus fractions in the buried surface soil (samples 5 and 5c) with those in Bh and Ah horizons in the study area. Unfortunately, it is evident that most of the phosphorus characteristics measured in this study do not allow one to clearly differentiate Ah from Bh horizons or to allocate the buried soil to one of these groups. The typically higher concentration of phosphorus in the organic matter of the Ah samples constitutes a partial exception, but the samples from the buried surface have intermediate values, and in any case it is highly probable that the values in these Ah horizon samples have been affected by additions of FYM during medieval use of the land (see 5.4.2). This somewhat pessimistic assessment does not mean that it is pointless to examine the phosphorus patterns in the palaeosol and its overburden; in fact, these patterns can still reveal important information about long-term changes in soil phosphorus in the study area.

As in the case of the medieval palaeosol investigation, variation in the amount of fine earth per unit volume of soil due to differences in stone content, organic content and (presumptively) the structure of soil materials make it necessary to examine and present the results of the phosphorus analyses in several different ways (Figs. 5.33 - 5.48). Unlike the medieval overburden, the stone content of the prehistoric overburden is much lower than that of the buried soil and the adjacent stagnopodzol; this difference reflects the origin of the overburden material and, in this instance, is particularly large because the standard 40 cm sampling depth includes part of the BCux horizon in the undisturbed profiles. These factors produce an overburden 'profile' that, despite a low content of organic matter, has a slightly greater quantity of fine earth than the adjacent stagnopodzol (see Fig. 5.31) and so the apparent deficiency in the weight of all phosphorus fractions evident in Figs. 5.33 - 5.35 does indicate a real deficiency of phosphorus in the overburden materials. The strongly leached character of the overburden is also clearly evident in the diagrams depicting the distribution of concentration values (Figs. 5.36 - 5.48). On the other hand, the buried soil has much less fine earth than the adjacent profile (mainly because of the extra material in the Oh horizon of the stagnopodzol, but partly because of the generally higher soil bulk density of the mineral horizons of the stagnopodzol - the significance of this is discussed later) and, in this case, the lower weight of phosphorus (in all but the Pa fraction) is misleading; the overall concentration of Pt in the buried soil (625 mg kg^{-1}IFe) is indistinguishable from that in the adjacent stagnopodzol (628 mg kg^{-1}IFe) and this is curious for, taken at face value, it would suggest that none of the phosphorus leached from the overburden has been retained in the underlying soil. An explanation for this pattern and an assessment of transfers from the overburden and accumulation in the buried soil will be offered after its other characteristics have been described.

Like the medieval palaeosol, the prehistoric buried soil also has a much higher proportion of its phosphorus in the Pa fraction than the contemporary soils but, as can be seen in Fig. 5.41 and 5.47 (which can be compared with Fig. 5.15 and 5.22), the distribution is very different; although both buried soils have an absolute maxima in the BCux horizon, in the prehistoric soil, there is a secondary maxima in the upper horizons. A further difference is that, whereas in the medieval soil an 'excess' of Pa was matched by a 'deficit' of Pf and the nett difference in Pi was very small, the Pf values in the prehistoric soil are similar to those in the stagnopodzol but the latter has substantially more Po (this is partly but not wholly atributable to the large amount of Po locked up in the Oh horizon). The difference in distribution and in the fractional composition are best explained by treating the buried soil and its overburden as a single profile.

In such a model, the secondary maxima in Pa can be attributed to accumulation beneath the strongly leached layers of the overburden and the higher concentration of Pa in the deepest sample from the buried soil compared to its counterpart in the adjacent profile may indicate that the presence of the overburden has conferred a little extra protection against weathering (as it appears to have done in the medieval profile), though, in this case, it is harder to find evidence of significant protection in shallower horizons. The differences between samples 5 and 5c may be attributable to this factor (see Figs. 5.43 - 5.45 and note that the values for the bAh horizon used in all other figures are the values for sample 5c); indeed the replicate sampling of this stratigraphic level was prompted by the possibility that the slight colour change within this horizon might be due to differences in preservation of relict characteristics. If the higher concentration of Pt (and the inorganic fractions) in sample 5c compared with sample 5 is due to better preservation of relict qualities in the former, then this would constitute the best evidence that can be adduced for suggesting that the buried soil was, at the time of burial, more similar to the contemporary Humic brown podzolic soils than the stagnopodzols; both the high Pt and high Pa concentration would be appropriate for a surface Ah horizon of phosphorus accumulation and inappropriate in a sub-surface eluvial Ah/E horizon. This view carries with it the implication that sample 5 has, like the overburden, suffered nett, post-burial leaching losses and that the principal zone of accumulation must occur in the subjacent horizons; the maximum concentration of Pt (mg kg^{-1} IFe) does in fact occur in sample 7 (Fig. 5.43), which lies immediately below the buried surface horizon.

The absence of a marked difference in the concentration of Pf in the buried soil and the adjacent stagnopodzol (see Figs. 5.37 and

5.44) can be regarded as evidence for the mature stage in soil development reached by the profile that has formed in the overburden and buried soil as a whole. The overall concentration values for this insoluble fraction in the prehistoric and medieval soils and their overburdens are shown in Fig. 5.49, which also indicates the variation in the proportion of Pt that occurs in this fraction. Two units have substantially lower concentrations of Pf - the medieval palaeosol and the prehistoric over-burden - but in the former, Pf forms a relatively low proportion of Pt, while in the latter, it forms the highest proportion found in any of the units which have been examined. This pattern is consistent with the explanations for changes in the Pf fraction offered above (5.2.1.1). The low value but high proportion of Pf in the overburden would be expected to occur if intense weathering within the strongly-developed E horizons had minimised Pf accumulation (or induced losses) and at the same time had produced very high losses from the soluble Pa fraction and the degradable Po fraction.

There can be no doubt that the intense weathering in the overburden has substantially reduced its phosphorus content; Table 5.13 shows that both the absolute weight and the concentration of Pt (and Pao) is far lower than that in either the buried soil or the adjacent profile. However, it is difficult to make a quantitative assessment of these losses. In the first place, it is unlikely that the soil materials in the overburden were ever equivalent to those once present in an undisturbed soil profile (see above) and, secondly, even if this is assumed (for the purpose of establishing the general magnitude of the losses), neither the buried soil nor the adjacent profile provide a suitable baseline for comparisons; the phosphorus content of the buried soil may well have been augmented by transfers from the overburden and phosphorus has certainly been added to the adjacent soil during the occupation of this house (see 5.2.2.1). Even the soils in the nearby part of zone A (sub-zone B) seem to have been enriched during this occupation (see 5.4.3) and it cannot be assumed that the phosphorus present in virgin land (sub-zone F) has remained unchanged; it was estimated earlier (2.2.2.2) that long-term nett losses of 0.02 kg ha^{-1} $year^{-1}$ (0.002 g $m^{-2}year^{-1}$) could be expected. If the latter estimate is used to provide estimates of the initial phosphorus content of the soils in sub-zones F and B (an arbitrary period of 3000 years is used in these 'order of magnitude' calculations) and the resultant Pao concentration values (F: 393.9 mg kg^{-1}IFe; B: 435.5 mg kg^{-1}IFe) are applied to the materials in the overburden, the buried soil and the adjacent profile, phosphorus losses and loss rates can be calculated (see Table 5.14, in which Pao values are used since Pt values are not available for sub-zone F and B). Although clearly these estimates are crude, the indication of a far higher loss rate in the overburden than would be expected in the normal soils is not inconsistent with the unusual eluvial qualities of these soil materials. The estimates of the amount of translocated phosphorus retained in the underlying palaeosol vary substantially as a function of the assumptions made about its initial state. Column 1 assumes both overburden materials and the palaeosol were similar to those in virgin land; column 2 assumes both were enriched to the extent found in sub-zone B. It is also possible that the overburden materials but not the palaeosol had been enriched. In that event, the nett loss would be 60.151 g m^{-2} at a rate of 0.201 kg $ha^{-1} year^{-1}$.

Table 5.14 also provides an estimate of the likely order of magnitude of phosphorus enrichment in the profile adjacent to the prehistoric house, a calculation which shows that the lower weight of phosphorus in the buried soil is unlikely to be due solely to its failure to share in such anthropogenic enrichment. Even if it is assumed that the adjacent stagnopodzol was enriched by 20.399 g Pao m^{-2} and that only 1.551 g Pao m^{-2} has been added to the buried soil by translocation, the latter would still have had a lower initial weight of phosphorus. The explanation for this pattern lies in the significantly lower weight of ignited fine earth in the buried soil. As Table 5.15 shows, despite the high stone content of the adjacent stagnopodzol (a property shared by the buried soil), it does not have a deficiency of ignited fine earth compared to nearby soils of similar type. However, the low value of the buried soil is matched (and is well matched) by the low values in the Humic brown podzolic soils of the North Lobe and, in both cases, partly reflects the lower soil bulk density of the mineral horizons compared to equivalent horizons in the stagnopodzols (see also 5.4.2). Since a relict pattern of soil bulk density was noted in the medieval palaeosol and is also found in the prehistoric overburden (where, although the soil has a much higher bulk density than that of the underlying soil (due to its low organic matter content), the bulk density observed is much lower than would be predicted by its organic matter content), it is not unreasonable to regard the low bulk density of the buried soil as a relict pattern; if this is the correct explanation, then it provides a further, if tenuous, indication of the similarity of the North Lobe soils and the second millennium palaeosol.

The concentration of phosphorus in the organic matter fraction of the prehistoric soil and its overburden (Fig. 5.50) does not yield any evidence for the survival of organic matter with an unusually high phosphorus content. Like the pH and organic matter distributions, this pattern of vertical distribution appears to reflect the coalescence of overburden and buried soil into a single pedological entity. The strong rise in values within the E horizon has been observed in podzol E horizons on Vag Hill near Rowbrook farm (see 5.2.2.2), and is also found in the less well-developed E horizons of the normal stagnopodzols, though none of these examples exhibits values quite as high as those reached here; SP 29 in sub-zone B provides one of the closest analogues (see Table 5.16). Note that here, as in the medieval palaeosol and the contemporary stagnopodzols, there is a decline in values in the lowest horizons, which could be due to a disproportionate loss of phosphorus from the oldest and most degraded organic matter (for further discussion see section 5.3). The values in the upper part of the buried soil are slightly higher than the mean values for B horizons in sub-zones B (3032) and F (2847), but do not lie outside the range of values recorded for illuvial horizons in these zones. However, it is likely that the value recorded for sample 5c has been depressed by the presence of charcoal (oak and probable pine) in the sample - all large lumps were removed (and some were used for radiocarbon assay) but remaining smaller fragments will have slightly increased the LOI value. Allowance for this factor would increase the apparent similarity of this sample to the samples from the Ah horizons of the North Lobe soils (see Table 5.12), but there is a wide range of values for this variable in the contemporary soils (see 5.4.3), and it would be difficult to argue that the values recorded in the buried soil have been strongly influenced by the presence of a relict pattern.

Insomuch as the principal goal of this investigation was the recovery of information about the prehistoric soils of the study area, one must concede that it has proved at best a partial failure. Quantitative information about the initial state of the buried soil is beyond recovery; in particular, continued soil development precludes any clear indication as to the stage reached in the trajectory of Pf - Pa dissolution and accumulation. On the credit side, there are some indications that the buried soil was different from the modern soils and, although none of these features can be unambiguously interpreted, it would be perverse to reject this possibility totally. The investigation has also shown that very substantial movement of soil phosphorus can occur in these soil materials on a time scale relevant to archaeological enquiry, though no item in the data collected allows one to estimate the rate of leaching in the undisturbed soils of Holne Moor.

5.2.1.3 Discussion and general conclusions

Although buried palaeosols may, in theory, provide the best information about sequential soil development, it is evident that in practice, the severe problems posed by post-burial changes may outweigh the theoretical advantages. Only the most recently buried soil provides clear information about its initial state and much more deeply buried palaeosols will need to be discovered and investigated, if models of earlier stages in pedogenesis on Dartmoor are to be adequately tested. However, the longer time available for pedometamorphic processes to alter the prehistoric soil may not entirely explain its much more degraded state. The medieval soil may have been doubly protected from change by a feature not present at the prehistoric house - namely the deep ditch which flanks the medieval boundary. This must have reduced lateral fluxes between the buried medieval soil and the surrounding soils. A similar reduction of flux must also have affected soil development in overburden materials and it seems unlikely that processes observed in these soils are representative of processes (and particularly the rates of processes) in undisturbed soils. In consequence the overburden soils have only been considered in detail where an understanding of their alteration was able to contribute to interpretation of the buried soils.

These studies indicate that the basic mineral fabric of the buried soils has been well-preserved; structural change due to compression cannot be detected in the mineral soil horizons. It also seems that in the younger palaeosol some of the original patterns of composition and distribution of organic matter and phosphorus have survived, though the 'survival' of much of an apparently relict pattern of pH cannot be explained in terms of stasis; this pattern must reflect current dynamics within the palaeosol, which must be very similar to those in the surrounding soils. In this case, the similarity would seem to reflect the survival of many of the pre-burial characteristics of the soil and the fact that these were very similar to the modern stagnopodzols. In contrast, in the older soil, there has been substantial alteration and movement of phosphorus and organic matter, and, almost certainly, parallel changes in iron and aluminium; in this soil, relict features are rare. Nevertheless a case can be made for viewing the prehistoric palaeosol as a much-altered brown podzolic soil rather than a stagnopodzol. The very low proportion of Calluna pollen in samples from this soil (less than 2% - see 3.2.1) is an important clue, which can be linked to the ambiguous indications provided by the soil evidence.

In all the modern stagnopodzols and in the buried medieval soil, Calluna pollen values tend to rise in the uppermost sample(s) from the mineral soil beneath the Oh horizon, a pattern which is thought to indicate that heather became a more important element in the moorland ecosystem at least shortly before the growth of a significant accumulation of 'mor' humus had occurred and indeed that the spread of heather may have played an important role in this soil development. If this is correct, the near-absence of heather from the prehistoric soil would place this soil in a 'pre-mor humus' stage of development. The argument is certainly not conclusive but it accords with the absence of any evidence for an accumulation of even the thinnest of peats beneath the wall of the prehistoric house and it is also consistent with the shallowness of the peat accumulation beneath a boundary built over two thousand years later. Substantial changes in the pattern of iron loss and accumulation - the emergence of iron-pan soils on Holne Moor - seem to have arisen even later; a mainly post-medieval age seems probable and the process of pan formation may well be continuing today. However, one cannot exclude the possibility that some iron-pans in the study area date to an earlier period. In particular, there is no evidence for the age of the iron-pans which occur immediately above the BCux horizon.

This interpretation of the evidence implies that the differentiation of the North Lobe soil (S - IV) from the stagnopodzols has involved both direct metapedogenetic processes (e.g. destruction of the pre-existing peat surface) and subsequent pedogenetic change in the stagnopodzols (e.g. further peat growth and the formation of iron-pans) - these matters are pursued in section 5.4.2. The similarity of the physical appearance of the prehistoric palaeosol to the metapedogenetically-altered soil in the North Lobe and to other non-peaty soils on Dartmoor carries no weight in itself, since there is no evidence that the similarities arise from the preservation of relict features in the palaeosol and much evidence that the present qualities of the latter are products of post-burial alteration; Gerasimov's warning about over-reliance on morphological features of palaeosols in interpreting their genesis is in no way contradicted by these findings.

The desirability of studying both buried soils and their overburdens, and the need for quantitative assessments of physical and chemical parameters is clearly brought out by these studies; the highly-degraded state of the prehistoric overburden is one of the principal pieces of evidence for alteration of the underlying soil, and only quantitative study of the phosphorus fractions gave any indication that the soil tilled by medieval farmers may have been a more fertile soil than those in the study area today. Moreover, despite the fact that the much-altered state of the older palaeosol prevented the recovery of information about the Pa - Pf division in prehistoric times, the conformity of the evidence from the medieval palaeosol to the model of Pa - Pf transformations outlined earlier, allows the further inference that prehistoric farmers will also have encountered soils in which phosphorus availability may not have been the serious problem it would be today.

Finally, although by no means as conclusive as one would have liked, there is evidence here that the shift from a non-peaty podzolic soil to a soil with stagnopodzol characteristics occurred after ca. 1250 bc and that by ca. AD 1000 significant progress had been made along this new trajectory. Peat may well have started to accumulate during the cool and wet climatic phase after ca. 850 bc (see 3.2.1, and further discussion in 5.4.2), but further studies of well-preserved palaeosols of intermediate age and radiocarbon assay of soil organic matter in buried surface soils will be needed, if the timing, and relative contribution of climatic changes and other changes in the factors affecting the soil-organism ecosystem, are to be more closely assessed. However it is worth noting that, even if allowance is made for post-burial loss of organic matter, the buried soils discussed here and those observed during the field survey (see 4.3.1 and Table 4.2) indicate that a large proportion of the present peat accumulation dates to historic times.

5.2.2 Metapedogenesis

This section reports the results of investigations undertaken to define more clearly the way in which metapedogenetic inputs of phosphorus and organic matter affect soils of the type encountered in the study area. Among the questions to which answers were sought were: to what extent are such inputs dissipated from the site of input by subsequent lateral or vertical movements? Do such inputs preferentially accumulate in any one soil phosphorus fraction? Do they lead to an increase in the nett accumulation of organic matter? If answers to some of these questions had been sought solely among the data produced during investigations of the ancient agricultural enclosures of the study area, the explanations offered for the patterns found in such circumstances could have involved an unacceptable degree of circularity of argument. In the studies reported in this section, the fact (and in some cases, the nature) of inputs is either known or there is an *a priori* case available to justify an initial assumption of phosphorus inputs.

These studies also serve to demonstrate the ability of the selected methods of phosphorus analysis to identify both recent and ancient metapedogenetic alteration of soil phosphorus. Although it was not possible to obtain Pt estimates for the samples discussed here, the nature of the general relationship between Pt and Pao values, which was considered in section 3.3.2 , allows one to infer that changes in Pao values do reflect changes in total soil phosphorus. The similarity of the proportion of Pt found in the Pf fraction in samples from the Iron-pan stagnopodzols of the North Field and the Humic brown podzolic soils of the North Lobe that was noted above (5.2.1.1), despite metapedogenetic phosphorus enrichment of the latter during medieval farming (see section 5.4.2) suggests that the level of phosphorus enrichment evident in the Pao fraction may underestimate the true level of metapedogenetic input of phosphorus by *ca.* 30%.

This section is subdivided; the first half looks at the present characteristics of soils in which it is assumed that prehistoric activities would have led to phosphorus enrichment; the second half examines the effect of very recent additions of phosphorus in the fields of nearby farms.

5.2.2.1 Prehistoric activities

The vast majority of archaeological investigations of soil phosphorus have concerned themselves with demonstrating more or less satisfactorily that the soils of ancient habitation sites have been enriched by phosphorus; it is usually assumed that this enrichment has been caused by the deposition of food wastes, excreta and other forms of domestic refuse, though the use of dung in wall and floor construction may also be a factor in some cases. The work of Arrhenius (1931, 1938, 1955, 1963), of Cook and Heizer (1965) and more recently of Provan (1971) provide a fair sample of such studies. In view of this work, one is certainly entitled to an expectation of phosphorus enrichment in and around the houses which were built within the prehistoric field system on Holne Moor. Three of these houses have been investigated.

On site F in zone A (see Fig. 3.5), Fleming's total excavation of a large house (diameter 7.3 m) and its surrounds offered an opportunity for large scale soil sampling with minimal damage to the archaeological record; some 300 samples were taken from the Ah/E and B horizons (see Appendix 1 - group 18) with the dual purpose of providing information that could contribute to an understanding of human activity on the site and would further the objectives outlined above. The Oh horizon was not sampled on this site since it had been disturbed by both the deposition of many small boulders in the house after the initial occupations (presumably during the medival outfield cultivation of the surrounding fields) and by the construction of a small shelter (see 3.2.2) of (presumptively) still later date. Forty samples covering two transects of the site plus a few additional locations have been analysed and are used in this report.

To obtain information about metapedogenetic alteration of the Oh horizon characteristics (and their relationship to alteration within the Ah/E horizon), some twenty Oh (and corresponding Ah/E) horizon samples were taken along two transects through a smaller house (diameter 4.5 m) which lies about 200 m east of site F at the southern edge of sub-zone D (see Fig. 3.5). There were indications that this house had also been disturbed after its initial occupation but it had not been filled with boulders and apparently normal Oh and Ah/E horizons were present at most sampling locations (see Appendix 1 - group 12). Analyses of one transect are reported here.

In zone C, a third house, which lies just within the Western field of the North Lobe and is of similar size to that on site F, was also sampled (see Figs. 3.4 and 5.1). In this case a single standard 'small' sampling pit was dug (towards the centre of the house) and the entire profile (SP 33) was sampled in the standard manner. This investigation was primarily undertaken as an adjunct to the examination of the surrounding soils (see 5.4.2) but is reported here since it provides the only evidence available for the total amount of additional phosphorus that has accumulated on sites of this kind.

The fourth site considered in this section is the stone row which lies at the south-western extremity of the study area (see Fig. 3.4). In the author's view, this setting of stones marks a graveyard which was probably in use during the second millennium bc. This is an interpretation of the archaeological and pedological evidence; only a far from satisfactory circumstantial argument could be put forward for expecting phosphorus enrichment on 'ceremonial' monuments of this class. Knowledge about the latter has recently been reviewed (Emmett 1979) but without apparent interest in the function of these sites. However, their association with barrows and cists led Worth to assert that they were '. . . undoubtedly sepulchral monuments . . .' (Spooner and Russell 1967: 246); unfortunately soil phosphorus analysis was not employed to test Worth's hypothesis during the only modern excavation of a stone row at Cholwichtown (Eogan 1964) despite other investigations of the soil on that site (see 3.2.1). The nature of the soil evidence from the Holne Moor stone row is very similar to that found at the Mesolithic graveyard at Kilteri in southern Finland (Nunez 1975) and thus strongly supports Worth's hypothesis, but the full case for a functional equivalence of these sites cannot, for reasons of space, be presented in detail in this thesis (it is hoped that a full account and interpretation of the evidence will appear elsewhere in the near future). If the author's interpretation of this site is correct, then the study provides valuable evidence for the long term fate of phosphorus that was initially placed (mainly in the form of hydroxy-apatite) in the sub-soil horizons rather than being deposited on the soil surface.

Houses

Figs. 5.51 - 5.65 present the results of the investigation on site F; the bulk density of all these samples was estimated from their LOI value (see 3.3.2) and their stone content was assumed to be similar to that of the surrounding soils in sub-zones A and B. The spatial patterns of sample values make it abundantly clear that both the fractions that have been measured, Pa and Po, individually and collectively (as Pao) provide evidence which confirms the assumption that human activities in the house and its surrounds have led to phosphorus enrichment of the soil (Ah/E horizon: Fig. 5.51; B horizon: Fig. 5.52). It is particularly interesting that despite the strongly-leached character of the Ah/E horizon, the values for Pa, low as they are, nevertheless form a very similar pattern to that formed by the Pao values; in this horizon, unlike the B horizon, Pa values are closely correlated with Po values as can be seen in Fig. 5.53 (compare with Fig. 5.54).

The strong positive correlation evident in Fig. 5.53 indicates that the proportion of Pa and Po in the Ah/E horizon today has not been affected by variations in the initial amounts and forms of the ancient phosphorus input. Subsequent pedogenetic processes appear to have established an equilibrium throughout the site, an equilibrium which maintains an equality of the proportion rather than the amount in either fraction. The absence of a similar equilibrium state in the B horizon will be considered later. One pattern is common to both scattergrams, namely, the tendency for both Ah/E and B horizon samples from the west side of the house to have a higher proportion of phosphorus in the Pa fraction; this may be connected with observed variation in pedological qualities within the house.

In conforming to what seems to have been the original, slightly levelled floor surface, the excavation cut into the slope on the western, upslope side of the house. Only a patchy and very thin horizon with Ah/E qualities was present in this upper quadrant and at an early stage in the excavations patches with brighter, B horizon colours were visible on the excavated surface alongside eluvial mineral soil and even zones of peaty soil. Development of soil horizons was less aberrant on the eastern side of the house but here too the Ah/E was thinner than usual and, beneath an area of paving adjacent to the eastern arc of the wall, no typical Ah/E horizon was present; instead the stones covered an unusually drab-coloured B horizon with grey patches beneath each stone. The latter has commonly been observed during the Holne Moor excavations. The higher Pa values on the western side of the house may then simply reflect the fact that these samples were drawn from layers that were pedologically 'deeper' than their archaeological equivalents on the eastern side of the house.

The spatial patterns of the values for the concentration of phosphorus within the organic fraction of the soil in both Ah/E and B horizons (Figs. 5.55 and 5.56) are very similar to the patterns of phosphorus concentration by volume of soil (Figs. 5.51 and 5.52); it is clear that incorporation of additional phosphorus as Po has led to the accumulation of organic matter with an unusually high phosphorus content and, therefore, need not necessarily have involved any substantial increase in the amount of organic matter that has accumulated in the mineral soil. However, the pattern of LOI values in the Ah/E (Fig. 5.57) does suggest that some of the phosphorus-enriched samples have a slightly higher than normal organic matter content, but in part this could be due to charcoal inclusions from hearth and midden areas. Most of the B horizon samples (Fig. 5.58), which should be much less affected by such factors, are well within the normal range of values from upper B horizons (due to the differences in sampling procedures on this site and during the 'field' sampling - see Appendix 1 - there are no strictly comparable data sets).

Exceptionally, two samples from the area east of the house (M1 and M2) exhibit unusually high B horizon LOI values (Table 5.17 lists the only Bh samples from the entire study area that provide near matches for these samples) and M1 also has the highest phosphorus concentration (Po and Pao) by volume of all the B horizon samples from the site (Fig. 5.52); note that this sample lies immediately downslope from the location of the most organic-rich and phosphorus-rich Ah/E sample recorded on the site (M). This is an interesting pattern and possibly an instructive one.

Although the M1 B horizon sample was directly overlain by an enriched Ah/E horizon sample, it seems to have a larger accumulation of Po than the general pattern of the relationships between Ah/E and B horizon samples on this site would lead one to expect. In nearly all the scattergrams, which illustrate these relationships (Figs. 5.59 - 5.65), this sampling location appears as an outlier due to its anomalous B horizon characteristics (for this reason, the samples from this location have in several cases been omitted from the regression analyses). The anomaly could have arisen as a result of translocation of soil organic matter (and, with it, Po) which involved a substantial component of downslope movement in addition to vertical movement. Exceptionally large movements of organic matter and phosphorus would be expected to occur if the phosphorus enrichment adjacent to the house had been largely due to deposition of excreta (see 2.3.3.1).

There could also have been some downslope movement of phosphorus even within the Ah/E horizon on this site, but such movements are very difficult to document. The particularly high concentration of phosphorus in the central sample immediately east of the house (M) is not matched by an especially high value in the Ah/E sample that lies directly downslope (M1), nor is it conceivable that the generally high values in this area are the result of downslope movement from the house for in that case the flow would have had to pass through a thick and complex wall structure; this pattern must reflect the pattern of phosphorus deposition and this seems likely to be true of the site pattern in general.

However, vertical movement of phosphorus through the Ah/E into the B horizons can be inferred from the systematic relationship between the phosphorus values in these horizons that is clearly demonstrated in the scattergrams (Figs. 5.59 - 5.63). The values for Po in the B horizon are plainly linked to both Po and Pa values in the Ah/E horizon (Figs. 5.59 and 5.60), but it is notable that the Pa values in the B horizon show no clear linkage either with Pa or Po in the Ah/E (Figs. 5.64 and 5.65), or, it will be recalled, with Po in the B horizon itself (Fig. 5.54). The correlation between Po values in B and Ah/E horizons involving both normal locations and those in which enrichment is evident points to downward movement of phosphorus as Po and to substantially greater movement of Po in enriched locations; indeed such movements seem to have been pretty well proportional to the degree of enrichment. This would be expected if the greater movement of Po involved, not greater movement of organic matter but, similar movement of organic matter which, however, had a higher concentration of phosphorus. If the Po movements were not accompanied by similar movement of Pa, they could lead to distortion of the Pa - Po fractional composition in the B horizon and this may well be part of the reason why there is no clear linkage between Po and Pa in this horizon.

It is, in fact, difficult to demonstrate that enhanced levels of Pa are present in any of the B horizon samples. As noted earlier, the high values in the west of the house may be due to pedological factors; only the sample east of the house (M), which was overlain by the most-enriched Ah/E sample on the site, has a slightly higher value than one might expect. It is of course quite possible that inorganic phosphorus moved into the B_1 horizon as a result of metapedogenetic inputs but that subsequent translocation, either upward due to plant uptake or downward to a position below that which has been sampled, has eroded the evidence. Small changes to Pa values would in any case be difficult to observe since B_1 Pa values in the study area typically exhibit a particularly high level of natural variability (see section 5.4.3 and Table 5.48).

The best linkages revealed by the scattergrams and regression analyses are those which exist between Pa in the Ah/E and Pao in the B horizon (Fig. 5.61), and between Po in the Ah/E and B horizons, when expressed as Po per unit weight of organic matter (Fig. 5.66). The former may achieve its tighter linkage because the values of these particular variables are sensitive to both the metapedogenetic pattern of input - Pa in the Ah/E (which is itself strongly correlated with Po in the Ah/E) and Po in the B horizon - and the pedogenetic pattern of the sampled surfaces - the Pa fraction in each horizon. This explanation suggests that the Po pattern in the Ah/E may provide the least distorted evidence for the original pattern of input. The second scattergram (Fig. 5.66) tends to confirm both this and the movement of phosphorus-enriched organic matter into the B horizons. The anomalous character of the samples east of the house, which have high concentrations of Po by volume of soil but low concentrations per unit weight of organic matter, is clearly evident in this scattergram, and reflects the unusually high organic matter content in these Bh horizon samples. A similar pattern is evident in two profiles in sub-zone C (CC1 and CC2) which, it will be suggested later (see 5.4.3), probably lie within old animal camps. All these samples and, indeed, the other enriched samples on site F, which have anomalously high concentrations of phosphorus in the B horizon organic matter, nevertheless share one characteristic; unlike the 'normal' profiles (represented on this scattergram by the $\bar{x}$ values for sub-zones A, B and F as well as three samples from the site itself) in which Po (mg kg^{-1}LOI) values are highest in the B horizons, in these profiles, the highest values are found in the mineral surface soil.

Figs. 5.67 - 5.80 present the results of the investigation of the smaller house which was sampled in order to assess how metapedogenetic inputs affect the Oh horizon; the bulk density of these samples was also estimated from their LOI values (see 3.3.2) and the stone content of the Ah/E samples was, again, assumed to be similar to that in sub-zones A and B. The latter figures were used since the house lies in an area for which these is no fully adequate set of samples and by choosing to use the same set as were used on site F, comparisons between the sites would not be affected merely as a result of changing the stone content estimate. Only in the unlikely event that the stone content of the soil in these two sites was radically different would such comparisons be distorted by this procedure.

The Ah/E samples drawn from this north - south transect line, which lay along the contours, have very similar phosphorus concentration values to those recorded for samples in and around the house on site F (compare Fig. 5.67 with Fig. 5.51). If a similar background level of soil phosphorus is assumed, then all the sampling points except location 0 may have been enriched by activities centred on the house and there is no indication that this smaller house attracted less phosphorus deposition than the larger one.

The Oh samples from locations 0 and 20 show no sign of phosphorus enrichment; the values for location 0 are practically identical to the mean value of Oh samples from the virgin land sub-zone F ($\bar{x}$ Pao: 347 μg cm^{-3}; Pa: 63 μg cm^{-3}; Po: 284 μg cm^{-3}). Fig. 5.67 also shows that Oh samples from inside the house are more phosphorus-rich than those outside, with the exception of the sample from location 16 which lies next to the house wall.

Two peat layers were present on the southern side of the house; in each case, the upper sample has a lower LOI value than the sample below and has phosphorus characteristics similar to neighbouring samples (location 8 is very similar to 4; 9 is more similar to 10). The lower samples are anomalous in several ways. Table 5.18 lists information about other profiles in the study area where two peat layers were identified and analysed; normally LOI and phosphorus values decrease with depth in such double Oh layers - the reverse of the pattern observed in the house samples. However both sets of samples share a pattern of reduction in the Pa fraction (both in concentration values and as a proportion of Pao) in the basal samples (a decline that invariably continues in the subjacent Ah/E horizon), and it is notable that Pa forms a particularly low proportion of Pao in the lower samples from the house (8.5 and 8.9% compared to a range of 11.2 to 19.4% in the lower samples in Table 5.18). The natural pattern of Pa decline with depth clearly does not always, and may never, coincide with the major changes in soil character used to define units of sampling in these studies. The author suspects, but cannot reliably demonstrate from the data obtained thus far, that the processes determining Pa values and proportions in the surface and near-surface soils impose a depth-related pattern that bears no simple relationship to the pattern of change in other soil qualities; the low Pa values in the basal Oh samples from the house, which are similar to the Pa values in the Ah/E samples from the house, may mainly reflect the fact that the basal Oh and the Ah/E samples lie at a similar depth below the soil surface.

Just what form of disturbance led to the superimposition of peat layers in the house has not been determined. Low LOI values for the peat on the northern side of the house also suggest disturbances after the onset of peat accumulation, but the depth of peat is similar to the mean depth in undisturbed land (see 4.3.1.1); this might indicate minimal loss of organic matter during disturbances or it could be that the phosphorus-rich soils in the house have accumulated more peat due to higher organic matter production rates despite disturbances. Although, as Fig. 5.68 shows, locations 10, 11 and 12 have a greater accumulation of organic matter than any other points on the transect, the multiplicity of factors which may have affected the peats outside the hut (see 4.3.1.1) make it hazardous to interpret this pattern.

The relationship between Pa and Po concentration values in the Oh and Ah/E samples from the transect is shown in Fig. 5.69, where the anomalous, basal Oh samples are labelled 8-2 and 9-2. Each of the latter samples fall almost precisely on the regression line generated by the Ah/E samples from site F, a circumstance that supports the hypothesis concerning the depth-'determined' nature of the Pa values in these samples, which have not been included in any of the correlation and regression analyses. As on site F, there is a strong positive correlation between Pa and Po values in the Ah/E samples (though the regression line they generate is slightly steeper) and the differences between samples from inside the house, from its surrounds and from location 0 are clearly evident in this type of scattergram.

In contrast, there is no statistically significant relationship between Pa and Po values in the principal group of Oh samples, though here too it is evident that samples from the house tend to have higher concentrations in both fractions. The samples from the area north of the house are substantially different from both the house samples and from the samples at the southern end of the transect. Locations 20 and 16 have, respectively, the lowest and highest Po and Pao values along the transect but their 'extreme' character does not extend to their Pa values. In fact, the sample from location 18 has the lowest Pa value among the 'normal' Oh samples, but it has fairly high Pao and Po values. It seems that in the small set of Oh samples, which have been affected by relatively low metapedogenetic inputs, there is no evidence of a systematic relationship between Po and Pa values; on the other hand, where larger inputs have occurred, one is entitled to expect that this will be reflected in higher concentration values in both fractions. Note, however, that if the phosphorus content of these samples is expressed on a weight basis (mg P kg^{-1}Fe) as in Fig. 5.70, only the Pa fraction appears to have been affected by metapedogenetic inputs and the separation of house samples from the other samples is poorer.

The anomalous character of samples from the northern end of the transect is also very evident in the scattergrams (Figs. 5.71 - 5.79) which illustrate the relationships between phosphorus concentration values in Oh and Ah/E samples from the same locations; in nearly half these diagrams, the samples from locations 16 and 20 appear as outliers in distributions which, but for these samples, would indicate very high positive correlations. The regression lines and r values in these diagrams take account of all the samples for which the relevant variables are available (exceptionally, 9-2, the relationship between the Ah/E and the lower Oh at location 9 has been excluded), but in Table 5.19, a second set of r values, calculated after exclusion of samples from locations 16 and 20, has been included in order to illustrate the strong influence exerted by these two samples. There are, however, no satisfactory grounds for excluding them and although one may suspect that some of the relationships, which, on the basis of all ten samples, must be regarded as insignificant, may nevertheless be important, such a conclusion cannot flow from this data. Taking the results of analyses of the larger data-set, one can see that only the Pa fraction in the Ah/E is strongly linked with the phosphorus concentration values in the Oh horizon and that it is, perhaps, more strongly linked to the Pa fraction than the Po fraction in that horizon. It is particularly notable that despite the strong correlation between Pa and P o within the Ah/E horizon, the Ah/E Po and Pao values are at best much more poorly correlated with values in the overlying horizon.

In explaining a linkage between phosphorus values in the Oh and Ah/E horizons two paths to equilibrium can be pursued. One might choose to regard the Ah/E phosphorus values as dependent on the Oh values and explain inequalities in Oh values as the products of the biological component of the soil-organism ecosystem (e.g. patterns of variation imposed by lateral, biological transfers during and/or after the period of peat accumulation). In this model, translocation of phosphorus to the Ah/E horizon ensures that, in the long run, a systematic link between Oh and Ah/E phosphorus characteristics becomes established. However, in the short run such transfers might lead to a disequilibrium between phosphorus values in the peat and the underlying soil if most of the phosphorus accruing from such transfers was retained in the peat and little or none reached or was retained in the Ah/E horizon. Alternatively, one may regard the Oh phosphorus values as dependent on the phosphorus values in the underlying mineral soil; pre-existing inequalities in the latter then determine the pattern of variation in the former through upward translocation by the biological component of the system. Clearly these explanations are not mutually exclusive and, in some cases, assessing which of these processes has been dominant may be the main task.

This investigation was, however, predicated on the reasonable assumption that anthropogenic transfers would have left pre-existing inequalities in the mineral soil and the observed linkages between Oh and Ah/E phosphorus values are, therefore, most economically explained as arising from upward biological translocation. If this is correct, the particularly strong linkage between Pa values in the Ah/E horizon and the amount of phosphorus in the peat samples may indicate that Pa values provide a good measure of the long-term phosphorus-supplying power of the soil, while the especially high phosphorus content of the Oh sample from location 16, which lies in the lee of the house wall, could be regarded as an indication that it has been affected by relatively recent phosphorus enrichment due to sheltering sheep. The latter possibility draws attention to the problem of distinguishing between 'original' anthropogenic transfer patterns and early post-occupation enrichment of ruined houses due to transfers by sheltering animals; analysis of the relationships between soil phosphorus patterns and archaeological features (e.g. structures, artifact patterns) or ethnographically-observed behavioural patterns provide the best way out of this dilemma. If the hypothesis advanced to explain the pattern at location 16 is correct, a disequilibrium between Oh and Ah/E phosphorus values could prove to be a valuable indicator of relatively recent patterns of phosphorus enrichment.

The concentration of phosphorus in the organic soil fraction is entirely consistent with these explanations. Although there is no statistically significant correlation between the concentration of phosphorus per unit weight of organic matter in the Oh horizon and the Ah/E horizon, the pattern revealed by a scattergram of these values (Fig. 5.80) shows a separation of house samples from other samples. With the exception of the sample from location 12, the Ah/E samples from the house have similar values to those recorded in the house on site F, and all the Oh samples from the house have values in excess of 1500 mg Po kg^{-1}LOI, whereas with the exception of the sample from location 16, all Oh samples from <u>outside</u> the house have values <u>below</u> 1500 mg Po kg^{-1}LOI - the value at location 0 (1254 mg Po kg^{-1}LOI) is again closely similar to the mean value in the virgin land sub-zone F (1287 mg Po kg^{-1}LOI). The highest Ah/E value recorded outside the house (3216 mg Po kg^{-1}LOI) is identical to that of the lowest value recorded <u>in</u> the house on site F, while the lowest sample (2208 mg Po kg^{-1}LOI) is slightly lower than any recorded on site F but slightly higher than the mean value in virgin land (2037 mg Po kg^{-1}LOI); such a range of values could be expected in samples which have varying degrees of metapedogenetic enrichment.

The exceptional character of location 16 need not be considered further, but the low value in the Ah/E sample from location 12 does require explanation. The phosphorus concentrations by volume of soil in this sample are similar to those in other house samples but it has an unusually high LOI value; the situation is therefore analogous to the pattern observed in the B horizon samples from the area east of the house on site F and may be due to similar processes. It can be noted, finally, that, as on site F, there is no other evidence that organic matter levels in the mineral soil have been enhanced as a result of the metapedogenetic phosphorus inputs.

The final example of a house soil consists of a single profile from zone C, whose relevant characteristics are listed in Table 5.20, together with the mean values for profiles in the surrounding area. Further details of this zone are discussed in section 5.4.2. Unlike the similar-sized house on site F, the house from which these samples were obtained had not been filled with clearance stones despite its location inside a medieval arable field; the house is in fact in a very well-preserved condition and both these circumstances suggest that it may have been refurbished and re-used at least casually during the time when the surrounding field was tilled. The very thin layer of peat now present on this profile points in the same direction (although the surrounding soils in the North Lobe have no peat, the nearby stagnopodzols in the North Field have 10-15 cm of peat), for it seems likely that this thin layer has re-formed after a re-occupation destroyed the original peat layer. As a result of its unusual history, the profile displays a pattern of horizon development for which there are no precise analogues; in consequence, direct comparison of the concentration values of phosphorus fractions in this profile with those from site F, the smaller house in zone A or even the stagnopodzols in zone C are of little value and will, therefore, be considered very briefly.

The phosphorus concentrations by volume of soil in the upper three horizons of this profile can, in fact, be more or less matched by enriched samples taken from the houses in zone A. However, such similarities are misleading; samples from this profile have much lower soil bulk density and higher organic matter content than the equivalent samples from zone A and, as can be seen in Table 5.20, there is slightly less phosphorus (g Pao m^{-2}) in the upper two layers of the house profile than is present in the equivalent layers of the nearby stagnopodzols, whose concentration values are not unlike those of the 'control' values used earlier in the zone A comparisons. The concentration of Pao (mg kg^{-1}IFe) in these horizons is also slightly lower than the local 'background' level in the stagnopodzols and the concentration of Po per unit weight of organic matter is only slightly higher; very much higher values were recorded for this variable in the zone A houses. Taken together, this data provides no clear evidence of phosphorus enrichment in the upper horizons of the house profile.

The samples from the B horizon tell a different story, and it is the very large amount of phosphorus in these horizons that is responsible for raising the phosphorus content of the profile as a whole to a level well above that of the surrounding soils. Pa values are quadrupled, whereas Po values only double, but Po remains the dominant fraction. The pattern of enrichment copies the natural pattern of fractional change; Pa enrichment rises steadily with depth while Po enrichment is at its greatest in the Ah/Bh horizon. Despite the abnormall y high LOI values in these horizons, the concentration of phosphorus in the organic matter is far higher than the highest values observed on site F, but it is notable that, as usual, the basal sample shows a decline. This decline is also evident in two nearby Humic brown podzolic profiles (SP 34 and SP 1 - for their location see Fig. 5.1) which share many of the characteristics of the house profile (Table 5.21).

In the light of the pattern on site F, it is not surprising to find that SP 34, just outside the house, is even more enriched than the house profile or that SP 1, 10 m further away, is less enriched. Most of the differences between these profiles and the house profile can be attributed to the failure of the former to revert to stagnopodzol-type horizon development. In addition to explain fully the differences in phosphorus concentration and distribution in the surface horizons, one must also take account of the relatively low-level, but general, phosphorus enrichment that has affected the soils in this medieval arable field (see 5.4.2). This will not be pursued here since these profiles have been introduced merely to show that, as in the house profile, phosphorus enrichment is mainly confined to the lower soil horizons. Even in the most heavily enriched profile, SP 34, where the surface soil does show some signs of extra enrichment, the bulk of additional phosphorus is found in the B horizons.

This pattern is then substantially different from the pattern observed in the stagnopodzols in zone A, where enrichment was still clearly evident in the upper soil horizons; greater movement of phosphorus may well be the result of the destruction of the peat layer during medieval cultivation of these soils and a consequent release and translocation of Pa (see discussion in 5.4.2). Since in two of the three profiles studied, the highest concentration of Pao is found in the basal layer (SP 33 and 34), it must be possible that extra phosphorus would also have been found in the BCux horizon if it had been sampled and that some of the phosphorus added to these profiles has now been entirely lost from the solum. On the other hand, the compact structure of the BCux horizon may have provided a barrier to leaching movements (see 5.2.2.2 - profile RF 2), and it is certainly worthwhile to consider the amounts of additional phosphorus that are still present in these enriched profiles.

Due to differences in structure and organic matter content, the North Lobe soils (including the house profile) have a much lower weight of ignited fine earth per unit area (to a depth of 40 cm) than the stagnopodzols in the North Field; in consequence, the apparent increases, estimated from differences in the weight of phosphorus per unit area, understate the real degree of enrichment (see 5.4.2).

Better estimates can be calculated from the differences in the concentration of Pao per unit weight of ignited fine earth and these have been included in Table 5.22. Taking zone C stagnopodzols as a baseline, it seems that about 80-110 g Pao m^{-2} may have been added to these profiles of which only a quarter can be attributed to additions to the field as a whole (see also 5.4.2). Although it cannot be distinguished with certainty, the rise in Pao due to prehistoric inputs may have exceeded 100 g m^{-2}. Even though this amount could represent as much as 75% of the original level of soil phosphorus, it is but a very small proportion of the phosphorus which would be likely to accumulate if, for example, seven people had occupied the house for a hundred years - a conservative estimate.

Cook and Heizer (1965: 4-9) estimated that the soils of a site occupied by 100 people could receive some 62 kg P $year^{-1}$ in excreta and they guessed that as much again could be added in general domestic rubbish. The latter seems a high estimate and a convenient figure of 1 kg P $person^{-1}year^{-1}$ (excreta + rubbish) will be used here. The large houses on Holne Moor enclose a living space of about 40 m^2, but, from the results of the survey of site F, it can be estimated that heavy deposition of rubbish and excreta occurs over a zone of about 400 m^2. Using these values, it can be estimated that seven people could add some 17.5 g P $m^{-2}year^{-1}$ to the soils in this 'rubbish zone'. Even allowing that such an estimate could be in error by 50% and that the increases in Pao values probably underestimate, by a third, the true extent of phosphorus enrichment, one is forced to conclude that the extra phosphorus now present in the soil could have accumulated in less than five years and is unlikely to represent more than ten years occupation debris.

The leaching losses from these profiles may well be higher than those from the stagnopodzols, but it would be necessary to postulate unacceptably high rates of leaching to explain the discrepancy between the 1750 g P m^{-2} that could be added by seven people during a one hundred year occupation and the present Pao enrichment of about 100 g m^{-2}. It was pointed out earlier (see 2.2.2.2) that typical losses of phosphorus recorded in the drainage water from fertilised arable and grassland lie between 0.15 and 0.30 kg $ha^{-1}year^{-1}$, but even these relatively high rates are about twenty to forty times lower than the rate of leaching that would be required in this case. The inevitable conclusion one must reach is that a very high proportion - around 90% and possibly higher - of the phosphorus in the excreta and rubbish produced by the prehistoric occupants of this house was deposited outside the 'rubbish zone' within which phosphorus enrichment is clearly evident. It would be possible to alter greatly the parameters which have been assumed in these particular calculations without endangering the conclusion.

A ceremonial monument

In 1977, two soil profiles were sampled within the gently sloping (2-5^{o}) strip of land traversed by the 150 m triple stone row that lies to the south-west of the main study area on the supposition that soil characteristics within areas of the monument where standing stones still survived would not have been affected by land use events post-dating the erection of the stones. The thickness of peat on the profiles tended to confirm the supposition, but the phosphorus values in the B horizons of these profiles (Fig. 5.81 and 5.82) were so at variance with each other, and in one case with all other profiles that had been investigated prior to that time, that it was felt necessary to instigate further studies of both the physical and chemical properties of surface and sub-soils in the row. The enlarged project was conceived as having both an archaeological purpose - assessment of the function of the monument - and a pedological purpose - assessment of natural variability and, if the author's hunch was correct, assessment of the fate of phosphorus added to this particular type of soil by human burials some four thousand years ago.

In all, 30 profiles were examined at randomly selected distances along two transects, one of which bisected the row, while the other traversed its length; about 100 soil samples were taken and two-thirds of these have now been subjected to the full range of physical and chemical analyses listed in the appendices. Further details of sampling and recording are given in Appendix 1 (groups 6 and 11). Much, indeed most of the information gained during this project will be presented elsewhere; there is only space here for a brief description of the principal results and one or two conclusions which they allow.

At present, analyses of Oh, Ah/E and B horizon samples from all of the 12 profiles located within the row have been completed, and analyses of Oh and Ah/E samples in a further ten profiles outside the row are also available, but the B horizon samples from only five of the latter group have so far been analysed. The following account will therefore mainly be based on the 17 profiles for which there is complete information.

Table 5.23 lists the mean concentration of Pao by weight of fine earth in Oh and Ah/E samples from the row and the surrounding land. Although, there seems to be somewhat lower variability among samples from within the row, there is no significant difference between the mean values of the groups, nor did the analysis of these samples reveal any 'abnormal' pattern of spatial variation in phosphorus values that will assist the functional interpretation of the row. The B horizon samples were, as expected, much more helpful. Samples from within the row carry an identification number that indicates the distance (m) of the sampling pit from the transverse orthostats that mark the western terminal of the row; Fig. 5.83 shows, therefore, that samples drawn from the central portion of the row have substantially higher concentrations of Pa than samples drawn from either end of the row or the surrounding land (see also Fig. 5.84). Po values also tend to be higher in these samples but the difference is much smaller. Note that locations 109 and 125 are the profiles sampled in 1977, and that location 16 marks the position of the one profile in the bisecting transect that fell within the row. It was hoped that this transect might indicate whether the phosphorus anomaly within the row extended north or south of the east-west alignment of stones. As luck would have it, the bisecting transect was laid out too far to the east to provide any answer to this question.

Fig. 5.85 shows the vertical distribution of Pao values in the two complete profiles sampled in 1977, together with similar information for the profile at location 46, and B horizon Pao values from the three other locations where Pa enrichment is evident. The profile at location 46 possessed an unusually deep, layered, very stony, loose and structureless eluvial zone from which iron and phosphorus has been leached, and in view of this, one must suppose that part of the particularly large B horizon accumulation of phosphorus in this profile is due to redistribution. However, redistribution cannot explain any significant proportion of the Pa enrichment at locations 94, 102, 107 and 109. Fig. 5.86 provides a summary of the phosphorus analyses; in this diagram, the 17 complete profiles have been allocated, irrespective of their location, to groups 'with' or 'without' B horizon Pa enrichment. Although the enriched group has very slightly lower mean Pao values in the Oh and Ah/E horizons, the differences between the groups are not significant and, in any case, this deficiency is far too slight to have produced the trebling of Pa values in the underlying soil.

It can be concluded that it is extremely improbable that pedogenetic processes created these anomalous accumulations. It can also be noted that fractional analysis has revealed a pattern of (presumptively) metapedogenetic enrichment quite unlike that observed in the houses on Holne Moor. In those studies, the Po fraction always showed substantial enrichment; this does not occur in the stone row. Moreover, the studies of enriched stagnopodzols showed that ancient metapedogenetic surface input of phosphorus could still be detected in the Oh and Ah/E horizons, but there is no enrichment of the surface soils in the stone row. It can be argued that each of these differences would be expected if a large quantity of inorganic phosphorus had initially been placed at a depth which lay below the zone explored by the rooting systems of the contemporary and succeeding plant communities. The enriched zone seems to start 20-25 cm below the mineral soil surface and thus might well lie below most of the root system of an acid grassland community (see 2.3.3.1). An alternative scenario could invoke the strong leaching observed in the house (and nearby Humic brown podzolic soils) in zone C as evidence that phosphorus from surface inputs or shallower burials in a soil without a cover of peat could have been leached down into the B horizons; however, this model cannot provide an economic explanation for the very low proportion of added phosphorus that has been incorporated in the Po fraction.

Three aspects revealed by this investigation will be stressed. First, the study provides strong, if not compelling evidence that the reserves of soil phosphorus held below a depth of 20-25 cm may have played a very limited role in plant nutrition during the past four thousand years; B horizon accumulations of phosphorus below that level are unlikely to have been significantly degraded by upward biological translocation of phosphorus. Secondly, although it has not been possible to assess changes in the Pf fraction (the only Pt analysis undertaken showed that the iron-pan in location 109, which was enriched, contained 690 mg Pt kg^{-1} Fe of which 42% was Pa, 43% Pf and 15% Po), at least some of the phosphorus additions, which were very probably emplaced as hydroxy-apatite have been retained, in an extremely acid B horizon soil environment, as acid-soluble inorganic phosphorus despite roughly four thousand years of leaching and stagnopodzol soil development. Finally, this study, together with the studies of house enrichment, provide a convincing demonstration of the value of fractional analysis of soil phosphorus in investigations of ancient metapedogenetic alteration of the distribution of this element.

5.2.2.2 Modern farming

Numerous studies at agricultural experimental stations across the globe have demonstrated the substantial effects on farmland of modern agricultural practices; however, the multiplicity of both practices and effects confounds simple extrapolation of the results of such studies to farmland near the study area. Although some of the latter has been 'tested' by local agricultural advisors there do not appear to have been any previous, quantitative studies of phosphorus in the granite soils of Dartmoor farms. This section includes abbreviated reports on tw o such investigations, one at Rowbrook Farm, which lies 1 km north of zone C, the other at West Stoke, which lies 1 km east-south-east of zone C (see Fig. 3.1). In both cases, the fields investigated lie at a similar altitude (280-310m) to the study area and have similar soil parent material, but whereas there are no significant differences between the natural soil-forming factors in the study area and those in the Brake Field at West Stoke, the Upper and Lower Western Fields at Rowbrook enclose land that slopes more steeply (8-10^{o}) than any land w i thin the principal zones of the study area. Both farms were in existence by the end of the 13th century (see 3.2.2), but nothing is known about the antiquity of intensive land use in the specific fields that have been investigated.

The Brake Field at Stoke Farm and immediately adjacent moorland on Bench Tor (see Fig. 5.87, which shows sampling locations) were sampled in order to evaluate the differences between soils used in a system of convertible husbandry that has involved regular ploughing and sizeable inputs of inorganic and organic phosphorus, and moorland soils subjected to far less intensive agricultural exploitation. (Some information about this investigation appears in Appendix 5 and Fig. A5.2). Like the study area, Bench Tor is criss-crossed by prehistoric reaves, medieval boundaries and leats, but these features have not yet been studied with sufficient intensity to allow any statement about the pattern of past enclosure and land use. Cultivation artifacts appear to be absent from the sampled zone, but the soil evidence discussed below suggests that peat cutting has affected all the profiles sampled on Bench Tor. Mr Norman Perryman, who has farmed West Stoke since 1952, has supplied detailed information about soil treatments on Brake Field, but since written records were not kept and there remain a number of uncertainties, no attempt will be made to provide a precise nutrient balance sheet for this land.

Before 1952, Brake Field appears to have been kept mainly under grass, though it may have been ploughed with horses in the inter-war years. The gorse and bracken that had colonised this neglected land was burnt off in 1952 and the land has been used in a so-called seven-year rotation ever since. This rotation starts with swedes, for which a ca. 1.25 t ha^{-1} dressing of basic slag is applied, continues with oats (undersown with timothy, cocksfoot and rye grasses plus clover), for which a ca. 7.5 t ha^{-1} dressing of ground limestone is applied, and is followed by a five year grass ley during which the land is mainly grazed by beef and milk cows. The basic slag is harrowed in after ploughing to a depth of ca. 15 cm and sheep are folded on the swedes during autumn and winter. Dressings of FYM (ca. 20 t ha^{-1} - cow and pig excreta plus straw) and/or 20/10/10 general NPK fertiliser (ca. 250 - 300 kg ha^{-1}) are also applied in most years. In all, Brake Field has been cropped in eight of the twenty-six years prior to sampling in 1978 and some 25-30 t ha^{-1} of limestone and 4-5 t ha^{-1} of basic slag have been added to the soil during this period. At the time of sampling (August 1978) the land was in the third year of a grass ley.

The Upper and Lower Western Fields at Rowbrook Farm and the moorland on Vag Hill to the west of these fields (see Fig. 5.88, which shows sampling locations) were sampled to assess the effect on these granite soils of lengthy use as permanent grassland. Like the study area and Bench Tor, the moorland area in which 'control' profiles were sampled seems to have been affected by agricultural activity in pre-historic and medieval times, but here too the precise pattern of earlier land division has not been determined. However, signs of land clearance taking the form of irregular linear 'cairns' or 'boundaries' were observed and have been included on Fig. 5.88. The soil evidence discussed below suggests that four of the six control profiles have been significantly altered by (probably medieval) farming. Mr Algy May, who has worked Rowbrook Farm for the past thirty years, has provided information about soil treatments in his fields, but in this case also, there remain too many uncertainties for a precise balance sheet to be drawn up. It is, however, evident that the Rowbrook soils have received less phosphorus in the form of basic slag and FYM than the West Stoke soils.

For most of this century, the steeply sloping Lower and Upper Western Fields have lain in grass. Regular ploughing and cropping has probably not occurred since the First World War, but a single crop appears to have been taken during the Second World War. In 1960, the land was ploughed and re-seeded (rye grass and white clover were sown, but both species are now rare) but has lain undisturbed since that time. Limestone dressings (of 5 t ha^{-1}) were applied in 1954 and 1978 (some four months prior to sampling) and on two occasions in the intervening years (total of ca. 20 t ha^{-1} since 1954); a dressing of basic slag (1.25 t ha^{-1}) was applied in 1974, and this treatment may have occurred some ten years earlier. A 'good cover' of FYM has been applied four times since 1954 (FYM included bracken bedding, and horse and cow excreta). General inorganic fertilisers do not appear to have been used on this land, which has been grazed by beef cattle, horses and, to a lesser extent, sheep. Cows, calves and, to a limited degree, horses consume bought-in feedstuffs, which represent another pathway of soil nutrient enrichment.

On both farms, sampling pits were sited well away from boundaries; the intention was to obtain data from cropping and/or grazing portions of the fields rather than areas strongly affected by the factors discussed in section 2.3. Recovery of the vertical pattern of soil phosphorus fractions was a principal goal, and, in addition, these studies were to be used to assess the advantages of different sampling strategies.

Rowbrook Farm and Vag Hill

Ten soil pits were examined and sampled in this study (see Appendix 1 - group 14 and Fig. 5.88); in each case an attempt was made to sample all horizons above the BCux horizon, though in one case (RF 2), the latter was encountered at the unusually shallow depth of 35 cm and in this case, the two basal samples were taken from this indurated horizon. On the basis of their field appearance, all profiles within the enclosed land (RF 1-4) would be assigned to the Moretonhampstead Series (see 3.2.1) of Typical brown podzolic soils, while the moorland profiles on Vag Hill fall into two groups. RV 2,3,5 and 6 are similar to the S - IV type soils of the study area (Humic brown podzolic soils); these profiles occur widely in the area immediately west of Rowbrook Farm. RV 1 and 4 cannot be allocated to any of the soil groups defined in chapter 4; they are podzols with very humose surface horizons which have a peaty appearance, but, unlike Oh samples from Holne Moor, possess a stone content similar to a mineral soil (see Appendix 2: Table A2.1). This soil type has a very limited distribution within the surveyed area (see Fig. 5.88) but may be the only soil type that has not been substantially affected by metapedogenesis; the high mineral content of its peaty surface soil may reflect natural erosion on this steeply sloping land.

Figs. 5.89 - 5.103 provide quantitative information about these soil profiles; pH (Fig. 5.89), LOI (Fig. 5.90) and the concentration of phosphorus fractions by weight (Figs. 5.92 - 5.94) are given for all profiles, and this data clearly supports the three-fold division of soil types outlined above. In view of the generally similar pattern of values among profiles assigned to these groups, concentration by volume and absolute weights of phosphorus in profiles (Figs. 5.95 - 5.100) have only been calculated for RV 1 (representing the podzols), RF 1 (representing the field soils) and RV 2 and 6 (which appear to encompass the range of variation observed among the Humic brown podzolic soils).

A full consideration and explanation of all the patterns revealed in this study cannot be included here; the following discussion will therefore concentrate mainly on general features rather than details of specific profiles. It is clear that liming has had a marked effect on the pH of the field soils (Fig. 5.89), an enhancement that can be detected at all sampled depths; however the most recent liming (limestone aggregates were still visible in the turf) may not yet have contibuted heavily to this pattern. The differences among the moorland profiles could reflect more intensive leaching of the podzolic profiles due to the absence of a thick, very humose surface layer. It is particularly notable that even the eluvial horizons of the podzols have substantially higher pH than any samples from the moorland podzolic soils.

Despite the rarity of ploughihg and cropping in the fields, the LOI (%) values (Fig. 5.90) for these profiles are generally lower than samples from equivalent depths in the moorland profiles. However the surface samples from the fields have higher soil bulk density than the moorland samples and when organic content is assessed on a volume basis (Fig. 5.91), it is clear that there is little difference between the organic content of samples from the first 25 cm of the field and moorland podzolic profiles. Nor, when variation in density is taken into account, do there appear to be any substantial differences in the organic content of samples from below 50 cm. (The two samples from the indurated horizon of RF 2, which have very low LOI values, constitute exceptions. It would appear that the compact, platy structure in this profile has reduced translocation and probably rooting depths and there is evidence for a 'build-up' of organic matter above the indurated horizon; a similar pattern is evident in the Po values (Fig. 5.94)). However, there does seem to be a real deficiency of organic matter in the upper B horizons (ca. 25 to 50 cm) of the field soils, and this probably reflects a higher rate of organic matter decomposition in the surface soil and consequent reduction in the amount of organic matter that has become available for translocation. The vertical distribution of organic matter in both the field and the moorland podzolic profiles contrasts strongly with the classic podzol distribution in RV 1 and 4, and this contrast is equally apparent in the vertical distribution of phosphorus fractions (Figs. 5.92 - 5.97).

Before considering the phosphorus values and their distribution, it must be pointed out that the higher pH of the field soils could have had a profound effect on the proportion of phosphorus in the inorganic fractions. The form taken by phosphorus inputs in manures and fertilisers is mainly governed by the soil pH at the time of application (Mattingly and Talibudeen 1967: 232), and at pH levels of 5 to 6, one would expect that much of the applied phosphorus that remains in an inorganic form would be relatively loosely adsorbed to aluminium; some secondary Ca-P could also be present and both forms could contribute substantially to Pa values. On the other hand, in the strongly acid, moorland soils, the Pa fraction may include a far higher proportion of iron-bound phosphorus. Unfortunately, it was not possible to obtain Pt values for any of these samples and so changes in the acid-insoluble Pf fraction have not been monitored.

Despite these limitations, the fractional analyses that have been undertaken provide valuable evidence of the way in which metapedogenetic processes have altered the distribution and proportion of phosphorus fractions. The substantial increase in the amount of phosphorus in the field soils has involved enhancement of both Pa and Po fractions (Figs. 5.92 - 5.97), but, as in the moorland profiles, Po remains the dominant fraction. There has, however, been a small rise in the proportion of phosphorus in the Pa fraction, which (calculated to a depth of 67 cm) accounts for 28.9% of the phosphorus in RF 1, but only 18.6% in RV 1; RV 2 and 6 have intermediate values of 24.9% and (to a depth of 55 cm)

26.2 respectively. The vertical distribution pattern of Pa values (Fig. 5.92) does not appear, at first glance, to have been much altered; all profiles (except RF 2 - see above) have a subsoil minima. However, closer examination (and assessment on a volume basis - see Fig. 5.96) suggests that in the field soils, this minima may lie at a slightly greater depth. This could reflect higher levels of phosphorus uptake from more extensively-developed and deeper root systems in the field soils.

In the podzol, RV 1, there is a precise correspondance between the Pa and Po eluvial and illuvial zones and this creates a single, clear zone of B horizon phosphorus accumulation; this is not evident in the field soils. In all these profiles both Pa and Po concentrations drop sharply in the highest sub-surface samples, but whereas Pa values tend to recover in subjacent horizons, Po values continue to fall. Only in RF 1 is there some evidence for a distinct zone of Po accumulation; this lies some 20 cm lower than the equivalent zone in RV 1. The podzolic soils outside the modern enclosures also show little trace of distinct Po accumulation zones, but it must be noted that Po values in the B horizons of these podzolic soils and the field soils are in general slightly, and in some cases substantially, higher than the Po values in the B horizon accumulation zones of the podzols. While rooting depths may also be greater in all the podzolic soils, which could lead to a greater *in situ* supply of Po in the B horizons, it is still difficult to argue that downward translocation processes play a more important role in the development of the podzol distribution pattern. To the contrary, the existence of a distinct accumulation horizon suggests that downward movements may be limited to a shallower zone. In this connection one must also note that the substantial deficiency of Pa and Po in the eluvial horizon of RV 1 mainly seems to reflect the strength of plant uptake and consequent accumulation in the overlying humose Ah horizon; the amount of Pao ($g\ m^{-2}$ - Fig. 5.98) to a depth of *ca.* 30 cm (i.e. to the base of the eluvial zone) is in fact very similar in all the moorland profiles.

Despite the strong differences in field appearance and vertical distribution patterns of organic matter and phosphorus fractions among the moorland soils, there is no evidence that they differ in overall phosphorus content. If, as the author suspects, the Humic brown podzolic soils owe their present, distinctive morphology to historical cultivations (a view supported by analogy with the changes observed on Holne Moor and the indications of local stone and boulder clearance), then either such cultivations were not accompanied by substantial inputs or outputs of phosphorus or such fluxes were balanced. Although a slightly higher rate of leaching on these more steeply-sloping soils must be possible, the Humic brown podzolic profiles in zone C discussed in the previous section (5.2.2.1 - see also Table 5.24), which lie on a 5-6° slope, retain evidence of enrichment at a level similar to that observed in the modern field soils at Rowbrook, and in the face of this evidence complete dissolution even of lower levels of enrichment seems most unlikely.

The similarity of phosphorus enrichment in the field soils and the profiles in zone C extends also to the enrichment of the organic matter fraction. However, in the soils affected by recent inputs, the effect of enrichment is even more spectacular. In zone C, many samples had values higher than 5000 mg Po kg^{-1} LOI, but in the samples from Rowbrook's fields, values of up to 7500 mg Po kg^{-1} LOI have been recorded and the concentration of phosphorus in the organic matter of these permanent pasture fields is in general some two to three times higher than that in the adjacent moorland profiles (Fig. 5.103); only a few of the deeper samples from the fields can be matched by samples from the moorland. The heavy enrichment in the fields has led to a reversal of the pattern of increase with depth that is evident in the podzols (RV 1 and 4), which themselves have a far more coherent and clear pattern of change with depth than is apparent among the moorland podzolic profiles. Whereas for the most part, the latter vary irregularly (and very little) around values of ca. 2500 - 3500 mg Po kg^{-1} LOI, the podzols exhibit a pattern of change that includes a strong inverse relationship to the organic matter content of samples; the lowest phosphorus concentrations occur in the organic-rich Ah and Bh horizons and higher values are found in the strongly-leached eluvial horizons and in the basal samples.

Unusually high phosphorus concentrations in the organic matter have also been observed in the relatively rare and poorly-developed E horizons in the stagnopodzols on Holne Moor (see 5.2.1.2), and in some of these cases, as in the podzols, the E horizon value exceeds the subjacent Bh horizon value. The general level of values in the upper parts of the podzol B horizons (2252-3179 mg Po kg^{-1} LOI) can also be matched on Holne Moor, and only the sharp rise in values in the basal samples (50 - 70 or 75 cm) is clearly at odds with the trend observed in the stagnopodzols. Nevertheless, the overall pattern of change with depth in the podzol is distinctive, and unlike the stagnopodzol pattern, none of its features is inconsistent with the hypothesis that attributes variation in these values to a process of organic matter decomposition which involves preferential retention of phosphorus compared to other elements. It is not surprising to find some differences in organic matter patterns in well-drained podzols on steeply sloping land and stagnopodzols on flatter land; the implications of these differences will be followed up in discussion in section 5.3.

The very substantial increase in the phosphorus content of the Rowbrook soils is matched by very much higher levels of phosphorus in the animal faeces deposited on this land (Table 5.25). Although very much more intensive work would be required to assess the extent to which the animal component in the soil-organism ecosystem of these permanent pastures influence the proportion and distribution of phosphorus fractions in the underlying soils, these analyses demonstrate the strong response of one element in this system (higher excretal nutrient return) to changes in another element (higher soil nutrient supply), presumably through the go-between of a third element (higher nutrient levels in the sward). They also illustrate the transfer of nutrients from enclosed land to nearby moorland; the odd man out in these analyses is sample XRVS, which, although taken from moorland, contained as much phosphorus as the sheep faeces sampled in Upper and Lower Western Fields. This apparently anomalous result arose because the Vag Hill samples were recovered during the time when sheep were being released from the enclosed land where they had been held for some three or four days during shearing.

West Stoke Farm and Bench Tor

The homogenous field appearance of soil profiles in the Rowbrook fields led to the adoption of a far less time-consuming sampling strategy at West Stoke; only two large soil pits (GSP 10 on Bench Tor, GSP 11 in Brake Field) were examined and sampled to provide evidence of the vertical distribution patterns, whose representative character was to be assessed from examination and sampling of four small 'satellite' pits randomly sited around each large pit (see Fig. 5.87). Similar surface samples (Oh, Ah/E and Ap) were taken from all locations, but B horizon qualities at the satellite sites were tested only by an auger sample of the soil lying between 20 and 40 cm beneath the mineral soil surface. Although this policy provided satisfactory samples from the moorland soil (satisfactory in the sense that there is no conflict between samples from the main pit and the satellites), unfortunately this was not the case with the field soil samples. Table 5.26 lists some of the data from GSP 11 and its satellites; it is clear that satellite samples from the B horizon are quite unlike those recovered from the main pit. Such sizeable differences seem unlikely to be due to sampling of a single, highly variable population and in the author's view, the most likely explanation for this pattern is that the profile at GSP 11 was sited at a point where boulder clearance has substantially disturbed the subsoil. Very large boulders are still present in this field and Mr Perryman has had to undertake boulder clearance in recent years. If this view is correct (and it is hard to believe that all four satellite pits are atypical), the subsoil samples from GSP 11 (with, perhaps, the exception of the BCux sample) are best discarded as unreliable, and this is the course that has been adopted. This exclusion reduces the utility of the remaining data, but certain important patterns are evident and will be briefly considered.

Field examination showed that Humic brown podzolic soils similar but not identical to soil type S - IV on Holne Moor were present in Brake Field, while Bench Tor possessed typical Stagnopodzols. Quantitative data for these soils is given in Figs. 5.104 - 5.110. Despite heavier liming, it is notable that pH values in Brake Field (Fig. 5.104) are not as high as those at Rowbrook; this may reflect the longer period that has elapsed since a dressing was applied and the rapid dissolution of lime dressings in land subjected to <u>ca</u>. 1750 mm annual precipitation. Nevertheless, liming has led to a marked reduction in soil acidity and, in consequence, interpretation of changes in phosphorus values must take into account the limitations noted earlier.

The organic matter content of samples is shown in Figs. 5.105 - 5.106. On Bench Tor there is a very thin peat ($\bar{x}$ depth: 4.8 cm excluding litter) with high LOI values; since this flat plateau area would, by analogy with Holne Moor, be expected to have some 11 - 14 cm of peat excluding the litter layer (see chapter 4), either peat cutting or cultivation seems likely to have affected this area. In fact, as will be discussed below, peat cutting seems the more likely explanation. The Ap horizon in Brake Field is very humose; LOI values range from 13.5% to 16.1 % compared to values between 9.8% and 11.4% in the grassland Ah at Rowbrook. Since Brake Field has, recently, been regularly tilled, its higher organic matter content is somewhat surprising (see 2.3.3.2). It could reflect both poorer soil drainage on this plateau top and the substantially higher inputs of FYM, but later reclamation could be a factor; this is considered later. The same contrast is apparent in the subsoils; although, as at Rowbrook, the field subsoils have less organic matter than the moorland subsoils, the difference is smaller.

It is no surprise to find that phosphorus values in the surface soils of Brake Field are very much higher than those in the adjacent moorland (Figs. 5.107 - 5.109). They are also higher than those in the surface soils of the Rowbrook fields; Po values ($\mu g\ cm^{-3}$) are only slightly higher, but Pa values are twice as high, and this fraction accounts for ca. 45% of Pao as opposed to ca. 27% at Rowbrook. However, if the B horizon samples from the satellite pits in Brake Field are representative of soil qualities between 20 and 40 cm, the subsoils have only slightly higher Po, Pa and Pao concentrations than the subsoils on Bench Tor, a much less substantial contrast than was evident at Rowbrook. Note that the greater similarity mainly reflects higher values in the stagnopodzol 'control' subsoils compared with the values in the podzol 'controls'; subsoil values on the farms are not very different. Although without statistical significance, the slightly higher concentrations in Brake Field compared with Bench Tor may indicate that some of the very high phosphorus input to this land has penetrated below 20 cm, but clearly there has been much less movement of applied phosphorus in this land than in the permanent grassland at Rowbrook. These contrasts are also readily apparent in the figures for the concentration of Po in the organic matter (Fig. 5.110). Whereas in the Rowbrook fields all samples above 40 cm had values greater than 4800 mg Po kg^{-1} LOI, none of the samples from Brake Field reach this figure, and the range of subsoil values (3411 - 4395) overlaps that in the Bench Tor satellite samples (2627 - 3553); even higher values occur in GSP 10, which has a vertical distribution of values typical of the stagnopodzols on Holne Moor.

It is possible to estimate the total weight of phosphorus fractions within Brake Field by combining together the information from GSP 11 and its satellites (see Table 5.27); although these estimates are not strictly comparable with other estimates from individual profiles, the general patterns that emerge from such comparison are probably a fair indication of the differences between the Brake Field and other soils. As one would expect, the higher phosphorus input in this field is reflected in higher Pao levels, but most of this enhancement has occurred in the Pa fraction, which has increased by a factor of more than three (compared to the Bench Tor soil) and is nearly twice the level in the Rowbrook profile (RF 1).

The fields at Rowbrook and West Stoke differ not only in management but also with respect to topography and it is not easy to decide which of the various soil differences that have been observed should be ascribed to each of these factors (unfortunately, a 'management only' contrast on level land could not be located among the fields close to the study area - most of the flatter land is, like Brake Field, used in a system of convertible husbandry). Nonetheless, it seems likely that the greater penetration of applied phosphorus at Rowbrook reflects the fact that a greater proportion of the input has been incorporated in the Po fraction, which, as noted above (see 2.3.3.1) is generally more mobile, and this, in turn, seems likely to be due to the differences in land use and soil treatments rather than the difference in topography. Superphosphate (in the general fertiliser), much of which tends to be rapidly 'fixed' in the soil in a sparingly 'available', inorganic form, has only been used at Stoke; here too, there have been regular if infrequent cultivations, which must have destroyed organic matter (the organic matter content of the Ap horizon in Brake Field (14.90 kg m^{-2} calculated to depth of 12.5 cm is one third lower than that in the combined Oh and Ah/E horizons on Bench Tor (22.63 kg m^{-2} calculated to the same depth below the mineral soil surface)) and thus led to the release of organic phosphorus by mineralisation. Each of these treatments would tend to enhance or maintain higher Pa values.

At first sight, comparison of the proportion of Pao present as Po in the moorland locations adjacent to each farm (Table 5.27: RV 1 and GSP 10) appears to refute the contention that the topographic difference may be of little importance, for these profiles also differ, and differ in a very similar fashion to the field soils; the percentage of Po at Vag Hill is 13.3% higher than that at Bench Tor, while the percentage of Po in the Rowbrook fields is 16.5% higher than that in the Brake Field at Stoke. However, this comparison may not be valid if, as is thought, peat cutting has affected phosphorus values in the Bench Tor soils; when, instead, RV 1 is compared with Holne Moor stagnopodzols that do not appear to have been altered by peat cutting (see Table 5.27), the difference between the percentage of Po in these two natural soil types (4.2%) is very much less. Nor is there any substantial difference in the percentage of Po in the podzolic profiles on Vag Hill (RV 2, RV 6) and the principal group of similar profiles within the more gently sloping land in the North Lobe on Holne Moor.

The suggestion that the depth of peat on the Bench Tor sampling sites has been affected by peat cutting arises from the large deficiency in Pao and Po (as well as organic matter) in GSP 10 compared with other stagnopodzols in the main study area (see Tables 5.27 and 5.28). The similarity in the concentration of Pao (mg kg^{-1} IFe) in GSP 10 and the profiles in zone C (both in the mineral soil and in the profile as a whole) suggests that the latter provide a better analogue for the possible state of the soil at GSP 10, prior to peat cutting, than the 'virgin' soils in zone A (differences between zone C and zone A values are discussed further in sections 5.4.2 and 5.4.3). It is, therefore, important to note that the apparent loss of Pao from the Oh horizon of GSP 10 (29.3 g m^{-2}) is, in itself, large enough to explain the lower Pao content of the Bench Tor profile compared to several of the zone C profiles. This is also true of the Oh deficiency of organic matter, though since regrowth of peat may have occurred, this comparison is less satisfactory. If it is assumed that the peat which seems to have been removed by peat cutters was similar in quality to that still present, one can utilise the figures for the apparent losses of Pao and organic matter from the Oh as a means of estimating the thickness of peat that has been lost.

From the Pao values one obtains an estimate of 13.3 cm which, if the present peat layer is entirely residual, would imply a pre-peat cutting thickness of 18.1 cm excluding litter or ca. 23 cm including litter. This is some 4 - 7 cm deeper than one might expect, an excess that may indicate the amount of post-peat cutting accumulation of organic matter. From the deficiency of 18.07 kg LOI m^{-2} in the Oh horizon one obtains an estimated loss of 7.3 cm of peat, and the difference of 6 cm between this estimate and the phosphorus estimate can also be taken as an indication that little if any residue of peat was left by the cutters and that the present peat has largely or wholly accumulated since their exploitation. The argument put forward here is not conclusive; it is just possible that peat destruction was the result of cultivation and that the apparent phosphorus deficiency reflects cropping uptake and/or natural variation in these soils. However, the consistent nature of the pattern of phosphorus and organic matter deficiencies is most economically explained as an artifact of peat exploitation.

The nature of the variation among the moorland profiles at Rowbrook precluded assessment of the extent to which metapedogenetic processes might have altered the variability of phosphorus values; however this can be attempted with the data from West Stoke and Bench Tor.

Table 5.29 lists the coefficients of variation calculated from the volume and weight concentration data gathered in this investigation (see also Appendix 5 and Fig. A5.2). Although it would be wrong to read too much into such relatively small data sets, particularly since the variability of the stagnopodzols may have been affected by peat cutting, the most important changes that are evident can be linked to the difference in land management. The most important change in both surface and subsoils occurs in the Pa sample values. The variability of Pa values in the Ap horizon compared to the Oh and Ah/E horizons of the stagnopodzols shows that the large rise in the amount of phosphorus in this fraction has been accompanied by an increase in the spread of sample values; it is also evident that Pao values have been affected by this change, but there is no evidence that the spread of Po values has been increased. More substantial variation in soil bulk density and stone content make the B horizon data more difficult to interpret; there may have been little change in the subsoils. If the apparently sharp decline in the variability of the field soil samples is real, it might be an artifact of the greater and perhaps more evenly distributed withdrawal of phosphorus by sown crops compared with semi-natural plant communities.

Finally, it is worthwhile to consider the possibility that the differences between the soils at Rowbrook and Stoke may reflect not only topographic and present differences in land management, but also a difference in the length of time that has elapsed since the land was reclaimed from the waste or at least brought into intensive agricultural use. Several of the soil characteristics in Brake Field are consistent with an hypothesis that this land may have been more recently reclaimed for intensive agricultural use than the Upper and Lower Western Fields at Rowbrook; in particular, there is the still very high organic matter content of the Ap horizon and the very limited movement of applied phosphorus below the ploughing depth of ca. 15 cm. Moreover, unlike Rowbrook, there is no evidence that the land outside Brake Field has been used for intensive agriculture during historical times; on this farm the present boundaries could well lie at the high-tide mark of reclamation. On the other hand, at Rowbrook, a contraction in the land used for intensive agriculture seems to have occurred and it is possible that the Upper and Lower Western Fields lie on land that has been in regular use for nearly seven hundred years. Although, a small accumulation of soil on the down-slope boundaries of these fields indicates some soil movement, which could have affected, in particular, the vertical pattern of soil properties, it seems probable that the soils have been stable during the last century under grass and that most of the present pattern of phosphorus enrichment has been imposed during this period of stability. However, the soils into which modern fertilising materials were introduced may well have been much-modified by earlier use and could have been similar to the moorland podzolic profiles on Vag Hill; some soil properties, therefore (e.g. the relatively low organic content of the surface soil), may mainly represent an inheritance from an earlier phase (and, possibly, different type) of land use.

5.2.2.3 Discussion and general conclusions

The investigations reported in the previous sections had two overall purposes: assessment of the ability of the chosen analytical methods to identify metapedogenetic alteration of phosphorus in the granite soils of the study area, and, due to the paucity of relevant, previous research, collection of information about the nature of such changes in soils which could be presumed to have been affected by known agencies. It will rarely be possible to study metapedogenetic artifacts in ancient soils in an untransformed state; soils buried during enclosure will very often be virgin or little-altered soils and, in any case, will frequently have been affected by post-burial peda-metamorphic processes. Study of soils affected by contemporary metapedogenesis provide, therefore, an essential baseline against which one may assess the evidence from soils affected by early metapedogenesis and subsequent pedogenesis.

The studies at Stoke and Rowbrook show that despite coarse texture and high organic matter content, the granite soils of Dartmoor react to phosphorus input in much the same way as many other agricultural soils. Land which has received high inputs of phosphorus shows strong enrichment and, although it has not been possible to draw up any balance sheets, it seems unlikely that leaching has completely removed any substantial proportion of these inputs. There is, however, evidence of phosphorus movement; on permanent grassland, subsoil enhancement has been substantial and probably reflects translocation of Po. Despite higher phosphorus inputs and a higher profile content of phosphorus, very much slighter movement has occurred in land which has been used for convertible husbandry. Only very long-term experimental studies on a single small site could establish with certainty the extent to which variation in the type of input, in topography, in present land use or in pre-modern land use is responsible for the differences that have been observed. Nevertheless, one can note that in the permanent grassland, despite substantial inputs of inorganic phosphorus in basic slag and both inorganic and organic phosphorus in direct excretal input as well as FYM, the proportion of soil phosphorus in the Pa and Po fractions is not substantially different to that observed in nearby moorland, whereas in land regularly affected by ploughing and general inorganic fertilisers, a far higher proportion of soil phosphorus is found in the Pa fraction.

None of the observations in modern fields could be used to assess whether the liberal supply of phosphorus had produced any change in the amount of soil organic matter; although one would expect higher rates of organic matter production, decomposition rates are also likely to have been increased. It is clear, however, that rises in the amount of Po are accompanied by an increase in the concentration of Po in the organic matter and, at a minimum, this demonstrates that any increase in organic matter that may have occurred must be less than proportional to the increase in Po; in fact it could, and in some cases almost certainly does, indicate that a decrease in the amount of organic matter has occurred at a time when the amount of organic phosphorus has increased.

The studies of soils affected by much earlier phosphorus enrichment reveal patterns of alteration which are in many respects similar to those evident in the modern fields. More than three thousand years of leaching has been unable to dissipate these accumulations, but here too, there is evidence for substantial phosphorus movements through plant extraction and leaching. Since the B horizon reserves of phosphorus in the stagnopodzols appear to have played little part in plant nutrition, almost all the phosphorus in surface peats must have been extracted from the Ah/E horizon alone, and this is consistent with the observation of a significant linkage between the Pa values in the Ah/E horizon and all phosphorus fractions in the peat. Downward translocation of Po has also removed phosphorus from the Ah/E horizon, but there is little evidence that metapedogenetic enrichment of the surface soil leads to anomalous subsoil accumulations of Pa in the undisturbed stagnopodzols. It is possible that deeper sampling on site F would have revealed B_2 accumulation of Pa similar to that observed in the highly enriched Humic brown podzolic soils within the North Lobe, but the pattern of subsoil accumulation in the latter, whose surface horizons seem to have suffered substantial leaching losses (see 5.4.2), may not be the same as that in the stagnopodzols. In the light of the evidence from the stone row it certainly seems unlikely that (hypothetical) early, upper B horizon accumulations of Pa in the stagnopodzols have been attenuated or removed by plant uptake.

Although difficult to evaluate, lateral translocation of phosphorus within the soil does not appear to have significantly disturbed the spatial distribution of phosphorus values on site F and, therefore, it is reasonable to interpret the distribution of anomalously high values as a pattern of phosphorus deposition; the values for the concentration (by volume) of the dominant, Po fraction in the Ah/E horizon may provide the least distorted picture of initial spatial inequalities in deposition. Changes in the concentration of Po per unit weight of organic matter, which were spectacularly evident at Rowbrook farm, are also clearly evident in the soils affected by much earlier inputs; where the latter have been particularly high, a reversal of the normal pattern of increase in values from Ah/E to B horizons has been noted, and in such cases the values in the Oh and B horizons are also enhanced. There is only very slight and ambiguous evidence for increased organic matter accumulation in the phosphorus-enriched soils, and it does appear that, as in the modern fields, phosphorus inputs increase the amount of Po in the soil by phosphorus enrichment of the organic matter rather than by increasing the amount of organic matter.

Although the relatively small increase in the proportion of Pa in the Rowbrook field profiles compared to nearby moorland profiles can be matched by a similar increase in the two highly enriched Humic brown podzolic profiles in the North Lobe, there is no good analogue for the much more sizeable shift evident in the Brake Field at Stoke. The heavy enhancement of Pa values in the subsoils of the stone row shows that pronounced changes in fractional composition can be created (and survive for long periods) in these soils, but probably only in those instances in which positional unavailability prevents the phosphorus input from contributing to the biological component of the soil system. Where this has not occurred, the fractional division between Pa and Po in the stagnopodzols appears in general to be similar in all profiles. This is certainly the case in samples from the Ah/E horizon where very little change in the proportion of Pa and Po was observed among samples spanning a very wide range of Pao values; however, in this horizon mineralisation of Po may be an important source of Pa, and if this is the case, the apparent 'survival' of metapedogenetic anomalies of inorganic phosphorus may simply indicate that the rate of mineralisation of Po is proportional to the amount present. If the fractional composition of phosphorus in this horizon is considered in isolation, one might also suspect that much of the mineralisation occurred not in situ, but in the laboratory drying ovens (see 3.3.2 and Appendix 5), and that this sample drying could be an important, perhaps even the main, factor contributing to the very strong correlation of Po and Pa values. However if this were the case, it would be difficult to understand why Oh horizon samples (in which mineralisation of Po must also be an important source of Pa) do not conform to a similar tight pattern. In fact, the Pa concentration values in the Oh horizon samples from the small prehistoric house, which were all dried in a single batch, show no clear linkage with the Po concentration values. From this one may conclude that although drying procedures have probably affected Pa values in samples from all horizons, it would be a mistake to assume that they have introduced distortions on a scale that would invalidate any attempt to interpret differences in fractional ratios in terms of pedological processes.

Although there is a broad similarity in the Pa - Po ratio among samples drawn from any specific horizon, metapedogenetic inputs of phosphorus have sometimes distorted this relationship. Translocation of phosphorus-enriched organic matter seems to have affected the ratio in B horizon samples from site F, and must also be a factor contributing to the ratio in the enriched profiles in the North Lobe, though the outstanding feature of these profiles is the very strong accumulation of Pa. In one of these profiles (SP 34), the very sharp rise in the concentration of Pa in the B_2 horizon strongly suggests that the underlying indurated horizon may be influencing the vertical distribution of Pa in a similar fashion to that observed in one of the Rowbrook profiles (RF 2).

Measurement of the Pf fraction and, perhaps even more important, assessment of the extent to which apatite, Fe-P, Al-P and 'laboratory mineralised Po' contribute to the values recorded in the Pa fraction, could certainly have increased understanding of both recent and ancient metapedogenetic alteration of soil phosphorus. Nevertheless, the more limited system of analysis that has been used is evidently capable of detecting many important changes in these soils and offers a clearer understanding of the fate of phosphorus additions than could be adduced from study of changes in Pt values alone; it has also provided information about long-term pedogenetic changes, and both these types of information can now be employed to reassess some of the ideas incorporated in the models of pedogenesis and metapedogenesis presented in chapter 2.

5.3 Models of pedogenesis and metapedogenesis - a reconsideration

The quantitative studies of organic matter and phosphorus reported in section 5.2 were not designed to cast light on models of the lateral patterning of soil variables in enclosed agricultural land, and in consequence have not provided any substantial amount of information which would require and allow a formal reconsideration of these models. However, one should note, in passing, that the evidence from Stoke farm for a substantially higher level of variability in phosphorus values in land used in a system of convertible husbandry compared to the values in, probably peat-cut, moorland profiles, suggests that in earlier discussion (see 2.3.2.1, 2.3.4 and 2.4.1) the homogeneity of tilled soils may have been overestimated. Also, one may point out that the recovery of coherent spatial patterns of phosphorus enrichment in and around the prehistoric houses and a monument on Holne Moor suggests that lateral movement of phosphorus within the soil is probably not a serious distorting factor in these particular soils. On the other hand, the contributory studies have provided information about metapedogenetic processes and post-occupation pedogenesis; changes to soil organic matter and to the fractional composition and vertical distribution of soil phosphorus have been identified, and these studies do allow and require one to reassess the ideas and opinions offered on such topics in chapter 2 (see particularly: 2.2.2.2, 2.2.3, 2.2.5, 2 .3.3, 2.4.1). The wider implications of some of the observations made during these studies have already been commented upon (5.2.1.3 and 5.2.2.3) and will only be noted again in this discussion if they can contribute to the main purposes of this section - more precise prediction of the way in which ancient metapedogenetic alteration of the soil should still be evident, and from this, guidance in the selection of the specific variables that should be evaluated in order to assess ancient land use in enclosures within the study area.

The investigations of palaeosols produced evidence that supports Clayden and Manley's model of the nature and timing of Stagnopodzol soil development on Dartmoor (see 3.2.1), and confirms that many of the present characteristics of the dominant soils of the study area post-date its prehistoric settlement and, to an important extent, its medieval settlement as well. Although changes to soil phosphorus in the stone row provide an exception, ancient phosphorus inputs have for the most part become integrated with the 'native' supplies of phosphorus during post-occupation pedogenesis and in consequence such enrichment is now visible not only in the uppermost mineral soil, which received such inputs, but also in the Oh horizons, which were not even present at the time of enrichment. Evidence of leaching into B horizons extends still further the number of horizons that must be monitored in order to fully assess the residua from early activities that may have promoted changes in soil phosphorus. There is a hint that much more recent inputs to the stagnopodzols due to redistribution of nutrients by grazing animals may mainly change phosphorus values in the Oh horizon and in so doing alter the relationship between values in the Ah/E and Oh horizons.

It has not proved possible to provide any quantitative estimates of natural inputs, outputs or nett changes in phosphorus due to precipitation and leaching in the study area, but the similarity in the phosphorus content of the medieval palaeosol, its overburden and surrounding soils does suggest that over the past thousand years such fluxes must have been very small. The much older overburden covering a prehistoric soil has suffered heavy losses of phosphorus, and only a small proportion of such losses appear to have been trapped in the underlying soil, but the creation of unusually thick and well-developed eluvial horizons in this profile must have involved much higher rates of phosphorus loss than occur in the surrounding normal soil horizons in which a clear pattern of metapedogenetic enrichment still survives. Taken together, the evidence for minimal change in the last thousand years and the survival of phosphorus anomalies in prehistoric houses and in the stone row tends to support the estimates of input, output and nett loss compiled in section 2.2.2 (see Table 2.2), and, low as they are, these figures may be of the right order of magnitude.

Although it is clear that a proper account of the changes to soil phosphorus that may have occurred in the ancient enclosures of the study area cannot be provided by analysis of any one phosphorus fraction or soil horizon, the covariation of some of the variables examined in the contributory studies indicates a measure of redundancy in the information they convey, and in several cases it has been possible to suggest that a particular variable may have more utility in a specific context than some other variable. For example, it has been suggested that metapedogenetic enrichment of the upper B horizon on site F is only clearly evident in the Po values ($\mu g\ cm^{-3}$), and that variation in Pa values in this horizon may mainly reflect pedogenetic factors. The sensitivity of Pa values to pedogenetic factors was also evident in A h/E horizon samples from this site, and although there is clearly much redundancy in the information provided by Po and Pa values from this horizon, it was suggested that the clearest picture of the spatial pattern of phosphorus deposition on this site might be obtained by ignoring the Pa values. Where high inputs may be presumed to have affected the soil, it has also been possible to detect differences in the amount of phosphorus that has been transferred to the Oh horizon, but since the pattern of enrichment in this layer seems to be but an indirect reflection of the pattern of phosphorus availability in the mineral soil below, and moreover may have been affected by more recent inputs, peat samples alone can only provide at best a very poor guide to early inputs and at worst could be highly misleading.

Changes in the Pf fraction were not monitored in any of the preliminary studies of metapedogenesis (evidence for such changes will be presented and considered in section 5.4.2), but the palaeosol investigations did reveal patterns in the values for this fraction that are consistent with Floate's model of long-term change in phosphorus fractions due to pedogenetic factors (see 2.2.2.2). Although the variability of Pf values from individual horizons in some of the stagnopodzol comparative profiles was so high that one could do no more than note that the vertical distribution of Pf values in the buried medieval soil was consistent with the expected weathering pattern, the concentration and proportion of Pf in entire <u>profiles</u> and groups of profiles (summarised in Fig. 5.49) was much less variable, and these data provide convincing evidence of an overall increase in both the concentration and proportion of Pf in the stagnopodzols since early medieval times. However, one must also note that where soil materials had been subjected to unusually intense leaching (e.g. in the prehistoric overburden), the <u>proportion</u> of Pf was particularly high, but the <u>concentration</u> of this fraction may have been much less substantially altered; this pattern seems to reflect the greater ease with which the other phosphorus fractions may be leached.

It was also noted that the concentration of Po in the organic matter of the medieval soil was somewhat higher than in nearby stagnopodzols and it was suggested that this difference might be, at least in part, a relict feature reflecting the greater availability of phosphorus in the early medieval soils. Information from the other studies in section 5.2 does not refute this contention, but it does indicate that the present concentration of phosphorus in the organic matter of a sample may reflect a complex interaction of several factors and that in consequence, this parameter is particularly difficult to interpret.

Both the studies of modern and ancient metapedogenetic enrichment showed that in these soils an increase in the phosphorus supply does cause phosphorus enrichment of the organic matter, and that in the contemporary field soils and the enriched stagnopodzols a particularly strong rise in Ah and Ah/E horizon values reverses the normal trend in the vertical distribution of values. However, in two of the three highly enriched soils of the North Lobe, subsequent leaching appears to have re-imposed the normal vertical pattern; substantially enhanced values are now only present in the B horizons. Clearly one may conclude that the production of organic matter with a high phosphorus content has a major influence on the pattern of values, and it also seems that, at least in B horizons, these phosphorus-rich organic compounds may survive for very long periods. All these observations are consistent with the proffered interpretation of the high values in the medieval soil. However, other observations suggest that the processes of decomposition can also affect the pattern of values.

In the podzols (and some stagnopodzols), low organic matter concentrations in the better-developed E horizons are accompanied by exceptionally high concentrations of phosphorus in the organic matter; this pattern suggests that, in addition to translocation, an especially high rate of *in situ* decomposition may be responsible for the particularly low organic matter content of these horizons, and that during the course of this decomposition, phosphorus losses are lower than losses of other elements. If decomposition in lower horizons also involved preferential retention of phosphorus, the concentration of this element in the organic matter should continue to rise in subjacent horizons, but this has not always been observed. Lower values occur in podzol Bh horizons, and a decline in values also occurs in many B_2 and all BCux horizons in the stagnopodzols. The latter pattern suggests that decomposition in these lowest horizons may involve especially high losses of phosphorus compared to other elements. The upper B horizon values in the stagnopodzols are usually higher than Ah/E horizon values, but if organic compounds produced at an earlier time had a higher initial phosphorus content than those produced today (Oh sample values are much lower than values in other horizons), this pattern could wholly, or in part, reflect the greater age of B horizon organic matter compared to that in the Ah/E horizon. By the same token, the generally lower values in the podzol Bh horizons could indicate that these accumulations include a far higher proportion of more recently created organic matter, and this could in turn reflect a higher rate of transfer of organic matter from surface to subsoils in the podzols compared to the stagnopodzols.

There have been very few studies of the carbon age of subsoil organic matter in soils similar to those of the study area, but very large differences in the age of podzol B horizons have been noted (Tamm and Holmen 1967) but not explained. However, the authors cited did suggest that, by slowing the decomposition of organic compounds, poor drainage might have been responsible for an atypically high age in one of the iron-humus podzols they studied, and a difference in soil drainage is certainly one of the principal differences between the stagnopodzols and podzols examined on Holne Moor and Vag Hill.

The analyses undertaken in these studies cannot alone resolve all the issues raised here, but they do clearly demonstrate that when, as in the study area, a very high proportion of Pt is found in the Po fraction, evaluation of the concentration of Po per unit weight of organic matter can provide a very sensitive indicator of metapedogenetic distortions; changes in values and in vertical distribution patterns can in some cases clearly be linked to ancient phosphorus enrichment. However, interpretation of this parameter must take into account that pedogenetic factors can produce values and patterns which mimic those produced by enrichment.

The studies of contemporary fields used as pasture and for convertible husbandry have provided information about the way in which such activities can affect soils of the type found in the study area, and in particular, have shown that phosphorus inputs have penetrated far more deeply into the grassland soils. However, although these studies provide information which can be used when interpreting the patterns found in ancient enclosures, they cannot be used to predict such patterns. This flows both from the impossibility of precisely modelling the way in which the substantial post-occupation soil changes will have altered initial patterns, and from the author's inability to locate fields close to the study area which had not been affected by modern inorganic fertilisers and in which all the natural factors of soil formation could be held constant. Moreover neither of these studies, nor any of those undertaken within the main study area, provide clear, positive information about the effects of phosphorus extraction by grazing animals and cropping in the absence of fertiliser inputs. From the stone row study one might infer that extraction, at least in grassland, may largely affect the upper 20 cm of the soil profile, but the distinct minima of Pa in the upper B horizon at Rowbrook points to the possibility of deeper extraction, and reminds one that, even though Po values may sometimes provide a better picture of the pattern of phosphorus input, the Pa fraction cannot be ignored in studies of changes to soil phosphorus arising from grazing and cropping activities.

The contributory studies - of palaeosols, of modern farmland, and of soils enriched during the prehistoric settlement of Holne Moor - have yielded a history of soil development and some insights into processes affecting soil phosphorus; in conjunction with the field survey of soils and vegetation, they provide an indication of the kind of sampling tactics and the range of analytical techniques that should be used during investigations of the ancient agricultural enclosures of the study area, and they also provide a sound basis for interpreting the results of such investigations.

5.4 Prehistoric and medieval enclosures

The investigations reported in this section represent the final step in the research program outlined in section 3.3, but can only be regarded as preliminary attempts to test some of the ideas incorporated in the models discussed and presented in sections 2.3 and 2.4. The prehistoric and medieval settlement of the study area, which has been concisely described in section 3.2.2 and further discussed in section 4.3, created a rich archaeological landscape that includes many suitable targets for detailed, quantitative soil analysis. Three main areas were chosen - zones A, B and C (for their location see Fig. 3.8). A general description and some discussion of the soils in these zones was included in chapter 4 (see in particular sections 4.2.3 and 4.3.1 and Figs. 4.2 and 4.3).

The land encompassed by zone A starts on the southern extremity of the study area, which lies beyond the bounds of both medieval and prehistoric enclosure, reaches across the southern boundary of a medieval outfield (the Outer South Field) and includes a small portion of the prehistoric field system w hich terminates on the Venford Reave. This area was chosen for detailed sampling because it was thought it would provide opportunities for comparing virgin land with land used during the prehistoric settlement, the medieval settlement, and during both these periods. Western parts of the zone lie on the flat plateau summit, while the eastern and most southerly portions include gently sloping land.

Zone B straddles the medieval droveway that runs between the principal outfield enclosures; in addition to these features, which probably date to the late 13th century, prehistoric boundaries cross the zone from north to south, and, as noted in section 3.2.2, this zone also includes discontinuous segments of reave-like boundaries, which may be remnants of a pre-reave enclosure. To a large extent, the investigation of this area can be regarded simply as a continuation of the work begun in the contributory studies (section 5.2). There was and is little doubt about the function of the medieval features; at least for a brief period and, perhaps, until farming was abandoned in the 15th or 16th century, this narrow file of land between the fields must have served as the route to and from a moorgate used by farmers in the Venford Brook valley, and very probably by farmers from further afield, when they drove their livestock on and off the open moorland. There were, therefore, very strong grounds for expecting nutrient anomalies in this zone (see 2.3.1.1), and the studies were undertaken and designed partly as a further check on the efficacy of the methods of analysis, and partly to discover the pattern and strength of surviving changes in soil phosphorus. All of this zone lies on the flat plateau summit.

The investigations in zone C provide quantitative information about the differences between the stagnopodzols (soil type S - Ia) in the northern outfield and the Humic brown podzolic soils (soil type S - IV) in the North Lobe. Here too, some of the processes which led to the marked contrast in soil qualities across the boundary which separates these enclosures are known. Sizeable lynchets and the system of land division within the North Lobe testify to medieval cultivations that may have affected the land for several centuries, perhaps for much of the medieval period (see 3.2 .2 and 4.3.1). By contrast, only the soil qualities and, at most, slight lynchetting on some of the reave boundaries within the North Field indicate that this area may have been much more briefly tilled as an outfield in late medieval times. This zone provided, therefore, an opportunity to discover and quantify the legacy of medieval metapedogenesis.

The results of the studies in each of these zones are presented and considered in separate sections, starting with the more straightforward studies in zones B and C, and concluding with the more complex and still incomplete investigation in zone A. A general discussion of the relationship between the results of these studies, the research goals formulated in section 3.3, and the expectations generated by the models presented in section 2.4 is provided in the following section (5.4.4).

5.4.1 A medieval droveway - zone B

Today the droveway consists of two parallel earthern banks (ca. 1 m in height) roughly 15 m apart. Internal ditches, which presumably provided the soil for these banks, are visible along some stretches, particularly those running down the eastern slopes to Central Lobe 1. In most places on the plateau top, the ditches are filled with highly organic sediments and peat; the slight depression that remains may in some places mainly reflect the movements of contemporary sheep, ponies and cattle, whose tracks tend to follow the banks for short stretches. The sections in which sampling took place (see Fig. 5.111, which shows all sampling locations and their code numbers), lie less than 100 m from a contemporary sheep camp, and both faecal deposits and changes in vegetation indicated that in some places sheep make use of the shelter provided by the banks. All the soils in this zone are stagnopodzols with type III subsoils and types S - I and Ia surface soils (see 4.2 .2); peat-cut profiles were encountered in this zone, but none of the profiles discussed below exhibited clear evidence of this activity. However, some of the profiles discussed have almost certainly been affected by outfield cropping and/or other disturbances described earlier (see 4.3.1.1), but the limited sampling in this zone was not intended to provide, and does not allow, an evaluation of the effects of such disturbances.

Details of recording and sampling methods appear in Appendix 1 (groups 4, 9 and 16). Two groups of soil profiles were sampled. The first group (PP series) covered randomly selected locations in the outfield enclosures and in the droveway itself, but also included a gateway (PP 12) and samples from ditches and soil profiles adjacent to them (PP 6, 18, 10). All PP series samples were taken from standard small pits, but no volume samples were recovered, and the soil bulk density of samples in this group has been estimated from their LOI values. The second set of samples (PT series) were taken along a transect which ran from the Outer South Field (PTS samples), through the droveway (PTD) and into the North Field (PTN). The location of most of the pits on the transect, which provided a full exposure of the Oh and Ah/E horizons, was determined by random numbers, but four additional pits either side of the banks were sampled, since observations in contemporary droveways and fields (see 2.3.1.1) suggested that such places would be most likely to exhibit unusual soil properties. Each of these pits (PTS-X, PTD-S and N, PTN-X) was sited ca. 1 m away from the banks to avoid the ditches and the area affected by contemporary animal tracks. Oh and Ah/E volume samples were taken from all 20 locations along the transect, and the observed soil bulk density values have been used in all calculations involving these samples. However, samples from the B horizons were taken at only 11 locations (see Fig. 5.111) and were recovered by auger; the bulk density of these samples has been estimated from their LOI values. A flint flake was discovered in the Ah/E sample from PTN-10, the most northerly location on the transect.

The standard range of laboratory analyses were first applied to all samples from the transect. Since, on its own, this data appeared to provide an adequate picture of the nature of variation in the soils of the western part of zone B, and because of the differences in sampling techniques, most of the PP profiles in this area, some of which had been peat cut, have not been analysed. However, it was decided to proceed with the analysis of five of the eight PP profiles in the eastern part of the zone, since this area included a feature - a gateway - not present in the western area. In presenting the data obtained from these two groups of pits, differences in sample context (i.e. ditch sediments as opposed to soil profiles) and methods of recovery, which can affect the utility and reliability of comparisons, have been borne in mind. Samples from ditch sediments beneath contemporary animal tracks are likely to have been affected by modern or recent faecal deposition (indeed, it will be suggested below that such 'contamination' is evident in Oh sample values), and for this reason have been excluded from the main series of statistical analyses. Although information about the composition of entire profiles is provided for all the soil profiles analysed, inter-horizon comparisons employ only the strictly comparable samples from the transect series (PT). Unlike most of the studies on Holne Moor, all profile values in zone B have been calculated to a base of 30 cm below the mineral soil surface; this limitation arises from the use of auger sampling in the transect.

Fig. 5.112 shows the spatial distribution of Pao concentration values (mg kg^{-1} IFe) and the percentage of Pa in all the profiles for which this information is available. Although several pits lie close to banks, ditch sediments were not encountered at any of these locations. The values shown at PP 10 refer to a soil profile adjacent to the ditch (which was also sampled at this location); at PP 18, the only atypical properties seen in the field were an unusually thin (5 cm) Ah/E horizon and a very stony Bh horizon (56.3% by weight of soil, which can be compared with values between ca. 15 and 35% in all other B horizon samples in the zone); a similar, thin Ah/E horizon was found at PP 12, but in all other respects this profile possessed the normal stagnopodzol characteristics of the zone. It can be seen that 7 of the 9 profiles within the droveway have Pao values greater than 450 mg kg^{-1} IFe while only one profile outside the droveway (PTS-X) surpasses this value. Table 5.30 shows that the latter profile is very unlikely to be a sample drawn from the same population as other samples outside the droveway, and Table 5.31 shows that if this profile is ignored, the higher mean value of profiles within the droveway is statistically significant. It can be concluded that, as expected, the soils in the droveway have been enriched; the mean concentration value is now some 20% higher than the mean value in the surrounding outfields and there may have been a slight increase in the variability of these values.

The enrichment has not led to a significant shift in the fractional contribution of Pa and Po in the profiles as a whole (see Fig. 5.112).

Although it is, in itself, worth demonstrating that this particular droveway retains evidence of the faeces left by livestock moving on and off the moor, the main purpose of this study was methodological, and the most important data recovered concerns, not the expected, overall increase in phosphorus concentration values in the droveway soils, but the way in which this increase is reflected in individual horizons and phosphorus fractions, and the extent to which the different measures used in these studies provide a concordant picture of changes in soil phosphorus. In most of the studies considered in section 5.2.2, the comparisons between samples or whole profiles involved such substantial differences that, despite the distortions caused by variation in profile content of ignited fine earth due to differences in structure, and in stone and organic matter content, all the measured variables (e.g. concentration by weight and by volume, concentration per unit weight of organic matter, etc.) followed the same trends; only in a few cases was it necessary to point out that a slightly different picture emerged if variation in soil density was taken into account. When assessing the reality or otherwise, and the cause, of slighter variations, the need to assess the basic physical parameters of the materials under comparison is far greater.

Fig. 5.113 shows the spatial distribution of phosphorus concentration values by volume of soil (g Pao m^{-2} to 30 cm mineral soil). On the whole, it provides a similar picture of phosphorus enrichment to that evident in Fig. 5.112 ; if, as before, one excludes location PTS-X, the mean value of profiles within the droveway (110.1 g Pao m^{-2}) exceeds the mean value of profiles in the outfields (95.6 g Pao m^{-2}) by ca. 15%. However, it is notable that using this parameter, only four out of the nine profiles in the droveway have values higher than the highest value recorded in the surrounding soils. The discrepancies between these two methods of measurement are most easily illustrated in a scattergram (Fig. 5.114) in which two regression lines have been included (see Table 5.32); one indicates the solution for all 17 samples, the other for a selected group of 12 samples. Both correlations are highly significant, but it can be suggested that the substantial drop in the proportion of the variation in the volume measurement 'explained' by the variation in the weight measurement when all 17 samples are included, points to substantial anomalies in the amount of ignited fine earth in the excluded profiles. Differences in the profile content of IFe can be due to abnormal soil structure, stone and/or organic matter content or some combination of all three parameters. Figs. 5.115 - 5.117 show that the 'deficiency' of IFe in each of the five excluded profiles is associated with either an abnormally high content of organic matter or an abnormally high stone content. Rigorous evaluation of the way in which these abnormalities have reduced the IFe content of the profiles would require one to assess changes in pore space, but it can, nevertheless, be noted that in three profiles (PTS-X, PTD-2 and PTS-O), the unusual quantity of organic matter may have led to greater soil expansion, while in the other two profiles (PTD-7.5, PTN-X), the deficiency of fine mineral material seems to be matched by an excess of coarser mineral material.

In profiles affected by unequal expansion, the amount of phosphorus per unit volume will vary merely as a direct function of the variation in the amount of expansion, and changes in the amount of phosphorus per unit weight of IFe provide a better guide to nett inputs or outputs of soil phosphorus; this implies that in profiles PTS-X and P TD-2 , the apparent rises in Pao (g m^{-2}) shown in Table 5.33, column B, may seriously underestimate phosphorus inputs and that the figures in column D may more closely approximate the true input at these locations. When abnormal quantities of stone depress the amount of IFe, as appears to be the case at location PTN-X, Pao (g m^{-2}) values provide an accurate indication of a natural deficiency in the phosphorus content of the profile (allowing that nothing is known of the phosphorus content of the stone fraction), while the discordant, relatively higher values for Pao (mg kg^{-1}IFe) indicate that there is nothing unusual about the amount of phosphorus within the finer soil fractions. However, if phosphorus is added to a profile of this kind, as may have occurred at location P TD-7.5, the resulting rise in Pao (mg kg^{-1}IFe) values will be greater than would occur if an equal input was added to a 'normal' profile, and a comparison of changes in such values will therefore tend to overestimate the input. This may have affected the profile at location PTD-7.5, which at one time may have been similar to the profile at PTN-X. If it was, the input indicated in column D of Table 5.33 (2 0.9 g Pao m^{-2}), which is less than the similarly estimated input to the profiles at PTD-S and PP 10, neither of which appear to have had a natural deficiency of phosphorus, has nevertheless managed to raise the Pao (mg kg^{-1}IFe) value of this profile to a level slightly higher than that observed at PTD-S and PP 10.

It is clear from this discussion that where variation in IFe content due to more than one factor may be present in a sample, both weight and volume concentration values of phosphorus can yield a misleading picture, and that the best estimate of changes in soil phosphorus may be obtained by combining these types of information in the manner attempted in Table 5.33. In most locations, the small differences between values in columns B and D will be due to 'real', natural variation in the original phosphorus content plus error due to sampling and analysis. It is notable that apart from the 'anomalous' profiles considered above, the only discrepancy greater than 10 g Pao m^{-2} occurs with profile PP 16, and in this case seems to reflect the particularly low stone content of this profile (see Fig. 5.115). At PP18, high stone content is balanced by low organic matter content and there is little difference in the estimates of enrichment in columns B and D. It is worth noting, too, that columns B and D also concur in indicating that the profile from which an artifact was recovered (PTN-10) may have been affected by phosphorus inputs of the same order of magnitude to those which it has been suggested may have affected the profile adjacent to the house on site F (see 5.2.1.2 and Table 5.14).

It was not possible to make a quantitative prediction of the rate of phosphorus enrichment within droveways. However, the estimates of change (column D in Table 5.33) in the five transect samples within the droveway indicate an overall mean enrichment of 20.7 g Pao m^{-2}, and this would imply a rate of faecal phosphorus deposition of ca. 1.0 kg ha^{-1} $year^{-1}$ if the droveway remained in use from the late 13th to the late 15th century; this rate is equal to the estimated minimum rate of input within the modern sheep camps on Holne Moor (see 2.2.4 and Table 2.4; note also that, since the droveway estimates are based on Pao values rather than Pt values, they may underestimate the true input by ca. 30% - see comment in section 5.2.2). The relatively high level of enrichment strongly suggests that the droveway did, in fact, remain in use long after the brief outfield episode which led to its construction.

Discrepancies between volume and weight measurements of phosphorus also affect the values within individual horizons, but comparison of Figs. 5.118 and 5.119, which indicate Pao concentration values (by weight and by volume) in individual horizons of the transect shows that either measurement provides a similar picture of phosphorus variation in the mineral soil horizons. In the Oh horizon, large differences in the small amounts of IFe, produce strong fluctuations in Pao (mg kg^{-1} IFe) values, which in consequence tend to be more a measure of IFe variation than phosphorus variation; evaluation of phosphorus patterns involving all three horizons is, therefore, best pursued using volume concentration values. For the present purposes, the most important patterns evident in Fig. 5.119, are the strong, positive covariation of Oh and Ah/E values at most locations and specifically at locations which have probably been affected by medieval phosphorus inputs, and the indication that, at least among droveway samples, Ah/E and B horizon values may be negatively correlated. In Figs. 5.120 and 5.121, which indicate the fractional values, Pa and Po, in each horizon, it can be seen that the inverse relationship between Ah/E and B horizon Pao values within the droveway reflects the same tendency in both Pa and Po fractions except in location PTD-5 (the only location in the transect that shows little sign of phosphorus enrichment), where the high Pa value in the B horizon is not matched by a corresponding deficiency in the Ah/E horizon. It can also be seen that for the most part, positive correlation of Pao values in Oh and Ah/E horizons within the droveway (and to some extent outside the droveway as well), mainly reflects the contribution of the Pa fraction to Oh Pao horizon values. This pattern is similar to that observed among the samples from the small prehistoric house in zone A (see 5.2.2.1 and Table 5.19), but the negative relationship in Ah/E and B horizon samples is quite different from the relationship between equivalent samples from the large house (site F) in zone A, where a strong positive linkage between Pa and Po values in the Ah/E and Po values in the B horizon was observed. The strength of inter-horizon covariations of this kind can be more rigorously evaluated in scattergrams and associated statistical analyses.

Figs. 5.122 - 5.124 show that the positive correlation of values in Oh and Ah/E horizons is statistically, highly significant, and they also show that the Oh sample from location PTS-X has a far higher phosphorus content, both absolutely, and in relation to the values for the Ah/E sample from this location. It will be recalled that a similarly discordant sample or outlier was found adjacent to the small house in zone A, and that it was suggested that such disequilibrium in Oh -Ah/E sample values might be due to relatively recent phosphorus inputs. Here too, the profile affected lies in a sheltered location and a similar explanation seems appropriate. However, one must also note that the quite exceptional enrichment of this profile (its overall concentration value, 711 mg Pao kg^{-1} IFe, is similar to the values in and near the house in the North Lobe - see 5.2.2.1 and Tables 5.20 and 5.21), is not merely due to unusual enrichment of the surface peat, but reflects high phosphorus values in the B and, to a lesser extent, the Ah/E horizons (see Fig. 5.118).

Figs. 5.125 - 5.129 show that taking the transect sample as a whole, there is no statistically significant relationship between Ah/E and B horizon phosphorus concentration values, but in two cases (Figs. 5.125 and 5.127), if the phosphorus deficient profile PTN-X is excluded, the remaining profiles do exhibit such a relationship. The peculiar character of the inter-horizon relationship of profiles within the droveway is particularly evident in a plot of B horizon values against a combined value for the Oh and Ah/E horizons (Fig. 5.130); for some reason, phosphorus inputs at locations PTD-2 and PTD-7.5 seem to have been far more readily leached into the B horizons. Although, the available information does not allow one to assess several of the possible explanations for such a pattern, one factor which may be responsible for, or could contribute to, more substantial leaching of the Ah/E horizon is the high stone content of the Ah/E horizons in each of these profiles (see Fig. 5.132).

One of the consequences of the difference in the vertical distribution of phosphorus among the droveway profiles is illustrated in Fig. 5.131. Where phosphorus enrichment has been retained in the Ah/E horizon, the concentration of Po (mg kg^{-1}LOI) in the upper horizons is high (but note that only the sample in which an artifact was found (PTN-10) reaches the range of values seen in the house on site F), and much higher than the concentration in the profiles in which inputs appear to have been leached into the B horizons. The pattern in the B horizons is more complex and can only be understood by simultaneously considering the varying amount of organic matter in the samples (see Fig. 5.133). Po (mg kg^{-1}LOI) values in the droveway tend to be slightly higher than those outside (the principal exception is the sample from PTN-3, which has a particularly low organic matter content), but none of these samples exhibits the strong enrichment observed in the B horizon on site F. Note also that the reversal of the normal trend of values, which was evident at many of the enriched locations on site F, only occurs in two profiles here, both outside the droveway (the highly enriched location PTS-X, and PTN-10). One of the strongly leached profiles (PTD-7.5) does have a higher than usual B horizon value, but the other (PTD-2), which has a particularly high, B horizon organic matter content, has a normal value.

It is evident that aside from the location in which an artifact was found, where most of the measured variables suggest soil changes similar to those recorded in the areas around the house on site F, phosphorus enrichment of soils in zone B has not involved very substantial rises in the concentration of Po in the organic matter. If one looks at the pattern in the profiles as a whole (Fig. 5.131, Oh + Ah/E + B), only the two 'edge' locations, PTD-N and S, show clear signs of enrichment. At P TS-X and PTD-2 , the low values, despite high phosphorus inputs, can be attributed to the diluting effect of the abnormally large amount of organic matter, but at PTD-7.5 (and this may also have affected P TD-2), the main factor must be the rapid removal of the inputs from the surface layers. Since there is little evidence among the contributory studies that phosphorus enrichment by increasing organic matter production raises soil organic matter levels, the high organic matter content of the profiles which seem to have received the highest phosphorus inputs could be a direct reflection of organic matter deposition in animal faeces. However, none of the contributory studies provided clear information about the specific effects on the soil of faeces deposition, and the restriction of organic matter increases to these two profiles could indicate that particularly high inputs of faecal phosphorus can lead to increased organic matter production and, consequently, accumulation (see 2.3.3.2). This would be consistent with the absence of phosphorus enrichment of the organic matter in PTD-7.5, which suggests that much or all of the enrichment evident in the surface horizons of other profiles is not a direct result of the input of faecal organic matter with a high concentration of phosphorus, but reflects relatively recent organic matter synthesis in profiles where the supply of phosphorus in the surface horizons has been enhanced. It would also be consistent with the evidence for increased organic matter production and accumulation in sheep camping areas in New Zealand (see 2.2.4).

It was noted earlier that phosphorus enrichment had not changed the fractional contribution of Pa and Po in the profiles as a whole; for the most part this is also true of individual horizons and samples. Figs. 5.134 and 5.135 show Pa-Po relationships in the Oh and Ah/E soil horizons and equivalent samples from ditch sediments; Fig. 5.136 gives the same information for the B horizon samples from the PT series. Like the samples in and around the prehistoric houses in zone A, Pa and Po values in Ah/E samples show a strong positive correlation; only the samples from the ditch at PP 10 and the soil profile at PP 18 appear as outliers due to their abnormally high proportion of Pa. This abnormality does not occur in the ditch sediment sample from PP 6. The clustering of values in the scattergram illustrating Pa-Po relationships in the Oh horizon shows that here, as in the small house in zone A, Pa and Po values are poorly linked; it can be doubted whether such a distribution can be regarded as suitable for correlation and regression analysis. If such techniques are applied, the correlation coefficients (calculated with or without the ditch samples) are barely significant, and it is evident that little of the variation in Pa can be attributed to variation in Po. Several of the samples from locations near to the droveway boundaries have higher concentrations of Po (PP 6, 10 (ditch and soil profile), 12, 18 and PTS-X), and, except for PP 18, a higher proportion of their phosphorus in this fraction; all of these samples also appear as outliers from the regression line which summarised the linear relationship between Pao values in Oh and Ah/E samples in the PT series transect (see Figs. 5.122 and 5.137), and so share the pattern of values that has here been attributed to relatively recent additions of phosphorus in animal faeces.

Figs. 5.134 and 5.135 show that the profile at PP 18, which was located in the ditch 'zone' but contained no ditch sediments, has an abnormal quantity of Pa in both Oh and Ah/E horizons. High Pa values continue into the B horizons and, as can be seen in Fig. 5.112, this profile, as a whole, has a markedly higher proportion of its phosphorus in the Pa fraction than all other profiles in zone B. It also has an abnormally high stone and low organic matter content (Figs. 5.115 and 5.116), and an unusually thin Ah/E horizon. Taken together, these features strongly suggest that what has been sampled at this location is a 'juvenile' profile that has developed in an area where the earlier profile was truncated by excavation of a relatively shallow scoop ditch.

As on site F, there is no discernible linear or curvilinear relationship between Pa and Po values for B horizon samples from the transect (see Fig. 5.136). Once again, the absence of such a coherent relationship probably reflects both the high natural variability in B horizon Pa values and differences in the translocation of Po, which in the zone B profiles seems to reflect variation in natural factors and variation in phosphorus inputs.

The most important aspects that emerge from the study in zone B seem to be: the confirmation that spatial patterns in soil phosphorus values conforming to expectations generated by observations in modern droveways can be discerned in the soils of the study area, but that neither estimates of concentration by volume nor those based on weight alone provide an adequate measure of the changes to soil phosphorus implied in such patterns; the evidence that due to factors not necessarily monitored in these investigations, the spatial pattern of phosphorus values in individual horizons are not always concordant with the patterns evident in measurements on entire profiles; the evidence that where phosphorus inputs have been wholly, and perhaps rapidly, leached into B horizons, phosphorus enrichment of soil organic matter, which was so evident in all the contributory studies, may not occur (a circumstance that, together with the complications caused by either concurrent inputs of organic matter or subsequent enhancement of organic matter accumulations, provides additional problems of interpretation of Po (mg kg^{-1}LOI) values); and finally, the further evidence that several more locations which could be expected to have been affected by recent faecal deposition, retain an unusual concentration of phosphorus, and an unusual proportion of Po, in the surface peat.

None of the evidence reviewed here provides a clear guide to the age of the phosphorus anomalies in the transect samples from the droveway (though none of these locations appears to have been affected by relatively recent deposition of faeces). However, the pattern of modern and recent faecal deposition revealed both by vegetational anomalies and the dung itself is, by and large, one of confinement to a thin zone beside the banks (and thus, within the droveway, to the surface of the silted-up ditches); such a pattern could be typical of deposition during the period since the droveway went out of use. If so, most of the extra phosphorus in the transect samples can be attributed to the medieval period of droveway usage.

5.4.2 A medieval sub-divided arable field - zone C

Zone C encompasses sloping land (ca. 5°) just below the north-eastern edge of the plateau (Fig. 3.1). A parallel reave crosses the zone from south to north, and the corn-ditched southern boundary of the North Lobe, dating to ca. AD 1000, crosses it from east to west; a prehistoric house lies just inside the North Lobe. All these features are illustrated in Fig. 5.1, which also shows the location of all the standard sampling pits in this zone. Details of sampling are given in Appendix 1 - groups 5, 10 and 17. Major changes in soil and vegetation occur across the medieval boundary, which buried a soil of stagnopodzol type (see 5.2.1.1). To the north of the boundary, all pits revealed a Humic brown podzolic soil with type III subsoils and type S - IV surface soils; to the south, all the profiles were Iron-pan stagnopodzols with type IVa subsoils and type S - Ia surface soils (see 4.2). Heather and purple moor grass are the principal species on the stagnopodzols, while grasses and bracken cover the podsolic soils (see 4.3.2, Fig. 4.10 and Table 4.5 - map references 1 and 2).

Lynchets are evident at the edges of cultivation divisions within the North Lobe, and a particularly large lynchet has formed along the section of the reave that lies within the Lobe. In the North Field, this boundary and other prehistoric boundaries show at best indistinct and ambiguous traces of lynchetting, but the LOI values in the Oh horizons of the stagnopodzols, (see Table 5.34), which are substantially lower than values from virgin areas, suggest that some outfield tillage may have occurred in this area as in other parts of the North Field (see also 4.3.1.1). Peat cutting also appears to have affected at least three of the four stagnopodzol profiles in the area to the east of the reave. As Table 5.35 shows, the peat in this area is substantially (and significantly) thinner than the peat to the west of the reave, which does not appear to have been substantially thinned by the outfield tillage. Taken together, the LOI and peat thickness data suggest that this part of the outfield has been affected in much the same way as segments XIII and XIV in zone A (see 4.3.1.1), which, it is thought, were tilled very briefly at a relatively late date. The similarity of LOI values either side of the reave suggests that the peat cutting post-dates the tillage.

During the initial sampling of zone C, an attempt was made to establish whether the soil movement indicated by the lynchets had led to a nett downslope loss of soil within the Lobe; the depth of mineral soil above the BCux horizon was taken as a measure, and the position of this horizon was judged from the depth of auger penetration through the base of the excavated pits. The data, shown in Table 5.36, is in itself inconclusive due to the wide range of values that were recorded. However, it will be shown below that the mineral soil in the North Lobe has substantially lower soil bulk density than the mineral soil in the North Field, and it may well be that the slightly shallower depth of auger penetration in the North Lobe provides an underestimate of soil erosion due to cultivation in the Lobe.

In zone C, 15 small pits and two large pits were examined, and _ca._ 80 soil samples were recovered during two bouts of fieldwork. All of these samples have been analysed using the standard range of laboratory procedures, but some of the measured phosphorus values have been adjusted to overcome laboratory shortcomings (see Appendix 5). After statistical examination, the mean stone content (% weight) of B horizon samples in the zone was substituted for the observed values in all calculations involving these samples (see 3.3.2), but observed values were retained for Ah and Ah/E horizon samples. Since satisfactory volume samples could not be obtained from **all** horizons in all pits (mainly due to stoniness - 35 volume samples were obtained), the soil bulk density of all samples has been estimated from LOI values using the regression equations which were presented in section 3.2.2. This was thought to be a more satisfactory procedure than the use of a mixture of calculated and observed values. In some of the analyses, maps and figures presented and discussed below, data from all these profiles appears. However, most of the diagrams and the principal comparisons between the North Lobe and North Field soils utilise the data from only ten of the profiles sampled, six in the Lobe and four in the outfield. This exclusion of data requires some justification.

It has been suggested in section 5.2.2.2 that peat cutting led to the removal of a substantial amount of phosphorus and organic matter from the stagnopodzols near West Stoke farm; although a greater depth of peat survives on the group B stagnopodzols in zone C than was present on Bench Tor, and the losses appear to be smaller, it was thought wisest to exclude this entire group of samples and, thus, to rely solely on the data from group A for the principal comparisons. Exceptionally, data from the large pit, GSP 2, which may be the only profile in group B not affected by peat cutting (Oh depth of 13 cm including litter), and for which Pt determinations are available, are used (together with data from SP 8 in group A) for estimates of changes in Pt and the Pf fraction. SP 37, in group B would in any case have had to be excluded since this profile contained a very large 'grey stone zone' (see 4.2 .1.1), an abnormality that affected its chemical qualities as much as its physical appearance.

Nine profiles were sampled within the Lobe, but one of these lay in the prehistoric house (SP 33) and was never intended to provide a sample of the Lobe soils, while two others (SP 1 and SP 34) possess phosphorus characteristics similar to those in the house profile, although their field appearance was identical to all other profiles in the Lobe (data from these three profiles has been discussed in section 5.2.2.1). The sampling of profiles in the house and at a location midway between the house and SP 1 (all other locations were determined by random numbers used as cartesian co-ordinates) was in fact undertaken in order to test whether the abnormal phosphorus content of the subsoil at SP 1, which had been sampled and analysed during the first season's work, might be part of an extensive area of enrichment associated with occupation of the prehistoric house. Tests for discordancy in the phosphorus content of SP 1 and SP 34 compared to all other profiles in the Lobe, in zone C as a whole, and in zone C after exclusion of SP 37 or the whole of group B (see Table 5.37), indicate that it is statistically improbable that these profiles provided samples from the same population as had been sampled elsewhere in the Lobe or the zone. Since these particular tests cannot simultaneously take account of the differences in fractional composition and distribution (see 5.2.2.1 and below), they may be seen as a minimal statistical assessment of the discordant nature of these profiles.

The analysis of a palaeosol beneath the medieval boundary in zone C (see 5.2.1.1 and 5.2.1.3) allowed a quantitative assessment of the differences between the contemporary Iron-pan stagnopodzols and their early medieval predecessor, and demonstrated, inter alia, that some of the present differences between the stagnopodzols and the soils of the North Lobe must be a legacy of early metapedogenetic processes (e.g. the absence of peat on the Lobe soils), while others reflect continued pedogenetic processes (e.g. the presence of iron-pans in the outfield soils). In this section, quantitative comparisons can be extended to the Humic brown podzolic soils of the Lobe in order to quantify such legacies and, more speculatively, assess the nature of the initial metapedogenetic factors and processes.

Table 5.38 provides quantitative information about the differences in the organic matter content of the podzolic soils, the stagnopodzols and the medieval palaeosol; the values for the latter rely on the model presented earlier (see 5.2.1.1 and Tables 5.5 and 5.6). Since the podzolic, mineral soils of the North Lobe have probably lain in grass for more than 400 years, and perhaps as much as 600 years, it is most likely that their organic matter content reflects a steady-state equilibrium (see 2.2.3 and 2.3.3.2) which has been established at a level some 30% lower than the level that obtained when the soils were first taken into cultivation. This event must have been attended by heavy organic matter losses, but these cannot be estimated from the available data. However it is possible to quantify the differences in the dynamics of organic matter accumulation in the podzolic soils and the stagnopodzols. Whereas it is almost certain that, in the former, production and decomposition of organic matter have long been in balance, in the latter, there appears to have been a nett accumulation of organic matter in the surface peat of 10.25 kg m^{-2} during the past millennium. Although outfield tillage may have slightly reduced this value, it is notable that the overall accumulation rate between AD 1000 and AD 1978 implied by this value (10.48 g $m^{-2}year^{-1}$) lies comfortably in the middle of the range of values estimated on nearby Exmoor (pre-AD 1833, 6 - 17 g $m^{-2}year^{-1}$ - see 2.2.3). Furthermore, if it is assumed that peat has been accumulating at this rate ever since growth started, the implied date for the onset of accumulation (693 BC) is less than 100 years earlier than the estimated date for this event on Exmoor.

Although the calculation of these estimates has involved a number of plausible but uncertain assumptions that undermine their utility, it is worth noting that, taken at face value, a date for the onset of peat accumulation on Holne Moor of 693 BC would place this event some three hundred years later than the estimated date for the onset of what may well have been the largest climatic change during post-glacial time (see 3.2.1); this could indicate that the coarse-tcxtured and freely-drained, pre-stagnopodzol soils responded very slowly to this change. However, a similar slow response cannot easily explain why an Oh horizon has not been re-established within the North Lobe during the 400 or more years since tillage ceased. It is possible that the climatic deterioration of the first millennium bc produced soil conditions that have not been matched on this moderately sloping land in historical times and/or that, as postulated above (see 2.3.3.2), 'delayed' metapedogenetic factors such as the diversion of soil water by the ditched boundary of the Lobe (see 4.3.1.2) coupled perhaps with changes in soil structure created by lengthy cultivation, have reduced soil moisture levels and so effectively changed the 'climatic factor' for the Lobe soils.

Although the data in Table 5.38 show that there is much less organic matter in the podzolic soils than the stagnopodzols, they also indicate that this is entirely due to the extra organic matter held in the Oh horizons; there is in fact more organic matter in the podzolic soils than the mineral horizons of the stagnopodzols. Fig. 5.138 shows that this is due to the greater concentration of organic matter (mg cm^{-3}) in the upper 30 cm of the podzolic soils. The difference is statistically significant (Table 5.39) and very important, since the greater accumulation of organic matter in the podzolic mineral soils is accompanied by a substantial reduction in the amount of ignited fine earth per unit volume. Fig. 5.139 provides a diagramatic summary, and Table 5.39 a statistical summary, of the physical properties of the soils in zone C. Unlike some of the profiles in the medieval droveway in which a lower content of IFe was balanced by a higher stone content, the lower IFe content of the Lobe soils compared to that in the Stagnopodzol mineral horizons seems to be solely due to extra soil expansion associated with their higher organic matter content; it can be estimated that to obtain a similar weight of ignited fine earth it would be necessary to sample the Lobe soils to a depth of about 47 cm instead of the standard sampling depth of 40 cm. The consequences of differential soil expansion will be considered further below.

Fig. 5.140 illustrates the vertical pattern of pH measurements on oven-dried samples from two stagnopodzol and four podzolic profiles in the zone. Subsoil values are indistinguishable; only the pattern in the upper horizons, where the stagnopodzols have a clear eluvial minima in the Ah/E horizon, while the podzolic soils show a steady rise in values with depth, allows the two soil types to be distinguished. Ah and Ah/E horizon values also fall in the same range, but the B_1 samples from the stagnopodzols (beneath the iron-pans, whose pH was not determined) have slightly higher values than the A_2 or A/B samples which lie at a corresponding depth in the podzolic soils. These patterns merely indicate that current soil processes reflect the differentiation of these soils due to metapedogenetic intervention and there is no indication here either of the survival of a difference in base status created by metapedogenesis or of the creation of a difference due to contemporary differences in biotic factors.

Due to the very much lower weight of ignited fine earth in the Lobe soils, comparison of their phosphorus content with that of the outfield soils on a volume basis (g Pao m^{-2} to 40 cm) provides a spurious picture of equality. Although, as can be seen in Fig. 5.141, the very large inputs of phosphorus to the profiles in and near the prehistoric house manage to provoke an anomaly despite the low IFe content of the profiles, there is no indication of a systematic difference between the other profiles in the Lobe and the outfield profiles; the mean values in each area are almost identical (Lobe $\bar{x}$ 161.4 g Pao m^{-2} (n = 6), North Field group A $\bar{x}$ 160.0 g Pao m^{-2} (n = 4)). However, a map of the concentration of Pao per unit weight of IFe, Fig. 5.142, which also shows the proportion of Pao within the Pa fraction, reveals an entirely different picture. It can be seen that, in addition to the exceptionally high values for the profiles in and close to the house (in which there is also an abnormal proportion of Pa), the concentration of Pao is generally higher in the Lobe soils than in the stagnopodzols, but that there is no difference in the relative contribution of Po and Pa. An even clearer separation is evident in a map of the concentration of Po in the organic matter (Fig. 5.143); both the concentration in the stagnopodzol profiles as a whole, and in their mineral component alone, are substantially and systematically lower than the concentration in the podzolic profiles.

Table 5.40 provides a statistical summary of phosphorus measurements in the ten profiles used for comparisons of the Lobe and outfield soils; it shows that despite the need to restrict comparison to a small number of profiles, the differences evident in the maps can be regarded as statistically significant. Exceptionally, the comparison between Po (mg kg^{-1} LOI) values in the North Lobe and the mineral soil of the group A stagnopodzols revealed no statistically significant difference, a result that appeared to fly in the face of the mapped data. Inspection of the profile values showed that profile SP 7 had an unusually high value (see test for discordancy in Table 5.41), which seriously distorted the mean value and variance of the group A profiles. Since this particular comparison omits the soil horizon most affected by peat cutting, the mean value of groups A and B combined may provide a better indication of the stagnopodzol mean value; as Table 5.40 shows this value is much lower than the value in the podzolic soils.

Total phosphorus determinations are only available for SP 4, GSP 3, GSP 2 and SP 8, and this sample is too small for statistical comparisons. However, there are only small differences between the mean Pao, Pa and Po values in the 'Pt' profiles and the equivalent values in their respective 'Pao' profile groups, and this suggests that the mean Pt and Pf values in Table 5.40 may well be as representative of the zone C soils as the Pao values derived from the slightly larger sample. In view of the close linear correlation of Pt and Pao (and Po) values (see 3.3.2), it is not surprising to find that the higher concentration of Pao and Po in the Lobe soils is matched by higher Pt and Pf values, but this observation does provide positive confirmation that there is a higher concentration of soil phosphorus and thus disposes of the possibility that the higher Pao values merely reflect a shift in fractional composition; it is clear that all phosphorus fractions have been enriched and that there has been only a slight and, perhaps, insignificant change in the proportion of phosphorus within each fraction. As a proportion of their initial values, the inorganic fra ctions appear to h ve gained slightly more than the organic fraction.

In order to estimate the probable input of phosphorus implied by these changes, one may adopt the procedure used to estimate the inputs on the medieval droveway (see 5.4.1 and Table 5.33). Fig. 5.144 shows the difference between the present weight of Pao (g m^{-2}) and an 'initial' weight calculated by assuming that all profiles 'started' with a concentration of Pao (mg kg^{-1}IFe) equal to the mean value observed in group A today. By the nature of the calculation, there is a nett zero balance in group A, but group B has a nett deficit of 11.6 g Pao m^{-2}, while the six 'normal' profiles in the Lobe have a nett surplus of 24.9 g Pao m^{-2}, which implies a nett surplus of 34.6 g Pt m^{-2}. Note that these figures indicate that the similarity of the mean values for the 'Pt' and 'Pao' profile groups in the Lobe arises from the fortuitous selection for Pt determinations of profiles which, it seems, have been affected to the greatest and least extent by phosphorus inputs.

In order to determine when and how these changes in soil phosphorus may have been induced it is necessary to consider also the differences that are evident in the vertical distribution of phosphorus in the stagnopodzols and the Lobe soils; these patterns are illustrated in Figs. 5.145 - 5.156, which allow one to make inter-horizon and inter-soil assessments on either a volume or a weight basis. To a large extent, both methods of presentation provide a similar picture of the relationships between soils and between horizons. The principal difference occurs in the Oh horizon where mg P kg^{-1}IFe measurements provide a misleading impression of the importance of surface accumulation of phosphorus; in this instance, the volume based figures provide a more realistic means of assessing differences between the podzolic soils and the stagnopodzols.

There is a good deal of redundancy in the information provided by the figures which illustrate the vertical distribution of Pt and the major fractions, Pao and Po. In the stagnopodzols, Pt values are at their lowest in the upper mineral soil, while in the Lobe soils, Pt values are highest at the surface and tend to fall regularly with depth. The same overall tendencies can be seen in the Pao and Po values, though, in the Lobe, values for these fractions fall sharply in the A_2 or A/B horizons, which have lower values than the B_1 horizons beneath them, and also decline in the B_2 and BCux horizons. These figures suggest that zones of phosphorus loss and accumulation similar to those in the stagnopodzols, may now be re-emerging in the podzolic soils; sub-surface accumulation seems to be occurring at a similar depth in the mineral soils. For the present purposes, the most important aspect to note is that all of these patterns indicate that the general phosphorus enrichment in the Lobe has only affected the upper 30 cm of the soil; below this level, samples from the stagnopodzols and the podzolic soils show only minor and possibly insignificant differences. This pattern contrasts very strongly with the pattern of enrichment in the soils in and near the prehistoric house, where, as noted earlier (see 5.2.2.1 and Tables 5.20 and 5.21), enrichment is most evident below about 20-25 cm; although there are differences even among these profiles (which need not, and will not, be considered here), in every case, Pao values rise to a very high maximum in the B horizon, and in two profiles the maximum values are reached in the B_2 horizons.

Higher Pf values for the Lobe profiles (and perhaps a slight increase in the proportion taken by this fraction) appear to reflect changes in the subsoils. As noted earlier (5.2.1.1), Pf values appear to vary erratically in the surface and near-surface horizons in the stagnopodzols, and this is also the case in the podzolic soils; a larger sample is needed to clarify the 'real' trends in these horizons. However, there does seem to be a real tendency for values to rise in the B horizons, reaching a maximum in the BCux horizon, and for values to be slightly higher in the Lobe soils. This could indicate that phosphorus enrichment in the Lobe has led to a slightly greater accumulation of Pf in the subsoils, but an alternative explanation can be envisaged. If, as seems likely, soil movement in the Lobe has involved a nett loss of soil, this thinning may have been accompanied by downward displacement of horizons, and if, as argued earlier (see 5.2.1.1), at least a part of the Pf fraction represents an inheritance from pre-Holocene weathering processes, then higher Pf values in the Lobe subsoils could reflect the sampling of less weathered soil materials retaining a higher amount of inherited Pf. More detailed fractionation studies than could be attempted here might shed further light on this issue, but it is worth noting that the same process could explain one of the differences between Pa values in the stagnopodzols and the Lobe soils.

The main contrasts in Pa values involve the samples from the upper and lower portions of the profile, and intermediate horizons exhibit much smaller differences. The high values in the Ah horizons of the podzolic soils compared to the values in the Ah/E horizon of the stagnopodzols must be seen in part merely as the result of the general transformation of a stagnopodzol into a podzolic soil in which a zone of surface accumulation of phosphorus has now been established in the mineral soil surface instead of a superimposed accumulation of peat. The incorporation within the mineral soil, either through prolonged cultivation and/or Denshiring, of the phosphorus formerly held in the Oh horizon must have initiated the new pattern, but additional phosphorus inputs, which must be postulated to explain the overall rise in soil phosphorus in the Lobe soils, may also be contributing to the high Pa values in the Ah horizon. The latter explanation could also apply to the higher Pa values in the B_2 horizons of the Lobe soils, but if so, it is, perhaps, odd that the B_1 horizons show little sign of similar enrichment; as the values in the highly enriched profiles near the house (see 5.2.2.1 and Table 5.21) demonstrate, the B_1 horizons are certainly capable of retaining enrichment in the Pa fraction. It is possible that B_1 (unlike B_2) Pa values were reduced during medieval cropping; alternatively, one can suggest that the high Pa values in the B_2 horizon may again be due to sampling of less weathered materials in the Lobe subsoils, which still retain a higher amount of primary phosphorus in the form of apatite.

The vertical distribution of Po per unit weight of organic matter in all the profiles in zone C is summarised in Fig. 5.157, a diagram that illustrates well the substantial contrast between the profiles in the Lobe affected by a general but relatively low level of phosphorus enrichment, and the highly enriched soils in and near the prehistoric house. In the former, the conversion of the stagnopodzol Ah/E horizons into podzolic Ah horizons has been accompanied by a large increase in the concentration of Po in the organic matter, but deeper horizons have been affected only to a much lesser extent, while in the latter many of the highest values were recorded for B_1 and B_2 horizon samples, and in two of the profiles samples from the upper horizons are closely similar to either the stagnopodzols (SP 33 in the house) or the other Lobe soils(SP 1).

The principal problem that must be confronted when interpreting the changes in soil phosphorus in zone C involves distinguishing phosphorus enrichment that seems to have occurred in prehistoric times, and may have been primarily associated with discard of rubbish and deposition of excreta around and in the prehistoric house, from enrichment that could have occurred during the medieval use of the field in which the prehistoric house now lies. The spatial pattern of enrichment evident in Fig. 5.144 provides equivocal information; on the one hand, the exceptional values in the 'discordant' profiles, SP 1 and SP 34, may be regarded as evidence for a significant disjunction that might be expected to occur if nett input in medieval times had been substantially lower than inputs to the prehistoric rubbish zone; on the other hand, there is a tendency for the values of apparent enrichment to be lowest in profiles furthest from the house, and this could be regarded as evidence for the view that all the enrichment in the Lobe soils should be attributed to the prehistoric occupation of the house. Against the latter viewpoint, one may raise the objection that the distribution cannot be explained by a model which envisages a simple fall-off in values as a function of distance, since on that hypothesis, SP 8 and SP 35, in the North Field, should have values similar to those of GSP 3 and SP 2 in the Lobe. Nor can the distribution here be explained by a simple fall-off model that has been modified to take account of the pattern of enrichment around the large house in zone A (see 5.2 .2.1); on that site, there was little evidence of enrichment at locations further than <u>ca</u>. 10 m from the house entrance, and in particular, only very minor enrichment was found in areas behind and to the side of the house (i.e. in locations equivalent to those occupied by SP 31 and SP 32 in zone C). However, it will be recalled that in section 5.2.2.1 it was argued that as much as 90% of the rubbish and excreta which might have been produced during the occupation of the house in zone C must have been deposited outside the 'rubbish zone' within which phosphorus enrichment was clearly evident; it must be possible that the general but much lower level of phosphorus enrichment in the Lobe soils reflects such deposition. However this hypothesis cannot explain why such general enrichment does not appear to extend to areas within the North Field that lie equally close to the prehistoric house.

It will be argued later (see 5.4.3) that differences between the phosphorus concentration (mg Pao kg^{-1} IFe) in stagnopodzols in sub-zones B and F of zone A (shown in Table 5.42, together with equivalent values in zone C) may well be due to general enrichment of a field which lies close to but beyond the 'rubbish zone' surrounding the pre-historic house on site F. Although zone C lies too far from the virgin land sub-zone (F) for a safe assumption that phosphorus values have been enhanced <u>throughout</u> zone C, this must be one possibility (see also discussion in section 5.4.3). If so, the higher values in the Lobe are quite economically explained as the result of further phosphorus inputs in medieval times.

The most powerful argument that can be advanced to support the view that phosphorus inputs of different age have affected the Lobe soils, relies on the substantial differences between the vertical distribution of phosphorus in the profiles near the house and in the other Lobe profiles. The studies of phosphorus enrichment in the zone A houses (see 5.2.2.1) entitle one to expect that, prior to medieval changes to the soils in zone C, any prehistoric inputs in the zone would have left as their legacy, substantial Po enrichment in the now-destroyed Oh horizon and in the underlying Ah/E. When, as it must have, medieval Denshiring and/or cultivation destroyed the former and, perhaps more gradually, reduced the organic matter content of the latter, a large amount of Po must have been mineralised. As Pa, this phosphorus would no doubt have contributed to crop success. However, at this time, large amounts of Pa could also have moved into the deeper layers of the subsoil, where, on the evidence from the stone row (see 5.2.2.1), they might have been unable to contribute further to phosphorus uptake in crops.

Clearly leaching of this kind could have occurred in all the Lobe soils. In most areas, however, a large proportion of the newly-released phosphorus might have been 'soaked-up' by crop removals before it could be leached into the B_2 horizon. On the other hand, where far larger quantities of Pa may have been released (in the soils close to the prehistoric house), a much larger amount of Pa might have 'escaped' into the subsoil. When the initially high levels of plant-available phosphorus produced by such mineralisation had been exhausted, additions of FYM or night impounding of livestock in winter or in fallow years could have been used to maintain crop yields, and this could have led to the more general enrichment of phosphorus that is evident in the upper 30 cm of all the Lobe profiles.

It is most likely that efforts would have been made to place manurial inputs evenly along the cropped 'lands' and, allowing for the effect of lynchet formation, this could have resulted in the creation of a pattern of more and less enriched zones (with a north-south axis) across the sampled segment of the Lobe (see 2.3.2.1). Unfortunately, this area encompasses one of the flattest parts of the Western Field in the Lobe and lynchet margins are extremely difficult to identify;

in consequence, the relationship between sampling sites and cultivation divisions could not be determined. In any case, it is doubtful whether a sample of six profiles would be capable of revealing such a pattern (in the light of the evidence now available, one can suggest that, if present, such patterns should be recoverable through high density sampling of the Ah horizon alone), though differences between profiles may reflect such factors. Although it is hard to envisage that medieval cropping spanning perhaps as much as five centuries was not accompanied by manuring, such inputs need not necessarily leave any trace in the form of residual phosphorus (see 2.3.2.2), and it can be argued that a general enrichment of the Lobe soils in zone C occurred in medieval times, but that it reflects deposition of rubbish and excreta during a medieval re-occupation of the prehistoric house rather than manuring of the field in which it lies. However, this hypothesis is confronted not only by the arguments concerning the spatial pattern that have already been discussed, but also by the lack of evidence for strong phosphorus enrichment in the surface horizons of the house profile (SP 33) and nearby SP 1 (see 5.2.2.1 and Table 5.21); in fact, the spatial pattern of phosphorus values (μg Pao cm^{-3}) within the Ah horizon shown in Fig. 5.158 (which also includes a combined Oh + Ah/E value for SP 33) offers no evidence that a putative medieval interest in the house involved accumulation of rubbish or excreta.

On balance then, one should probably conclude that the general enrichment within the Lobe does reflect medieval phosphorus inputs associated with cropping. Table 5.43 explores some of the ways in which an apparent residue of 34.6 g P m^{-2} might have accumulated; it assumes that the phosphorus input arose from FYM dressings which supplied 0.95 kg P t^{-1}FYM (see 2.3.2.2), and assesses both long term inputs over a period of 450 years and the possible size of individual dressings on the assumption that these were applied every third year. Recovery rates between 25 and 50% seem more likely than other solutions. If 300 harvests were taken and 3.5 - 5 kg P ha^{-1} removed in each harvest (see 2.3.2.2), between 1469 and 1943 t FYM ha^{-1} would have been required to produce the observed surplus; this would imply recovery rates of ca. 75-80%, a long term input rate of 3.3 - 4.3 t FYM ha^{-1}, and dressings of 9.8 - 13.0 t FYM ha^{-1}, if 150 dressings were applied. Given the manifold uncertainties as to the cropping period, the cropping system, phosphorus uptake in crops and the supply of phosphorus in the manures that may have been used, it would be unprofitable to pursue these estimates further, but it is worth noting that the lower recovery rates imply either far fewer harvests and/or that far less phosphorus was removed in each crop than has been assumed here. It is not particularly surprising to find indications of manuring in a field for which there is archaeological evidence for intensive tillage over a prolonged period, but the results of this investigation may be seen as confirming the archaeological interpretation of the field evidence. Taken together, a powerful case can now be made against the view that the fields in the North Lobe might merely have served as briefly and/or infrequently used outfields.

Finally, it is worth emphasising that this investigation indicates that, despite very substantial changes in the physical properties and appearance of the soil, neither medieval metapedogenetic processes nor subsequent pedogenetic processes along a new trajectory of soil development have left any substantial trace in the form of altered fractional composition of soil phosphorus. Although further Pt analyses are desirable, the lack of evidence for a substantial change in the proportion of Pf is particularly important, since it confirms that the studies of Pao values in zones A and B (where few or no Pt determinations were made - see section 3.3.2) are likely to have provided a reliable picture of variation in soil phosphorus.

5.4.3 Prehistoric and medieval enclosures - zone A

Some of the investigations in zone A have already been described (see 3.2.2 and 4.3.1.1); these studies played a crucial role in the assessment of medieval land use in the study area as a whole, but, unfortunately, in so doing, they also revealed a far more complex sequence of land use within zone A than had been imagined when the area was first selected for intensive archaeological and pedological enquiries. The discovery that medieval outfield cropping had affected much of the area covered during the first season's pilot sampling (see Fig. 3.9) seriously undermined the initial strategy of study in this zone, which had assumed, incorrectly, that all land beyond the bounds of the Inner South Field was either in a virgin state or had only been enclosed during prehistoric times (see 3.2.2).

Further sampling was carried out during the following two seasons (see Fig. 3.9), both to increase the density of sampling in areas covered during the pilot program and to extend sampling to new areas. In the course of this work, it became clear to the author that the prehistoric boundary between sub-zones C and J had been modified to serve as the outer boundary of the medieval outfields (the Outer South field) and this meant that only the samples from sub-zones F, G and J had been taken from land which had not been affected by medieval cropping. Unfortunately, it has not been possible in the time available to process more than a small proportion of the second and third seasons' samples, and as yet no quantitative analyses are available from sub-zone J. In consequence, although samples from virgin land are available for comparisons, none of the present data allows a comparison with land used only in prehistoric times, a situation that limits one's ability to resolve the complex problems of interpretation posed by multi-period land use. In this sense, the studies in zone A must be regarded as unfinished.

It is nevertheless desirable and necessary to present here what must be a preliminary report on the studies in this zone; necessary, because some samples from the zone constitute the 'control' data used in support of the contributory studies (see in particular 5.2.1.2 and 5.2.2.1) and desirable, because, despite the interpretative problems posed by multi-period land use, there are indications in the present data that distributions of soil phosphorus of the type envisaged in the models presented earlier may be present in the zone, and there are reasons for believing that such patterns are a legacy of prehistoric land use. Moreover, the variation in subsoil drainage (see 4.2.3.1 and Fig. 5.159) and in vegetation (see 4.3.2 and Fig. 5.160) which occurs within zone A provides an opportunity to assess the influence of such factors upon the distribution of soil phosphorus, and so serves well the methodological purposes of these studies. Thus some of the original objectives that prompted research in this zone have been achieved and, although it is hoped that further pedological and archaeological work (which is still continuing) will clarify and extend the present knowledge, this makes it worthwhile to include an account of the work completed, and to offer a preliminary assessment based on this work.

The location of zone A within the study area is shown in Fig. 3.8; archaeological data from the zone has been described in section 3.2.2 and the changes in surface soils that resulted from medieval land use were described and discussed in section 4.3.1.1, where also the pattern of land boundaries in this zone was considered. In addition to the random sampling in the zone described in section 3.3.1 (see also Appendix 1 - groups 3 and 8), a series of profiles adjacent to boundaries and in the corners of enclosures (see Appendix 1 - groups 8 (ED series) and 15) were also sampled to test the predictions of phosphorus enrichment in such locations.

As noted above, it has not been possible to complete analyses of all the samples taken from zone A; after processing the pilot samples, it became necessary to select a small number of the profiles sampled in later seasons for immediate analysis and to defer work on the rest. Two further profiles in sub-zone D were analysed simply to increase the sample from that area to a size comparable with that in other sub-zones; 12 new profiles in sub-zone C (including three corner and two edge profiles) were processed so that an adequate sample was available for at least one of the larger prehistoric fields, where a combination of archaeological and pedological data had already hinted at livestock use; finally, four additional profiles in sub-zone E were analysed to test whether apparent bimodality in the pilot samples from this area was merely an artifact of a restricted sample (this is discussed further below). A total of 47 profiles in zone A (excluding four profiles associated with palaeosol and lynchet studies) have been analysed and are used in the maps and analyses presented below.

The investigations of the medieval arable field and droveway involved sampling only within a very small proportion of the land occupied by these features. The advantages of this approach include the possibility of relatively high density sampling (e.g. the sampling density in zone C was about one profile in 125 m^2) and minimal or inconsequential variation in the natural factors of soil formation within the sampled area. However, it suffers from the disadvantage that, strictly speaking, such studies cannot reveal whether the sampled land is typical of the land within the features under investigation. Clearly this limitation must be overcome if one is to gain knowledge of the pattern of past land use in medieval farms as a whole or even quite small segments of prehistoric field systems, which on Dartmoor and elsewhere often cover hundreds, and in some cases thousands of hectares. The sampling in zone A was directed towards this problem and the profiles analysed thus far extend across three prehistoric fields (sub-zones A, B and C), part of a fourth (sub-zone D), and include an area within a medieval outfield (the Outer South Field) which was not enclosed during prehistoric times (sub-zone E) as well as apparently virgin land (sub-zones F and G). In all, the sampling in zone A covered an area of ca. 8 ha and, for practical reasons, this has involved a more than ten-fold reduction in the overall sampling density (ca. 1 profile in 1700 m^2) compared to the density in zone C. There is, then, a large difference in the scale at which variability in soil properties has been observed in this zone. The other advantage enjoyed by the studies in zone B and C has also been lost since, as noted above, significant variation in two of the natural factors affecting soil formation (subsoil drainage and vegetation) occurs within this zone, despite minimal topographic variation, a highly uniform parent material and a close similarity in the physical appearance of the soil profiles, all of which can be classified as stagno-podzols (see 4.2.3 and 4.3.1.1).

The standard laboratory procedures have been used in all chemical analyses of zone A samples; the method of estimating stone content has been described in section 3.3.2. Soil bulk density measurements were obtained from nearly all Ah/E horizons in this zone and the observed values have been used in all calculations. However, Oh and B horizon values have been calculated from sample LOI values using the regression equations presented in section 3.3.2; as in zone C, this procedure has been preferred to the alternative - a mixture of observed and calculated values.

It has been argued above (see 4.3.1.1) that peat cutting has occurred widely in zone A, and a procedure to make some allowances for the rather serious consequences of this exploitation has had to be invented. In zone C, it was possible simply to set aside profiles that seemed to have been affected by peat cutting, but this is not possible in zone A. Since, particularly in areas where the present peat cover is thinner than the peat in virgin land due to medieval tillage, it is not always possible to distinguish with certainty the profiles that have been peat cut (see 4.3.1.1), there can be no entirely satisfactory procedure which will accurately compensate for the losses arising from this activity. The procedure that has been adopted sought to bring the mean peat thickness in each sub-zone, calculated from the profiles for which chemical analyses are available, into line with the value in each sub-zone determined from the larger sample considered in section 4.3.1.1, where a statistical procedure was used to estimate the mean value for profiles unaffected by peat cutting. An adjusted value for peat depth has been applied in 12 of the 47 profiles in zone A (see Table 5.44, in which the nature of the adjustment procedure is clearly indicated); most of the profiles affected lay in virgin land or in sub-zone E. In making these changes, the author adopted the principle that a minimal increase should be sought in as few profiles as possible; as a result, it may be that in some cases insufficient compensation has been applied, but a bias tending towards preservation of observed values seems preferable to one which could over-compensate. Profiles with adjusted peat values did not in any way stand out as exceptional in a subsequent inspection of the complete data set from this zone.

Although the procedure adopted provides some redress for the losses that occur as a direct result of peat removal, it is at present impossible to make allowances for differences that may have arisen subsequently due to changed rates of phosphorus leaching or organic matter accumulation in such profiles. Nor is it possible to allow for the effects of medieval tillage on organic matter accumulations, and this 'overprinting' creates serious, and as yet unresolved problems in the interpretation of patterns of variation in organic matter content and related variables (e.g. the concentration of Po in the organic matter). In consequence, much of the available data of this type is not presented or considered in detail in the discussion below.

Fortunately, the very brief cropping thought to have affected this zone in medieval times is unlikely to have significantly altered the amount of phosphorus in the soil; even 15 years cropping at a removal rate of 3.5 - 5 kg P $ha^{-1} year^{-1}$ (see 2.3.2.2) would only reduce soil phosphorus by 5.3 - 7.5 g m^{-2} or _ca._ 5% of the amount present in most profiles in virgin areas, a loss that would be difficult to detect. Nor, if documentary descriptions of outfield practices in Devon are accurate, is it likely that soil phosphorus supplies were augmented by inputs of manure (see 3.2.2), though clearly this possibility must be reconsidered when the soil evidence from this zone has been presented. On the other hand, there can be no doubt that medieval tillage, like peat cutting may have altered the vertical distribution of phosphorus within the profiles in this zone.

The initial planning of sampling and analysis in zone A envisaged testing for significant variations in soil properties using analysis of variance and related statistical techniques. However, for several reasons these techniques, which were employed on some data sets at an peat depth has been applied in 12 of the 47 profiles in zone A (see Table 5.44, in which the nature of the adjustment procedure is clearly indicated); most of the profiles affected lay in virgin land or in sub-zone E. In making these changes, the author adopted the principle that a minimal increase should be sought in as few profiles as possible; as a result, it may be that in some cases insufficient compensation has been applied, but a bias tending towards preservation of observed values seems preferable to one which could over-compensate. Profiles with adjusted peat values did not in any way stand out as exceptional in a subsequent inspection of the complete data set from this zone.

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The initial planning of sampling and analysis in zone A envisaged testing for significant variations in soil properties using analysis of variance and related statistical techniques. However, for several reasons these techniques, which were employed on some data sets at an early stage in the analysis, have not been applied to the bulk of the data presented below. One reason is that some of the profiles for which chemical analyses are now available were selected from a random sample on a non-random basis (as described above) and this violates the conditions of these and indeed many tests for statistical significance. A second reason arises from the nature of the data sets themselves. It will be shown below that variation in soil properties in several of the sampling sub-zones that were intended to provide the 'groups' for anovar is not distributed 'normally' and this too violates the conditions of such tests. Nor do such tests provide a means of distinguishing patterns imposed by pedogenetic processes and metapedogenetic processes when both types of processes may have been acting in concert, and this seems to be the case in zone A. Although when further analyses have restored the random quality of the sample it may be possible to undertake some other forms of advanced statistical analysis, the preliminary assessment offered here will instead rely heavily on a null hypothesis of parent material homogeneity; it is assumed that substantially greater variation among samples drawn from horizons above the BCux horizon than is evident among samples from that horizon must reflect either pedogenetic or metapedogenetic redistribution and that it is worthwhile to offer interpretations of coherent and systematic patterning of soil variables when these are evident. In zone A, unlike the smaller study zones, there is a sufficient number of samples from the BCux horizon for an assessment of parent material homogeneity.

Table 5.45 shows the concentration of Pao (mg kg^{-1} IFe) in samples from the BCux horizon in each of the sub-zones in zone A and zone C. Although it has been suggested earlier (see 3.2.1) that material in the BCux horizon may not correspond precisely with the material once present in the upper parts of the soil profile, the variation within this data set provides the best estimate that can be made of the proportion of variation in soil phosphorus values that should be attributed to a combination of parent material variation and analytical 'error'. Although the classification of these samples as BCux samples implies their alteration by soil processes - alteration that may be evident particularly in the shallow samples from the prehistoric palaeosol in sub-zone B and in the sample from sub-zone D - the general similarity of samples from each sub-zone in zone A, and furthermore the close correspondance of these samples with those taken from zone C, some

750 m north-north-east of zone A, strongly supports the view that the granite solifluction sheet provided a parent material of remarkably uniform quality so far as phosphorus is concerned. In the author's view, the level of homogeneity is such that it provides some justification for believing that soil phosphorus values in the virgin land in zone A (sub-zones F and G) provide a relevant baseline against which to measure values anywhere in the study area (and thus gives some support to the argument advanced in section 5.4.2, that all profiles in zone C may have been affected by prehistoric phosphorus enrichment).

Because of the many different factors both natural and cultural that can be expected to have affected the properties of soils in zone A, it is instructive to consider the pattern of values within individual horizons before evaluating the pattern of values calculated for entire profiles. Fig. 5.161 shows the concentration of Pao ($\mu g\ cm^{3}$) in the Oh horizon at all sampling points in zone A and a statistical summary of the values in each sub-zone appears in a histogram (Fig. 5.162), which also indicates the range of values within the three vegetational communities recognised in this area. Although at first sight the latter might appear to indicate an association between relatively higher phosphorus concentrations and the presence of bracken, a closer examination shows that this pattern in the total dataset is largely the product of the relatively higher phosphorus values in sub-zone B, an area entirely covered by bracken. The pattern of values in sub-zone C, where profiles lying within all three types of vegetational community were sampled, shows no such association. There are differences in the representation of <u>Calluna vulgaris</u>, <u>Erica tetralix</u> and <u>Molinia caerulea</u> within the non-bracken areas in zone A, but such variation has not been recorded with sufficient precision to assess whether, as Loach (1966, 1968) suggested, differences in the ability of these species to extract nutrients from the subsoil could be responsible for at least some of the observed variation in surface soil phosphorus values.

Although there is no clear indication that variation in the concentration of phosphorus in the surface soil is related to the major pattern of change in vegetation, there is some evidence that it may be influenced by the pattern of weak subsoil gleying in this zone (see Fig. 5.159). Nearly all the half dozen profiles lying in the flattest land on the plateau summit have lower phosphorus concentrations than profiles elsewhere. The soils in which weak gley features are present in fact occur over a far wider area than this 'low phosphorus' group, but it must be possible that, despite the similar field appearance of subsoils over a wider 'weak gley' zone, the soils in the highest parts of the zone are more strongly affected. Since subsoil phosphorus values are much more clearly linked to the incidence of gleying, this factor will be considered further below.

There is some evidence that cultural factors have influenced the pattern of surface soil values. Values in the virgin areas (F and G) do not differ significantly from the values in two of the Outer South Field sub-zones (E and D), but there is a sharp change in the range of values observed either side of the boundary separating D from A and B. It will be recalled that this prehistoric boundary also marks the western edge of a 'mixed' peat area created by late medieval tillage (see 4.3.1.1 and Fig. 4.7), but it will also be noticed that if the pattern of change in phosphorus values at this boundary were to be attributed solely to the effects of land use practices in sub-zone D, then one might reasonably expect a similarly marked change in values at the boundary between D and E, and this is not evident. It is more economical to suppose that land use within sub-zones A and B could be responsible for the contrast. There is in fact a very wide range of values in the areas within the Outer South Field where 'undisturbed' peats are present (sub-zones A, B, C and E), but it is notable that these small (0.27 ha) prehistoric fields (A and B), individually and collectively possess a much narrower range of (exclusively) high values. Similar values (and even higher ones) were found in sub-zone C, and two of the highest values in the entire zone were recorded among the non-random set of samples from this sub-zone (CC2 and ED 3).

Study of the phosphorus concentrations in the small prehistoric house in sub-zone D (see 5.2.2.1) indicated that the concentration of Pao in the surface peat soil reflected phosphorus concentrations (and in particular the Pa values) in the underlying Ah/E horizon. Figs. 5.163 and 5.164 show that no clear relationship of this type is evident among the samples from zone A as a whole, and in fact only in sub-zones A and B is it possible to suggest that Oh Pao values may in part reflect Ah/E Pao values (Fig. 5.164). The failure to observe such a pattern may mainly reflect the larger scale of observations in this zone and a consequent increase in variability due to pedogenetic factors alone. However, samples from some sub-zones tend to form groupings in these scattergrams which bear no simple relationship to the physical distances between sampling points in the zone as a whole, and this suggests that varying incidence in metapedogenetic factors may in part be affecting the relationship between phosphorus values in the Oh and Ah/E horizons. It has been suggested that some of the sampling locations in zone B had been affected by one such factor - relatively recent deposition of excreta - and that this could be identified by an abnormal concentration of phosphorus in the Oh horizon samples (see 5.4.1 and also 5.2 .2.1). The great spread of values in zone A makes it impossible to confidently recognise such patterns in this zone, but it is worth pointing out that a group of five profiles lying close to the prehistoric (and probably robbed) boundary that partially bisects the field forming sub-zone C may conform to this pattern. These profiles share similar and abnormally high concentrations of Pao in the peat surface, and four of the five profiles also have an abnormal proportion of the phosphorus within this horizon in the Po fraction (see Fig. 5.165); this too copies the pattern seen in zone B. Exceptionally, the profile lying north of the boundary (C 6) has high Po and Pa in the peat, as well as high Pa in the Ah/E horizon and is thus, in several respects similar to the profile in the south-eastern corner of field C (CC 2), which, as will be discussed below, shows phosphorus enrichment in all horizons.

One can, therefore, tentatively identify three areas in zone A where the concentration of phosphorus in the surface peat may be said to be 'abnormal'. First, there is a group of profiles on the plateau summit in which abnormally low values may be associated with weak gleying in the subsoil; secondly, there is a group of profiles in the northern part of the southern half of sub-zone C, where abnormally high values may indicate the site of an abandoned, but relatively recent, sheep camp (the location of these profiles conforms to the type of location presently selected by sheep in the study area (see 3.2.2) and elsewhere (see 2.2.4 and 2.3.1.1)); thirdly, there are the profiles in the small prehistoric fields that form sub-zones A and B, where uniformly high values and the abrupt change in values at the eastern boundary of these fields suggests that metapedogenetic factors associated with the agricultural use of these fields may be influencing phosphorus values. Both in this area and on the plateau summit, Oh phosphorus values may reflect the values in the underlying mineral soil (see Fig. 5.164), which must now be considered.

At an early stage in the investigation of soils in zone A, it became apparent that one could not properly assess variation in chemical properties unless allowance was made for variation in physical parameters such as stone content and soil bulk density. The need for such assessments was prompted not only by an awareness that samples often exhibited substantial variation in such parameters, but by clear indications that this sample variation was not randomly distributed in the landscape; an aspect that is illustrated in Fig. 5.166, which shows the spatial pattern of soil bulk density in the Ah/E horizon samples from zone A. In this particular case, it is also evident that the spatial pattern is closely linked to the pattern of ancient land enclosure. Analysis of variance within this dataset (after exclusion of non-random samples from banks, lynchets, corners and edges of enclosures) confirmed the obvious - that the bulk density of samples from the small prehistoric fields is significantly lower than that of samples in most other areas (see Table 5.46). Some of the variation in bulk density is certainly due to variation in the organic matter content of the samples, but, as noted earlier (see 3.3.2 and Fig. 3.21), the relationship between bulk density and LOI values is not the same in all the sub-zones within zone A. This is evident in the scattergram (Fig. 3.21) and can also be inferred from the results of a parallel analysis of the variance in the LOI values of these samples (see Table 5.47). The lower than average stone content of samples from fields A and B, and the higher than average values in virgin areas (see Table 3.6) may be another factor contributing to this pattern of bulk density values. Since differences in soil structure, pore space, etc., which have not been studied, might also be involved, a partioning of the separate responsibility of these factors will not be attempted here, nor, in view of the high variability in the stone content of samples (and the problems of meaningful measurement of this soil fraction - see 3.3.2) will it be argued that the patterns evident in this fraction have been created by tillage, though this is certainly a possibility. However, a conclusion that must be drawn from these observations is that investigations of the relatively small changes in soil phosphorus that may be expected to be found in ancient fields (small, that is, by comparison with the changes that may occur in the soils of houses, byres, etc.) must be accompanied by studies of such physical parameters, if reliable information is to be gained.

Fig. 5.167 shows the concentration of Pao ($\mu g\ cm^{-3}$) in the Ah/E horizon (a format that takes the variation in stone content and bulk density into account) at all locations in zone A; a histogram (Fig. 5.168) indicates the distribution of these values in each sub-zone and indicates the profiles affected by weak gleying. For the most part, this pattern is very different from that in the Oh horizon. As already noted, the samples from profiles in the putative sheep camping area in sub-zone C show no anomalous values in this horizon, and although most of the profiles on the highest part of the plateau do continue to display values within the lower range of those observed in zone A, these no longer present an anomaly, since they merely form part of a much wider area in which such values are common. It is notable, however, that in this horizon the profile in the south-western corner of field C (CC 1) provides a sample with an anomalously high value similar to that in the south-eastern corner of the field. Once again, there is little difference in the values in virgin areas and the western half of sub-zone E, but three of the four profiles in the eastern part of this sub-zone have very much higher concentrations of Pao. This apparently bimodal distribution was evident in the pilot sample, a pattern that prompted the analysis of four additional profiles in this sub-zone (two in the eastern half and two in the western half). Values in the samples from the small fields, A and B, are slightly lower than the values in the eastern part of sub-zone E, but, as in the Oh, remain substantially higher than the values in the virgin land. However, in this horizon there is no substantial contrast across the boundary that separates A and B from sub-zone D. The overall pattern is clearly one of high values to the east and lower values to the west, a division which broadly corresponds with the pattern of change in subsoil drainage.

Po concentration values, which, it was thought, provided the best measure of metapedogenetic enrichment of phosphorus on site F (see 5.2.2.1) are shown in Fig. 5.169); as these earlier studies would lead one to expect, the pattern of variation in Po mainly reproduces the Pao pattern. This is not the case with the pattern of concentration of Po within the organic matter (Fig. 5.170). Although by no means entirely discordant (the eastern part of sub-zone E and fields A and B continue to display higher than average values), there are some significant discrepancies; values in sub-zone D are little different from those in the western part of sub-zone E, and neither area has values substantially different from those in the virgin sub-zone F. Note also that in this map all three corner samples in field C have anomalously high values (the fourth corner could not be sampled due to tinning disturbances). The most important aspect evident in both these maps (Figs. 5.169 and 5.170) is the existence of a plateau summit zone in which particularly low values are recorded; the profiles affected are, with one addition (E 14) and one deletion (CC 1), the same as those which contributed to an analogous pattern in the Oh horizon samples.

Although it could be argued that much of the pattern of phosphorus variation in the Ah/E horizon may be linked to the variation in subsoil drainage impedance, there is in fact a substantial overlap in the phosphorus values recorded in the 'freely-drained' and the 'weakly-gleyed' groups of profiles (see Figs. 5.168 and 5.171), and there are, for example, equal numbers of profiles with Pao concentrations equal to or greater than 250 ug cm^{-3} in each of these groups. Moreover, this hypothesis cannot explain much of the detailed pattern revealed by these samples. Examples that tend to refute it include the distributions in fields A and B, where the highest values tend to occur in the weakly-gleyed profiles, and the distribution in sub-zone E, where freely-drained profiles contribute a similar number of samples to the low (western) mode and the high (eastern) mode. In addition, samples in this sub-zone (and to a lesser extent the samples in sub-zone F) can be regarded as providing values along a topographic transect identical to that which has been sampled further north, but the pattern of change in phosphorus values from field C to field D (via fields A or B) is certainly not identical to the pattern in sub-zone E (it should be noted that the division of sub-zone E based on properties of the surface peat (see 4.3.1.1 and Figs. 4.4 and 4.7), lies some 25-30 m west of the phosphorus 'boundary' that can be postulated from this dataset). In fact, it can be plausibly argued that, at worst (from a prehistorian's point of view), the spatial pattern of phosphorus in the Ah/E horizon probably reflects the operation of pedogenetic and metapedogenetic processes (with the latter mimicking and so accentuating a natural pattern), and that, at best, only the samples from the profiles on the highest part of the plateau, in which Po concentrations (both ug cm^{-3} and mg kg^{-1} LOI) are particularly low, should be regarded as having been substantially affected by redistribution or losses of phosphorus as a result of pedogenetic processes accompanying gleying. The latter view would not be inconsistent with the available evidence for the nature of phosphorus losses in gleyed soils mentioned earlier (see 2.3.3.1). Where it has been studied (e.g. Williams and Saunders 1956a, 1956b, Williams 1959, Runge and Riecken 1966), it has been found that the low levels of Pt in poorly-drained soils reflect low levels of Po, and inorganic forms may sometimes take slightly higher values (higher levels of Pi in the soils studied by Williams and Saunders were due to the large amounts in the coarser soil fractions in which phosphorus was thought to be present mainly as apatite). Runge and Riecken (1966) also found higher C:Po ratios in poorly-drained profiles (as occurs in the plateau summit profiles in zone A), though their imperfectly-drained soils had ratios only slightly higher than the freely-drained soils and Williams et al (1960) claimed that lower C:Po ratios were typical of poorly-drained soils.

The pattern of phosphorus values in the subsoils provides further evidence of the effects of poor drainage. Due to the difficulty of measuring the physical parameters of soil in the B horizons and the consequent need to utilise regression equations to obtain soil bulk density values, and to use sub-zonal and zonal mean values for stone content, the B horizon phosphorus data are here expressed not only in terms of volume (in this case, g P m^{-2}, a convenient measure when, as here, the values in two or three horizons have been combined for the sake of brevity and simplicity), but also in terms of concentration by weight of ignited fine earth. Fig. 5.172 shows the overall concentration of Pao (mg kg^{-1} IFe) in the B horizons (sampled to a depth of 40 cm), and Fig. 5.173 summarises this data in the form of a histogram which indicates the drainage status of the profiles. In these horizons, unlike the overlying horizons, there are substantial differences in the relative contribution of the inorganic and organic fractions to Pao values in samples from some of the sub-zones, and this can be seen in the maps and histograms which illustrate the individual patterns of Pa and Po (Figs. 5.174 - 5.177).

The overall pattern of Pao values has some features in common with the pattern in the Ah/E horizon. Higher values occur more frequently in the eastern than in the western part of the zone; the mean value for the four profiles in the eastern part of sub-zone E (410 mg Pao kg^{-1} IFe) is higher than the equivalent value for the five profiles in the western part (356 mg Pao kg^{-1} IFe), but in view of the high standard deviation of the sample means (73 and 88 respectively - see Tables 5.48 and 5.49 , which provide a statistical summary of these and other sample values in the zone), this difference cannot be regarded as significant. On the other hand, the higher values in sub-zone D ($\bar{x}$ 452 SD 46) could indicate higher subsoil phosphorus concentrations in this area compared to the virgin sub-zone F ($\bar{x}$ 353 SD 58) and the greater frequency of low values in sub-zone C (and perhaps also field A) could indicate a real deficiency in this area.

It would be difficult to argue convincingly that this pattern in the overall phosphorus content of the B horizons has been much influenced by the drainage factor; in this map (Fig. 5.172), profiles on the plateau summit do not stand out as anomalous, and the principal areas of deficiency seem to occur further east in sub-zones C, A and B. However, the histograms of Pa values in these samples (Fig. 5.175) provide what appears to be clear evidence of an association between drainage status and phosphorus values, though it can be seen that, even in this case, there is a substantial overlap in the values in freely-drained and weakly-gleyed sub-soils. An even larger overlap occurs with the distribution of values for the dominant Po fraction (Fig. 5.177), and the spatial distributions of each of these fractions (Figs. 5.174 and 5.176) largely repreduce the patterns evident in the map of Pao values (Fig. 5.172); none of these maps indicate abnormally low values in the area that is likely to be most affected by sub-soil gleying. Nor is this apparent in a map of the concentration of Po in the organic matter in the B horizons (Fig. 5.178). Samples from the plateau summit profiles do tend to have low values (as in the Ah/E horizon) but no clear anomaly emerges since similar values occur throughout the zone. There is in fact a very wide range of values in this dataset and little difference between the distribution of values in the freely-drained and weakly-gleyed soils (Fig. 5.179). The mean values in sub-zones are much less variable see Table 5.49) and these figures indicate that values in sub-zone G and the southern half of field C may be slightly lower than average while the samples from the eastern part of sub-zone E have above average values, an anomaly that is clearly evident in the map (Fig. 5.178).

There are, then, some indications that subsoil Po values may have been affected by gleying, but, as in the Ah/E horizon, it would be unreasonable to attribute all or even a substantial proportion of the pattern to this factor. The apparently better linkage between Pa values and soil drainage is puzzling, since,from the previous research noted above, one would expect this fraction to be least affected. However, none of the published information reported such patterns in moorland stagnopodzols, and it may be that the pattern in zone A is typical of such soils (low values for 'available' inorganic phosphorus in poorly-drained soils were reported by Runge and Riecken (1966), though their soils were of very different character to those on Holne Moor). Of course, constant conjunction does not necessarily indicate a causal relationship, but, in this case, the pattern of Pa, particularly in sub-zones A and B (Fig. 5.175) strongly suggests that a causal relationship is involved.

The spatial pattern of Pao values (both mg kg^{-1}IFe and g m^{-2}) in complete profiles is summarised in Figs. 5.180 and 5.181, and Po values (g m^{-2}), which may have been less affected by the variation in soil drainage than the Pa values, are shown in Fig. 5.182. Histograms (Figs. 5.183 - 5.186) provide a summary of the distribution of these values in sub-zones and in soil drainage 'groups'. In addition, Fig. 5.187 shows the mean concentration of phosphorus (mg Pao kg^{-1}IFe) and the spread of sample values in each sub-zone. In this figure and in the figures which illustrate the vertical distribution of soil phosphorus in each of the sub-zones in zone A (Figs. 5.189 - 5.192), the samples from sub-zone E have been split into a 'western' and an 'eastern' group and the mean values in sub-zone C have been calculated from the values in the eight randomly selected profiles in the southern part of the field. The unique pattern of values in CC 2, the profile in the south-eastern corner of field C is also shown in these figures. This arrangement of the data flows from the pattern of values in individual horizons that have already been introduced and/or from the patterns that are evident in the values for complete profiles. The same format has been used in Tables 5.48 and 5.49, which provide a statistical summary of the measured soil properties in zone A, and these sub-divisions have also been indicated on the principal histograms. To allow more wide-ranging comparisons, Fig. 5.183 and 5.185 also include the equivalent values in the palaeosols, their overburdens and the comparative profile adjacent to the house on site F (see 5.2.1), as well as the main profiles in zone C (see 5.4.2).

As one would expect in an area where there are no major systematic soil differences of the kind evident in zone C, the spatial pattern of soil phosphorus revealed by Figs. 5.180 and 5.181 is very similar (and this is also true of the pattern of values for the dominant Po fraction shown in Fig. 5.182). The minor discrepancies may largely reflect differences in the way in which 'error' in the estimation of both physical and chemical properties is incorporated in calculations, and if this is correct, Fig. 5.188, which shows values for apparent phosphorus enrichment or deficiency in each profile in zone A (taking the mean values in sub-zone F as a baseline) may provide the best estimate of the 'real' differences between profiles; the profile values in this map were calculated by taking the mean of the two values that can be obtained using the procedures introduced and described in section 5.4.1. Equivalent sub-zonal mean values and the values for the non-randomly selected profiles are listed in Table 5.50, which also precisely indicates the method of calculation.

Although, for the most part, the sub-zone sampling divisions have been retained for the presentation of summary statistics, the pattern of values revealed by all these maps (Figs. 5.180 - 5.182 and 5.188) cannot be described as concordant with the system of land boundaries on which these sampling divisions were based. Once again, there is some tendency for an east-west split in values, but, in this case, neither the spatial pattern, nor the histograms showing the distribution of values in freely-drained and weakly-gleyed soils (Figs. 5.184 and 5.186) allow one to invoke the difference in drainage as the major factor responsible for the variation in profile values (see, in particular, the distribution of values in sub-zones A, B, F and G, and note the absence of enrichment in the northern part of field A and the adjacent areas in sub-zone D, a pattern that is inconsistent with an explanation which envisages that the high values further south are the result of downslope redistribution of phosphorus from the apparently deficient plateau area of sub-zone C). Although other pedogenetic factors must be responsible for some of the variation in these values, there are several indications that metapedogenetic factors are also involved.

In sub-zone C, all three sampled corners and both the random profiles from the area north of the bisecting boundary, together with the 'edge' profile lying close to the eastern end of this boundary (ED 3), have a substantially higher phosphorus content than other profiles in the sub-zone. Although further sampling is needed to confirm or refute the notion that the northern area as a whole has anomalously high soil phosphorus, the corner pattern does seem to be a feature inescapably linked to the pattern of <u>prehistoric</u> land division. Although the boundaries at the south-western corner of field C must have been significant landscape features in medieval times, as they are today, this is not the case in the other two corners; the reave which separates fields A and B from field C is a very inconspicuous feature, especially towards its southern terminus with the Venford Reave (i.e. at the point where it forms the corner that shows the greatest amount of phosphorus enrichment.

Fleming's research (see 3.2.2) has revealed possible 'cobbling' of an area close to a prehistoric gate in the north-eastern corner of the field, but he found no traces of houses or settlement debris. Unfortunately, there have been no excavations in the southern corners and it is, therefore, at present impossible to exclude that, as in sub-zone D, timber houses were built in these locations and that the phosphorus enrichment in these spots reflects occupation of such houses. However, it would be perverse not to recognise that the pattern of corner enrichment in this field corresponds with one of the patterns predicted by the models of nutrient transfer in animal enclosures that were presented earlier (see 2.4.1 and, in particular, Fig. 2.11, the predicted nutrient pattern in a sheep enclosure), and, therefore, that the pattern may indicate deposition of faecal phosphorus in prehistoric sheep camps. If, as one may suspect, this field was in use for ca. 350 years (see 3.2.2), an overall rate of phosphorus input of ca. 2.4 kg $ha^{-1}year^{-1}$ would be required to account for the extra phosphorus present in the highly enriched soil of the south-eastern corner of the field (see Table 5.50). This rate is some two and half times greater than the minimum rate of input estimated for contemporary sheep camps on Holne Moor (see 2.2.4 and Table 2.4; note also that these estimates and those in the following paragraph, which are based on changes in Pao rather than Pt, may underestimate the real changes by ca. 30% - see comment in 5.2.2), but this is not surprising, since grazing densities (see 2.3.1.2) and the concentration of phosphorus in surface soils (see 5.2.1.3) and, therefore, almost certainly in herbage and excreta were probably higher than they are today.

Although phosphorus deficiencies in grazing areas also form part of the predicted nutrient pattern in sheep enclosures, the deficiency in the southern part of field C is probably larger than can be explained by grazing redistribution and removals alone. Again assuming 350 years of sheep grazing, an overall rate of phosphorus losses due to cropping and transfers of ca. 0.5 kg $ha^{-1}year^{-1}$, a rate ten times greater than the rate estimated for contemporary grazing on Holne Moor (see 2.2.4 and Table 2.4), would be required to account for the nett phosphorus deficiency in these areas (see Table 5.50). If one also assumed that 6% of the pasture was gaining phosphorus (see 2.2.4) due to transfers from grazing areas at a rate of 0.2 kg $ha^{-1}year^{-1}$, this would provide an input of ca. 3.1 kg P $ha^{-1}year^{-1}$ to the camps and would raise soil phosphorus levels in these areas by ca. 109.7 g m^{-2} after 350 years. Once again, somewhat higher loss, transfer and input rates may indicate higher grazing densities and higher concentrations of phosphorus in herbage and excreta; however, it is highly probable that losses associated with gleying have affected the values in some parts of the field, and there is certainly no need to postulate any other mechanisms (e.g. removals during arable cropping) to explain the phosphorus deficiency in this field.

The second pattern in phosphorus values that may be of metapedogenetic origin is the area of apparent enrichment that extends from, perhaps, the most southern portion of field A to the eastern part of sub-zone E, and takes in all of field B and the adjacent, southern part of sub-zone D (see Figs. 5.180 - 5.182 and 5.188). It must be admitted that this pattern does not correspond to any of the patterns predicted by the models presented earlier, that no simple metapedogenetic process can be invoked to explain all aspects of the pattern, and that further soil analyses will be needed to clarify its origin and to test the ideas advanced below.

The apparently enriched area does not correspond to any of the areas separated by prehistoric land boundaries, nor to the divisions of land used during medieval outfield cropping (see 4.3.1.1 and Fig. 4.7), and it may be said at once that the absence of a significant change in phosphorus values across the Outer South Field boundary supports the view that the outfield cropping episode which left ploughmarks sealed beneath 'undisturbed' peat (this occurred in sub-zones A, B, C and E) did not produce any measureable change in the total amount of phosphorus in the soils affected. Likewise, the presence of a substantial change within sub-zone D, an area with a very homogenous, 'mixed' peat surface, argues against, although it does not disprove, the proposition that manures accompnying the later cropping episode, which produced this surface soil, created the phosphorus enrichment that is evident only in the southern part of the sub-zone. If, therefore, this area of apparent enrichment is a metapedogenetic artifact, it is most likely to be one which dates to the occupation of the several prehistoric houses and other structures which lie within the affected area. It should be noted that the extent of prehistoric settlement around and beyond the Venford Reave is still under investigation; Fleming, who has already found some evidence that settlement may have extended into the eastern part of sub-zone E, is, at the time of writing, excavating in this area.

The simplest explanation for the enriched area is that it merely represents two, adjacent zones of low level enrichment produced by unorganised deposition of rubbish and excreta within areas centered upon the stone houses now visible, but it may also reflect a more complex pattern of (probably earlier) settlement. Enrichment in field B could have a more deliberate origin associated with prehistoric agricultural activities, but at present only the sharp change in values at this field's western boundary, which is thought to have been an effective barrier (see 3.2.2) could be used in support of this hypothesis.

It is evident from the preceding discussion of the spatial patterns in individual horizons that there is considerable variety in the vertical distribution of phosphorus within this enriched area (and, indeed, other parts of the zone), and this can be more easily appreciated through examination of the figures which summarise the vertical distribution patterns in each sub-zone (Figs. 5.189 - 5.192). In interpreting these figures, it must be pointed out that, if it is correct to identify the areas of enrichment described above and to attribute them to a single period of deposition, then the sub-zonal mean values for A and D represent a summary of values from profiles both within and outside the affected areas; however, there are at present too few samples from the enriched parts of these sub-zones to support meaningful analysis of the patterns in these areas alone.

The studies in zones B and C (see 5.4.1 and 5.4.2) have shown that several factors, both pedogenetic and metapedogenetic, can affect the vertical distribution of phosphorus in individual profiles, and in view of the complexity of land use within zone A, the author is at present unwilling to offer more than a few descriptive and speculative comments on what seem to be the more interesting and, in some cases, puzzling aspects of this data. The studies of enrichment of houses in this zone (see 5.2.2.1) suggest that, prior to outfield tillage, prehistoric inputs of phosphorus would mainly have been retained in the Ah/E and, to a lesser extent, the Oh horizon, but, as appears to have occurred in zone C, one could expect the medieval cultivations to have led to mineralisation of Po and its translocation as Pa. The substantial Pa accumulation in the B_1 horizons of sub-zone D (Fig. 5.189) could reflect this process, but in addition, the particularly high subsoil values in this area may indicate that the thoroughly mixed peat/mineral surface soil has exceptional infiltration characteristics which, over a longer period, have allowed greater leaching of phosphorus.

A very different pattern is present in fields A and B, which share a unique pattern in the vertical distribution of Po (see Fig. 5.190), and, it will be recalled, have similar, particularly low, Ah/E horizon bulk density values (Fig. 5.166). The principal differences between these fields are the generally lower Po values in field A and the substantially higher amount of Pa in the B_2 horizon of field B. The latter could reflect higher Pa translocation losses when more enriched surface horizons in field B were tilled, while the overall similarity of the soil in these fields suggests that both were subjected to similar exploitation in medieval times. It w as suggested earlier (see 4.3.1.1) that medieval tillage may have persisted rather longer in these fields than in other parts (e.g. sub-zone C) of the area with 'undisturbed' peats; both the special physical properties of the Ah/E horizon and the greater concentration of phosphorus in the surface and near-surface soils in these fields (an accumulation that appears to have been created at the expense of reduced levels of Po in the B_1 horizon - see Fig. 5.190) could reflect this more prolonged exploitation. The former could be, at least partly, a direct artifact of tillage, while the latter might have arisen later as a result of better-developed rooting systems in a soil with altered structural qualities.

These patterns are not evident in the strongly phosphorus-enriched soils of the eastern part of sub-zone E. Despite high phosphorus values in the Ah/E, the 'undisturbed' surface peat shows no sign of enrichment; as in sub-zone D, there are relatively high Pa values in the B_1 horizon, but in this area B_1 Po values are also high (see Figs. 5.189 and 5.190). This pattern could indicate some Pa movement as a result of medieval tillage, but the latter does not seem to have had the substantial effects evident in fields A and B, and may have been of shorter duration.

Most of the profiles in sub-zone C display a vertical distribution of phosphorus similar to that in the virgin land and there is no evidence here of exceptional accumulation in the surface and near-surface soils of the grazed areas. Lower values of Pa and Po in the B horizons may reflect a combination of losses due to gleying and removal of phosphorus to camp areas. In CC 2, the highly enriched corner profile, most of the extra phosphorus has been retained in the Ah/E horizon or has been transferred to the thick (20 cm including 5 cm of litter) and almost certainly virgin peat accumulation above, though some enrichment is evident in the B_1 horizon (Po) and rather more in the B_2 (Pa and Po). As noted earlier (see 5.2.2.1), two of these corner profiles share the pattern seen among enriched soils on site F, where, against the normal trend, the concentration of Po in the organic matter in the B horizon is lower than that in the Ah/E horizon (Fig. 5.192; see also Fig. 5.66). In CC 2, the pattern is in essence identical to that in most of the site F samples, which did not have exceptional LOI values. However, in CC 1, the contrary trend appears, despite relatively depressed Po concentrations in the organic matter that are the result of exceptionally high LOI values; this phenomenon also occurred on site F in samples from a putative midden area. As occurred in some of the profiles in zone B, phosphorus enrichment is accompanied, in these corner profiles, by exceptionally high accumulations of organic matter by comparison with most other profiles in the sub-zone, but these accumulations are not substantially greater than those which occur in virgin profiles with which they must properly be compared. Unfortunately, phosphorus - organic matter relationships of this type cannot usefully be pursued in zone A until further work allows a resolution of the several problems raised by the destruction of organic matter during medieval tillage and its removal by peat cutters.

The results and implications of the unfinished research in zone A will not be summarised here, but will be considered further in the next section, where general conclusions flowing from the work in all three zones are discussed.

5.4.4 Discussion and general conclusions

The investigations of soils in agricultural features in zones A, B and C had several objectives. A first objective was to obtain data capable of testing some of the propositions incorporated in the models presented in section 2.4.1, and, by so doing, gain scientific knowledge of the ancient agricultural activities in these areas and of the way in which these had affected soil properties; a second objective was to recover evidence of patterns in soil properties that could not be reliably predicted from existing information (e.g. the vertical distribution of soil phosphorus), but which might have been altered in a systematic fashion by different land use practices and, if so, could provide a 'land use indicator' that could be used during future research; a third objective was to establish whether it would be possible to adopt less time-consuming sampling and analytical strategies and still obtain a reliable picture of past land use and its effect on soil properties. None of these objectives could be achieved unless relatively weak, ancient metapedogenetic signals could be distinguished against the background noise created by pedogenetic and recent metapedogenetic processes, and an assessment of the influence of such factors may be regarded as a fourth major objective.

The relatively small-scale studies in zones B and C relied upon a justifiable assumption of uniformity in the natural factors of soil formation within the sampled areas and yielded no certain indication that such an assumption was invalid. However, major changes in vegetation are present within zone A and, since these do not appear to have been associated with any significant variation in measured soil properties, one may conclude that this potential source of noise is of negligible importance. On the other hand, this zone yielded evidence that what would normally be regarded as quite slight variations in subsoil drainage were associated with variations in the amount and distribution of soil phosphorus. In this instance, it has been argued that the noise generated by this factor has not in fact swamped metapedogenetic signals from the zone, but clearly the presently available information and analysis leaves room for argument as to the relative contribution of pedogenetic and metapedogenetic factors in the creation of some of the observed patterns, and, bearing in mind that few land surfaces of this size are likely to provide more uniform soil conditions, points to the very severe difficulties that confront large-scale enquiries into the relationship between soil properties and ancient land use. The failure to 'complete' studies in zone A is itself a testimony to the equally severe difficulties that can arise when medieval and later land use create what must in part be seen as noise in the context of investigations of earlier land use. Again, it has been suggested that, in this instance, relatively brief cultivation and 'manageable' changes due to peat cutting have not wiped clean the slate of earlier land use, nor, if more recent noise created by free-ranging sheep has been correctly identified, have the changes caused by this low density grazing created the serious problem that had been anticipated (see 2.2.4). Moreover, the recovery of information about the effects of later land use, however unhelpful in certain respects, cannot be seen in this context or any other as an unmitigated disaster! To the contrary, the evidence that tillage in a medieval outfield failed to create measureable changes in the amount of soil phosphorus usefully confirms historical accounts of such practices.

More positively, these potential difficulties have not in fact thwarted the principal objective of these investigations. Anomalous spatial patterns of soil phosphorus of the type precisely predicted by the models based on modern studies of animal redistribution of soil nutrients have been identified in both zone B and zone A. The latter case, in particular, highlights the need and so vindicates the decision to put considerable effort into this aspect of the research prior to the analysis of samples; without a model to guide one, it would have been difficult to arrive at the conclusion that the pattern of soil phosphorus in the large prehistoric field in zone A was entirely consistent with its use as a sheep pasture. The absence of any other phosphorus anomalies (positive or negative) concordant with the pattern of prehistoric land division in zone A, and the presence of a pattern of phosphorus enrichment which seems to indicate haphazard disposal of rubbish and ex. reta rather than systematic placement within fields, are also important; both of these features tend to refute the notion that, in particular, the small fields beside the house on site F were used as 'infields' in which intensive cropping was accompanied by systematic and heavy manuring. However, in this case too, the review of soil nutrient changes in arable land guides one to the limits of inference that can be sustained by this evidence; it certainly cannot be excluded that some rubbish and excreta was deliberately and carefully spread on these fields and that the extra phosphorus in such manures was removed during subsequent cropping.

The inferences about land use that can be derived from the studies in zones B and C seem to be largely unremarkable, but it is worth noting the suggestion that the level of enrichment in the droveway implies that this feature must have enjoyed a far longer period of use than the outfield enclosures through which it passes; more important, the conclusion that manuring may be responsible for the phosphorus enrichment evident in the Western field of the North Lobe is not trivial, since very little is known about the agricultural practices within medieval sub-divided arable fields on the moorland margins. However, the main lesson that emerges from these studies is a methodological one; namely the demonstration that to obtain reliable information about these changes, even within small areas of land, where potential sources of noise can be held to a minimum, it is necessary, at least in the first instance, to undertake very detailed, careful and laborious analyses of entire soil profiles. In some cases it may then be possible to propose less time-consuming procedures; the pattern of phosphorus in the surface soil of the North Lobe may be capable of revealing whether folding of livestock or applications of FYM are the more likely source of phosphorus enrichment, but sampling of this horizon alone could not demonstrate conclusively that such enrichment had occurred. Nor would samples drawn from a single horizon in the droveway have yielded an accurate picture of the pattern of phosphorus deposition; this study demonstrated that the vertical distribution of phosphorus can vary substantially over very short distances even among profiles whose field appearance reveals negligible differences.

These observations also undermine any simple or straightforward use of the vertical distribution patterns as 'land use indicators'; the pattern in any one or two profiles cannot even be presumed to provide a clear indication of the general pattern in any particular type of soil. On the other hand, as the studies in all three zones have shown, investigation of these patterns and, in particular, the often discordant vertical distributions of the inorganic and organic phosphorus fractions can provide essential information; many of the land use interpretations offered here rely inter alia, on patterns revealed by such data.

The variety in the vertical distribution of phosphorus clearly provides a serious obstacle to the development of simplified sampling strategies which could reduce the workload during future research. However, multi-period land use in the study area may well have created greater difficulties than would be encountered in areas subjected to a single farming episode. Initially, it was hoped that analysis of samples from the Ah/E horizon alone might be capable of yielding a clear, if approximate, picture of phosphorus deficiencies and enrichment in the soil as a whole, and the preservation of coherent patterns of anomalously high phosphorus concentrations in the Ah/E horizon in and around both the prehistoric houses investigated in zone A gave some support to this view. In contrast, scattergrams (Fig. 5.193 and 5.194) illustrating the relationship between the concentration of Pao in the Ah/E horizon and that in entire soil profiles in zone A reveal no clear correlation of these values; only the most highly enriched or deficient profiles could have been correctly characterised by analysis of their Ah/E samples alone. However, it can be argued that the poor correlations evident here principally stem from the distortions created by later land use and that where these are absent (as in the prehistoric houses), there could be a much better concordance of such values. If this can be demonstrated, much less time-consuming sampling and analytical programs could be adopted and investigation of the spatial patterns of soil phosphorus in a much larger sample of the prehistoric fields of Dartmoor would become a practical proposition; judging from the results of the investigations of enclosures on Holne Moor, this could reveal much about the pattern of land use in these ancient fields.

6. PEDOGENESIS, METAPEDOGENESIS AND ARCHAEOLOGY

This short chapter provides a summary of some of the principal conclusions arising from the research reported in earlier chapters, briefly discusses their wider implications, and suggests directions for future research.

At the outset of these enquiries, surveys designed to uncover the full extent and pattern of the well-preserved system of prehistoric land enclosure on Dartmoor were being pursued with great vigour, but in common with similar work elsewhere in Britain had yielded little unambiguous evidence about the purposes of these land enclosures, a lacuna that provided the mainspring for the research reported in this thesis. A critical evaluation of earlier, archaeological investigations revealed that past and current procedures for assessing ancient land use in abandoned field systems provided, at best, some limited information about cultivation; none of the current techniques provided clear evidence of pastoral land use, a limitation which it was felt might be of peculiar importance to studies of ancient land use in upland field systems like those on Dartmoor. It was also evident that although there had been few, scientifically rigorous studies of the soils in ancient settlements and fields there were indications that soil analysis could provide important new information about past land use, but that, to be successful, such studies would need to include assessment of the products of natural soil development and of the way in which more recent and contemporary land use in old enclosures might have altered their soil properties, and should start with explicit models of the interaction of soils and agricultural land use based upon contemporary observations; the failure to adopt a methodology embracing all these aspects was identified as a major weakness that had undermined the utility of most previous research. It is hoped that the results of the studies reported here have demonstrated the value of adhering to these maxims.

A number of important conclusions emerged from scrutiny of pedological research. It w as found that although the vast influence on soil properties of intensive agricultural land use is accepted as a commonplace by soil and agricultural scientists there have been few studies of the 'human factor' in soil formation and no overall integration of the widespread data that documents the changes in soils that accompany arable and pastoral land use. Moreover, it was found that, as is frequently the case when archaeologists adopt the methods or try to benefit from the results of research in another discipline, matters of crucial archaeological importance had received little attention. The small amount of information available about the lateral distribution of soil phosphorus and of the way in which variation in other soil properties may affect its distribution provides one striking example; the absence of research into the development of soils on the granite plateaux of south-western Britain, despite recognition of the potential value of these areas as a testing ground for basic pedological studies, provides another. Information about the distribution of soil nutrients in pastoral enclosures is also not abundant, but in this case it did prove possible to make tentative identifications of patterns of nutrient redistribution associated with particular species of livestock and to summarise this information in formal models that allowed predictions; although further, quantitative information about these patterns and the behaviour that creates them would certainly improve the precision and reliability of these models, they represent, even in their present form, an important step forward in the establishment of a scientific approach to assessment of land use in abandoned enclosures. Perhaps inevitably, but certainly ironically, the redistribution of nutrients during recent and contemporary grazing was also identified as one of the more important factors that must be taken into account when offering explanations for the present pattern of soil properties in rough-grazed moorland pastures.

It proved far more difficult to offer any firm predictions about the way in which arable land use might have affected the amount and distribution of soil phosphorus, but even this has important implications. Some prehistorians have recognised the questionable reliability of the evidence presently taken to indicate the practice of manuring within prehistoric fields and, in this regard, have pointed to the desirability of soil analyses (e.g. Megaw et al 1961, Bradley 1978b:41). However, although the latter are certainly capable of demonstrating phosphorus enrichment of land that may be the result of manuring, examination of the results of modern farming experiments revealed that even regular applications of manures during cropping need not necessarily leave significant phosphorus residues, and it was concluded that their presence would constitute a strong indication that some form of 'infield' strategy had been in use. It was also pointed out that regular cropping without manures might result in a detectable reduction of soil phosphorus and that, in general, there was a greater likelihood of nett losses of phosphorus from arable land than pastoral land.

Alterations to the surface horizons of stagnopodzols during historical cultivations proved easier to predict. Models based initially on Conry's (1970) studies of Irish moorland reclamation and other evidence for the changes in soil organic matter that accompany land abandonment were later modified to take account of the field evidence recovered by the author, and in this final form offered coherent and economic explanations for the pattern of variation in surface soil properties within a study area on Holne Moor.

It was found that very detailed information about the medieval farming on Holne Moor had been incorporated in its surface soils, and furthermore that a substantial amount of this information could be recovered from field survey alone. Identification of the soil artifacts created by specific metapedogenetic processes - brief outfield tillage, more long-lived arable exploitation, intensive pastoral land use - benefited greatly from the knowledge provided by intensive survey of other forms of archaeological evidence - lynchets, boundary forms and relationships - and clearly it is in this context that field studies of soils can sustain the most powerful inferences about past land use. However, only the soil evidence was capable of revealing the areal extent of outfield cropping and that two or more cropping episodes in which different techniques of land preparation may have been employed had taken place. Moreover, the pattern of pedogenetic reversion of the soils in the major medieval enclosures, the Lobes, provided important, independent evidence for a sequence of land abandonment which it would have been difficult to insist upon from the evidence provided by more traditional techniques of archaeological field survey.

Some of the wider implications of the study of medieval enclosure and land use on Holne Moor have been presented elsewhere (Fleming and Ralph: in press) and will not be repeated here, but some of the methodological aspects of this work do deserve consideration. One of the more basic lessons that can be learned from this study is the need to adopt techniques of soil survey relevant to the purposes of enquiry. Standard soil survey procedures and soil classification within the presently recognised Soil Series, which have been designed to meet the needs of modern farmers, soil scientists and planners, would have revealed little of the detailed pattern of soil variation on Holne Moor that has proved crucial for land use interpretation; much information about the husbandry and economic history of rural areas and in particular upland, marginal lands can be recovered from the soil, but this requires high density survey and large scale collection of quantitative information about surface soil properties. Neither technique was employed during the recent archaeological and environmental survey of Shaugh Moor on the south-western edge of Dartmoor (Smith et al 1981) and, in consequence, it is not surprising that this survey failed to uncover any clear evidence that soil properties had been modified by medieval and post-medieval land use or that the surveyors reached the questionable conclusion that in general the pattern of soils solely reflected pedogenetic processes.

The conclusions of another recent archaeological study of Dartmoor soils also deserve reconsideration in the light of the evidence from Holne Moor; Price and Tinsley (1976) addressed the vexed problem of the function of Dartmoor's prehistoric 'pound' enclosures by examining a stagnopodzol soil in a small prehistoric enclosure on Wigford Down and a brown podzolic soil inside a pound at Trowlesworthy Warren. They found lynchetting that post-dated the construction of part of the latter, multiphase enclosure, but attributed its distinctive soil to rabbit disturbance although no bury was found within the pound. It may be more economical to conclude that, as in the North Lobe on Holne Moor, the distinctive soil and the lynchets testify, each in their own way, to cultivations within the pound during historic times.

A more far-reaching implication of the Holne Moor studies arises from the clear evidence they have provided that surface soil characteristics on Dartmoor, and in particular its fringes, may largely reflect the intervention of historic and modern farmers. Although soils on the lowest flanks, particularly on the drier eastern side of the Moor, might in any case have developed as brown podzolic or even brown earth soils rather than stagnopodzols (a possibility that could be investigated by a research program similar in techniques and design to that of Conry et al (1972), it is clear that in many areas brown podzolic soils may be primarily an artifact of cultivation. Consequently, correlation of prehistoric settlements with these soils, in some areas, may indicate, not that prehistoric communities chose to farm in places with soils especially suited to cultivation (pace Simmons 1969: 209), but that medieval and modern farmers chose the same locations. Fox (1954a: 89-90) provides evidence that this is often the case on Dartmoor, and it may well apply on the fringes of other parts of upland Britain.

As expected, the pattern of surface soil variation on Holne Moor gave no reason to suppose that prehistoric land use had left a legacy similar in character to that provided by medieval farmers, nor could the information gained during field survey alone provide a history of the changes in soil character that might have occurred since prehistoric times. However, detailed studies of palaeosols have provided information about early soil development, and knowledge of both prehistoric and medieval farming practices has been uncovered during quantitative studies of soil phosphorus and organic matter; these studies also informed on the efficacy and reliability of sampling and analytical procedures.

Despite severe problems of interpretation caused by massive post-burial alteration of the prehistoric palaeosol, the studies of buried soils on Holne Moor have provided support for Clayden and Manley's (1964) model of stagnopodzol soil development on Dartmoor; there is little doubt that the near surface iron-pan in the soils of Holne Moor must mainly have developed during medieval and post-medieval times, and there is no reason to think that the process of pan formation has now ceased. The accumulation of a surface peat started much earlier, certainly prior to AD 1000; a date of ca. 700 BC has been suggested, but, although highly plausible, this estimate is derived from calculations which incorporate several unproven assumptions. What is certain is that much of the peat on Holne Moor has accumulated during historic times. These major and readily observable changes in soil character appear to have been accompanied by important changes in soil phosphorus of the type predicted by Floate's (1962) model of long-term phosphorus dynamics in moorland soils. Although, until further research provides confirmation or refutation, processes inferred from studies of a single palaeosol must be regarded with some scepticism, comparison of the fractional composition of phosphorus in the medieval palaeosol and contemporary soils has provided evidence that the acid-insoluble inorganic phosphorus fraction may have started to increase prior to the burial of the medieval soil (and thus, perhaps, at a time not far removed from the period when peat started to accumulate on these soils). There is also evidence that the surface soil buried in medieval times possessed a higher concentration of organic and acid-soluble inorganic phosphorus than the modern soils, implying a decline in fertility that could well be linked to the shift in fractional composition. It has therefore been possible to conclude that, although many of the difficulties which would face a modern farmer on Holne Moor - stoniness, acidity, low base-status - were certainly or probably present well before prehistoric farmers settled the plateau, the problems presented by iron-pans, substantial accumulations of peat and very low levels of plant-available phosphorus may mainly have arisen and have certainly worsened since early medieval times. It is also hard and perhaps even perverse to avoid the conclusion that changes in the climatic factor affecting the soil-organism ecosystem are primarily responsible for these soil changes; the onset of peat accumulation may well have occurred during the climatic deterioration of the first millennium bc and a substantial further growth of peat must have occurred during the Little Ice Age of late and post-medieval times.

The palaeosol studies also confirmed that simple descriptions of present-day features of buried soil horizons cannot be relied on as sources of evidence for the nature of earlier soil development, that relict features must be distinguished from pedometamorphic ones and that examination of changes within overburdens can provide a key to the identification of relict features; these investigations cast doubt on the reliability of the conclusions reached during other, recent studies of buried soils on Dartmoor (e.g. Macphail 1981).

Many other cautionary tales have been derived from the results of the other, contributory studies on Holne Moor but these will not be repeated here. These investigations of the distribution of phosphorus and organic matter in the soils of prehistoric houses, a monument and modern fields were undertaken to fill the serious gap in knowledge created by the absence of any previous studies of phosphorus in Dartmoor soils; they obtained their place in this thesis, not principally because they supplied, inter alia, some information about the way in which the prehistoric inhabitants of Holne Moor disposed of their rubbish, their excreta and their dead, but because they provided information about the way in which ancient and modern metapedogenetic processes affect soil phosphorus, and so allowed sensible interpretation of the patterns found in the ancient, agricultural enclosures on Holne Moor. This in itself points to the indispensable role of small scale studies of soils, which one can safely assume have been affected by metapedogenetic processes of known character and age, as precursors to the more difficult task of analysing the information provided by studies of larger, lower density samples of the soils in abandoned fields.

The latter were themselves always envisaged as preliminary studies that would allow a proper judgement to be made about the utility of soil analysis for investigating ancient land use; in this they have been successful. A 15-20% mean increase in the amount of soil phosphorus has been detected within a medieval droveway that is unlikely to have been in use for more than about two hundred years, and a much larger increase (ca. 60%) was evident in the soil from a putative sheep camp in the corner of a large, prehistoric field which was probably in use for ca. 350 years, and in which, in the field as a whole, there was a spatial distribution of soil phosphorus conforming to the pattern predicted by a model based on observations of nutrient redistribution in modern sheep enclosures. The magnitudes of the estimated rates of faecal phosphorus deposition in the droveway and the sheep camp were not in conflict with the (few) available estimates of transfer and deposition rates in contemporary sheep pastures and it has been concluded that the deposition of animal excreta in ancient, abandoned fields and droveways can be predicted and detected using the techniques developed here, and so can provide a means of assessing pastoral land use in old field systems. If more and better information about contemporary rates of transfer and input were available, the soil changes could be used to provide estimates of the longevity of such land use; alternatively, if the latter was known, it might eventually be possible to estimate grazing densities in ancient pastures.

It has also proved possible to detect an increase in the amount of phosphorus in the soils of a medieval sub-divided arable field that may have been in use for ca. 450 years; in this case, the relatively small phosphorus residue (the level of enrichment is similar to that in the medieval droveway) provides a useful indication of the limited nett changes in soil phosphorus that may occur in arable land even after long periods of intensive tillage. The possibility of a balance between crop removal and manurial addition of phosphorus has been suggested as one possible explanation for the absence of clear phosphorus anomalies, positive or negative, concordant with the boundaries of two small, prehistoric fields in which stone clearance has been taken to indicate tillage. However, much more work will be required before the pattern of phosphorus redistribution within the prehistoric landscape of Holne Moor can be clearly understood.

It would be worthwhile to extend the research on Holne Moor in several ways. The now well-documented medieval landscape of the study area provides innumerable further opportunities. More extensive, quantitative assessment of the pattern of variation in the organic matter content of the surface soils could be used to refine and test the validity of the present units of classification and their distribution, and so verify, refute or modify the land use interpretation offered here; it would unquestionably provide further, quantitative information about soil organic matter dynamics and the way in which they have been modified by medieval land use, and this could be linked with information gained by additional, detailed studies of the many soils buried in medieval and post-medieval times. Further, small scale studies akin to that undertaken in the North Lobe would also be valuable; in particular, the anomalous properties of the soil in the small, apparently pastoral enclosures, the Close and the Lower South Field, deserve quantitative physical and chemical evaluation.

It would also be useful to undertake further investigations of the prehistoric landscape <u>within</u> the study area before moving into zones unaffected by medieval land use. High density sampling of the field corner anomalies presently interpreted as sheep camps could reveal whether or not these anomalies exhibit the sharp fall-off in values that has been predicted, and so test the interpretation that has been offered. Further analyses are also needed both to allow a resolution of the interpretative problems created by medieval tillage and to define more closely the pattern of phosphorus deposition adjacent to prehistoric houses; if it should prove that, aside from the anomalies created by pastoral land use, the only detectable, positive phosphorus anomalies in the prehistoric landscape occur as zones of enrichment close to the houses, then comparison of the enrichment in such zones might at least provide a useful means of assessing the length of occupation of individual houses. However, this, and large scale study of the patterns within the prehistoric enclosures will only become a practical proposition if further research can confirm that variation in the amount of soil phosphorus in the upper mineral soil of land unaffected by later tillage is in general consonant with that in entire soil profiles. For a prehistorian, this must be the priority in future research, since it would provide a realistic means of assessing the large scale pattern of land use within the parallel reave systems and, thus, reveal much about the economy of the reave builders.

Although one can identify many fruitful ways of extending the work on Dartmoor, further application of the methods of soil analysis pioneered on Holne Moor need not, of course, be restricted to the Dartmoor soils. There is little doubt that, with suitable testing and, perhaps, modification, both the techniques of field survey and of soil phosphorus analysis could be successfully employed to study the pattern of medieval and prehistoric land use in many other parts of the moorland and mountain zones of Britain.