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THE NATURE, ORIGIN AND DISTRIBUTION OF QUATERNARY BRICKEARTH AND ASSOCIATED SOILS IN SOUTH HAMPSHIRE

PAUL JOSEPH REYNOLDS

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ABSTRACT

This thesis aims to clarify the distribution, characteristics and age of the superficial brickearth deposits located in and around the New Forest. Following introductory chapters which review the literature relevant to the local geology, brickearths and loess, the main part of the thesis describes the field characteristics, texture, mineralogical composition and micromorphology of the sediments and soils examined mainly at 16 selected sites.

These analyses show that the brickearth is divisible into upper and lower members. The upper brickearth is the younger and more extensive and is dated by thermoluminescence as Late Devensian. Its occurrence on all terrace levels suggests it is aeolian and its mineralogical composition and texture indicate it is composed of far-travelled material (mainly silt) mixed with local material (mainly fine sand) derived from Tertiary strata. The proportion of sand decreases upwards in many profiles so that the base of the sediment resembles aeolian sand and the top resembles loess. This probably occurred because local sources of sand were progressively reduced as they were blanketed by the far travelled loess. Because of erosion, the full thickness of the deposit is preserved only rarely. Studies of colluvium, including palynological work, show that some of this erosion occurred during the Flandrian, probably as a result of agricultural activity since the Late

Bronze Age/early Iron Age or earlier.

The lower brickearth is more variable and includes sediments thought to be loess, aeolian sands and estuarine clays. The common factor among these sediments is the presence of a paleoargillic soil horizon indicative of pre-Devensian soil formation. At most sites studied the lower brickearth contains micromorphological evidence of only one period of interglacial soil formation which suggests the sediments are no older than the Wolstonian. However, elsewhere, at least two phases of interglacial pedogenesis are evident which shows that some of the sediments are at least of Hoxnian age. These dates for the lower brickearth have been used to infer minimum ages for some of the terrace surfaces.

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CHAPTER 1

INTRODUCTION

1.1. Outline of the Problem

One of the major contributions to Quaternary studies from the work of the Soil Survey of England and Wales has been the recognition that over much of southern England soil profiles are developed partly or wholly in a thin veneer of loess. This recognition has been achieved through detailed field and petrographic studies, building on earlier mapping by geological surveys of brickearth - an omnibus term for loamy superficial deposits.

In south Hampshire, brickearths were mapped by the Geological Survey (later the Institute of Geological Sciences) at a few localities mainly bordering Southampton Water, in the Test valley and at Barton-on-Sea. However, in a soil survey of an area east of Southampton Water, Kay (1939) noted that the brickearth was much more extensive than indicated on the geological maps. Subsequently, brickearths have been described at a number of new localities by researchers working mainly in the New Forest district, and various processes, both aeolian and non-aeolian have been invoked to account for their formation. In a survey of the Pleistocene gravel terraces of the area, Everard (1952, 1954) found brickearth up to 1.5m thick mantling the gravel. He suggested that it could be a decalcified head (gelifluction deposit) reworked partly by fluvial and partly by aeolian processes during several Quaternary stages. Lewin (1966 a,b) described deposits lying on the gravel terraces and in the bottoms of valleys incised into the terraces. In common with White (1917), he concluded that they were floodloams, using as evidence their particle size distribution and geomorphological position, but suggested that they may contain windblown material. Swanson (1968) agreed with this suggestion for most of the brickearths he found in the New Forest and around Southampton, but thought that at three sites there were weathered loesses. Fisher (1971), Tuckfield (1974) and Keen (1980) also agreed that the brickearths are floodloams containing some loess, and showed that they most commonly occur in the southern New Forest. Keen followed White (1917) in suggesting that these floodloams are little younger than the terraced gravels on which they lie, and are therefore of several ages. Fisher (1975) showed that the surface horizons of some brickearth soils, on all terrace levels appeared to be enriched with coarse silt and fine sand particles, which he interpreted as a late Pleistocene aeolian addition, post-dating the brickearths.

From this brief summary of previous work (dealt with more fully in Chapter 2), it can be seen that although the brickearths of South Hampshire are likely to be partly composed of loess, they also seem to be partly non-loessic, and there may be loessic and non-loessic brickearths of different ages. Therefore in studying them, the opportunity exists to contribute both to the knowledge of British loess stratigraphy and distribution, and to a general understanding of Quaternary events in the Hampshire Basin. This latter aspect is particularly important because knowledge of the Quaternary history of south-Hampshire is poor compared with, for example, the Thames Valley. This is partly because little work has been done on the superficial deposits, and partly because there are few dateable organic remains. However, Chartres (1980) has shown that where an absolute chronology cannot be established by conventional dating methods, pedological and petrographic studies of superficial deposits of different ages provide a useful means of establishing a sequence of Quaternary events.

Previous work on the south-Hampshire brickearths largely ignored detailed petrographic and field techniques which are now regarded as essential for comparison of pedological and lithological features of Quaternary superficial deposits from different areas (Catt, 1979 a) These comparisons allow the correlation of soils of similar characteristics and age so that a stratigraphic framework can be constructed. This has already been partly achieved mainly through the study of Flandrian soil profiles and pre-Devensian paleo-argillic horizons (Avery, 1980) developed on and buried beneath tills (Rose et al., 1976, 1978; Rose and Allen 1977; Sturdy et al., 1979) and lying on Quaternary river terraces (Chartres, 1980). The mineralogical characteristics of loess deposits of different ages can also be used to elucidate Quaternary stratigraphy (Rose and Allen, 1977; Avery et al., 1982).

1.2 Objectives.

It was the intention of the present study to map and explain the distribution of the south-Hampshire brickearth and associated soils, to assess the extent to which they are composed of Late Devensian and older loesses, to re-assess previous theories of their formation and to suggest subdivisions of the deposits based on composition, chronology and mode of deposition. New data have been obtained by detailed field mapping and description, and by laboratory studies of the deposits mainly using particle size, mineralogical and micromorphological analyses. The techniques used are those already established by recent work elsewhere in Britain, so it is hoped that the maximum comparability of results will be obtained.

1.3 The Study Area

The study area is that part of south-Hampshire bordering the Solent (excluding the Isle of Wight) lying approximately between Highcliffe (SZ215931) in the west and Solent Breezes (SU502040) in the east. The northern boundary extends to the Tertiary escarpment of the New Forest running from Minstead (SU280110) to North Charford (SU198196) so that the New Forest occupies most of the area. Fig 1.1 shows the area.

1.4 Quaternary Correlation

In this thesis the subdivision of the British Quaternary proposed by Mitchell et al., (1973) will be used (table 1.1). Whenever possible, discussion of material by authors using other systems will be converted to this system.

1.5 Solid Geology

The study area lies within the Hampshire Basin, a broad east-west trending asymmetrical syncline formed by the Alpine earth movements culminating in mid-Tertiary times (Chatwin 1960). The Chalk forms the floor of the Basin and was partly eroded during the early Tertiary before being covered by Palaeocene, Eocene and Oligocene strata. These Cretaceous and Tertiary rocks are the most likely local sources of material for the superficial deposits. The nearest Chalk outcrops are now on the Isle of Wight, but chalk originally formed a continuous ridge to the mainland via the Wight-Purbeck monocline which was probably breached by rising sea-levels during the Flandrian period (Everard, 1954). To the east of the study area the Chalk is exposed on the Portsdown anticline, and to the north along the rim of the Hampshire Basin. These outcrops are the original source of the flints which are the dominant constituent of the local Pleistocene terrace gravels (Keen, 1980).

The Tertiary strata, particularly Eocene and Oligocene beds, form the major solid outcrops in the study area, and total 487m thick in Whitecliff Bay, Isle of Wight, where about 90m of strata have already been eroded (Wright & Curry, 1958; Rayner, 1967). They were deposited in several cycles of marine-continental-marine sedimentation

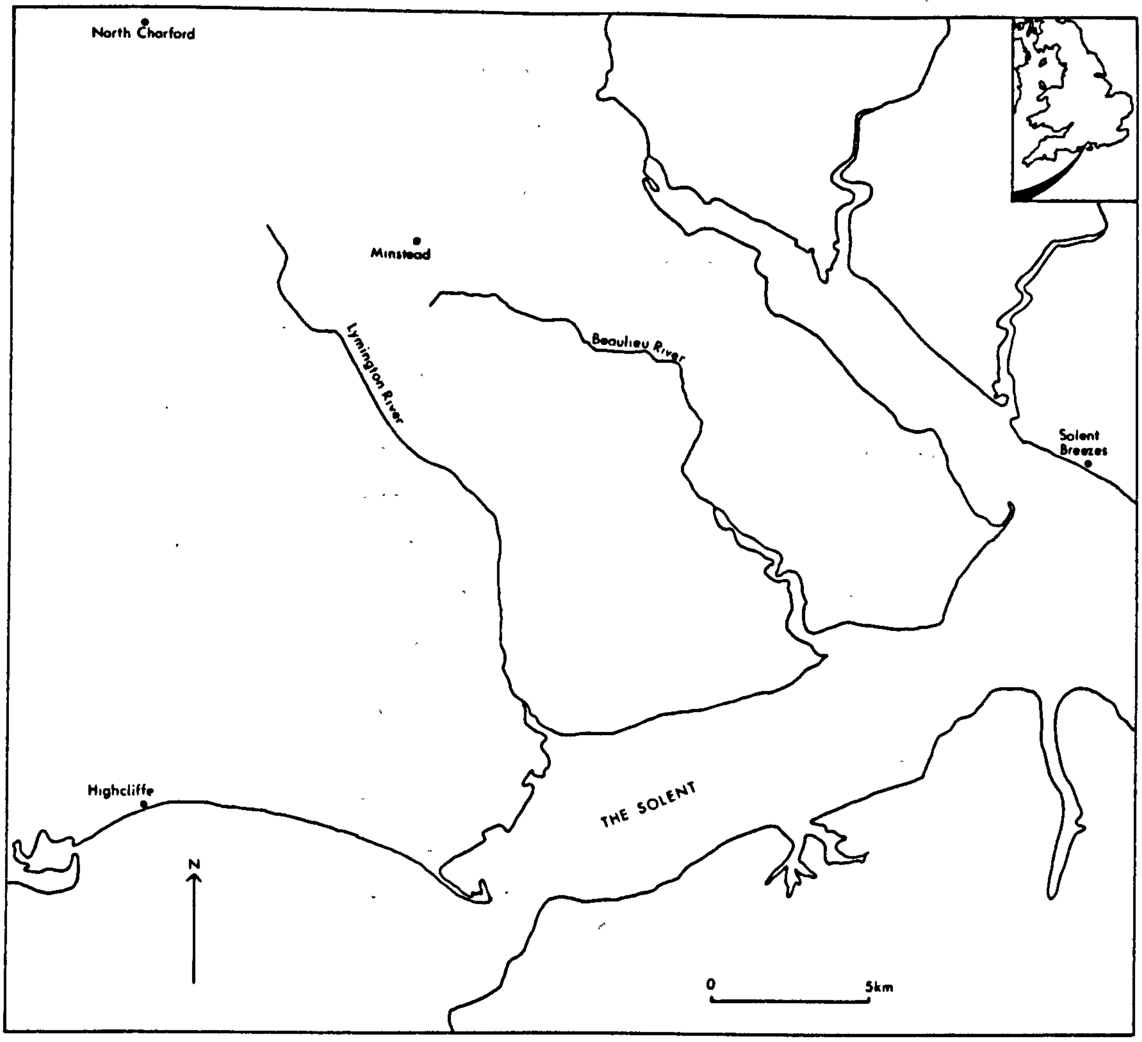

Fig. 1.1 The study area

ERA		STAGE	DATING (years b.p.)		CLIMATE
Holocene		Flandrian	after	10,000	temperate
			late -	26,000 to 10,000	cold
		Devensian	middle -	50,000 to 26,000	cold
			early -	before 50,000	cold
	upper	Ipswichian		128,000	temperate
		Wolstonian		200,000?	cold
		Hoxnian			temperate
		Anglian			cold
Pleistocene	middle	Cromerian			temperate
		Beestonian			cold
		Pastonian			temperate
		Baventian			cold
		Antian			temperate
	lower	Thurnian			cool
		Ludhamian			temperate
		pre-Ludhamian		2,000,000 approx.	cool
		Pliocene			

Table 1.1 British Quaternary Stages (from Mitchell et al., 1973, with additions from West, 1977 and Catt, 1979a)

due to intermittent invasions of the sea from the east over an area of low lying coastal swamps and lagoons (Stamp, 1921). As a result, marine, estuarine, fluviatile and lacustrine sands, silts and clays are present, with the sandier fluviatile beds being more prevalent towards the west of the Basin (Table 1.2). Over most of the study area the Tertiary rocks dip gently towards the south east at a slightly greater angle than the land surface so that successively younger rocks outcrop in that direction. Thus in the north-west the oldest outcropping beds are the largely fluviatile Bagshot Sands and the predominately marine sands and sandy clays of the Bracklesham Beds. These are followed by the sands, sandy clays and clays of the Barton Beds which are marine and fluviatile in origin. The Barton Sands have the most extensive outcrop in the area not mantled by Pleistocene gravels, and occupy a broad piece of land in the central New Forest from Cranes Moor through Lyndhurst to Dibden Purlieu. Further south, Headon beds outcrop between Beaulieu Heath and the coastal fringe of the New Forest, but are largely covered by up to 6m of gravels and brickearth. These beds are mainly fluviatile fine sands and silty sands, with the Middle Headon Beds being more clay-rich, marine sediments (Reid,1902 a; White 1915, 1917; Chatwin, 1960; Hodson, 1964).

1.6 Quaternary Geology and Geomorphology

The land surface of the study area descends from 127.4m at Bramshaw Telegraph on the northern Tertiary escarpment in a south easterly direction towards the Solent and Southampton Water. Over much of this area the Tertiaries are mantled by Plateau Gravel and the much smaller spreads of Valley Gravel in the valleys of the major streams such as the Lymington River. This division of the gravels is based solely on geomorphological position as they are similar in composition (Chatwin, 1960). The Plateau Gravels are arranged in a series of terraces which are moderately dissected below

Table 1.2 The Lower Tertiary (Palaeogene) Succession in the Hampshire Basin (From Rayner, 1967)

OLIGOCENE	Upper Hamstead Beds Lower Hamstead Beds Bembridge and Osborne Beds Upper and Middle Headon Beds
EOCENE	Lower Headon Beds Barton Beds Upper Bracklesham Beds Lower Bracklesham Beds London Clay
PALAEOCENE	Reading Beds
CRETACEOUS	Upper Chalk

40m, but are present only as a few isolated eroded remnants above that height. Keen (1980) examined the composition of the gravels at 24 sites below 40m and showed that they are composed predominately of flint (64.2% - 95.4%) with some quartz (0.8% - 27.2%) and lesser amounts of greensand chert and other far-travelled pebbles. Fisher (1975) showed that there is little variation in flint roundness between gravel samples from all terrace levels, and that the gravels are composed mainly of subangular flints in a coarse sandy matrix. The gravels also contain water-worn sarsens up to 2m long, and sometimes have incorporated into their base mud clasts and silt blocks derived from the underlying Tertiary beds (Keen, 1980).

Three depositional environments have been proposed for the formation of the gravels: fluvioglacial, fluvial and marine. A fluvioglacial origin for the high-level Plateau Gravels was first proposed by Burkitt(1931) and later restated in a model of the glaciation of Salisbury Plain (Kellaway, 1971) and the English Channel (Kellaway et al., 1975). These authors have suggested that the gravels date from the Anglian glaciation (Kellaway, 1971) or earlier (Kellaway et al., 1973), and that they are fluvioglacial outwash composed of material derived from the Clay-with-flints (a superficial deposit on the Chalk of Salisbury Plain) and local Mesozoic and Tertiary rocks. Kellaway et al., (1975) discounted marine or fluvial origins for the gravels on the basis that these agencies could not have moved such vast quantities of materials and that there was no evidence in southern England for high base-levels in the early Pleistocene.

Against this hypothesis, Kidson and Bowen (1976) have demonstrated that all the evidence used by Kellaway and co-workers to suggest a former glaciation of southern England and the English Channel can be interpreted far more convincingly in other ways that satisfy conventional notions of the Quaternary history of this area.

More specifically, Green (1973) has shown for the gravels of the Hampshire Avon and Fisher (1975) and Keen (1980) for the Plateau Gravels, that they contain no exotic pebbles from outside the Hampshire Basin, as would be expected if they had been derived from ice which originated from south Wales and Cornwall.

In a detailed field study of the form and distribution of the terraces Everard (1954) recognised levels at approximately * 128, 119, 113, 92, 70, 56, 50, 46, 31, 21, 11 and 5m O.D. as well as submerged terraces at - 9m and -18m below Southampton Water. Following Green (1946) and Bury (1923), he ascribed a marine origin to the three highest terraces, despite acknowledging that the gravels forming them have a non-marine, coarse, subangular appearance. He did this largely because White (1921) described beach cobbles at a similar level on the Isle of Wight, and because Sparks (1949a) mapped a 131m marine platform on the South Downs, although the authenticity of Sparks' platform has since been questioned (Hodgson et al., 1974). Kubala (1980) has recently reassigned the high level gravels to terraces of an ancestor of the River Avon, based on the observed geomorphological continuity of the terraces with known river terraces at lower levels (Sealy, 1955).

The poorly represented 92m terrace was regarded by Everard as the oldest fluviatile stage, because its longitudinal gradient is typical of fluviatile terraces. He felt it may have been partly formed by the 'Solent River' (Darwin Fox, 1862; Reid, 1902a), a hypothetical eastward-flowing trunk stream (a continuation of the Dorset Frome), which is alleged to have drained the area at times of low sea-levels during the Pleistocene prior to the breaching of the Wight-Purbeck ridge. Recently, Cornwell (1980) mapped the sub-gravel surface on

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*The Imperial units of Everard have been converted to the metric and rounded this terrace by geophysical methods in an attempt to locate obscured inter-terrace bluffs which were suspected after boreholes showed the gravel varies in thickness between 3.2 and 5.1m. No clear evidence for further subdivision of the terrace was found. The 70m, 56m, and 50m terraces also display west-east longitudinal gradients, and Everard suggested that the Solent River became well established at this time and was responsible for their formation.

The low terraces between 46m and 5 m are remarkable for their longitudinal horizontality across the full width of the study area. Everard therefore concluded that they were marine, despite his feeling that the gravels were (p.50) 'typically fluviatile in appearance'. He reconciled this by suggesting that the gravels were originally river deposited, possibly at the 92m and 70m stages, and were later eroded and redeposited by the sea in a sheltered **estuarine** environment, which did little to alter their character.

The submerged terraces at - 9m and - 18m in Southampton Water show the longitudinal slope of fluviatile terraces. Everard supposed that the Test formed these benches and was a tributary of the re-established Solent River. This theory has been upheld by Dyer (1975), who used seismic profiling to show that several submerged terraces occur in the Solent and can be tentatively correlated with those in Southampton Water. Dyer's **thalweg** of the Solent River at this stage shows that it was graded to a sea-level at least 46m below O.D.

Keen re-examined the evidence for the depositional environment of the gravel terraces between 40m and present sea-level, originally mapped as fluviatile by Green (1946) and as marine by Everard. Against Everard's five terraces between 40m and O.D., Green recognised four; Boyn Hill, Upper Taplow and First and Second Lower Taplow, based on altimetric and archeological correlations with the well-established Thames terrace sequence. Keen (1975) resolved these into three stages, his 'high', 'middle' and 'low' terraces based on field recognition of the most significant breaks of slope. He later (1980) argued against a marine origin for the three terraces principally on the basis that there would have been insufficient fetch in the Solent prior to the breaching of the Wight-Purbeck ridge to produce waves able to cut benches up to 4km wide. However, this proposal ignores evidence that ice-riving on shorelines during Pleistocene cold periods has cut wide marine benches in hard rock in sheltered areas of low fetch such as north-east Skye, Scotland (Sissons, 1981). Keen also felt that the fact that the sole known Pleistocene organic deposit in area, at Stone Point (Brown et al., 1975), provides evidence only of brackish conditions, supports a non-marine hypothesis for the origin of the terraces. However, this deposit is interglacial, not associated with terrace aggradation. Keen proposed a fluvial origin because current bedding structures in all three terraces suggest a broadly eastward flowing stream, because the presence ofchannels up to 6m deep in the gravel base indicate a fluvial regime, and because the gravels of all three terraces are mantled with brickearth which he interpreted as a floodloam deposited fluvially with the gravels.

1.7 Age of Terraces

The age of the South-Hampshire Plateau Gravels is largely conjectural because only one dateable organic deposit has so far been found, at Stone Point (Brown et al., 1975) However, their age is an important consideration in the study of the brickearths if the latter are associated with terrace aggradation. In general, coarse fluviatile flint gravels are regarded as the products of erosion and deposition during Pleistocene cold periods in southern England (Briggs and Gilbertson, 1980), because only then were discharges great enough to move this calibre of material. Similarly, the cutting of broad marine platforms by ice-riving (Sissons, 1981) may also have been exclusively a periglacial phenomenon. However, such terraces are often erroneously attributed to interglacials because dateable organic and archeological deposits associated with them often date to interglacials.

The organic deposits at Stone Point outcrop on the foreshore and have been dated to zone f of the Ipswichian interglacial (Reid, 1893; West and Sparks, 1960; Brown et al., 1975). The deposits apparently underlie a low cliff in the 'low terrace' of Keen (which Fisher (1975) has assigned to Everard's 5m stage). Brown and co-workers therefore date this terrace to the Ipswichian/Early Devensian transition. The organic deposits overlie a 'lower gravel' representing an aggradation from below sea-level to at least 2m above it. This gravel is thought to be Wolstonian in age and the submerged terraces of the Solent are attributed to the low sea-levels of the Devensian (Brown et al., 1975)

Kellaway et al., (1973) suggested that all the terraces between 113m and 21m O.D. are Hoxnian in age because of the Lower Palaeolithic implements found on them. However, the implements could have been dropped on existing terrace surfaces or subsequently incorporated in lower terraces by gelifluction (Bury, 1933; Green, 1946; 1947; Roe, 1975). There is consequently little justification for dating all of these terraces as Hoxnian, especially as correlations between Palaeolithic industries and British Quaternary Stages are at best tentative (Wymer, 1974). However, the inclusion of Lower Palaeolithic implements of the earlier Acheulian type (Roe, 1975) in the middle and high terraces of Keen, suggests that these terraces may belong to the Middle Pleistocene cold stages

The higher terraces (above 113m) are widely regarded to be of Lower Pleistocene age (Kellaway et al., 1973 suggest pre-Anglian), associated with falling base levels since the Pliocene (Everard, 1956). A Lower Pliestocene age is also indicated by the extensive dissection which they have undergone, and by the high degree of reworking by gelifluction compared with the lower terraces (Kubala, 1980; Tuckfield, 1974).

CHAPTER 2

THE NATURE AND ORIGIN OF BRICKEARTH

2.1 General Introduction

The term 'brickearth' has been used to describe a wide variety of sediments only some of which are suitable for brick-making. These have included materials of diverse origin such as glacial till (e.g. the Norwich Brickearth; West,1977), marine clays (in the Nar Valley; Rose,1865) and typical loess (at Pegwell Bay, Kent; Pitcher et al,1954). Although the term has mainly been applied to certain Quaternary superficial deposits, older strata such as the Tertiary Reading Beds have been so described if they are used in brick-making (Reid,1902a).

During the late nineteenth and early twentieth centuries brickearth was mapped extensively by the Geological Survey, mainly in southern England. Although this mapping class was never properly defined, it included many of the loamy superficial deposits found in the region even though it was recognised that they were not all formed by the same process. Pre-Quaternary deposits were not mapped as brickearth. Brickearth was a convenient term because many of the deposits included were texturally similar, though their precise mode of formation was often difficult to ascertain. However, better subdivision of the deposits could have been achieved but for the indifference which many early geologists showed them, often limiting their descriptions to thickness and colour.

2.2. Theories of Formation

Prestwich (1864) was an early proponent of a fluvial origin of brickearth. He proposed that the sediments he found in the valleys of the Thames, Medway and Stour were in every way identical to the loess of the Rhine valley, which was considered to be fluvial at that time.

Although the bulk of Rhine loess is now known to be aeolian, many Thames brickearths are still thought to be fluvial. Some are very similar to loess in texture, but have laminations and stony seams indicating fluvial reworking (Tamplin,1966; Zeuner,1959). Others, for example at Crayford, do not resemble loess, being fluvial or estuarine laminated sands and massive clays (Kennard, 1944; Hollin,1977). Hodgson (1963) described brickearth on the Sussex Coastal Plain, thought to be derived from loess, which had been locally reworked by stream action during the later stages of deposition. The idea that brickearth is synonymous with fluvially reworked loess is a persistent feature in the literature and has led to at least one definition: "Brickearth is a deposit generally possessing many of the grain-size characteristics of loess with horizontal bedding, consistent with sedimentation in water, a common feature" (Eden,1980). Such a definition makes no allowance for the fact that many deposits named brickearth in the past are clearly not fluvially reworked loess. Deposits which do fit this precise definition are more aptly labelled 'schwemlöss' after the INQUA Loess Commission recommendations (Fink,1976; Table 3.1).

Godwin Austen (1887) thought that the brickearth of the Sussex coast was a colluvial wash formed under far wetter conditions than at present. This hypothesis was supported by the observation that it contained land snails that are now scarce and that its textural composition was strongly influenced by the character of the underlying strata. Conversely, Reid (1887, 1903a) thought it was a gelifluction deposit, an altered fine-grained variant of the coombe rock which often underlies it. More recently, Hodgson (1967) showed that the deposit has been redistributed largely by gelifluction from an initial loess cover. In contrast, Sparks(1949b)presented evidence that the upper part at least of the brickearth at Angmering continued to accumulate as a wash until well into the Flandrian.

In the Chatham area of Kent, brickearth has formed by all three processes, hillwash, river action and solifluction, from pre-existing loamy, probably loessic (loess containing) sediments (Dines et al.,1954). The deposits are all similar and are thought to resemble Continental loess. These brickearths were mapped separately as 'head brickearth', 'river brickearth' and 'hillwash head'.

On the Chiltern Hills various superficial deposits, some of obscure origin, have been called brickearth. A variable, red mottled flinty sandy clay thought to be a mixture of disturbed Reading Beds and Clay-with-flints (Whittaker,1889; Woodward and Herries,1905) was mapped as brickearth on the original (Old Series) Geological Survey maps of the area. This deposit approximates to the Plateau Drift (Loveday, 1962) whose origin is not known with certainty, but may in part be glacial (Thomasson,1961; Catt,1981). 'True brickearth' is a term coined by Barrow (1919) to distinguish silty laminated almost stonefree sediments occupying funnel-shaped depressions in the Chalk dipslope of the Chilterns from the much more widespread flinty brickearth of Whittaker. The true brickearth has recently been investigated at a number of sites by Avery and co-workers (1982) who concluded that it was formed in long-established dolines which were infilled by mixed sediments washed and soliflucted from adjacent land surfaces during several stages of the Quaternary. They suggested that the silty infillings were derived by sorting from local deposits of Reading Beds, Plateau Drift, Devensian loess and Wolstonian and/or Anglian loess. Some of the true brickearth was affected by soil formation and rubification before the Devensian period. Elsewhere on the Chilterns, especially on sites sheltered from erosion, a silty drift composed largely of Late Devensian loess has been named brickearth, and supports soils of the Hamble, Hook, Charity and Batcombe series (Avery,1964; Avery et al.,1959; Avery et al.,1972).

The mapping of these soil series elsewhere in southern England has done a great deal towards extending the known distribution of loess-derived brickearth. The origin and distribution of British loess will be discussed in Chapter 3.

These examples show that the various deposits mapped or described as brickearth have neither genetic or stratigraphic unity. The term is an omnibus one; there is little need to give it a narrow definition because the constituent sediments can all be placed in already well defined classes. The advantage of its use, and the reason it has persisted is that fieldworkers can use it to describe loamy superficial sediments whose origin is not immediately clear and can only be clarified by detailed field and laboratory studies. Once such studies have established whether the brickearth is loess, or a fluvial deposit, or some other well defined category, then these precise sedimentological terms should always be used in preference to brickearth in order to avoid ambiguity.

2.3 The South Hampshire Brickearth

Because this thesis will examine the origin and nature of Quaternary brickearth of which some has already been mapped and described, a broad definition that encompasses all previously studied deposits is required.

Brickearth is defined here as 'a loamy superficial drift of Quaternary age', following Fisher(1971). In contrast, the Institute of Geological Sciences (Chatwin,1960) give a slightly narrower definition: "brickearth is a brown loam, consisting of a mixture of quartz and flint-sand and ferruginous clay. Sometimes finely divided chalk is present, as also scattered flints and gravelly seams"

2.3.1 Distribution

Brickearth appears on the 1:50,000 geological maps of south Hampshire at only a few localities, the largest patches of which are at Barton-on-Sea and in the Southampton area. However, the Geological Survey

Memoirs of the area (written well after the field survey) suggest it is more extensive than indicated, and is usually 0.3-1 m thick over the southern Plateau and Valley Gravels (White 1915, 1917). Near Milton it was reported to be up to 1.5m thick and was worked for brickmaking. Kay(1939) extended its known distribution in a soil survey of an area on the eastern side of Southampton Water, while on the New Forest terraces brickearth has been mapped near Fawley (Everard,1952) and Beaulieu (Fisher,1971) (Fig.2.1).

After systematic sampling of soils and superficial deposits on all terrace levels in the area, Fisher (1975) noted that the brickearth was common on terraces below 80m, including those in the Avon valley. Most authors from Reid(1902a)onwards have emphasised the close association between the South Hampshire brickearth and the terraced gravels, and Keen(1975) suggested it always overlies these deposits and never the extensive outcrops of the Tertiary sediments.

2.3.2. Origin

The early geologists working in south Hampshire considered the brickearth to be a floodloam, though their only supporting evidence was field observation of rare indistinct laminations and the association of the material with gravel terraces which were thought to be fluvial (White, 1917; Chatwin,1960). Probably more influential was the fact that, at that time, many other brickearths in southern England were regarded as fluvial by eminent geologists such as Prestwich and Lyell.

Subsequently most researchers have concluded that the South Hampshire brickearth was at least partly fluvial. Everard(1952) suggested it was originally a head (gelifluction) deposit which had been decalcified and reworked by fluvial and aeolian processes. As the brickearth usually has a coarser median particle size and poorer sorting than loess, Lewin(1966a,b) also thought it was a floodloam, but he considered a large proportion of the material was originally wind-deposited.

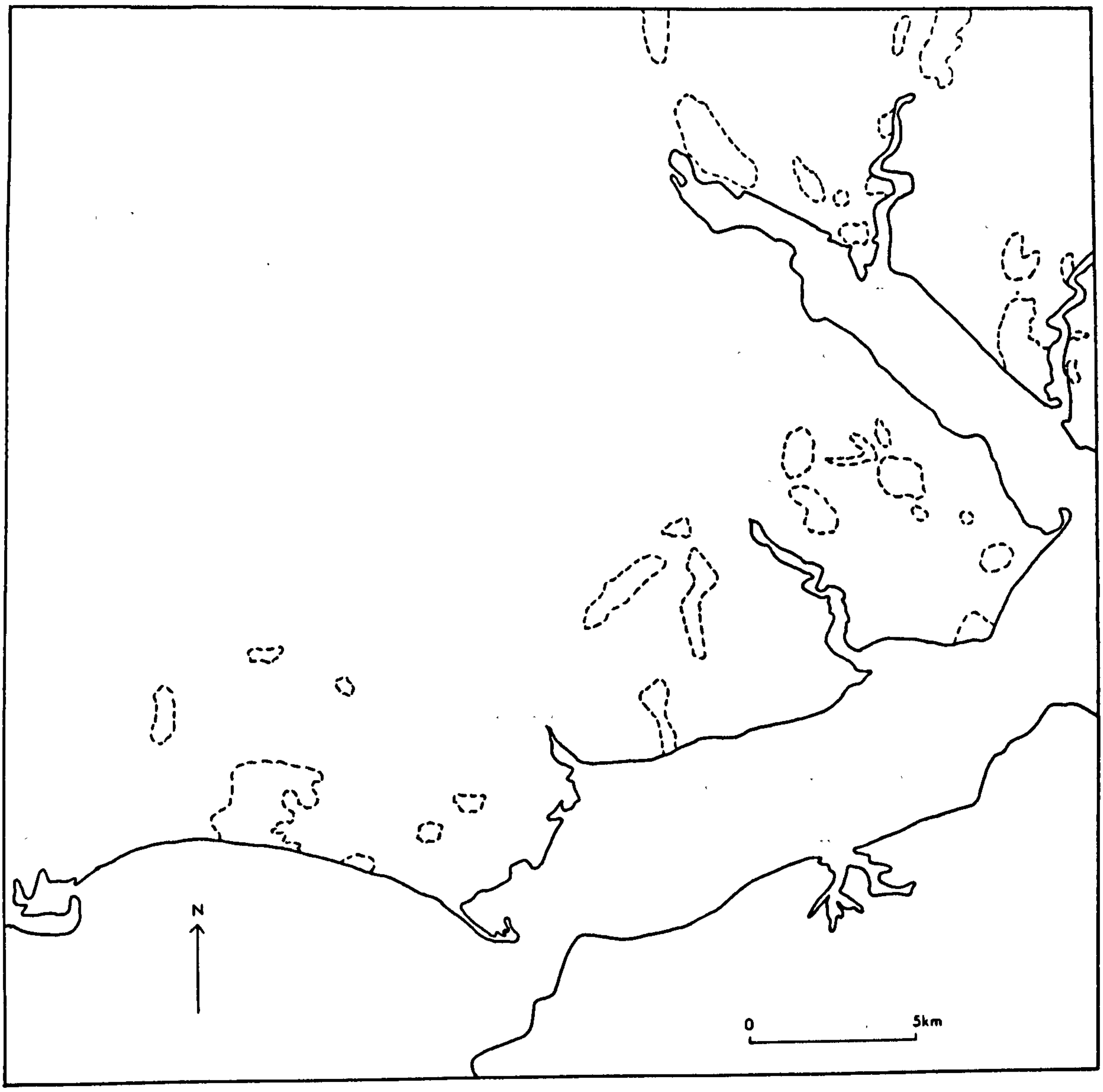


Fig. 2.1 Known distribution of brickearth in south-Hampshire (from Kay,1939; Everard, 1952; Fisher,1971 and the maps of the Institute of Geological Sciences)

Swanson(1968) compared the particle size distributions of several brickearth samples with known loess and modern floodloams (from the New Forest) and suggested they fitted neither category particularly well. He thought the high sand content of the brickearth could have been due to the mixing of saltated sand and silt from aeolian suspension. However, he felt that if it was aeolian, the brickearth would be more variable in thickness and would have been more eroded in England's moist oceanic climate. Without resolving this argument he concluded that at all but three sites the brickearth was a floodloam and could be distinguished from the loess at the other three by its greater tendency to podsolisation, detected by micromorphological analysis. It is questionable whether pure loess exists at these three sites because one (at Gore) had about 60% fine sand (60-200µm) which is far more than the upper limit set by most authorities for loess (Russel,1944; Pesci, 1968), and the other two were not distinguishable from the rest of the brickearth by particle size analysis alone.

Fisher (1971,1975) also thought the texture and sorting of the brickearth indicated a floodloam that probably contained some loess, and he suggested that in parts of the eastern New Forest the brickearth may represent channel infill in the gravels. His particle size distribution curves showed the brickearth is similar to the Pleistocene floodloams analysed by Zeuner(1949). He also demonstrated that the clay fraction of the brickearth is mineralogically much more variable than the fine earth of the Plateau Gravel, containing smectite, feldspar, chlorite and various forms of vermiculite which are rare or absent in the Plateau Gravel. This indicated that the brickearth and gravel may have different sources. The textural profiles of some soils at all terrace levels showed an increase of particles in the 10-100µm range up the profile, which Fisher(1975) interpreted as a late Pleistocene aeolian addition, post dating the brickearth.

Keen(1975,1980) argued for a fluvial origin of the brickearth because of its low silt content and because the presence of numerous flint chips could not be explained by an aeolian origin. However, he found no sedimentary structures typical of fluvial sediments. He developed a conceptual model whereby the terraced gravels and the brickearth were deposited as part of the same seasonal periglacial fluvial environment, the gravels being deposited in the high discharge conditions of the spring melt, and the brickearth under low energy summer conditions during which some aeolian reworking of material may have occurred on the floodplain. However, if the brickearth was deposited during low flow rates it would probably only lie on parts of the floodplain close to the stream channels, and the next high discharge event would either sweep it away or bury it. Previous authors, including Keen, provide no evidence that the brickearth is ever overlain by gravel which implies that, if they are floodloams, the sheets of brickearth must have been deposited in a single summer, the last before the stream graded to a new floodplain level. Yet Keen uses evidence that the brickearth is thicker on the highest of his three terraces to suggest that this terrace took longer to form, a view not tenable if the above interpretation of his model is valid.

Only Green and Calkin(1949) have suggested that the brickearth is completely aeolian, comparing it to similar material overlying the fluviatile gravels of the Somme. However, Catt(1977,1978) interprets the floodloams of Fisher(1971) and the brickearth mapped by the Institute of Geological Sciences as loess, qualifying this by demonstrating that most British loess has been reworked by widespread gelifluction, colluviation and stream action. Another indication that at least some of the brickearth may be more purely aeolian than previously thought comes from the work of Palmer and Cooke(1923) who showed that the upper brickearth at Lee-on-Solent near Gosport, Hampshire is contemporaneous with and resembles the widespread upper brickearth of the West Sussex

Coastal Plain which Hodgson(1967) and Perrin and co-workers(1974) have since shown to be loess. The brickearth mapped by Kay(1939) east of Southampton Water is probably a continuation of the upper brickearth of Palmer and Cooke.

The views of previous workers on the origin of the brickearth must be re-examined because their proposals are often based on doubtful evidence, and there are many contradictions and inconsistencies. The main distinguishing features of the Pleistocene fluvial brickearth in the Thames Valley, an aquatic fauna and fluviatile sedimentary structures (Kennard,1944; Hollin,1977), have not been observed in the south Hampshire brickearth. On the other hand, the main method of identifying loess in Britain, the mineralogical analysis of coarse silt and fine sand fractions, has not been attempted in south Hampshire.

2.3.3 Age

Reid(1902a) and White(1917) thought the brickearth was little younger than the gravel terraces on which it lies and is therefore of several ages. As he had divided the terraces below 46m into three stages, Keen(1975) considered there were three brickearths, but a specific age was only suggested for the lowest and youngest: the Ipswichian/Devensian transition. Fisher(1971,1975) suggested that since the brickearth is often involved in periglacial disturbances, some of it must pre-date Zone III of the Late Devensian, the last period when these features could have been produced. He also found (Fisher,1975) that although there were probably brickearths of different ages, a simple chronosequence could not be identified across the terraces because of periglacial mixing and erosion.

Swanson(1968) suggested ages for the brickearth at three sites, based on observations of weathering and comparison with the weathered loess section at St. Pierre Les Elbeuf, France. However, it is not clear if the weathering was assessed by field observation, mechanical analysis, micromorphological analysis or a combination of the three. At Holbury, the loess lies on the 31m terrace which he regarded as Hoxnian. He therefore suggested the loess may be Wolstonian as its weathering is similar to Eemian (= Ipswichian) weathering at St. Pierre Les Elbeuf. At Gore an aeolian sand overlies a floodloam of the 31m terrace. Swanson proposed that the floodloam was weathered in the Ipswichian and that the aeolian sand is Devensian. At Nursling Triangle he suggested the loess is weathered very similarly to the Wurm 1/2 soil at St. Pierre Les Elbeuf (Early Wurm soils of Lautridou,1974 = Early Devensian). This date is interesting because all the Devensian loess reported previously in England has been attributed to the Late Devensian (Catt,1978).

Despite the wide range of ages proposed for the South Hampshire brickearth , no author has suggested any of it is Late Devensian. This situation demands further investigation in view of the very widespread occurence of Late Devensian loess (and other superficial sediments) in southern England. Most of the proposed ages have been based on poor evidence, such as the ages of terraces which themselves have not been reliably dated, or on questionable estimates and comparisons of weathering. However, the upper brickearth of West Sussex and South Hampshire shown in the section at Lee-on-Solent is probably Late Devensian because the latter is younger than local Aurignacian industries (Palmer and Cooke,1923) and the former is mineralogically similar to Late Devensian loess elsewhere in England (J.A. Catt, pers.comm.).

Some of the floodloams described by Lewin(1966a,b) are probably even younger because they were found mainly on valley sides and riverside locations which would have been subject to severe gelifluction during the Late Devensian. They are therefore likely to date from the Flandrian Period.

2.3.4 Soil Formation

Although detailed soil maps of the study area have not yet been published by the Soil Survey of England and Wales (Jarvis,1980), the main types of soil likely to be found on the brickearth can be predicted from a variety of published and unpublished work. The soil survey by Kay(1939) of the strawberry growing district on the east side of Southampton Water described three soil types developed on brickearth, the Hamble, Hook and Park Gate series. These names have been adopted by the Soil Survey for similar soils mapped elsewhere in England and Wales. The study area west of Southampton Water is analagous to Kay's area in terms of soil forming factors, so it is not surprising that all three soils have been noted in Soil Survey internal reports (1962, 1967), in the south western part of the New Forest and at Efford Experimental Station. Fisher (1971, 1973, 1975) showed that the Hamble and Hook series were the most common soil types developed on brickearth and the Park Gate series less so, and found that all three were most prevalent on terrace levels below 70m.

The Hamble series is a typical argillic brown earth (Fordham and Green,1980; Avery,1980). It is almost stoneless (though stony variants have been described: Green and Fordham,1973), and is freely drained, lacking gley features within the upper 70cm. Near Netley in south Hampshire (SU463101) a shallow variant of the series has been described, occurring where brickearth is less than 60cm thick over the Plateau Gravel (Mackney,1974). Typically the horizon sequence is A (or Ap when cultivated), Eb and Bt. The upper two horizons have a weak structure which may suffer compaction if the soil is worked while at or near field (moisture) capacity (Hodgson,1967). The Bt horizon generally has a moderately developed prismatic or blocky structure, and is characterised by an addition of illuvial clay which often occurs as clay skins on ped faces and in pores. Because Bt horizons are most common in areas with a seasonal soil moisture deficit (south-east England in Britain), the translocation of clay has been related to this climatic feature (Hodgson,1967).

The Hook series is a gleyic argillic brown earth and the Park Gate series a typical argillic gley soil (Fordham and Green,1980; Avery,1980). They are formed in identical parent material to the Hamble series but differ in the occurrence of gleying in the profile. In the Hook series, grey and ochreous mottling indicative of imperfect drainage starts between 40 and 70cm, whereas in the poorly drained Park Gate soils it occurs above 40cm (Fordham and Green,1980). On Efford Experimental Farm, the level of the groundwater table and therefore the depth at which gleying appears in the soil profile is determined by the undulating upper contour of the clayey, relatively impermeable Headon Beds which underlie the Plateau Gravel. The distribution of Hamble, Hook and Park Gate series soils in this area is thus closely related to subsurface geology (Soil Survey Internal Report,1962). The typical horizon sequence in the Hook series is A (or Ap), Eb, Bt and Bt(g). In the Park Gate series it is A (or Ap), Ebg, Btg (Hodgson,1967; Fordham and Green,1980). The intensity of mottling in the latter series increases directly with acidity and organic matter content, and is therefore more prominent in semi-natural soils (Hodgson,1967). Both series display the weak structure of upper horizons and moderate prismatic or blocky structure of Bt horizons common in the Hamble series. Although the average ratio of% clay content in the Bt horizon to that in the A horizon is almost identical in the Hamble, Hook and Park Gate series, visible evidence of clay skins on ped faces and in pores is relatively rare in the Park Gate series. This feature has led Hodgson (1967) to suggest that the Bt horizon of the poor or imperfectly drained Park Gate soils formed at some period in the past under different climatic and water table conditions. More recent research by Weir et al.,(1971) on a soil profile in Kent developed in brickearth which was buried by Neolithic colluvium and virtually sealed from subsequent soil formation, showed thatBt horizons may well have formed largely in the early Flandrian. However, water table conditions in the buried soil may in fact have been very similar to those in Hook or Park Gate soils because distinct mottling was observed below 45cm, and radiocarbon dating of the buried surface organic horizon indicated burial at the end of the Atlantic period, a much wetter time than the present.

Although the Hamble, Hook and Park Gate series are likely to be the most common brickearth soils in the area, others may occur. Fisher (1973,1975) conducted a systematic sampling of terrace surfaces throughout the New Forest to assess the variety of soil types present. He identified (pers. comm.) a further five soil subgroups developed on brickearth using the terminology of Avery(1973), and to which series names have yet to be applied. They were: a stagnogleyic argillic brown earth; typical(humic) and non-humic brown podzolic soils; a typical (humus) gley podzol and a typical (argillic) stagnogley. Fisher found the gley podzols to be the most common of these subgroups. The brown podzolic soils are rare and usually develop where thin brickearth is mixed with gravel by crytorbution. The stagnogleyic argillic brown earths and typical argillic stagnogleys are also rare. The development of the podzolic variants is noteworthy because brickearths normally only support such soils in the wetter western parts of England and Wales (Catt and Staines, 1982; Clayden, 1971; Coombe and Frost, 1956). They probably occur in the New Forest due to the common presence of excessively drained coarse sands and gravels beneath the brickearth, as well as the preservation of acid heaths on the soils for common grazing.

The Bt horizons of brown earth soils developed in brickearth described by Fisher (1971, p.102) and in a Soil Survey Internal Report (1962) appear to have all the colour characteristics of paleo-argillic horizons, although micromorphological evidence is needed to confirm such a horizon designation. Paleo-argillic horizons are argillic B horizons with additional characteristics, including colour and microstructure, attributable to pedogenesis in the Ipswichian interglacial period or earlier (Avery, 1980). They were originally defined by Avery in 1973 and since that time their recognition has proved important in the elucidation of the Quaternary stratigraphy of some areas (Rose and Allen, 1977; Sturdy <u>et al</u>., 1979; Chartres, 1980). If this study can positively identify paleo-argillic horizons in the brickearth it will demonstrate that some brickearth is pre-Devensian. Thus soil studies will be useful not only to determine the post-depositional history of the brickearth, but also to establish its age and stratigraphy.

As defined by Avery (1980), paleo-argillic horizons have a dominant matrix chroma of 4 in hues redder than 10YR and/or red (5YR or redder) mottles, neither of which is inherited from pre-Quaternary rocks. In addition, micromorphological analyses show a more pronounced reorganization of clay sized material than Flandrian soils, resulting in complex sepic fabrics (Brewer, 1964), and there is a greater proportion of disrupted clay illuviation features as a result of cryoturbation in a succeeding cold period(s) (Bullock, 1974; Bullock and Murphy, 1979; Chartres, 1980).

The reddish colouration of paleo-argillic horizons is attributable to the segregation of iron oxides, partly as hematite. Schwertmann and Taylor (1977) suggested that the development of reddish colours (2.5YR-5YR) requires a climate with summers both warmer and wetter than those of present day Britain. Similar colours occur in interglacial soils found in parts of France (Federoff, 1966; 1971). The high degree of clay reorganization in paleo-argillic horizons can be attributable partly to stress caused by shrink-swell cycles induced by wet, followed by dry, seasons in a warm climate (Catt, 1979a).

CHAPTER 3

LOESS

3:1 The Origin of Loess

The term loess is derived from the German löss, the name for deposits used in the Rhine Valley brickmaking industry. Since Lyell first introduced the term to the English language by describing these deposits (1834) and others in the Mississippi Valley (1847), a huge literature has been generated relating to deposits from many parts of the world.

There has been great debate on the mode of formation of loess, especially during the nineteenth century. Richtenhofen (1877) popularised the idea of an aeolian origin, but other workers favoured fluvial, lacustrine, marine and even cosmic sources. Much of the argument arose because (as with the brickearths in England) the first deposits studied were associated with river terraces in major river systems such as the Rhine, Mississippi and Huang Ho. Fluvial hypotheses were therefore initially the most attractive, but as the full extent of the distribution of loess became known, blanketing the landscape in some regions, it became generally accepted that only aeolian deposition could account for its distribution.

The proposal that loess can form by in-situ weathering of rocks has been the only serious alternative to the aeolian hypothesis in the twentieth century. Around 1915, L.S. Berg (whose major works may be read in a 1964 English translation) began to study the origin of Russian loess from a pedological viewpoint. Among his objections to the aeolian hypothesis was that he thought wind speeds and directions would have been far too variable to produce such a uniform, well sorted deposit as loess. Instead, he thought the concentration of particles in the 10-50μm range could be accounted for by weathering and soil formation in a dry, steppe climate. Berg's theory is weakest where he tried to account theoretically for the presence of quartz in loess occurring over quartz-deficient 'parent materials' by the chemical transformation of silicate and alumino-silicate gels to crystalline quartz. No evidence has been found for this process actually operating in soils. (Obruchev,1945; Smalley,1971). Nevertheless, the in-situ hypothesis was considered seriously until quite recently (Ollier,1969).

Russell (1944), in a much quoted paper, supported the in-situ hypothesis. He considered that the field relationships of the Lower Mississippi Valley loess precluded the possibility of formation by aeolian, lacustrine, fluvial or other sedimentary processes. He suggested that the local river alluvium was the parent material of the loess. This weathered to a brown loam, crept downslope to mantle valleys and bluffs and then underwent a process of 'loessification', similar to that envisaged by Berg. In this process "carbonates accumulate and the size of particles becomes restricted mainly to 0.01-0.05mm." (Russell, 1944 p.1). Unlike Berg, however, Russell required that his parent material be rich in silt and clay, so the process of loessification was not required to produce silt.

As a result of the controversy raised by Berg's and Russell's work, geomorphologists produced more conclusive evidence in favour of the aoelian hypothesis. Swineford and Frye (1945) discounted the proposal that wind action could not produce a well sorted deposit such as loess by showing that the particle size distribution of dust collected during a Kansas dust storm was very similar to known loess samples, and satisfied all of Russell's textural requirements for loess. Doeglas(1949) demonstrated that the texture and mineralogy of Dutch loess samples was homogeneous over large areas of widely differing substrata, and indicated a source in glacial deposits lying well to the north of the loess area, from which it could only have been derived by wind. Doeglas also showed that the mineralogy of Lower Mississippi Valley loess precluded an in-situ origin from local alluvial deposits.

3:2 The Mechanics of Loess Formation

The formation of aeolian loess deposits requires four critical stages: 1) The production of silt grains; 2) the incorporation of silt in a deposit suitable for deflation by wind; 3) adequate winds blowing predominately from one direction; 4) a suitable place for deposition (Bryan,1945; Smalley,1966). As Smalley (1971) has indicated, it is often only the later stages of this complex sequence of events that are considered in the formation of loess, and this has led to confusion over the ultimate origin of some deposits.

It has long been recognised that the distribution of most of the world's loess is closely related to the occurrence of glacial deposits (Bryan, 1945); this has led to the proposal that the silt is produced by glacial grinding (Keunen,1960; Smalley,1966). Smalley showed that by grinding quartz sand in a ball mill (which he considered analagous to the crushing action of glacier ice), a bimodal particle size distribution was produced that had much silt present in the fraction peaking below 200µm. Another silt producing mechanism in cold areas is frost action and insolation weathering (Zeuner,1959) which breaks down large particles by the internal strains caused during thermal expansion and contraction of rock and freezing and thawing of water in interstitial spaces. These processes are probably much less efficient in producing silt than glacial grinding (Smalley and Vita-Finzi, 1968) although Zeuner (1959) thought that they were effective enough to produce loess-like deposits in-situ. A few of the world's loess deposits are derived from deserts and lie at their margins. Most of these require a different explanation for the production of silt; exceptions are the desert loesses of north China and Central Asia where the silt was probably originally produced by glacial grinding in nearby mountain regions (Smalley and Krinsley, 1978). Smalley and Vita Finzi (1968) suggested that spalling of colliding sand grains during violent sand storms was the only indigenous hot desert process likely to produce silt. Keunen(1969) refuted this, stating that his experimental evidence showed the vast majority of spalled particles are less than 2µm. However, despite its inefficiency, some loessial silt is probably produced by this process as a result of its continuous action over vast areas of sand (Goudie et al, 1979). Another silt producing process in hot deserts is salt weathering. Goudie and co-workers (1979) have shown by experimentally reproducing diurnal temperature and humidity variations typical of deserts that the presence of sodium sulphate helps to disintergrate quartz sand, possibly by crystal growth in cracks and other defects in the grains.

Bagnold (1941) investigated the physics of wind blown deposits and his studies show that the grain size distribution of source deposits has an important effect on the efficiency with which wind can deflate particles. Fine sediments composed mainly of silt and clay tend to have strong inter-particle adhesive forces which resist deflation. However, in moderate to poorly sorted (mixed grain size) deposits these forces are minimal. Furthermore, rough sediment surfaces cause wind turbulence that helps particles to become dislodged. The wind can most easily lift particles of about 80µm diameter from these deposits; higher wind velocities are required to lift particles with smaller and larger diameters. Bagnold's experiments also showed that particles up to 200µm diameter can be carried in suspension but larger grains will saltate. The impact of saltating grains in mixed grain size deposits knocks finer particles into the air and is often the main initiating force whereby fine grains are deflated. Once particles are moving in the air by saltation or suspension, the wind becomes an efficient sorting agent. Particles less than 80µm diameter are most easily carried by wind. Clay and fine silt particles are often swept high into the atmosphere and can be carried almost indefinitely; their deposition is dependent on rain (Syers et al, 1969).

Medium and coarse silt particles are carried long distances in suspension, but are deposited, as loess, when wind-speeds drop. Sands are carried relatively short distances, mainly by saltation, and are deposited as coversands. It is clear that a silt-rich, mixed grain size deposit is essential for the efficient production of loess. Bryan(1945) suggested therefore that the fluvioglacial outwash of Pleistocene glaciers was the main source of loess. The more extensive till deposits were less suitable because of their cohesiveness. In some areas it is likely that silt was eroded from glacial deposits by rivers and deflated from floodplains to form loess. (Fehrenbacher et al, 1965). This partly explains the association of loess deposits with river systems such as the Rhine and Danube (Smalley and Leach, 1978; Smalley et al, 1973). In deserts, wadi floors and alluvial fans may have been the main source of silt (Yaalon, 1969).

Desert loesses continue to accumulate today partly because the source sediments are unvegetated and partly because large deserts such as the Sahara are in regions of strong trade winds. The major loess deposits of North America and Europe accumulated during Pleistocene cold periods, because there was then a huge supply of silt in fluvioglacial outwash that remained largely unvegetated, and because winds were stronger than today. Rutten (1954) described modern ice-winds blowing radially off the Vatnajokull icecap in Iceland, which deposit loess and coversands derived from fluvioglacial outwash. Similar winds would have been prevalent locally on ice-caps during Pleistocene cold periods, whilst on a continental scale strong anticyclonic conditions probabably developed. Hobbs (1943a,b) showed how such anticyclones could have controlled the deposition of Pleistocene loess in North America and Europe. In north Europe there would probably have been a large anticyclone over the Scandinavian ice-cap and a lesser one over the Alps (Lill and Smalley, 1978).

Loess is deposited when windspeeds are no longer sufficient to support the particles. It has become an entrenched view in the literature that a vegetated surface is required to trap the silt (see, for example, Obruchev, 1945), because the faunal remains found in some loess deposits have suggested a dry, grassy steppe environment (Lozek, 1968) or even a forested one (Leonard and Frye, 1954). However, Cegla (1969,1972) has shown that ground vegetation is not an efficient silt trap and may infact hinder deposition due to the turbulence it causes. He proposed that ground moisture acts as the initial adhesive force which traps the silt. Once the silt is deposited inter-particle electrostatic attraction promotes adhesion (Smalley, 1966). Further wind erosion of the loess is also unlikely because the smooth surface of the fine sediment does not generate disturbing turbulence (Bagnold, 1941).

3:3 Definition and Characteristics of Loess

A perennial problem in establishing a definition for loess is to decide whether it should just describe the characteristic properties of deposits known as loess, or whether the definition should include the mode of formation of the deposit. No universally applicable definition has been produced because a considerable variety of deposits have been called loess, and once so-called, the label tends to stick. Definitions in terms of characteristic properties inevitably refer to local peculiarities that workers in other regions find unacceptable. Genetic definitions are problematical because some deposits known as loess, particularly in Eastern Europe and Asia, are non-aeolian (Obruchev, 1945). Furthermore, workers in some countries refer to deposits as loess that have obviously been extensively reworked by other processes since aeolian deposition.

The definition most often quoted is that of Russell (1944), who described the characteristics of the unweathered Lower Mississippi Valley loess as follows :'Loess is unstratified, homogeneous, porous, calcareous silt; it is characteristic that it is yellowish or buff, tends to split along vertical joints, maintains steep faces and ordinarily contains concretions and snail shells. From the quantitative standpoint at least 50% by weight must fall within the grain size fraction 0.01-0.05mm and it must effervesce freely with dilute hydrochloric acid."

The concentration of particles in the silt fraction is the most common point of agreement between definitions, although the degree of sorting and size limits to be adopted are disputed. Pecsi(1968) suggested at least 40% of the material should be in the 0.01-0.05mm range, whereas Zeuner(1945) proposed that 70-95% by weight falls in the 0.02-0.06mm fraction. Lysenko(1973) went even further and described the particle size distribution of loess and loess-like sediments in terms of narrow ranges of total silt content, steepness of cumulative frequency curve, inhomogeneity coefficient, sorting coefficient, ratio of coarse to fine silt, medium grain size diameter and coefficient of micro-aggregation. Narrow limits have proved difficult to apply, however, because of the variability of loess from region to region. This has led Smalley and Vita-Finzi(1968) to propose a broad definition that "Loess is a clastic deposit which consists predominantly of quartz particles 20-50µm in diameter and which occurs as wind-laid sheets". Their reference to quartz is unwise however, because Argentinian loess is composed of up to 60% volcanic glass shards (Teruggi, 1957) and New Zealand loess has at least as much feldspar present as quartz (Raeside, 1964).

Most unweathered loess deposits have a significant content of carbonates, and this has consequently been given an important place in some definitions. Indeed in the process of 'loessification' described by Russell(1944), and Berg(1964), the accumulation of carbonates was emphasized as one of the key properties of loess. However, in parts of the world where carbonate bedrock is rare, such as South Island, New Zealand and Nebraska, U.S.A., the loess is virtually non-calcareous (Raeside, 1964; Lugn, 1962); workers in these areas therefore, have not considered the carbonate content important. Some carbonates may be added to loess by capilliary movement of saturated groundwater (Smalley,1971), but the occurrence of calcareous loess containing derived Chalk foraminifera on non-calcareous bedrock in south-east England shows that at least some of the carbonate is wind blown and detrital (Catt et al., 1974).

The lack of stratification in loess deposits is probably due to slow rates of accumulation, each addition being an extremely thin layer (Embleton and King, 1975). Ives(1973) measured rates of 1cm in in 144-455 years for loess accumulating today in the Canterbury Plains region of New Zealand, and Pecsi(1972) has estimated that typical Hungarian Pleistocene loess was deposited at a rate of 10cm per 100 years.

The very high porosity of loess (40-65%) is probably also due to slow aeolian deposition which results in a loose packing of the silt grains. Electron microscopical studies have shown that the grains are often propped apart by clay bridges (Fookes and Best,1969), which means that rapid collapse and reductions in volume can occur on saturation under load. The adequate drainage of loess used as a foundation material is therefore very important (Krinitzsky and Turnbull, 1967). In sections and cliffs loess characteristically maintains steep vertical faces, which is unusual in a friable sediment. This is due to the cohesion between particles when dry, and the common presence of vertical sub-columnar jointing that is probably caused by internal expansion and contraction (Smalley, 1966).

While deposits with all the characteristics of typical loess described above and defined by Russell (1944) are present in southern England, deposits which have lost many of these features due to weathering, soil formation and reworking are much more extensive (Catt, 1978). These loess-like and loess-derived deposits need to be classified in terms of their distribution, mode of deposition, physical characteristics and chronology. Unfortunately, a workable classification has yet to be achieved, although the INQUA Loess Commission has begun by giving preliminary definitions to loess-related sediments for the Loess Map of Europe (Fink,1976; Catt,1977). Consequently, some British workers have preferred to "group under the single heading 'loess' all the deposits in Britain that could be shown from laboratory and other studies to contain a moderate or large amount of silt (4-9ø), the presence of which reflected an aeolian phase at or towards the end of the transportational history of the sediment" (Catt et al.,1974, p.37). This approach is diametrically opposite to that of Russell(1944) as it is a genetic definition and, apart from a moderate silt content, makes no statement of the physical properties of the material. Such a broad use of the term loess has been criticised. Leach (in Catt et al,1974) thought it would be less confusing if the German terms used by the INQUA Loess Commission were applied to British deposits. Catt et al,(1974) answered that these terms were as inadequately defined as loess itself and their use would ultimately lead to further ambiguity. In a similar vein, Lill and Smalley(1978) thought that the term loess should only be applied to deposits whose 'physical appearance' was similar to that of the classic loess deposits of Western Europe. They felt that the thin British loess deposits were often "so meagre as to make it difficult to decide whether they are silty drift or if enough loess parameters apply to allow them to be called loess" (Lill and Smalley, 1978, p.64). This view contradicts Smalley's earlier definition of loess (Smalley and Vita-Finzi, 1968) which, in common with that of Catt et al,(1974), emphasises only that the deposit should be aeolian with a predominence of silt particles.

Because of the inapplicability of Russell's(1944) rigid definition of loess to British deposits, a broad definition of the term consistent with that of Catt et al,(1974) will be used in this thesis. However, whenever possible, suggestions will be made as to how the sediments relate to the INQUA Loess Commission definitions (Fink,1976). These are listed in Table 3:1.

Table 3:1 Definition of the mapping units for the INQUA Loess Commission Loess Map of Europe (after Fink,1976)

1) LOESS. Sediment with an unequivocal dominance of grains in the 0.06-0.02mm fraction(coarse silt); usually unstratified; carbonatic; has well developed distinct capilliary joints; dry colour is generally yellow to brownish yellow (10YR 6-7/3-4, sometimes also near 2.5) Synonyms: Typischer löss (typical loess), aeolischer löss (aeolian loess), fluglöss (wind-blown loess).

2) Sandy loess. Sediment with a mixture of grains in the fractions 0.06-0.02mm (coarse silt) and 0.5-0.2mm (medium sand); the shape of the particle size distribution curve often shows a large peak in the coarse silt fraction and a smaller peak in the medium sand fraction (=bimodal sandy loess); however, there is sometimes an equal distribution of particles in the coarse silt, fine sand and medium sand fractions (=unimodal sandy loess); can be stratified or unstratified; carbonate content negligible or carbonate free; has coarser pores than loess; colour similar to loess.
Synonyms: Flottsand, lössiger sand (loess-sand), sandiger löss (sandy loess).

3) Clayey loess. Sediment with an unequivocal dominance of grains in the 0.06-0.02mm fraction (coarse silt) and containing more than 25%-30% in the fraction < 0.002mm (clay); usually unstratified; moderately well formed

capilliary joints; carbonate content and colour similar to loess

Synonyms: Toniger löss (clayey loess), tonreicher löss (clay-rich loess).

4) Derasion loess. Sediment with an unequivocal dominance of grains in the 0.06-0,02mm fraction (coarse silt); has stratification formed during weak slope movements; carbonatic; distinct capilliary joints; dry colour is generally yellow to brownish yellow (10YR 6-7/3-4).

Synonyms: Gehanglöss, hanglöss (slope loess); loess lité (stratified loess).

5) Brown loess. Sediment with an unequivocal dominance of grains in the 0.06-0.02mm fraction (coarse silt); generally has a higher clay content than loess; carbonate free; usually has a laminated and platy structure; weak capilliary jointing; dry colour is generally brown to brownish yellow (10YR 6-7/4-8).

Synonyms: Lösslehm (loess loam), schwemmlöss (alluvial loess), deluvial löss (flood loess), gehanglöss, barnafold, limon lité (stratified loam), limon à doublets, limon fendillé (cracked loess).

6) Loess derivates free of coarse material. In summary, this term is used for material that is predominately aeolian but has been altered by secondary pedogenetic and diagenetic processes; in general, it has a higher clay content than the original material, which was loess, brown loess or clayey loess, but not sandy loess; sometimes has secondary enrichment of carbonate but is usually carbonate free; compact deposit frequently with prismatic and/or blocky structure; always darker than loess, often strongly and variably mottled brown or

streaked blackish due to pedogenetic influences.

Synonyms: Staublehm (dust loam), decklehm (cover loam) gleylöss (gleyed loess), semipedolithe und pedolithe mit löss material (pedoliths and semi-pedoliths of loess), lössartige sedimente, lössahnliche gesteine (loess-like sediments).

7) Loess derivates containing coarse materials. In summary, this term is used for material that is predominately aeolian but has undergone secondary transportation by various processes and is enriched with coarse material from underlying rocks; is always richer in sand and stones than original material; variable carbonate content, frequently chalk-free; laminated or platy structure; colour usually darker than loess or brown loess.

Synonyms: Kryoturbationlöss (cryoturbation loess), solifluctionlöss (solifluction loess), flusslöss, löss fliesserde (gelifluction loess), berglöss, gebirglöss (mountain loess), steinlöss (stony loess).

3.4 Loess in Britain

3.4.1 Distribution

In-situ, unweathered, calcareous loess is present locally in south-east England mainly in north Kent and West Sussex. The best known of these deposits is at Pegwell Bay, Kent where Pitcher et al(1954) described material that satisfied the strict definition of Russell(1944). In common with Zeuner(1955), they found that it had strong mineralogical affinities with the underlying Thanet Beds and was therefore partly locally derived. However, Weir et al(1971) re-examined the mineralogy and suggested 80-90% of the loess had a distant windblown origin. Fookes and Best(1969) demonstrated that it had similar collapse and subsidence properties to loess from other parts of the world.

Most British loess deposits have been reworked and/or weathered, form part or the whole of soil profiles and are often not distinguishable from underlying deposits on field evidence alone. For example, Perrin(1956) studied thin 'Chalk Heath' soils which were once thought to have formed by weathering of the underlying Chalk. He found that their texture compared well with known loess, but was completely different from the acid insoluble residue of the Chalk. The mineral assemblage found in the soils was also far too rich to be derived from the Chalk and indicated a source in Pleistocene deposits. Similar techniques have subsequently been used to recognise as loess the thin silty soil horizons that are almost ubiquitous over the Chalk and Clay-with-flints in the Chilterns (Avery et al, 1959, 1969, 1972), the South Downs (Hodgson et al, 1967), Yorkshire (Catt et al, 1974), Wiltshire (Cope, 1977) and elsewhere. Thin loess also commonly overlies Carboniferous Limestone deposits, for example, in Derbyshire (Pigott,1962), Somerset (Findlay,1965), Yorkshire (Bullock,1971) and Westmoreland (Furness and King, 1972). The occurrence of loess over other types of deposit is less predictable, but it has nevertheless been recognised over an extremely wide variety of substrata. For example, it is often < 1m thick over Pleistocene sands and gravels in West Sussex (Hodgson,1967), Essex (Gruhn et al.,1974), Kent (Fordham and Green,1980) and Norfolk (Corbett,1977). In Devon and Cornwall it has been found over Serpentine (Coombe et al.,1956), granite, gabbro, schists, slates (Catt and Staines, 1983), limestone, Upper Greensand, gravels, Plateau Drift, Budleigh Salterton Pebble Beds and head (Harrod et al.,1973). In the London Basin and the Weald thin loess is found sporadically over pre-Pleistocene deposits such as the Blackheath Beds and London Clay (Burnham and McRae, 1974) and Hastings Beds (Bagenal and Furneaux,1949). Although most loess in northern England is associated with limestone outcrops, it has been reported on the Bunter Sandstone in Nottinghamshire (Robson and George, 1971) and on Basic Igneous rocks in Derbyshire (Johnson,1971). Loess is fairly rare over Pleistocene glacial tills, but has been found on the Chalky Boulder Clay in Hertfordshire (Thomasson and Avery,1970) and on the Norwich Brickearth in Norfolk (Corbett,1977). In Wales, loess has been found over Carboniferous Limestone in the Vale of Glamorgan (Crampton, 1972) and on head deposits near Aberystwyth (Watson and Watson,1967). Only one loess deposit is known in Scotland, overlying fluvioglacial material near Kinross (Galloway,1961).

A more comprehensive review of the literature up to 1977 relating to the distribution of loess in Britain has been made by Catt(1978). Several new deposits have been reported since then. Keen(1978) mapped thick deposits (< 5m) on the Channel Islands, mainly overlying grandiorite, gneiss, head and raised beach sediments.. In the Wirral Peninsula, Lee(1979) reported the occurrence of loess up to 2m thick lying between two tills at Dawpool. In north-east Essex, Eden(1980) confirmed that a coverloam overlying Pleistocene sands, gravels and tills contained loess. In the Kennet Valley, Chartres(1981) found that loessic silt had been incorporated in the upper horizons of soils formed mainly in Pleistocene river terrace deposits. Vincent and Lee(1981) extended the known association of loess with Carboniferous Limestone by recording further deposits around Morecambe Bay.

Because of the recent considerable interest in British loess, its distribution is now known in some detail, and a provisional map has been made (Catt,1977,1978) which may be amended as new information published. (Fig3:1). It can be seen from the map that loess blankets considerable areas particularly in south and south-east England south of the main glacial limits, as might be expected of a periglacial deposit. The deposits shown in south Hampshire were not all mapped as such, but were based on the limited mapping of brickearth by Kay(1939), Fisher(1971) and members of the Institute of Geological Sciences, using knowledge of the relationship between loess and underlying geology to extrapolate onto adjoining areas (Catt, pers. comm.).

Despite its widespread occurrence, British loess forms a less continuous cover than that in the loess areas of Europe. It has often been suggested that this is due to Britain's more oceanic Pleistocene climate, which ensured that possible source sediments remained moist and perhaps vegetated, thus inhibiting deflation (Embleton and King,1975). Supplies of aeolian silt may well have been less in Britain, because deposits thicker than 2m are rarely reported, but the complete absence of loess from some areas is probably due to erosion, as an aeolian deposit would have originally blanketed the landscape with a fairly uniform thickness. Erosion of loess is facilitated by a wet environment because it is so susceptible to structural breakdown on flooding. Catt (1978) has suggested that most erosion occurred during two periods, a) the later part of the Late Devensian and early Flandrian before the main Flandrian forest development, and b) later in the Flandrian after anthropic forest clearance. Loess lying on impermeable clay substrata is particularly susceptible to erosion, and Catt(1978) speculated that much of the former loess cover of the Weald and East Anglia could now be found in the silty river alluvium of these regions. Burrin(1981) recently confirmed the

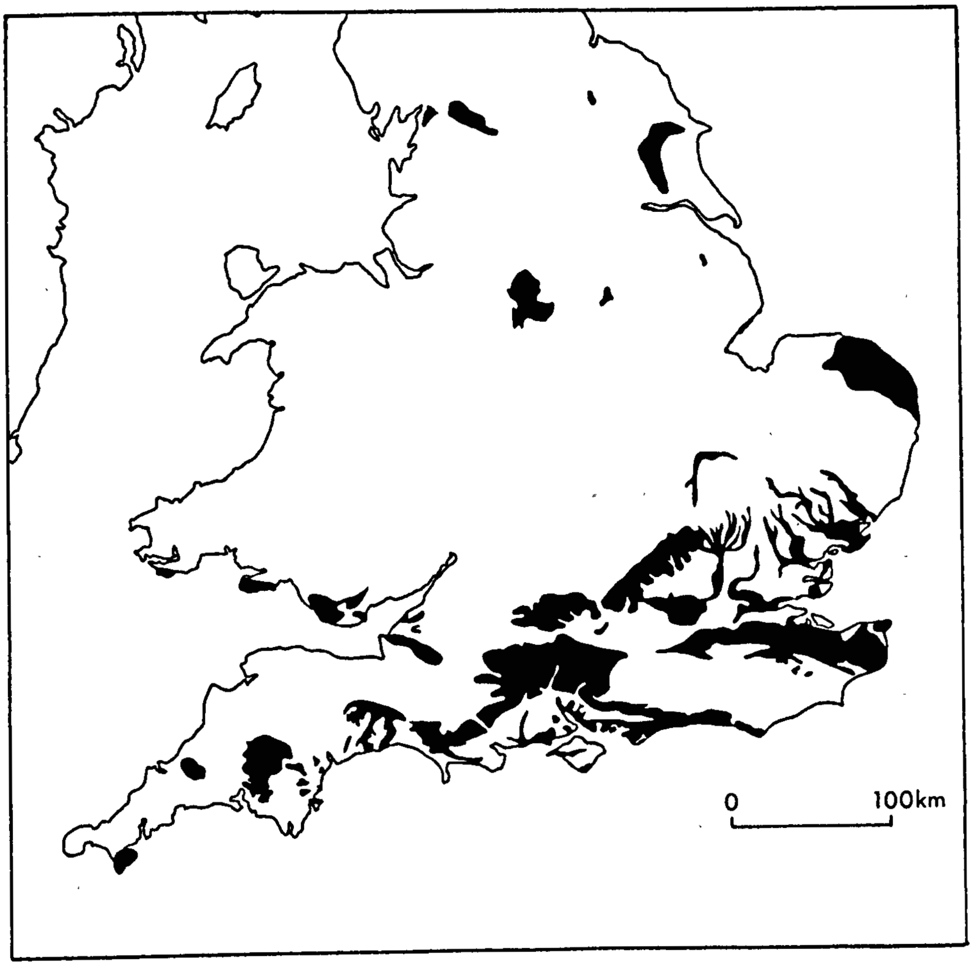


Fig. 3.1 Distribution of loess in Britain (from Catt, 1978)

loessic origin of the silty Flandrian alluvium of the rivers Ouse and Cuckmere which drain the Southern Weald. Loess has also been eroded from some permeable sandy substrata, particularly in northern England. Catt(1978) explains this in terms of sheet erosion of surface soil after drainage impedance caused by the eluviation of clay into subsoil drainage channels, and by wind erosion of loose, clay depleted surface horizons. The mechanics of the erosion of the relatively stable clay-enriched B horizons which must once have existed over these substrata remains obscure. On the sandy heaths of Surrey, Macphail (1979) explained the erosion of loess from interfluves underlain by sandy Folkestone Beds as due to fluvial erosion, triggered off by forest clearance and agricultural activity during the Bronze Age.

Much of the erosion of loess was probably due to gelifluction . Evidence for this lies in the very widespread presence of loess in Devensian head deposits, for example in Devon (Mottershead,1971), West Sussex (Hodgson,1967) and Wales (Watson and Watson,1967). The head deposits that accumulated on slopes and valley bottoms have subsequently been much eroded by Flandrian stream action. Paradoxically, the preservation of loess over Chalk and Limestone bedrock, particularly in northern England, is probably due to the effects of cryoturbation and gelifluction. In the Yorkshire Wolds, head deposits formed during the Late Devensian that consisted of a mixture of aeolian silt and frost-shattered chalk. During the Flandrian this head took much longer to decalcify than pure loess, so it was perhaps protected from fluvial erosion for much longer, due to the cementation effect of the abundant secondary carbonate (Catt <u>et al</u>,1974).

3.4.2 Source of British loess

Local sources have been claimed for some British loess deposits. For example, Pigott(1962) showed that the Millstone Grit could have supplied the heavy minerals present in the loess on the Derbyshire limestone outcrop.

Similarly, Coombe et al(1956) identified possible local sources for the loess on the Cornish serpentine. However, it has become increasingly apparent in recent years that most British loess deposits show a mineralogical similarity that indicates a derivation from one main source. Catt et al,(1971, 1974) first demonstrated the strong mineralogical similarity between the loess of eastern England and the main Late Devensian Till of that area, later named the Skipsea Till (Catt and Madgett,1978). Knowing the strong relationship between loess and proglacial outwash in other parts of the world, they proposed that the loess of eastern England was derived from the outwash deposits of the Late Devensian glacier (which are now largely submerged in the North Sea), presuming that the mineralogy of the Till and the outwash are similar. Eden(1980) found supporting evidence for this theory in the southward fining of the coarse silt mode and of heavy minerals in loess from Norfolk to Kent. This suggests northerly or north-easterly winds bought silt from the North Sea Basin, and Eden speculated that likely source sediments are found on Dogger Bank, Great Fisher Bank and Jutland Bank.

The loess of many other parts of England, for instance on the Chilterns (Avery et al.,1972), the Wiltshire Chalk upland (Cope,1977) and as far west as Devon (Harrod et al.,1973), also has a strong mineralogical affinity with the Skipsea Till, indicating that silt was blown across the country from the North Sea Basin. Strong evidence for the predominantely easterly wind direction that this implies has been found by Catt(1978) in the gradual westward decrease in the modal silt diameter in loess samples and the westerly increase in chlorite content, which he attributed to the winnowing effect of the wind.

It is unlikely, however, that all British loess deposits are formed mainly of material from one source in the North Sea Basin, particularly in view of the presence of potential source deposits in western Britain associated with the glaciation of the Irish Sea Basin. A number of authors (Lee,1979; Vincent and Lee,1981; Catt and Staines, 1982) have alluded to the possibility that loess in the extreme west of England could be derived from Irish Sea glacial outwash, but there has been no published mineralogical confirmation of this. However, D. Case (U.M.I.S.T.,pers.comm.) has found that loess on the Carboniferous Limestone of West Wales is mineralogically comparable to the Irish Sea Drift. Also, Catt and Staines (1982) have found that the loess in Cornwall and the Scilly Isles has a significantly different mineral assemblage and modal silt diameter from loess in east Devon, and is probably derived from a different source and direction. Therefore it seems likely that the western parts of England and Wales have received loess from proglacial outwash in the Irish Sea by westerly or northerly winds.

Nearly all British loess deposits have a component, mainly sand but also some silt and clay, that can be attributed to local sources (Weir et al.,1971; Catt et al.,1971; Avery et al.,1972; Harrod et al.,1973; Chartres, 1981). Often this material has been incorporated into the loess during reworking by gelifluction and fluvial action, but in some instances deposition with the far travelled silt by the wind is likely (Catt et al.,1971). It is reasonable to suppose that local sediments were reworked by the same periglacial winds as carried the silt, resulting in a small local aeolian component in the loess.

However, not all the sand in loess deposits is locally derived. Harrod et al., (1973) in Devon and Weir et al.,(1971) in Kent found that a proportion of the fine sand in the loess of those areas was mineralogically similar to the silt, and has far too rich an assemblage to be derived from local deposits. They concluded that the silt carrying winds also had a small saltation load of far travelled fine sand.

3.4.3 Age of British loess

As the bulk of British loess seems to be derived from Late Devensian glacial deposits, it has been proposed that the loess is also mainly Late Devensian (Catt,1978). Although no dateable deposits have been found under the loess to indicate when deposition began, overlying deposits have been dated at two sites at least. In Kent, Kerney(1965) has found loess underlying pellety chalk muds of the Older Dryas period, dated by molluscan analysis. In Yorkshire, loess-containing chalky head deposits are overlain by the Late Devensian Skipsea Till which also overlies organic deposits dated to 18,500 B.P. by radiocarbon assay (Penny et al.,1969). Catt et al.,(1974) concluded, therefore, that the loess was deposited in a few thousand years before 18,500 B.P., as the Late Devensian glacier advanced over the North Sea floor. Elsewhere in Britain, the incorporation of loess in head and other periglacial deposits also suggests deposition during or immediately before the severe periglacial conditions that preceded the Late Devensian glacial maximum of approximately 18,500 B.P.

In north-west Belgium and north east France, the parts of Europe nearest the English loess deposits in Kent, Pleniglacial B (Late Devensian) loess is also widespread and often overlies pre-Wurm (pre-Devensian) Pleistocene deposits (Paepe and Vanhoorne,1967). However, in Normandy (the part of continental Europe nearest south Hampshire) and in other parts of Europe, there are three separate loesses attributable to the Weichselian (Devensian) period, the uppermost of which is Late Devensian (Coutard et al.,1970; Juvigné,1978). Only one loess deposit in England has been attributed to an earlier Devensian period, that by Swanson(1968) in south Hampshire, so one problem in the correlation of continental loess stratigraphy with that of Britain is to explain the virtual absence of Pleniglacial A(Middle Devensian) and Early Glacial (Early Devensian) loess. In Belgium, the two early Vistulian

(Devensian) loesses were also derived from glacial outwash on the North Sea floor and have a very similar heavy mineralogy to the Vistule 3 (Late Devensian) loess (Juvigné,1978). It seems unlikely that aeolian silt was not deposited in southern England during the earlier Devensian cold periods as the same sources and wind directions were probably present as in the Late Devensian. The most likely explanation for its apparent absence is that it has been removed by erosion before the Late Devensian. Even if some has survived it is likely to have been incorporated in head and other deposits, and might be difficult to recognise because of mineralogical similarity to Late Devensian loess.

Isolated deposits of pre-Devensian loess have been reported in southern England at Northfleet, Kent (Burchell,1935; 1954), Bobbitshole near Ipswich, Suffolk (West,1958), Barham, Suffolk (Rose and Allen, 1977) and at Red Barns near Porchester, Hampshire (Avery et al., 1982). The Northfleet and Red Barns loesses are likely to be Wolstonian because they occur between Ipswichian and Hoxnian deposits and contain Lower Palaeolithic artefacts (Avery et al., 1982). The loess at Barham and elsewhere in Suffolk underlies the Anglian Lowestoft Till and is likely also to be Anglian in age (Rose and Allen, 1977).

Lill and Smalley (1978) suggested that pre-Devensian interglacial loess deposits are present in England, most notably in the Thames Valley (Kennard, 1944) and at Warren House Gill, Co. Durham (Trechmann, 1919). However, Catt(1979b) reviewed the literature relevant to these deposits and concluded that those in the Thames Valley are probably not aeolian, and that the loess in Co. Durham is likely to be Late Devensian because it is buried by Late Devensian till in a similar way to the loess in Yorkshire (Catt et al.,1974).

The pre-Devensian loess deposits of Britain have probably been eroded by the same mechanisms as have affected the Late Devensian loess, but over a longer period. This probably accounts for the rarity of deposits, but more will undoubtedly be recognised as their mineralogical characteristics become better known.

3.4.4 Relationship between Late Devensian loess and coversands.

Devensian aeolian sand deposits are quite common in England, though many are associated with a later phase of aeolian activity than that which deposited the Late Devensian loess. The Shirdley Hill Sand of Lancashire (Wilson et al., 1981) and the coversands of Lincolnshire (Straw, 1963) and the Vale of York (Mathews, 1970) were deposited c. 10,000 years b.p. (Late Devensian Zone 111) and belong to the later phase. In Norfolk, Suffolk, Essex and elsewhere, however, aeolian sands occur in close association with Late Devensian loess, though their precise age is not known. Perrin and co-workers (1974) showed that southern and eastern England could be divided into aeolian provinces according to the presence in topsoil samples of aeolian silt, sand or sand/silt mixtures (Fig 3:2). They suggested that where sand/silt mixtures occur, the sand arrived first and has a maximum age of 19,500 ± 650 years b.p. They found no sites where the silt was involved in periglacial structures and suggested that it therefore post-dated the last phase of intense periglacial activity (Zone 111 of the Late Devensian, c 10,000 years b.p.?). This age contradicts the views of Catt et al., (1971,1974), who attributed the silt content of the mixed sand/silt coverloams of Norfolk to the Late Devensian on mineralogical and stratigraphical evidence. Eden(1980) also found that the mineralogical evidence indicated that the silt in the coverloams of Essex was Late Devensian. Furthermore, he found no evidence for a stillstand in aeolian activity between the deposition of the silt and the underlying aeolian sand and thought that the sand was therefore Late Devensian as well. However, he regarded the origin of loess outcropping on the cliffs at Walton on-the-Naze as different

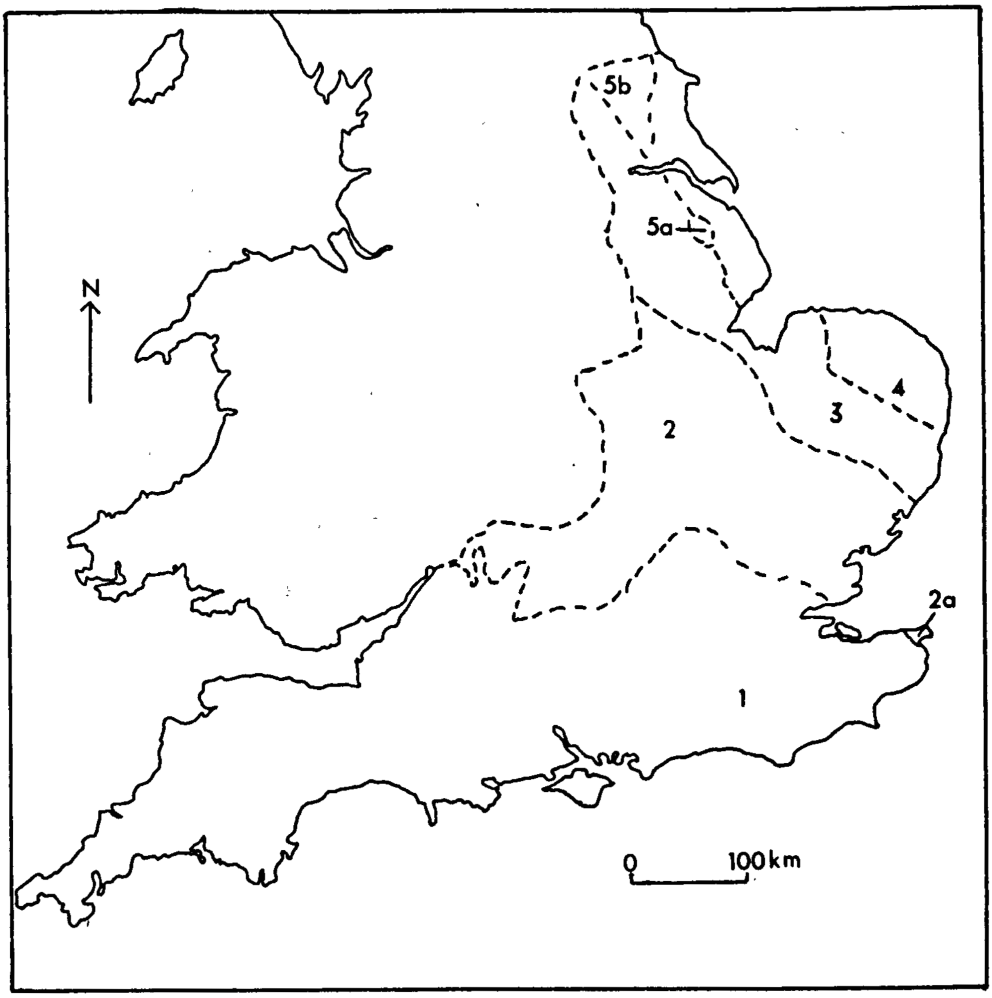


Fig. 3.2 Late Pleistocene aeolian provinces in eastern and southern England (from Perrin et al. 1974)

Key: 1 silt, 2 silt and sand, 3 sand,
4 silt and sand, 5 silt.

because it is not involved in periglacial structures; he suggested it may be contemporaneous with the Late Pleistocene silt of Perrin et al.,(1974) and Cover Loam II of Belgium (Paepe and Vanhoorne,1967). In contrast, Hails and White (1970) described a variety of periglacial features at the Naze, and the loess was seen to fill ice wedges, indicative of mean annual temperatures lower than - 6°C. (Pewé,1966).

The study area in south Hampshire falls entirely within province 1 of Perrin et al., where they claim the great majority of soils should only have had additions of aeolian silt. However, they found a few soils in this province with secondary peaks in the sand fraction, and suggested that aeolian sand may have been deposited locally. The well known aeolian silty sands of Somerset (Palmer,1934; Findlay,1965) fall within province 1, and Gilbertson and Hawkins(1978^{a}) have shown that they are Devensian.

CHAPTER 4

GENERAL FIELD SURVEY

4.1 Introduction

This chapter presents the results of work done in the study area which aimed to determine the distribution, characteristics and field relationships of the brickearth. A considerable programme of fieldwork was required because, as shown in Chapter 2, previous work has not adequately described these aspects of the brickearth. Two specific aims of the survey were as follows: 1) map the brickearth and describe its variability, particularly with respect to landscape facets such as the terrace levels (Everard,1954); 2) sample the brickearth for laboratory analysis at a large number of points chosen from the mapping programme.

4.2 Mapping of the Brickearth

4.2.1 Methods

As lack of time precluded detailed surveying of the whole study area, it was decided to make an intensive ground survey of a part that contains the full range of landscape facets present over the whole area, and use the knowledge gained to estimate the distribution of brickearth in adjoining areas. The part chosen was the triangle of land between Highcliffe (SZ215931), St. Leonard's Grange (SZ417982) and North Charford (SU198196). The full range of terraces (5 to 128m) is present and the solid geology includes Headon, Barton, Bagshot and Bracklesham Beds. The southern part forms the agricultural, coastal fringe of the New Forest District and the northern part consists mainly of heathland or woodland plantation.

The chosen scale of field maps was 1:25,000, a common scale for soil maps when publication will be at 1:50,000 or 1:63,360 (Clayden, 1971; Findlay,1976). Free survey practice was adopted (Burrough et al., 1971). The true useful scale of a map depends on the density of observations made to compile it. Burrough et al (op.cit.) suggested that a published soil map ought to have about 5 observations/cm^2 for optimum presentation of detail, this requires an average of 10 observations/km^2 in field survey for presentation at 1:50,000. In this study, during the initial stages of the survey on a 'new' landform unit, the density of observation was high, about 25-35/km^2; later this dropped to 5-15/km^2 as the relationship between brickearth, landforms and vegetation became better known.

Observations were made with a 90 x 3cm screw auger. A 122 x 10cm bucket auger or a 5cm diameter extending Dutch auger were used where information was required below 90cm depth. Use was also made of exposures on cliffs, ditches and gravel pits, and these proved valuable in assessing the lateral variability of the brickearth.

The minimum thickness of brickearth mapped was 20cm, as it was found that lesser thicknesses had a very patchy distribution that was difficult to map accurately. In Yorkshire and elsewhere in Britain the minimum thickness of loess that has been mapped is 30cm (Catt et al., 1974;Catt,1978), and for Europe the INQUA loess map shows a minimum cover of 40cm over at least 25% of any one area (Fink,1976). However, from the agricultural viewpoint it is desirable to map the thinnest detectable loessic drift as even a very thin cover can make considerable improvements in soil fertility (Catt,1978).

In parts of the study area mapping was aided by air-photograph interpretation. It was hoped that soil boundaries found by detailed ground survey could be related to tonal contrasts on the air-photographs, and then extrapolated into adjacent areas. In southern England tonal variations on monochrome air photographs indicate colour changes in the bare soil surface, crop patterns related to soil moisture status, or variations in semi-natural vegetation (Evans,1972). Ploughed soil surfaces are usually seen in March or April and crop patterns in July when the soil moisture deficit is at a maximum (Evans,1975). Thus the timing of photography is critical for detecting soil patterns.

R. Evans (Soil Survey of England and Wales, pers. comm.) studied air photographs of the area and observed relict periglacial features in the subsoil and semi-natural vegetation variations. It was therefore decided to examine air-photos that had been flown in summer. Unfortunately, none were taken during the extremely dry summers of 1975 and 1976. Of those taken in other summers, the 1971 coverage at a scale of 1:10,000 was the most complete; it was flown by BKS Survey Ltd., for Hampshire County Council during May, July and September. Financial constraints dictated that coverage for only part of the mapping area could be obtained, and this is shown in Fig. 4.1.

4.2.2 Distribution and Stratigraphy

As the mapping progressed, it became clear that the single mapping class 'brickearth' was inadequate and could be divided into at least two subclasses based on stratigraphical, lithological and pedological distinctions. 1) The upper brickearth is a silt loam, sandy silt loam or sandy loam and has a brownish (hues 10YR -7.5 YR) colouration throughout, suggesting soil formation in the Late Devensian and Flandrian periods only (Catt,1979a). 2) The lower brickearth is more variable in texture, but usually has a higher clay content and always a higher clay: silt ratio. It usually has a strong brown or reddish (hues 7.5 YR or redder) colouration and often has greyish streaks associated with pores, root channels and fissures. It often contains reddish mottles (hues 5YR or redder), and shows all other field characteristics of paleo-argillic B horizons as defined by Avery(1980), implying it was subjected to Ipswichian and/or earlier soil formation processes.

The lower brickearth is nearly always overlain by upper brickearth but the latter is more extensive and often directly overlies

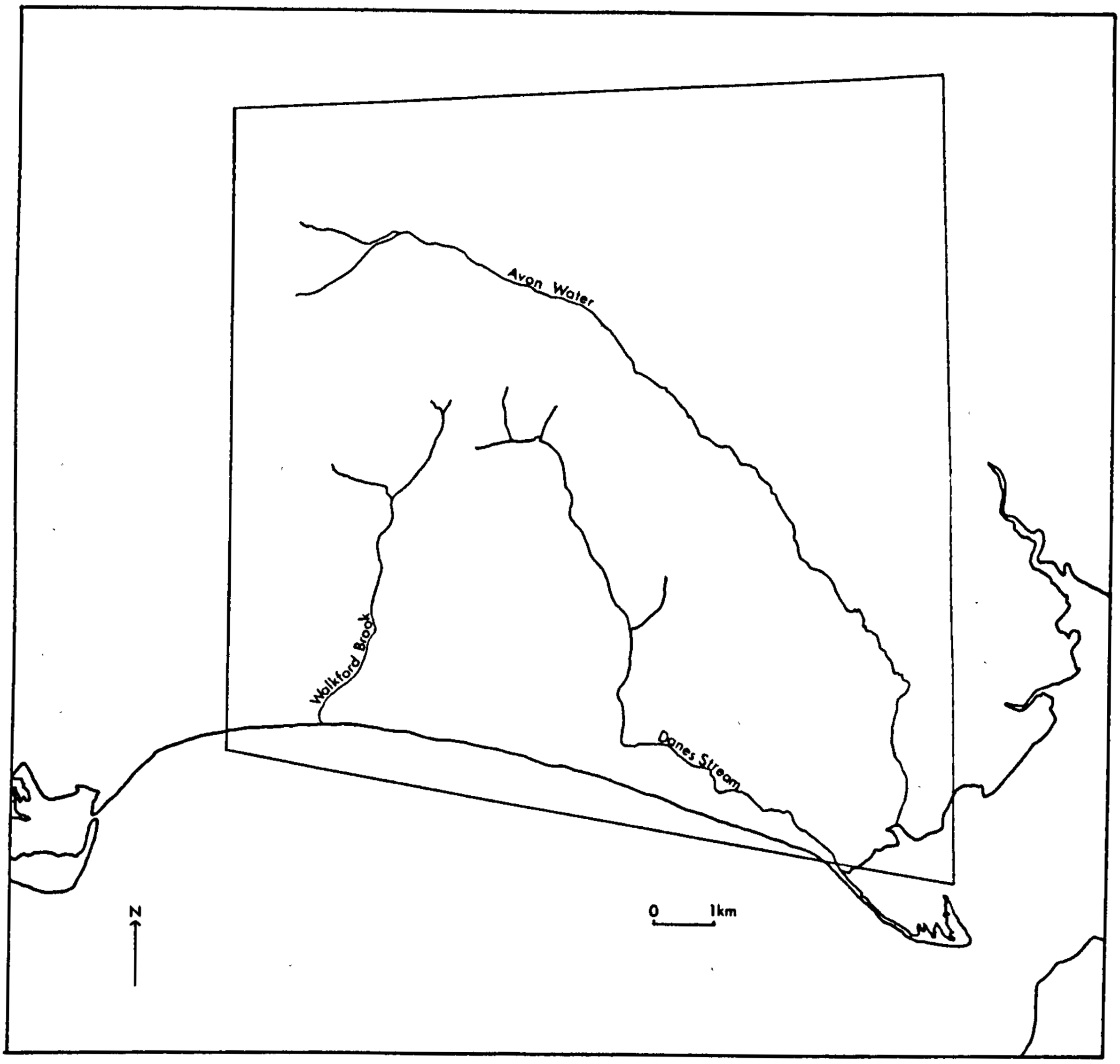


Fig. 4.1 Extent of air-photograph coverage.

gravels. The two classes are distinguished on the brickearth distribution map, Fig.4.2. (inside back cover).

The two brickearths have a far wider distribution than the brickearth shown on maps of the I.G.S. or other authors. As noted by Keen(1980) and other workers, the brickearths distribution is closely related to that of the Plateau Gravel; nearly every terrace fragment has at least a partial cover of brickearth. Notable exceptions are the very small, much eroded terrace fragments around Lyndhurst (SU300080), and the slightly larger terrace fragments at Matley Heath (SU325075) and Denny Lodge (SU360065), though thin (<20cm) patchy mantles were recorded on some of these. The inter-terrace bluffs of the area are covered in gravel that has been redistributed by gelifluction, and these too are usually mantled by brickearth. The Valley Gravels mapped by the I.G.S. north and west of Brockenhurst (SU295035) are also brickearth-covered. Although outwith the mapping area, the Valley Gravels of the Avon terraces were noted to have a brickearth cover near Godwinscroft (SZ183963) and Hinton (SZ189944), and it is likely that brickearth is widespread over gravels throughout the lower Avon valley.

This study confirms the tendency, noted by several authors, for the brickearth to be more widely distributed in the south of the New Forest. It is unlikely, however, that this is due to preferential deposition of the brickearth in the south. A simpler explanation is that the brickearth is less eroded in the south. This is because the gravel terraces there are younger, less dissected and consequently more extensive. These flat well-drained terraces provide stable sites for the brickearth, in contrast to the strongly dissected northern New Forest.

It was anticipated that some brickearth would occur on Tertiary strata. Only one site was found, however, on Balmer Lawn (SU310035) where a thin (20-40cm) layer of flinty upper brickearth overlies Headon Beds. It is possible that other such sites exist, but in general brickearth is absent from the Tertiary strata. This is probably because the Tertiary outcrops of the New Forest are subject to great erosion because of high water tables and the juxtaposition of unconsolidated permeable and impermeable strata.

E.C. Freshney recently remapped the Southampton Sheet (NO.315) for the I.G.S. and confirmed (pers.comm.) that no brickearth was found over Tertiary beds. He observed that Barton Sand outcrops are partiaularly unstable and liable to mudflow erosion when saturated after heavy rain. Tuckfield (1963,1973,1974) described a variety of erosional forms and processes active today on the Tertiary outcrops, including seepage steps, gully erosion and landslips. These processes would have been even more active during the wetter phases of the Late Devensian and Flandrian and probably led to the destruction of the brickearth cover.

The upper and lower brickearths both thin towards the edge of terrace fragments, though the lower brickearth usually feathers-out first. For example, on the northern edge of Beaulieu Heath west (SU363017) the upper brickearth occurs to within 100-200m of the break of slope that marks the terrace fragment edge, whereas the lower brickearth is generally absent within 400-500m of the edge (Fig 4.2). This relationship suggests that erosion between deposition of the two brickearths was greater than the erosion of the upper brickearth. On smaller fragments that are more readily eroded, the lower brickearth has often been almost completely removed and is present only as thin patches or pockets that are too small to map. On terraces below 80m O.D., dissection has been greater in the area west of the Lymington River than to the east, where, as a result, the lower brickearth is more extensive. On the broad 46m terrace fragment at Beaulieu Heath (SU345015), for example, the lower brickearth is well preserved, but at the same level at Barton (SZ235930) it is almost completely absent. It was previously widespread on the western terrace fragments, because it occurs within involutions in upper parts of the terrace gravel, as on Hordle Cliff (SZ269921; Section 5.2.12). This association with periglacial disturbances suggests that much of the erosion of the lower brickearth could have been by geliflucton.

Some of the brickearth eroded from terrace surfaces can still be found in the valleys incised into the terraces. Above the Tertiary deposits in many valleys there is usually a layer of gelifluctd gravel, and slope deposits derived from the brickearth frequently overlie this. For example, at Broadley Farm (SZ254983) the lower slopes of the Danestream Valley are mantled to 90cm depth with a poorly sorted mixture of brickearth and flints from the gravel. The reddish colour and clayey texture of this deposit suggests it is derived largely from lower brickearth. Weakly stratified colluvium derived from upper brickearth is present over geliflucted gravel in some valleys, particularly in the south-western part of the mapped area. In the Danestream valley south of Ashley Bridge (SZ265938) this deposit mantles almost all slopes to a depth of up to 90cm. Similar deposits are particularly well represented in the valleys incised into the 56m terrace near Wilverly Plain (SU255015) and have been mapped and studied in some detail (Section 5.2.14). Elsewhere, slope deposits were not mapped because the locating of their boundaries proved to be very unpredictable and therefore excessively time consuming.

4.2.3 Sampling of the upper brickearth

As the upper brickearth forms a very widespread cover over the gravel terraces of the area it was sampled (mainly for laboratory analysis) at many points to assess its variability. Grid sampling was avoided in case it mirrored periodicity in the landscape (such as the succession of terraces). Instead, a stratified random point sampling plan was chosen (Webster,1977). Random number tables (Fisher and Yates,1963) were used to provide a series of six-figure O.S. grid references; over-clustering of points was avoided by imposing a limit of one sample point per kilometre grid square. This method has the advantage over simple random sampling of requiring fewer sample points to achieve a given standard error and has similar precision to systematic sampling (Webster,1977).

The location of the sample points is shown in Fig 4.3 . The information recorded at each site was as follows: slope angle; vegetation; depth, colour and texture of the major soil horizons. Bulk samples for laboratory analysis were taken at 20cm from the surface.

4.2.4 The value of air-photograph interpretation

The air-photographs proved to be quite helpful in mapping the brickearth. The relationships found between the brickearth distribution and features seen on the air-photos are as follows:-

1. Strong soil/vegetation relationships were observed in areas of the New Forest with semi-natural vegetation. On well drained sites where >20cm of upper brickearth overlies gravel, gorse (*Ulex europaeus*) and/or bracken (*Pteridium aquilinum*) are often prolific with a ground cover of grasses (*Agrostis* spp.). In contrast, the very acid soils developed in gravel usually support heather (*Calluna vulgaris*; *Erica* spp.) Similar relationships have been noted by Fisher(1975). Fig 4.4 is an air-photograph of the Holmsley Ridge area (photo centre approximately SU209012) showing the terrace edge delineated by tonal contrasts between the very dark gray of *C.vulgaris* on the terrace surface and the lighter greys of *Molinia caerulea* growing on poorly drained head on the slopes. In the terrace centre the very light grey patch represents *Pteridium aquilinum* which ground checks showed to demarcate the distribution of upper brickearth very accurately. To the north the outlined light grey patches represent bracken growing on upper brickearth colluvium.

This technique must be used with frequent ground-checks or else misleading results may be obtained. For example, the distribution of

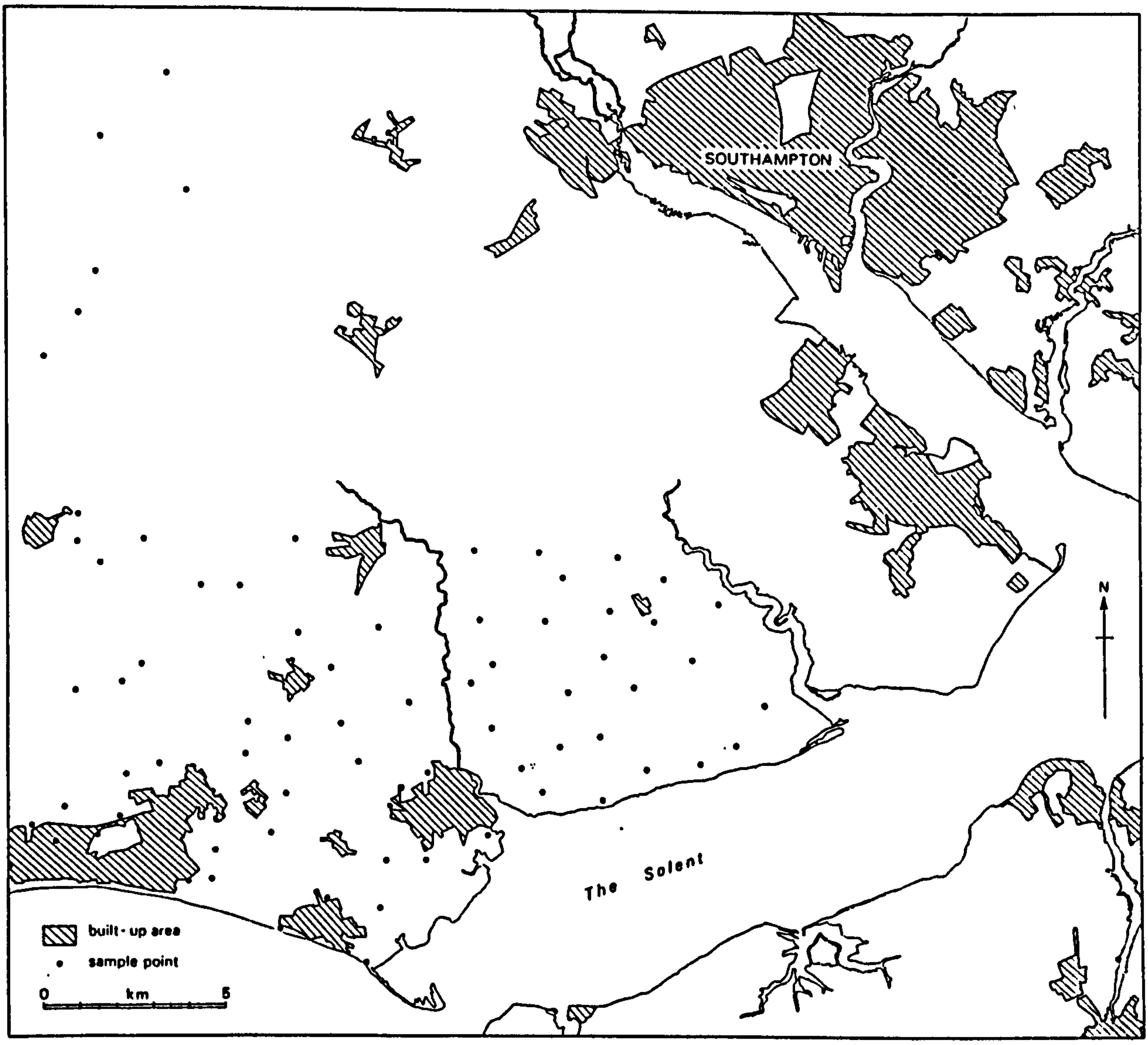


Fig. 4.3 Location of stratified random samples.

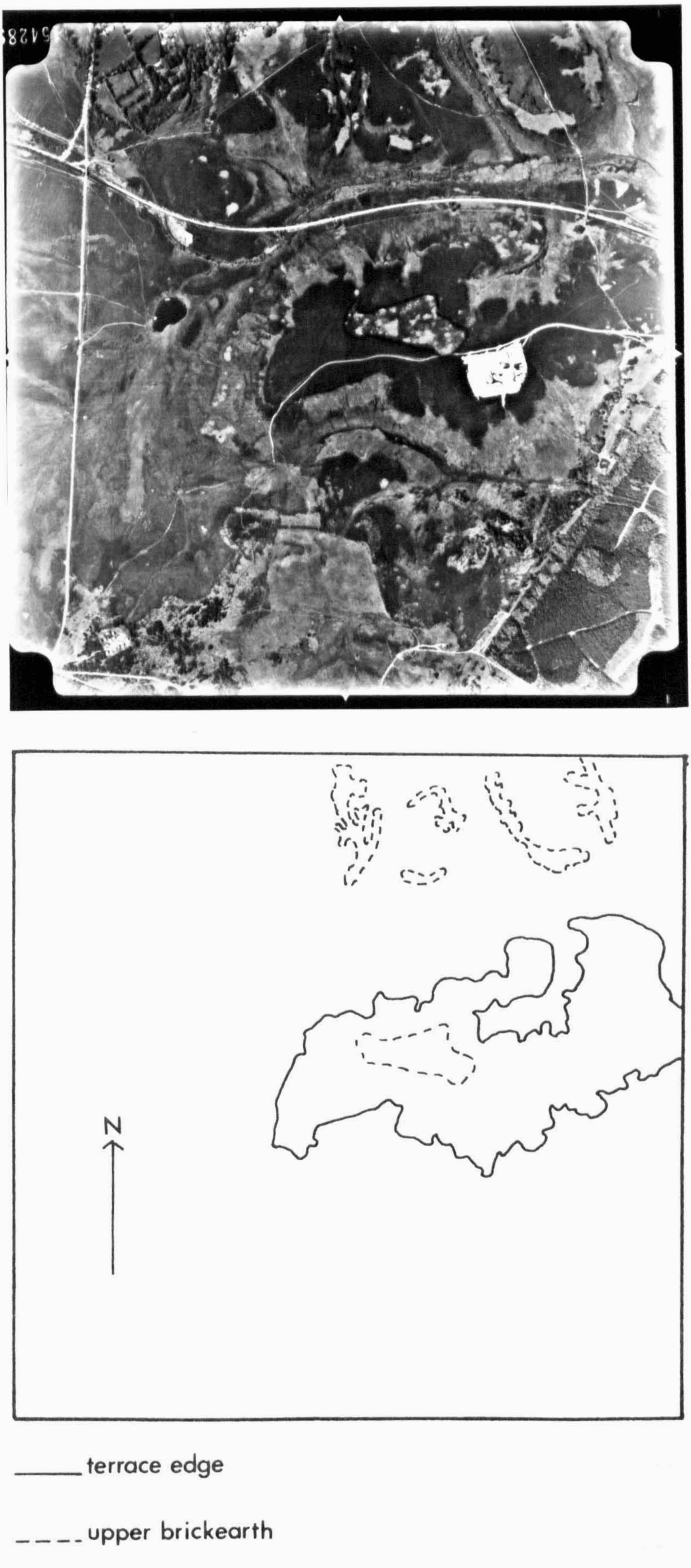


Fig. 4.4 Soil mapping interpretation of an air-photograph of the area around Holmsley Ridge (SU209012)

gorse is also related to sites of former cultivation and other disturbances where gravel soils have been improved by bringing nutrients to the surface (Jones and Tubbs, 1963; Tubbs and Jones, 1964). Also, C. vulgaris often succeeds burning of gorse on brickearth soils and this may appear on air-photos. In both of these examples the brickearth soils may be indistinguishable from gravels on the air-photos. Another interpretation problem is that a damp heath vegetation usually grows on soils with a thick, continuous lower brickearth horizon, probably because the lower brickearth impedes drainage and prevents growth of gorse or bracken. On air-photographs this damp heath produces a very dark grey tone that is difficult to separate from the tone of dry heath on gravel soils.

2. The second type of feature on air-photographs that helped with mapping was crop patterns resulting from variations in soil moisture deficit (Evans,1972). They are common where loamy drift overlies freely drained gravel. In typical British summer conditions the growth of crops is restricted when the depth of the loamy material falls below about 1.2m (Evans, pers. comm). If regular variations in the depth of loamy material occur, as with subsoils containimg periglacial stone or wedge polygons and stripes, the pattern of the features is reflected in crop growth. The identification of such features on air-photographs of gravel terraces reveals that loamy material exists over the gravel and that its average thickness is less than 1.2m .

Figure 4.5 is an air-photograph of the area surrounding Wilverly Plain (Photograph centre approx. SU260014). The three large light grey patches are the Wilverly Plain, Longslade Bottom and Yew Tree Bottom 'lawns'. These are unenclosed pasture sown to grass between 1948 and 1950 as part of the New Forest Pastoral Development Scheme (Browning, 1951). On each of the lawns a pseudomorph polygonal pattern can be seen on the flatter areas passing into stripes on the slopes, where the pattern is clearer because the brickearth is thinner.

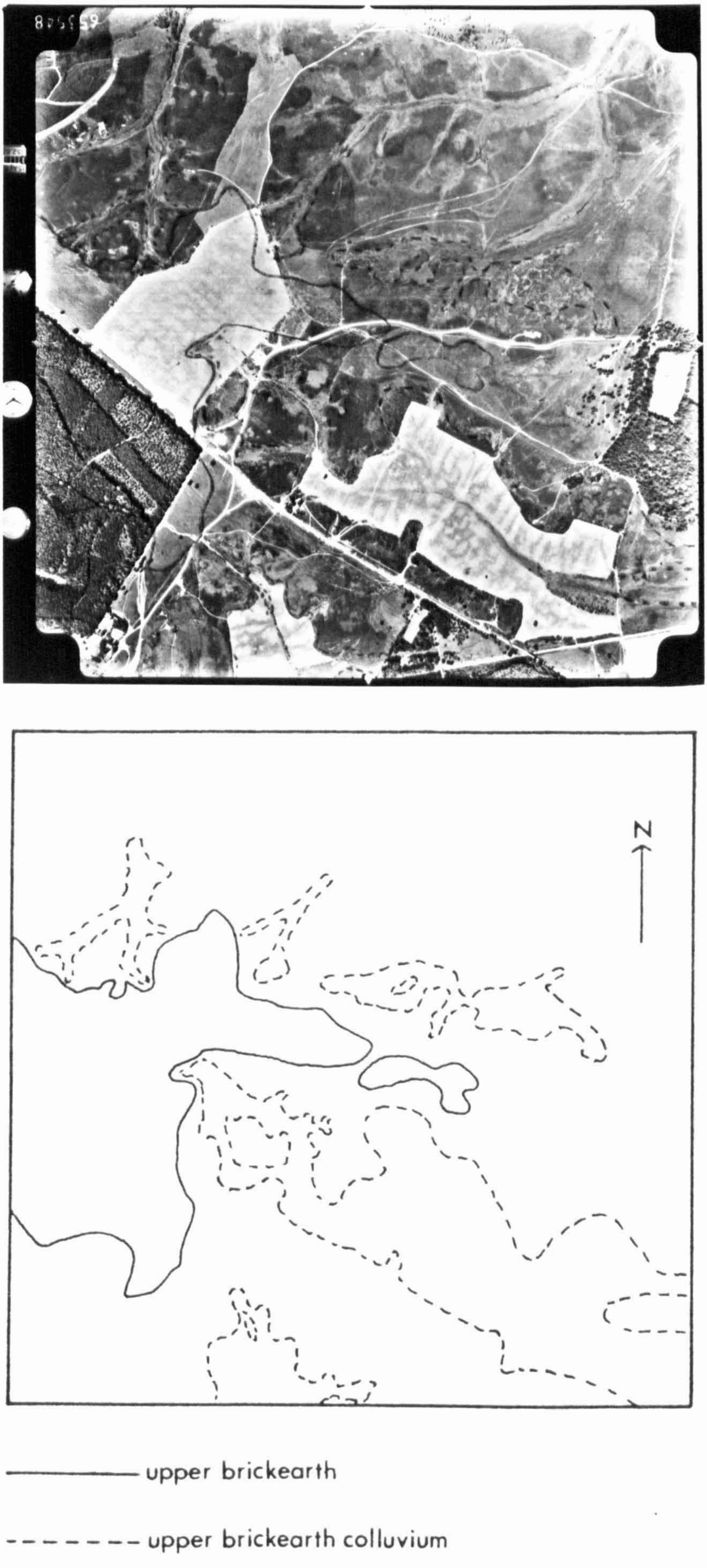


Fig. 4.5 Soil mapping interpretation of an air-photograph of the area around Wilverly Plain (SU260014).

Similar patterns are visible on all terraces with cultivated soils between 5 and 56m (there is no cultivation on the higher terraces). The patterns show up best near the edge of terrace fragments where the brickearth thins to less than 1.2m. Boundaries were placed where the patterndisappeared near terrace edges (due to feathering out of the brickearth), and adjusted after ground checks. On Fig 4.5 the solid line represents the edge of the upper brickearth on the terrace surface and the dashed line the extent of colluvium derived from upper brickearth on the slopes. The latter boundary was drawn in the adjoining areas of semi-natural vegetation from the distribution of gorse.

The main problem with this mapping aid is that the patterns do not show in all crops all the time, so an incomplete picture is obtained. On the photographs used in this study the best pattern was shown on the unenclosed grass leys. On the cultivated terraces the pattern is seen better in cereals than grass. Elsewhere in England crop patterns also show better in the cereals than grass, partly because cereals display stress at soil moisture deficits of 10 - 20mm less than grass (Jones and Evans, 1975). Why the unenclosed grass leys show the best patterns in the study area is not clear. On the cultivated terraces patterns were usually only seen in fields with cereals or grass, so intervening fields all required ground checks.

4.2.5 Origin of polygon and stripe features.

The polygons and stripes seen on air-photographs have remarkably consistent dimensions , tonal contrasts andform on all terraces. The polygons have diameters that vary between 30 and 60m and rims 10 to 30m wide (though most are 10 to 15m wide). The stripes are usually 30 to 60m wide and 10 to 20m apart. The centres of the polygons and stripes have a lighter tone than the rims. Dark-toned rims are indicative of better crop growth and suggest that there is a greater thickness of water-retentive soil beneath (Evans and Jones,1977).

In many other areas of England where loamy drift overlies gravel terraces the polygons seen on air-photos have been shown to reflect relict ice wedge polygons in the subsoil (Evans,1972). However, the examination of many miles of section in the study area has failed to locate a single convincing ice-wedge. Three ice-wedges were described at Highcliffe (SZ215931) by Lewin(1966b), but these are no longer visible, presumably due to cliff erosion. From the evidence compiled by West (1977, p317) it seems unlikely that Devensian ice wedges occur in south Hampshire, probably because the climate was never cold enough. The form of the patterns seen on the photographs suggests in fact they are not ice wedges, because ice-wedge polygons retain their shape on slopes (Embleton and King,1975) whereas the polygons in the study area pass into stripes.

Another type of periglacial patterned ground that forms polygons on level ground and stripes on slopes is caused by ice sorting of stones. However, concentration of stones on the rims would cause poor crop growth, so it is unlikely that the polygons in the study area are sorted stone features.

A third possibility is that the patterned ground represents trough polygons and stripes. These have previously been seen on the chalk landscapes, particularly the Breckland of Norfolk (Williams,1965). In section this pattern shows a rythmically undulating interface between the topsoil and the underlying Chalk-sand drift. The polygons and stripes are thought to have formed by frost-heave processes, the ridges (polygon and stripe centres) being the zone of maximum upthrust (Corbett 1973).

Undulations in the brickearth-gravel interface in the soils of the study area have previously been reported at Efford Experimental Station (SZ303937) (Soil Survey Internal Report,1962). On Wilverly Plain (Fig 4.5) augering at frequent intervals along several transects revealed regular variations in the depth of brickearth over gravel (Fig 4.6). Most auger borings showed 50-75cm of upper brickearth lying directly on gravel, but in about 20% of borings the upper brickearth was thicker and sometimes overlay lower brickearth to a total depth of up to 100cm. This suggests that there may be depressions in the gravel surface filled with lower brickearth and/or upper brickearth. Pockets of lower brickearth lying in shallow depressions in the gravel surface have been noted above (section 4.2.2), and the one at Hordle Cliff is described in section 5.2.12. A possible origin of these depressions is illustrated in Fig 4.7. In Longslade Bottom (Fig 4.5) where the air photographs show stripe features on the slopes, detailed augering has revealed that in about 20% of borings the colluvium derived from upper brickearth overlies Barton Sand rather than gravels (Fig 5.11, point 9). Possibly the stripes on air-photographs reflect lobes of gelifluсted gravel separated by gravel free zones where plant roots can obtain more moisture from the Barton Sand.

Thus the patterned ground could be associated with subsoil trough features, although, as far as is known, such features have never been reported before on gravel terraces. Its correlation with trough polygons and stripes on the Chalk is problematical because the diameter of the Chalk polygons are much smaller (average 10m; Evans,1972) than those in the study area.

4.3 Field Characteristics of the Brickearth

4.3.1 Thickness

As there is ample evidence to suggest that both the upper and lower brickearth have suffered considerable erosion, especially near the terrace margins, the best estimates of their original thickness will be obtained in the centre of large terrace fragments. On sites where upper brickearth directly overlies gravel, the maximum thickness of the upper brickearth varies only a little between terraces. For example,

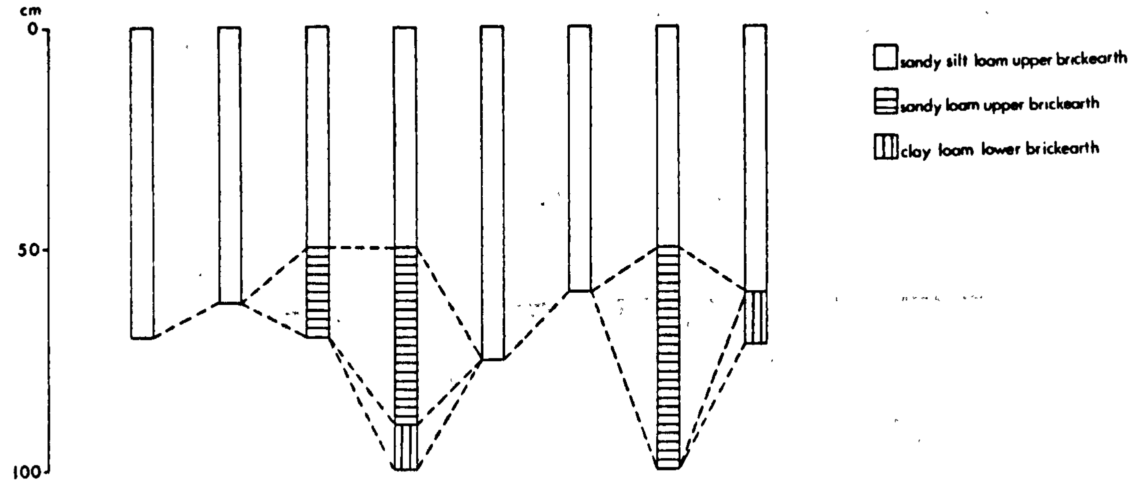


Fig. 4.6 Variation in soil characteristics in auger borings taken along a transect on Wilverley Plain (SU260014)

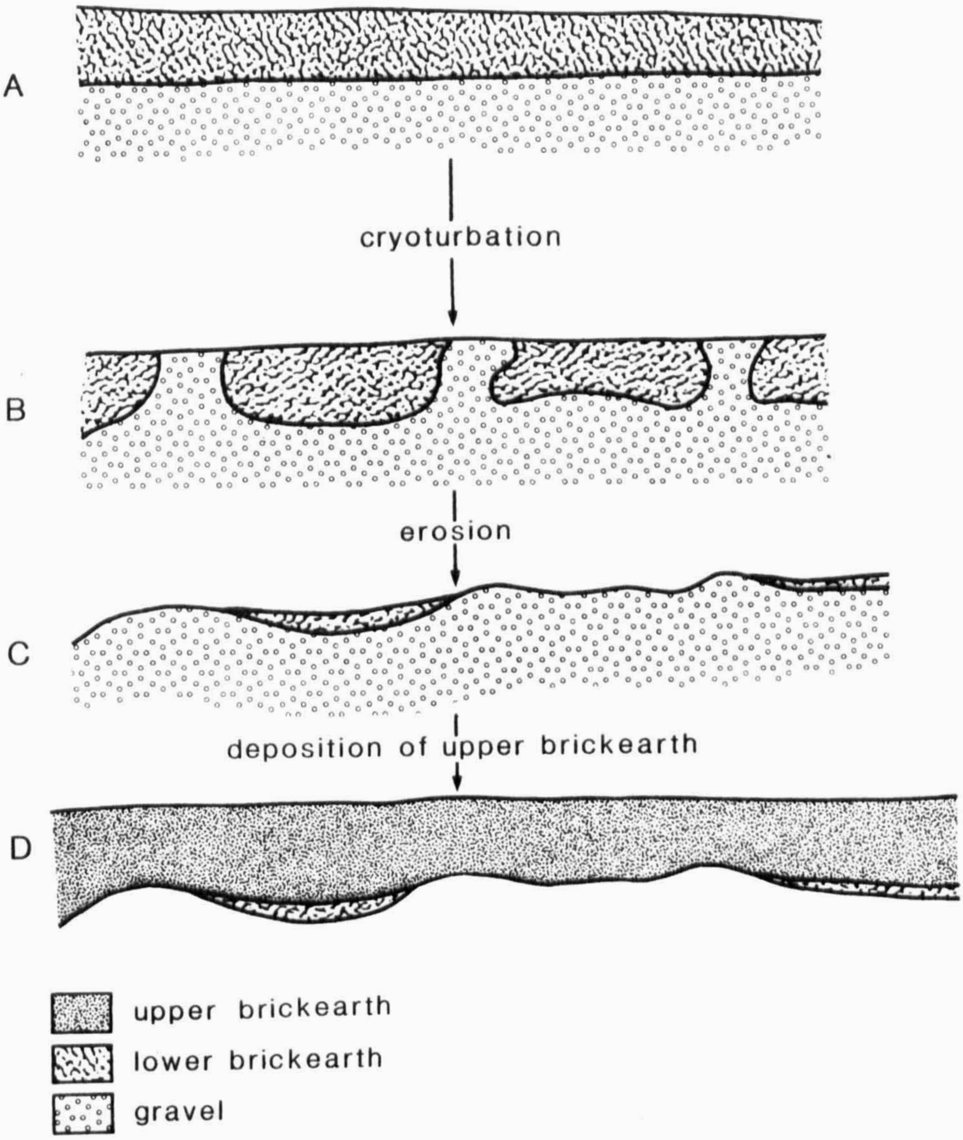


Fig. 4.7 Possible mode of formation of trough features

on the 56m terrace at Wilverly Plain (SU253003), the 46m terrace at Mount Pleasant (SZ292978), the 31m terrace at Ashley Manor Farm (SZ256940), the 21m terrace at Barnes Farm (SZ287925) and the 5m terrace at Vidle Van Farm the range of thicknesses recorded was 75 to 120cm. On the long cliff section between Barton on Sea (SZ220932) and Milford on Sea (SZ288913), traversing the 46, 31 and 21m terraces, the thickness in the centre terrace fragments ranged from 120 to 150cm. The greatest thickness recorded was 275cm at Bashley Manor Farm (SZ233962) but this was at the base of a bluff separating the 50m and 46m terraces and is likely to include material washed or geliflucted from the 50m terrace. The maximum thickness recorded at a terrace centre site was 230cm on the 46m terrace at Barton Cliff (SZ235930) so this is the best estimate of the original thickness of the upper brickearth. No evidence was found that significantly different amounts of upper brickearth had been deposited on each terrace.

The upper brickearth tends to be much thinner where it overlies a continuous layer of lower brickearth than where it overlies gravel. For example, on Beaulieu Heath (SU340015) its thickness rarely exceeds 35cm and on the narrow high level terraces (128, 119 and 113m) it averages only 20cm. The thinness of these deposits is almost certainly due to erosion. The rich-clay lower brickearth tends to impede drainage and therefore makes the overlying upper brickearth susceptible to structural breakdown and sheet or stream erosion. As with the Late Devensian loess cover elsewhere in England, much of the erosion could have occurred in the wetter periods of the Flandrian (Catt,1978).

The lower brickearth has a similar maximum thickness to the upper brickearth, but continuous thin sheets (less than 40cm) are not common. This is probably because it has been subject to erosion over a much longer period than the upper brickearth and those sites that are open to erosion have become almost completely denuded. Thus most continuous sheets, for example Fritham Plain and Ocknell Plain, are > 70cm thick. The thickest deposits, on Beaulieu Heath (SU340015) and at Holbury gravel pit (SU426049), are 100 and 180cm thick respectively, but the latter includes two separate lower brickearth deposits (Section 5.2.11).

4.3.2 Stone Content.

Both the upper and lower brickearth contain varying amounts of mainly flint stones, similar to those found in the underlying gravels. Thick deposits (> 90cm) of upper brickearth tend to be much less stony than thinner ones. Hodgson (1967) noted this in the brickearth of West Sussex and attributed it to greater frost heaving in the thinner deposits. Presumably in thick deposits the lower boundary of the mobile layer during summer thaws was above the gravel so there was little deformation of the brickearth-gravel interface.

The variations in stone-content can be seen in the cliff section between Barton and Highcliffe. At Barton (SZ235930) the 230cm thick section of upper brickearth is almost stone-free. Further west, it thins to 30cm on the break of slope at Highcliffe Castle (SZ211930) and here the upper brickearth contains 25 to 30% flints.

Although these stones are likely to have been introduced by frost heave, festoons are rarely seen in the upper brickearth; a few are visible at Tanners Lane (SZ365953) and at Highcliffe (SZ215931). This is probably because the stones have been redistributed within the upper brickearth by cryoturbation, gelifluction or bioturbation. The last is especially likely as soil fauna (mainly earthworms) are particularly active in Hamble, Hook and Park Gate series soils formed in brickearth (Hodgson, 1967). The fact that the effects of frost-heave are more prevalent at terrace edges where the brickearth thins demonstrates that at least some erosion of the brickearth occurred before the end of the last cold period that could have caused frost heave (the Loch Lomond stadial of the Late Devensian, c 10,000 years b.p.)

Festoons are much more common in the lower brickearth and are often much larger. This suggests that the processes of stone redistribution proposed above were much less effective in the lower brickearth. There is less evidence of faunal activity (earthworms and earthworm channels) in the lower brickearth, possibly because it is more compact, tenaceous and acid than the upper brickearth.

Stone lines approximately parallel to the surface sometimes separate the upper and lower brickearth. These were seen clearly at Lepe Cliff (SZ457984; Section 5.2.5) and in a roadside ditch at Ocknell Plain (SU223099; Section 5.2.8). In the Ocknell section the stone line is 1 to 2 stones (mainly flints) thick, though thicker (up to 6 stones) overlie festoons that penetrate the lower brickearth. At Lepe there are two discontinuous stone lines, one separating the upper and lower brickearths and the other within the lower brickearth. These are 1 to 4 and 3 to 8 stones thick respectively.

Ruhe (1958) concluded that stone lines in soils most often form as an accumulation at the ground surface of lag gravel after run-off has eroded the finer constituents of a stony sediment. This seems a reasonable explanation for the features described here. The stony lower brickearth was probably partially eroded by water on both sites before deposition of the upper brickearth. The thickness of the stone line is probably related to the abundance of stones in the deposit prior to erosion. This would explain why the stone line thickens over festoons at Ocknelland why the lines are generally thicker in the stonier lower brickearth at Lepe.

Ball (1967) described stone lines in some soils in North Wales, and from their relationships to deposits above and below suggested they originated in a periglacial environment and were formed by sheet erosion during a seasonal thaw. He thought that stone lines could be accepted generally as a feature of periglacial morphology and that to be preserved they must be buried soon after formation. If Ball's interpretations are also true for the stone lines found at Ocknell and Lepe, it means that on both a high (113m) and low (5m) terrace similar environmental conditions preceded deposition of the upper brickearth. The ground surface would have been a stone pavement. At Ocknell, some stones are shattered in situ, which is a common feature of periglacial mechanical weathering and is evidence that the stone lines originated in a periglacial environment. For the stone lines to have been preserved, the upper brickearth was probably deposited soon after their formation.

4.3.3 Sedimentary Structures.

Although White (1917) reported that the brickearth (he was probably referring to upper brickearth) at Barton-on-Sea showed indistinct laminations in places, no such features were found during the present field study. Indeed, wherever the upper brickearth lies on terrace surfaces and interfluves it is completely free of fluvial sedimentary structures. Keen(1980) also came to this conclusion. Sedimentary laminations are only found in colluvium derived from upper brickearth on slopes as at Duckhole Bog (SU253017). No sedimentary structures were found in the lower brickearth. However, on interfluve sites the lower brickearth shows evidence of far greater pedogenetic alteration and periglacial disturbance than the upper brickearth, and these may well have obscured original sedimentary structures.

4.4. Conclusions.

The field survey has yielded important new information about the distribution and characteristics of the brickearth. The brickearth has been divided into upper and lower members; the lower brickearth has paleoargillic characteristics.

The upper brickearth is widespread, but is confined to the Plateau and Valley Gravel outcrops, which provide relatively flat, stable sites. On the Tertiary outcrop, a former cover has probably been removed by erosion. Erosion of the upper brickearth has also occurred on the gravel outcrop, especially where there is an intervening layer of lower brickearth. The field characteristics of the upper brickearth (colour, stoniness, maximum thickness) are strikingly uniform, especially on terraces below 56m where thick deposits are common. This suggests it may all have the same origin; no evidence was found that the upper brickearth in its primary position is a fluvial deposit.

The lower brickearth is also confined to the Plateau and Valley Gravel outcrops, but it has been eroded more than the upper brickearth, particularly on terraces below 80m to the west of the Lymington River. The field characteristics of the lower brickearth are more variable than the upper brickearth, possibly resulting from the greater period of post-depositional alteration it has undergone.

Air-photograph interpretation proved useful in mapping the brickearth. Soil/vegetation relationships were observed on photographs of the areas of the New Forest with semi-natural vegetation and crop patterns reflecting patterned ground were seen on photographs of the cultivated parts of the study area. The patterned ground may reflect periglacial trough polygons and stripes in the subsoil.

CHAPTER 5

SITES SELECTED FOR DETAILED STUDY

5.1 Introduction

This chapter presents the field characteristics of soil profiles developed in brickearth at sixteen sites in the study area. These profiles were studied to provide more detailed information on the upper and lower brickearth than was possible from the general survey. There were two major objectives in the selection of the sites: a) to assess the horizontal and vertical variability of the upper brickearth by studying some widely separated, thick profiles; b) to assess the extent of pedological and lithological variation in the lower brickearth by identifying a number of contrasting profiles.

At most sites the soil profiles were described in detail following the method of Hodgson (1974) and where possible, they were classified using the system of the Soil Survey of England and Wales (Avery,1980). Moist soil colours were determined by reference to a Munsell Soil Colour Chart. Bag samples for textural and mineralogical analyses were normally taken from each soil horizon, and undisturbed samples for micromorphological analysis were collected in 4 x 6 x 8 cm Kubiena Frames from the most important soil horizons (Hodgson,1978). Some horizon designations required additional information on micromorphology (from Chapter 10) and particle size distribution (from Chapter 8)

5.2. The Selected Profiles

A brief summary of site and soil characteristics is given in table 5.1. The location of the sites is shown on Fig. 5.1.

5.2.1 Sturt Pond (SZ298910).

This is one of four described profiles that are developed entirely in upper brickearth. The upper brickearth here overlies gravel

TABLE 5. 1

SUMMARY OF SITE AND SOIL CHARACTERISTICS

Site	Terrace Level	Parent Material	Soil Type	Special Features
Sturt Pont	5m	upper brickearth	typical argillic brown earth	
Wilverley Plain	56m	upper brickearth	typical argillic gley	textural discontinuity at 54 cm.
Chilling Copse	11m	upper brickearth	typical argillic brown earth	textural discontinuity at 90cm
Hook Gravel Pit	11m	upper brickearth	typical argillic brown earth	textural discontinuity at 29cm
Beaulieu Heath	46m	upper and lower brickearth	stagnogley podzol (paleoargillic)	coarse red mottles: sand in cracks in lower brickearth
Lepe Cliff	5m	upper and lower brickearth	typical paleoargillic	rare fine red mottles; stone lines
Thorns Farm	5m	upper and lower brickearth	typical argillic gley (paleoargillic)	sand-filled fissures in lower brickearth
Tanners Lane	5m	upper and lower brickearth	typical argillic gley (paleoargillic)	coarse red mottles: rounded flint pebbles in lower brickearth.
Ocknell Plain	113m	upper and lower brickearth	paleoargillic stagnogley soil	rare fine red mottles; stone line
Calveslease Copse	46m	undifferentiated brickearth		fossil pingo? brickearth laminated
Rockford Common	70m	undifferentiated and lower brickearth	earthy man made humus soil (paleoargillic)	texturally similar brownish over reddish brickearth

TABLE 5.1 (Cont.)

Site	Terrace Level	Parent Material	Soil Type	Special Features
Holbury Gravel Pit	46m	lower brickearth		two layers of lower brickearth
Hordle Cliff	21m	lower brickearth		
Wootton Heath	56m	lower brickearth	typical argillic gley (paleoargillic)	
Longslade Bottom:				
Profile 1		colluvium	gleyic brown earth	
Profile 2		colluvium	gleyic brown earth/ (buried) typical cambic gley	
Scrape Bottom:				
Profile 3		colluvium	(Buried) gleyic brown earth	

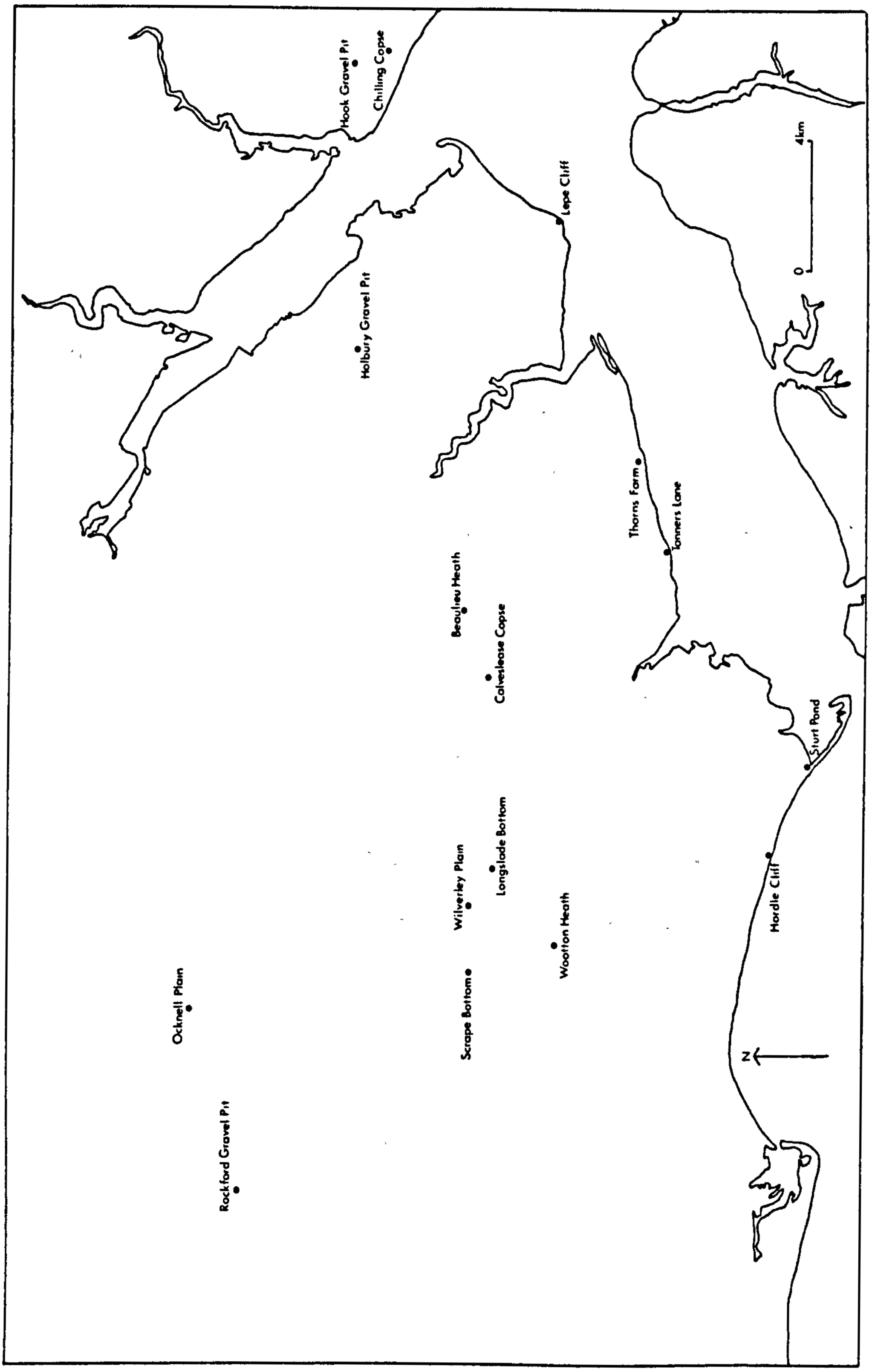


Fig. 5.1 Location of sites selected for detailed study.

of the 5m terrace, and is exposed for about 150m along an artificial channel that drains Sturt Pond into the Solent. Although only 1-2m above sea level, the site is sheltered from the sea behind the long spit of Hurst Beach. The upper brickearth maintains an almost constant thickness along the section and is covered by a variable amount of spoil, taken from the channel, that forms a field boundary bank.

<u>Description</u>

Altitude: 2m

Slope: level

Vegetation and land use: grass covered field bank

Horizon Depth (cm)

20-0 Spoil of disturbed gravel

Ah 0-37/40 Dark greyish brown (10YR 4/2) very slightly stony sandy silt loam; mainly small flint stones; moderate coarse and medium subangular blocky; moderately weak soil strength; slightly sticky; moderately plastic; semi deformable; many very fine fibrous and few fine and medium woody roots; many earthworm channels; clear wavy boundary

Eb 37/40-52/55 Dark yellowish brown (10YR 4/4) silt loam; stoneless; structure as above; moderately weak soil strength, slightly sticky; very plastic; semi deformable; many very fine fibrous roots; common vertical earthworm channels coated with dark greyish brown (10YR 4/2) organans; clear wavy boundary

Bt 52/55-115/120 Dark brown to brown (7.5YR 4/5) clay loam; stoneless, strong coarse and a few medium subangular blocky peds with common dark greyish brown (10YR 4/2) organans; moderately firm soil strength;

moderately sticky; very plastic; semi-deformable; common very fine fibrous roots; many vertical earthworm channels with dark greyish brown (10YR 4/2) organans; clear wavy boundary.

115/120 + Plateau Gravel.

Discussion

The soil is a Hamble series, a typical argillic brown earth (Avery,1980; Fordham and Green,1980), and in most respects it is remarkably similar to Hamble soils described elsewhere, for example in Kent (Green and Fordham,1973). An atypical feature of the profile is the amount of organans covering ped faces and earthworm channels in the Eb and Bt horizons. In West Sussex, Hodgson(1967) reported this feature in Hamble soils under long established permanent pasture which have relatively high organic matter contents. This suggests that the profile could have been uncultivated and at the field edge for many years.

5.2.2. Wilverly Plain (SU 253012)

This second profile developed entirely in upper brickearth was selected as an example of the poorly drained upper brickearth soils. It is situated on the 56m terrace which is the highest level at which extensive thick upper brickearth deposits occur. The thickness of upper brickearth is fairly constant at 50 to 100cm on Wilverly Plain, and thin deposits of lower brickearth sometimes lie between it and the gravel (section 4.2.5) The site was enclosed from open heath and cultivated during 1949 and 1950 but restored to permanent pasture afterwards (Browning,1951).

Description

Altitude:	62m
Slope:	level
Vegetation:	Grass sward

Horizon	Depth (cm)
Ah	0-33 Dark brown (10YR 3/3) very slightly stony sandy silt loam; mainly rounded and subrounded very small and small flint stones; weak to moderate fine and medium subangular blocky; weak soil strength; moderately weak ped strength; slightly sticky; slightly plastic; semi deformable; common very fine fibrous roots; clear smooth boundary.
Eb(g)	33-43 Brown (10YR 4/3) to dark brown (10YR 3/3) sandy silt loam with common fine prominent strong brown (7-5 YR 4/6) mottles; stones as above; weak medium subangular blocky; very weak soil strength; slightly sticky; slightly plastic; semi deformable; few to common very fine fibrous roots; few to common rounded fine ferri-manganiferous nodules; abrupt smooth boundary.
Btg	43-54/60 Brown (10YR 5/3) to yellowish brown (10YR 5/6) slightly stony clay loam with common fine and medium prominent strong brown (7.5YR 5/8) mottles with diffuse edges; mainly small and medium subrounded and rounded flint stones; weak to moderate medium blocky and prismatic ; moderately weak soil strength; slightly sticky; moderately plastic; semi-deformable; roots as above; gradual wavy boundary.
2Btg	54/60-81 Very pale brown (10YR 7/4) slightly stony (becoming very stony with depth) sandy clay loam with very many medium and coarse prominent strong brown (7.5YR 5/8) mottles with diffuse edges; small to large flint stones; structureless (loose); very weak soil strength; slightly sticky; non-plastic; semi-deformable; very few very fine fibrous roots; sharp irregular boundary.
	81+ Plateau Gravel

Discussion

The profile corresponds to soil subgroup 8.41, a typical argillic gley soil (Avery,1980) and is an example of the Park Gate series (Fordham and Green,1980). Although the textural classes suggest that a clear eluvial/illuvial relationship exists between the Eb(g) and Btg horizons, micromorphological analysis indicated that only about 1.6% illuvial clay was present in the Btg horizon. This is below the 2% minimum required by the Soil Survey of England and Wales for designation of a Bt horizon (Avery,1980). However, taking into account the errors involved in the microscopical estimates of illuvial clay (M^c^Keague et.al.,1981) and the likelihood that a higher value would have been obtained if the thin section was taken from a deeper part of the horizon, it was nevertheless decided to give a Bt designation.

The outstanding feature of the profile is the increase in fine sand content with depth. This was also noted in a number of auger borings on Wilverly Plain (4.2.5 and Fig. 4.6). The increase is especially noticeable below 54cm, so a lithological discontinuity has been marked in the horizon description at that depth, but there was no field evidence that the discontinuity represents a halt in deposition of the upper brickearth corresponding to a former ground surface of significant duration (Avery,1980, p.12). A similar increase in fine sand content with depth in the upper brickearth was noted at a large number of sites on a variety of terrace levels during the field survey, for example at Downlands Farm (SZ276972) on the 31m terrace, Holbury Farm (SZ292975) on the 46m terrace and at Efford Experimental Station (SZ303937) on the 5m terrace. This feature will be discussed further in Chapter 8.

5.2.3 Chilling Copse (SU515042) and Hook Gravel Pit (SU513053)

The upper brickearth at these sites was sampled for particle size, mineralogical and micromorphological analyses, but the profiles were only described briefly because of their similarity to that at Sturt Pond. The sites are about 1km apart on the flat, gently S.W. sloping 11m terrace. They were sampled because their location in the extreme S.E. of the study area provides an interesting comparison with sites further west in terms of the variability of the upper brickearth. The reason that two profiles so close together were sampled is that they revealed strong textural differences, detailed below. Both sites are very close to the location of the profiles first described as Hamble series by Kay (1939).

The Chilling profile was described from a soil pit and is located in a plot of semi-natural woodland. The Hook profile is located in the face of a gravel pit in soil that was formerly cultivated.

Description (Chilling Copse)

Altitude: 13m

Slope: level

Vegetation: *Pteridium aquilinium*; *Betula pubescens*; *Sambucus nigra*; *Corylus avellana*.

Horizon	Depth (cm)
L,F,H	10-0
A	0-16 Dark brown (10YR 3/3) stoneless silt loam
Eb	16-30 Brown (7.5YR 4/4) stoneless silt loam
Bt	30-90 Strong brown (7.5YR 5/6) stoneless silty clay loam
2Bt	90-160 Strong brown (7.5YR 5/6) stoneless clay loam.

Discussion

The profile characteristics are typical of the Hamble series. A lithological discontinuity has been marked at 90cm due to a marked increase in fine sand content although, as in the Wilverly profile, there is no evidence that this represents a halt in brickearth deposition.

Description (Hook Gravel Pit)

Altitude: 16m

Slope 1°

Vegetation: various grasses

Horizon Depth (cm)

Ah	0-29 Pale brown (10YR 6/3, dry) sandy silt loam; few small flints.
2Eb/Bt	29-60 Light brown (7.5YR 6/4, dry) to reddish brown (7.5YR 6/6, dry) sandy clay loam; stoneless.
2Bt	60-100 Reddish yellow (7.5YR 6/8, dry) to yellowish red (5YR 5/8, dry) sandy clay loam becoming sandy loam with depth; few small flints.

Discussion:

The profile is also a typical argillic brown earth, but it differs from normal Hamble series in two respects. First, there is no clear Eb horizon; the 2Eb/Bt horizon has characteristics of Eb and Bt and in particular has a higher (illuvial?) clay content than would be expected in an Eb horizon. Second, the colour of the 2Bt horizon is slightly more red than normal. The strong textural differences between the Hook Gravel Pit and Chilling Copse profiles concerns the fine sand content. At Chilling the surface horizon is silt loam and there is a marked increase in fine sand at 90cm. At Hook the surface horizon is sandy silt loam and a marked increase in fine sand occurs at 29cm. These trends will be discussed further in Chapter 8.

5.2.4 Beaulieu Heath (SU 339015)

This site was chosen as representative of the thick deposits of lower brickearth that are widespread on this part of the 46m terrace. Preliminary augering around the site revealed that the lower brickearth has a fairly constant depth of about 1m and is overlain by about 20cm of upper brickearth. The junction between the two is often marked by a discontinuous 4-10cm thick, platy horizon that is partially cemented (Bs horizon) and which is very difficult to penetrate by auger.

After excavation of the original soil pit at this site there was insufficient time to complete a detailed profile description, although soil samples were collected. The description that follows refers to a second profile dug about 5m away from the original, but the horizon sequence and dimensions are closely comparable. The description was made in the author's presence by M.G. Jarvis, A.J. Moffat and I.N Kilgour of the Soil Survey of England and Wales.

Description:

Altitude: 43m

Slope: level

Vegetation: *Erica tetralix*; *Calluna vulgaris*; *Molinia caerulea*.

Horizon	Depth(cm)
H/Oh	0-6 Dark reddish brown (5YR 2/2); abrupt smooth boundary
Ah/Ea	6-17/19 Very dark brown (10YR 2/2) humose sandy silt loam; stoneless; weak medium subangular blocky; moderately weak soil strength; moderately weak ped strength; slightly sticky; moderately plastic; many fine woody and common very fine fibrous roots; discontinuous dark brown (7.5 YR 3/2) patches (15% of horizon) in lower part of horizon; abrupt wavy boundary.
Bh	17/19-20 Black (5 YR 2/1) humose fine sandy loam; stoneless; weak medium subangular blocky; moderately weak soil strength; moderately weak ped strength; slightly sticky; slightly plastic; discontinuous brown to dark brown (7.5YR 4/2) layer 1cm thick at base of horizon impedes roots; roots as above; abrupt wavy boundary.

Bs(g)	20-24/36 Dark reddish brown (2.5YR 2/4) sandy silt loam with very many distinct medium brown to dark brown (7.5YR 4/4) mottles with clear edges; stoneless; very strong soil strength; very strong ped strength; weakly cemented; no roots; abrupt wavy boundary.
2E'g	24/36-35 Light brownish grey to light yellowish brown (2.5YR 6/3) clay loam with very many medium distinct yellowish brown (10YR 5/8) mottles with clear edges; stoneless; very weakly developed very coarse angular blocky with light grey to grey (10YR 6/1) faces; moderately weak soil strength, moderately weak ped strength; moderately sticky; moderately plastic; common very fine dead woody roots; pale brown (10YR 6/3) along root channels; clear smooth boundary.
2 B'tg1	35-55 Light olive grey (5Y 6/2) sandy clay loam with very many distinct medium yellowish brown (10YR 5/8) and few distinct fine to medium strong brown (7.5YR 5/6) mottles with clear edges; stoneless; moderate medium prismatic with pale olive (5Y 6/3) faces; moderately weak soil strength; moderately weak ped strength; very sticky, very plastic; few medium woody roots and dead roots as above; sandy loam facies occur locally, clear wavy boundary.
2 B'tg2	55-75 Light grey to grey (5Y 6/1) clay with many prominent fine to coarse strong brown (7.5YR 5/8) to red (2.5YR 5/8) mottles with clear edges; locally common small and medium flints; moderate coarse prismatic with light grey to grey (5Y 6/1) faces; very weak soil strength; very weak ped strength; very sticky, very plastic; few very fine dead woody

roots; well developed vertical fissures up to 1mm thick coated with fine sand, diffuse smooth boundary.

2B'tg3 75-110 Light grey to grey (5Y 6/1) clay with very many prominent medium strong brown (7.5YR 5/8) and few prominent fine dark red (2.5YR 3/6) mottles with clear edges; stoneless; moderate coarse prismatic with light grey (5Y 7/1) faces; moderately weak soil strength; moderately weak ped strength; very sticky; very plastic; light grey vertical fissures up to 10mm wide with many thick fine sand coats.

110 + Plateau Gravel.

Discussion

The profile corresponds to soil subgroup 6.43, a stagnogley podzol (Avery,1980). However, it has a paleoargillic Bt horizon which would allow its classification as a paleoargillic stagnogley podzol, but this differentiating class has not so far been included in the Soil Classification System for England and Wales although Avery (pers. comm.) now thinks it should be.

The textural variations within the profile are outstanding. The most distinct lithological discontinuity occurs at about 30cm. Below that depth an abrupt increase in clay content marks the junction between the upper and lower brickearth. Other lithological discontinuities caused by concentrations of fine sand, occur within the 2B'tg horizons below 35cm depth. In the 2B'tg2 and 2B'tg3 these concentrations occur in distinct verticle fissures that represent the faces of prismatic peds. The soil texture within the peds is clay, but the fissures allow movement of water when soil moisture levels are high. In the 2B'tg1 horizon the sand occurs in pockets, and in the 2E'g horizon a considerable proportion of fine sand is intimately mixed with other fractions. In both cases the sand might once also have filled fissures that have later been destroyed by cryoturbation.

The red mottling in the 2B'tg2 and 2B'tg3 horizons is typical of paleoargillic horizons. Chartres (1980) suggested that this degree of reddening was only found in soils in the Kennet Valley weathered during the Hoxnian interglacial and earlier, and Federoff (1966; 1971) came to a similar conclusion concerning the red soils of northern France; thus this may indicate that the lower brickearth on Beaulieu Heath is at least as old as the Hoxnian. The 2B'tg1 horizon has strong brown mottling and the 2E'g horizon has brownish mottling which may indicate they are both less weathered than the horizons below. But, there is evidence that both have been affected by cryoturbation, and this may have partially destroyed mottles that were formerly present.

5.2.5 Lepe Cliff (Stone Point) (SZ457984)

This location is one of the most important sites for the Quaternary history of south Hampshire because Ipswichian estuarine deposits outcrop on the foreshore (Reid,1893; West and Sparks,1960; Brown et al., 1975). These Ipswichian deposits are reputed to underlie a low cliff formed in the gravels of the lowermost 5m terrace (7.6m terrace of Brown et. al., 1975; low terrace of Keen,1980), and the terrace is consequently thought to date to the Late Ipswichian/Early Devensian transition (Brown et.al., 1975; Keen, 1980). However, the 5m terrace gravels are overlain in the cliff by lower brickearth and upper brickearth. The lower brickearth has paleoargillic characteristics and should therefore be Ipswichian or older, which would appear to contradict the dating of the gravels beneath as Late Ipswichian/Early Devensian. Brown et.al., (1975) noted brickearth overlying the cliff at this site, but they did not recognize a lithological discontinuity or the paleoargillic characteristics (Fig.5.2).

The lower brickearth, which averages 40cm thick, overlies the terraced gravels along a 30m stretch of cliff. The exposure may once have been greater, but recent excavations for a car park have removed superficial material along much of the cliff-top. Along the section the

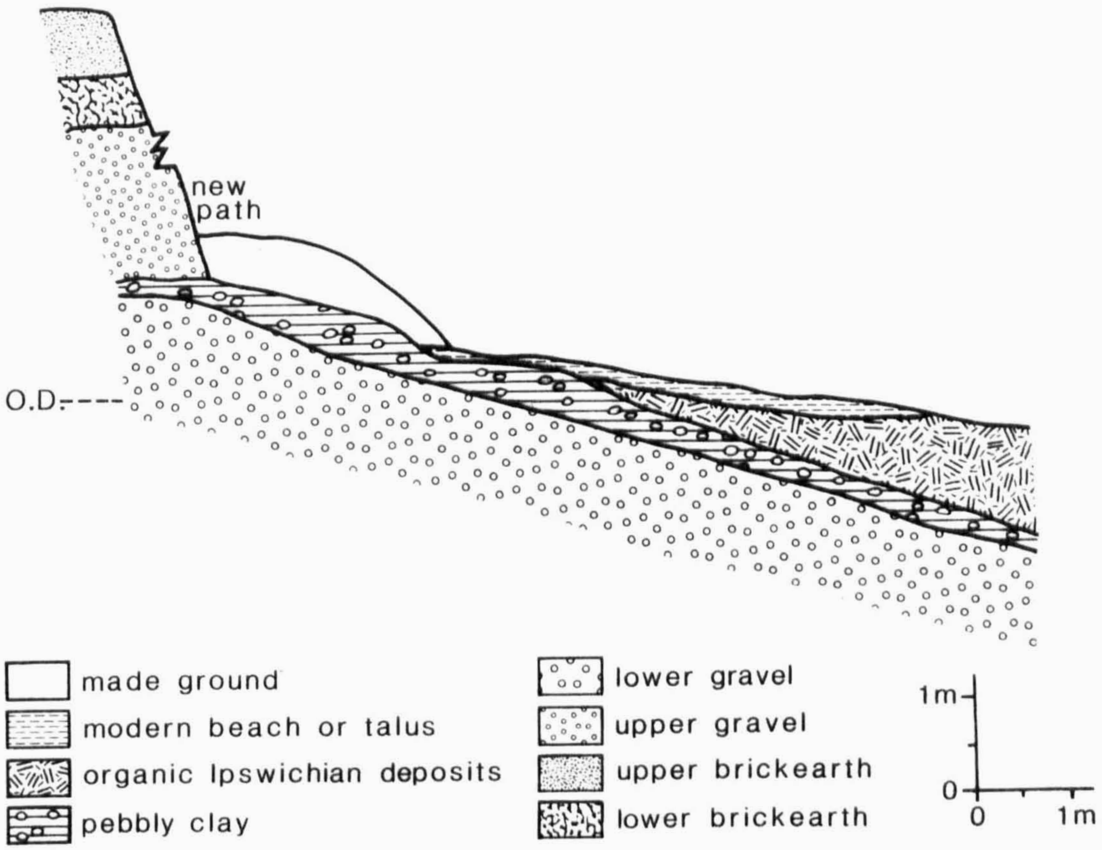


Fig. 5.2 Section through Pleistocene deposits at Lepe Cliff (Stone Point). From Brown et al. (1975) with amendments by the author.

junction between the lower brickearth and gravel is very irregular, probably due to cryoturbation, and a few festoons of gravel penetrate the lower brickearth. The stone lines within and above the lower brickearth may be evidence of periglacial erosion (section 4.3.2.). The upper brickearth averages 60 to 80cm thick along the section.

Description

Altitude: 8m

Slope: level

Vegetation and land use: various grasses (car park)

Horizon	Depth (cm)
Ah	0-30 Dark greyish brown (10YR 4/2) very slightly stony sandy silt loam; mainly small subangular flints; moderate coarse subangular blocky; moderately weak soil strength; slightly sticky; moderately plastic; semi-deformable; abundant very fine to fine fibrous and few medium woody roots; many earthworm holes and channels; clear smooth boundary.
Eb	30-48 Dark yellowish brown (10YR 4/4) very slightly stony sandy silt loam; stones as above; weak medium and coarse subangular blocky; moderately weak soil strength; slightly sticky; moderately plastic; semi-deformable; many very fine to fine fibrous and few medium woody roots; common continuous dark greyish brown (10YR 4/2) organans on vertical earthworm channels and on ped faces; clear smooth boundary.
Bt	48-78 Strong brown (7.5YR 4/6) very slightly stony clay loam; stones as above, strong medium and coarse prismatic; moderately firm soil strength; moderately sticky; moderately plastic; semi-deformable; common very fine fibrous roots; organans as above; abrupt irregular boundary.

2Bt 78-118 Strong brown (7.5YR 5/8) with yellowish brown (10YR 5/6) very slightly stony silty clay with rare (<0.5%) extremely fine and very fine prominent dark red (2.5YR 3/6) mottles with sharp edges; stones as above; massive; moderately weak soil strength; moderately sticky ; very plastic; semi-deformable; few continuous dark greyish brown (10YR 4/2) organans in vertical (earthworm?) channels; few fine fibrous roots; abrupt irregular boundary.

118 + Terrace gravel.

At 78 and 96cm there are irregular stone lines (1 to 4 and 3 to 8 stones thick respectively) of subangular very small to medium flints.

Discussion

The profile corresponds to soil subgroup 5.81, a typical paleoargillic brown earth (Avery,1980). This is one of the thickest deposits of upper brickearth found over lower brickearth and as a result a complete typical argillic brown earth profile has developed in the upper brickearth. There is only slight evidence of increasing fine sand content with depth in the upper brickearth, but, judging by the stone content, there has probably been more disturbance and mixing by cryoturbation at this site than at most others. Most characteristics of the upper brickearth are similar to those at Sturt Pond, Chilling Copse, and Hook Gravel Pit.

Because both are quite silty, the lithological discontinuity between the upper and lower brickearth is less clear than at many other sites. However, the lower brickearth has a much lower sand content and a much higher clay content than the upper brickearth, and conforms to the colour characteristics of paleoargillic horizons (Avery,1980), though reddish mottles are rare and only noticed on close inspection. These colour characteristics (7.5YR hues in the matrix and faint reddish mottles) are the same as those found by Chartres (1980) in soils in the Kennet Valley presumed to have been weathered only during and since the Ipswichian interglacial. Also, field measurements of γ radiation in the lower brickearth by Dr. A.G. Wintle (pers. comm) indicated levels similar to those found in Wolstonian and older loesses in Europe, which are quite different from those in Late Devensian loess.

5.2.6. Thorns Farm (SZ389964).

This site also lies on the 5m terrace about 7km south west of Lepe Cliff. The terrace gravel is again overlain by a continuous cover of lower brickearth with paleoargillic characteristics. The profile was described from a soil pit, but a similar sequence of horizons was seen in the extensive ditches that surround fields in the locality. The lower brickearth averages 30 to 80cm thick over the gravel and the junction is irregular, probably due to cryoturbation. Upper brickearth 40 to 80cm thick, overlies the lower brickearth, also with an irregular boundary. The soil at the profile site is cultivated.

Description

Altitude: 3m

Slope: level

Horizon	Depth (cm)
Ap	0-30/32 Very dark greyish brown (10YR 3/2) very slightly stony fine sandy loam; mainly small subangular and subrounded flints; moderate coarse blocky fragments and firm very coarse clods; moderately firm soil strength; slightly sticky; very plastic; brittle; common very fine fibrous roots; many added lime fragments; abrupt smooth boundary
Apg	30/32-40/44 Very dark grey (10YR 3/1) with streaks of dark brown (10YR 3/3) fine sandy loam with common strong brown (7.5YR 4/6) and brown (10YR 4/3) fine and

medium prominent and faint mottles with clear edges; stones as above; moderate coarse subangular fragments; moderately weak soil strength, slightly sticky; moderately plastic; semi-deformable; common irregular feruginous concentrations; roots as above; abrupt irregular boundary.

A/E(g) 40/44-60/62 Dark brown (10YR 3/3) fine sandy loam with many to very many strong brown (7.5YR 4/6), yellowish red (5YR 4/6) and brown (10YR 5/3) fine and medium prominent and distinct mottles with sharp or clear edges; stones as above; strong coarse subangular blocky; moderately weak soil strength; slightly sticky; very plastic; semi deformable; roots as above ; common irregular feruginous concentrations; common continuous very dark greyish brown (10YR 3/2) organans on ped faces and in earthworm channels; abrupt wavy boundary.

Eg 60/62-80/85 Light yellowish brown (10YR 6/4) fine sandy loam with common prominent strong brown (7.5YR 4/6) and yellowish red (5YR 4/6) fine and medium mottles with sharp edges; slightly stony; moderate coarse subangular blocky; moderately weak soil strength; moderately sticky; very plastic; semi deformable; few very fine fibrous roots; organans as above; abrupt wavy boundary.

2Bt(g) 80/85-143-150 Strong brown (7.5YR 5/8) clay loam becoming sandy clay loam at depth; slightly stony becoming moderately stony with depth; strong coarse prismatic structure with light yellowish brown (2.5Y 6/4) colours on ped faces; fissures between some peds are filled with light grey (2.5Y 7/2) fine sandy loam; very firm soil strength; very sticky; very plastic; semi deformable; roots as above; irregular clear boundary

143/150 + Gravel

Discussion

The profile corresponds to soil subgroup 8.41, a typical argillic gley soil (Avery,1980), though is somewhat unusual in that the Bt horizon is only slightly gleyed. The 2Bt(g) horizon is paleoargillic, but a paleoargillic subgroup is not provided for in the groundwater gley soils (Avery,1980).

As in many other profiles, the upper brickearth becomes sandier with depth, but the change is insufficient to cause a shift in textural class, so no lithological discontinuity has been marked within the upper brickearth. The uppermost 40cm have been mixed by cultivation and this has masked any textural variation that was originally present there.

The irregular junction between the upper and lower brickearth may have been caused by cryoturbation, as is common in paleoargillic soils (Avery,1980; Sturdy et al., 1979). Material with a similar particle size distribution to the Eg horizon, and probably derived from it, penetrates into the 2Bt(g) horizon along fissures to a depth of at least 100cm. This material has a different colour from the Eg horizon but this is probably due to the ped-face gleying that occurs in the 2Bt(g) horizon. These sand-filled fissures are not so common as in the Beaulieu Heath profile and do not seem to coat entire peds, but the similarity between the two profiles in this respect is nevertheless striking.

The 2Bt(g) horizon is much less rubified than the 2B'tg horizons in the Beaulieu Heath profile; it contains no reddish mottles but has a matrix colour (7.5YR 5/8) identical to the 2Bt horizon at Lepe which may indicate that both have been weathered over a similar time period.

5.2.7 Tanners Lane (SZ 365953)

This site also lies on the 5m terrace and was selected for study because the lower brickearth here is very different from that at Thorns Farm and Lepe Cliff. Upper brickearth about 50 to 60 cm thick and overlying lower brickearth is exposed in a very low (≃1m) cliff at the head of the modern beach (Fig 5.3). The exposure can be followed for 1km between Otter's Hill Copse (SZ362953) and Pitt's Deep (SZ371955). The upper brickearth is continuous throughout this length and in places it directly overlies gravel. The lower brickearth is discontinuous and has been penetrated in places by involutions of gravel. The modern beach gravel and the terrace gravel have a similar appearance, but the terrace gravel was distinguished by its weakly cemented nature.

The upper part of the described profile was exposed in the cliff but the lower part was examined by digging through the modern beach.

Description

Altitude: 1m O.D.

Slope: Level

Vegetation: Crataegus monogyna; various grasses

Land-use: field boundary.

Horizon Depth (cm)

H 4-0 Very dark grey (10YR 3/1); abundant very fine to medium fibrous and woody roots; abrupt smooth boundary.

Ah(g) 0-46 Dark greyish brown (10YR 4/2) very slightly stony sandy loam with few very fine to fine distinct dark yellowish brown (10YR 4/4) mottles; stones mainly small and very small subangular flints; moderate medium and coarse subangular blocky; moderately weak ped strength; slightly sticky; moderately plastic; common to many very fine to medium fibrous and woody roots; clear wavy boundary.

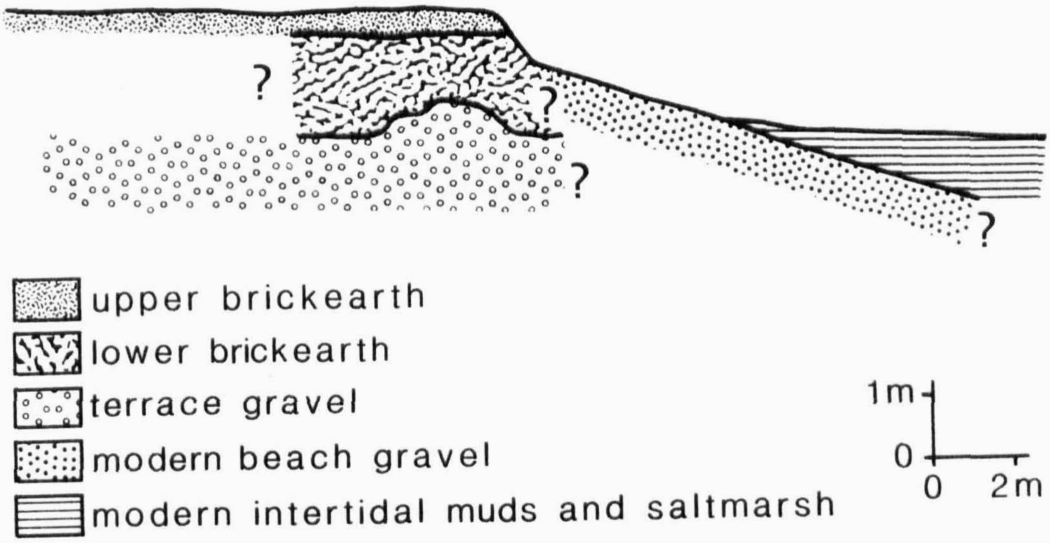


Fig. 5.3 Diagrammatic representation of the relationships between upper and lower brickearths and terrace and storm beach gravels at Tanners Lane.

Eb(g) & 2Btg	46–74 Strong brown (7.5YR 5/8) and yellowish brown (10YR 5/4) sandy clay loam with many distinct medium and coarse yellowish red (5YR 5/8) mottles with clear edges; stones as above; strong medium and coarse prismatic with common continuous very dark grey (10YR 3/1) organans on ped faces; moderately firm ped strength; slightly sticky; slightly plastic; common fine and medium fibrous and woody roots; diffuse smooth boundary.
2Btg2	74–133 Light olive grey (5Y 6/2) very slightly pebbly clay with many medium and coarse red (2.5YR 4/6), yellowish red (5YR 5/8) and strong brown (7.5YR 5/8) mottles with sharp edges; stones mainly small rounded flints and rare small subangular flints with white (weathered) patina; massive; few fissures coated with dark grey (5Y 4/1) organans; very firm soil strength; moderately sticky; very plastic; few very fine to fine fibrous roots; gradual boundary
2Btg3?*	133–170 (Auger boring) olive grey (GY 6/1) very slightly pebbly clay with common prominent coarse dark yellowish brown (10YR 4/6) mottles; stones as above; rare fissures contain fine sandy loam material; few very fine to fine fibrous roots; gradual boundary.
2Btg4?*	170–210 (Auger boring) Olive grey (5GY 6/1) very slightly pebbly clay with common prominent coarse yellowish red (5YR 5/8) and strong brown (7.5YR 5/8) and few fine prominent dark red (2.5YR 3/6) mottles; Stones as above
	210+ Coarse subangular flint gravel with reddish mottled clay matrix.

* These horizon designations are tentative because no micromorphological samples could be extracted.

Discussion

The profile corresponds to soil subgroup 8.41, a typical argillic gley soil, and as in the Thorns Farm profile, the Btg horizons qualify as paleoargillic. An unusual feature of the profile is that it is affected by daily fluctuations in groundwater level due to tidal movements.

The boundary between the upper and lower brickearth is extremely irregular, so much so that discrete pockets of each exist within one horizon, the Eb(g) & 2Btg. The irregularity of the boundary may be due to cryoturbation. Fissures filled with sandy loam (presumably derived from the Eb(g) horizon in the upper brickearth) were found only within the 2Btg3 horizon and were not seen to connect directly with the overlying upper brickearth.

In contrast to the Lepe Cliff and Thorns Farm profiles, the lower brickearth here is strongly red-mottled through most of its depth, although only yellowish-brown mottles were seen from 133-170cm. The degree of red-mottling in the 2Btg2 and 2Btg4 horizons is equal to that in the Beaulieu Heath profile which may indicate that the lower brickearth has been weathered during the Hoxnian interglacial or earlier.

5.2.8 Ocknell Plain (SU 223100)

This site lies on the 113m terrace and is typical of the paleoargillic soils that occur there. The profile was described from a section in a roadside ditch that traverses the entire width of the terrace remnant. The ditch showed the manner in which the lower brickearth thins towards the edges of terrace fragment (Fig 5.4). Along the flat central portion of the terrace boundary between the gravel and lower brickearth is smooth and few festoons occur, but the boundary becomes less regular and festoons increase as the lower brickearth thins towards the edge of the terrace. Eventually the lower brickearth only survives in

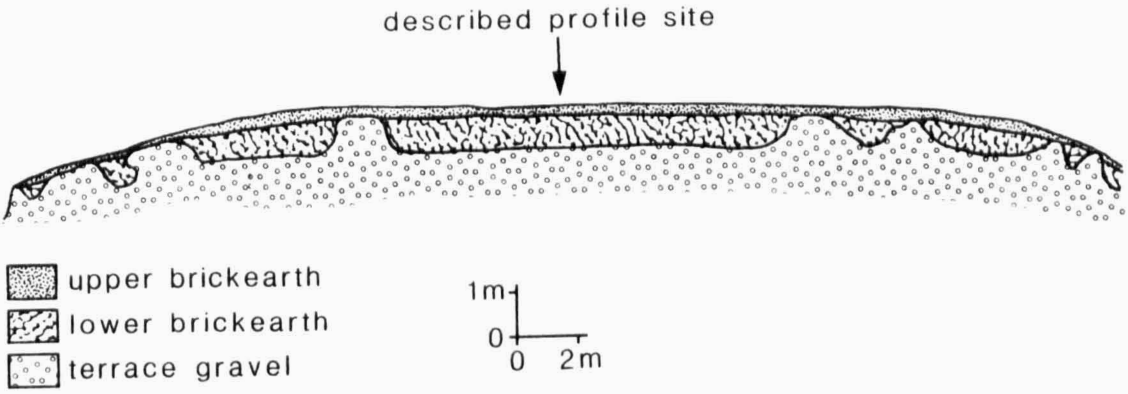


Fig. 5.4 Section through 113m terrace deposits at Ocknell Plain

in pockets in the gravel surface. The festoons halt abruptly, and may be truncated in places, at the junction of the upper and lower brickearth, indicating that they pre-date deposition of the upper brickearth. The upper and lower brickearth are separated by a stone line that is probably of periglacial origin and is discussed in section 4.3.2.

Description

Altitude: 106m O.D.
Slope: level
Vegetation: *Calluna vulgaris*; *Erica tetralix*; *Molinia caerulea*

Horizon	Depth (cm)
F,H	3-0 Black (10YR 2/1), abrupt smooth boundary.
Ah	0-7 Black (10YR 2/1) very slightly stony silt loam; mainly small subrounded and angular flints; very weak fine subangular blocky; moderately weak soil strength; slightly sticky; moderately plastic; semi deformable; many very fine to fine fibrous and woody roots; abrupt irregular boundary
Eag	7-11/13 Light brownish grey (10YR 6/2) silt loam; stones as above; weak fine and medium subangular blocky; consistence as above; roots as above; clear irregular boundary.
Bh & 2Bt(g)	11/13-17/20 Black (10YR 2/1) with brown (10YR 5/3) and strong brown (7.5YR 5/8) silty clay loam; few small subangular and subrounded flints; some stones shattered in-situ; moderate fine and medium subangular blocky; moderately weak soil strength; slightly sticky; moderately plastic; brittle; roots as above; clear irregular boundary

2Bt(g)2	17/20-37 Strong brown (7.5YR 5/8) silty clay with few fine to very fine prominent dark red (2.5YR 3/6) mottles with sharp edges; stones as above; strong coarse subangular blocky; moderately weak soil strength; moderately sticky; very plastic; semi-deformable; common very fine to fine woody fibrous roots; common brown (10YR 5/3) organans on peds, stones and root channels; diffuse smooth boundary.
2Bt(g)3	37-124 Strong brown (7.5YR 5/8) and yellowish brown (10YR 5/8) clay with few (fewer than above) very fine prominent dark red (2.5YR 3/6) mottles with sharp edges; stones, structure, consistence and organans as above; few very fine fibrous roots.
	124 + Plateau Gravel.

A stone line occurs at 13cm depth on the junction of the Eag and Bh and 2Bt(g) horizons.

Discussion

The profile corresponds to soil subgroup 7.14, a paleoargillic stagnogley soil (Avery,1980). The designation of the Bh horizon is only tentative because dithionite extractable Fe + Al and organic carbon were not determined.

Unlike nearly all the sites on the lower terraces (< 56m) the upper brickearth is very silty at its junction with the lower brickearth; this feature was found at many other sites on the high terraces. As at most other sites at all levels, the junction between the upper and lower brickearth in the Bh and 2Bt(g) horizons is highly irregular, probably due to cryoturbation. The Bh characteristics seem to have developed in less clayey pockets which may be of upper brickearth materials.

In terms of texture, colour and mottling, the lower brickearth is very similar to that at Lepe Cliff , and so may have been weathered over a similar time period. As the 113m terrace is likely to be considerably older than the Hoxnian, a much more red mottled subsoil might be expected. Strongly red-mottled lower brickearth does occur locally on this terrace, for example at Fritham Plain (SU 224136). It is probable, however, that similar veneers of superficial deposits were once more extensive but have been eroded almost completely from this and other high terraces during several periglacial and interglacial periods in the past. At the described site, the erosion of clayey (weathered loamy) material from the terrace surface would have exposed the freely drained gravel and thus favoured the preservation of subsequently deposited loamy material (the present lower brickearth). Thus the lower brickearth at the described site could be a relatively late addition to the superficial veneer of the 113m terrace.

5.2.9 Calveslease Copse (SU 323002)

This site is located in a small abandoned gravel pit at the western edge of the (Beaulieu Heath) 46m terrace fragment. The pit is on a gently sloping valley side beyond the edge of the 46m terrace as mapped by Everard (1954), but the gravels are stratified and show no evidence of having been involved in gelifluction, so they may lie on a slope formed by periglacial cambering (Fisher,1975). A depression in the gravels measuring 1.7 x 15m and filled with fine sediments was observed in the north face of the pit (Fig. 5.5). Augering revealed that the fine sediments thin to the north, and no evidence was found of them on the south face of the pit. The depression is thus presumed to have been an enclosed basin. It is possible that it formed as the result of the collapse of a small ground ice mound (pingo). Embleton and King (1975) suggest that the most reliable indicator of a fossil pingo is the presence of a small rampart around the perimeter. At Calveslease Copse, the normally horizontally stratified gravels are swept upwards at the perimeter, especially the western edge, indicating that a rampart could

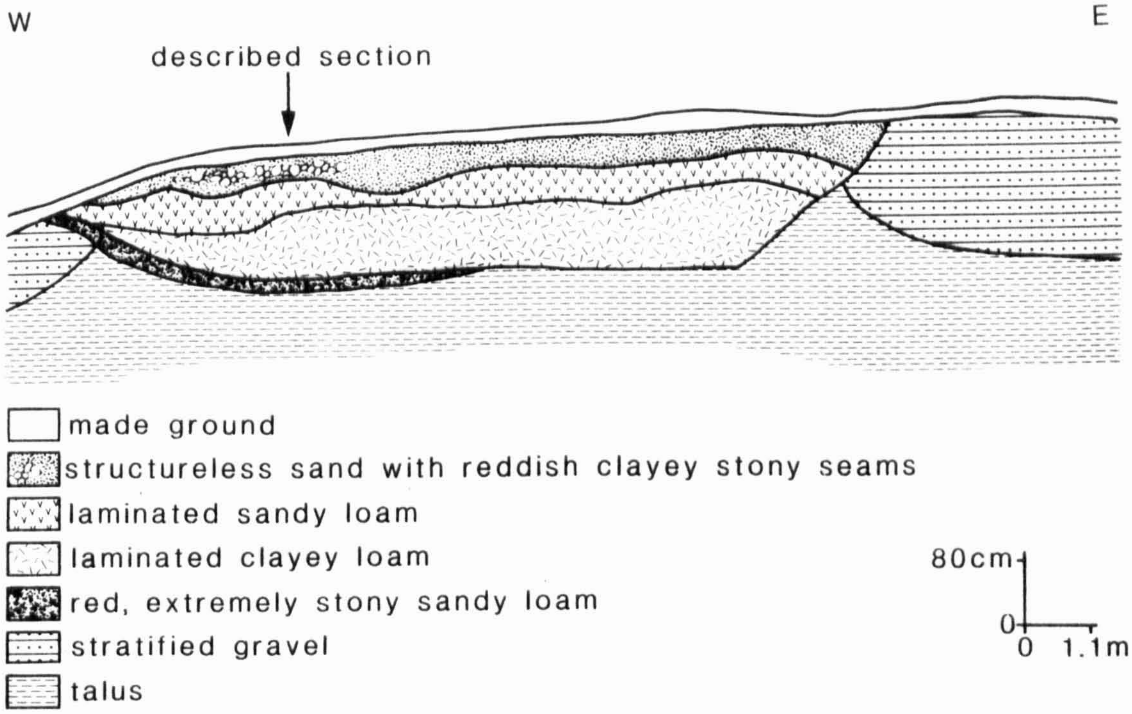


Fig. 5.5 Section through deposits at Calveslease Copse gravel pit.

formerly have been present. This may have been destroyed by subsequent cryoturbation or more recently by human activity. The basin left after collapse of a pingo is often filled with water and eventually by sediments derived from the surrounding land surface (West et al., 1974). At Calveslease Copse, the sediments filling the basin were studied because they could have been derived from brickearth that was formerly present on the gravel surface nearby.

Description

Altitude: 35m

Slope 2°W

Horizon	Depth (cm)	
	15-0	Made ground (spoil from gravel workings)
1	0-32	Brownish yellow (10YR 6/6) sandy loam with few horizontal streaks of light yellowish brown (10YR 6/4); stoneless except for rare pseudo-horizontal flinty seams; flints often surrounded by a yellowish red (5YR 4/6) clay rich material; structureless; clear wavy boundary.
2	32-60	Brownish yellow (10YR 6/6-8) very slightly stony sandy loam; strong fine angular blocky becoming fine and medium angular platy with depth; some ped faces especially at base of horizon coloured reddish brown (5YR 4/4); few vertical root channels coloured light grey (2.5Y 7/2); sharp wavy boundary
3	60-160	Strong brown (7.5YR 5/8) stoneless clay loam; fine angular platy structure; horizon penetrated through its depth by continuous vertical root channels about 15-25cm apart; channels coloured light grey (2.5Y 7/2); clear smooth boundary.

4 160-170 Red (10R 4/6) sandy loam; structureless; very to extremely stony; clear smooth boundary

170 + Stratified gravel.

Discussion

Because some part of the upper horizon(s) have been removed, no attempt was made at profile classification. Horizon 3 has a similar colour to many paleoargillic horizons, but it has fine stratification and cannot therefore qualify as a B horizon (Avery,1980). Lithological discontinuities occur between horizons 2 and 3 and between 3 and 4. As the sediments are unlikely to represent brickearth in-situ, they have not been differentiated into upper or lower members. The sandy loams forming horizons 1 and 2 have almost identical colour and texture; they were differentiated mainly on the basis of structure. Horizon 1 is structureless and is penetrated by stony seams probably derived from horizon 4. Horizon 2 has fine stratification, and the lenticular sedimentary structures now form peds; there is no evidence of disturbance by cryoturbation. It is possible that horizon 1 formerly displayed stratification, but that this has been destroyed by cryoturbation.

The contribution of upper brickearth to horizons 1 and 2 is not clear from the field evidence. Their texture suggests they could be derived from the sandy lower parts of the upper brickearth, and this is supported by brownish matrix colours (10YR hues) suggesting Flandrian soil formation. However, the nearest upper brickearth deposits on the terrace surface (at Dilton Farm, SU 325004) have a much lower sand content.

The junction between horizons 2 and 3 is not as irregular as that found between lithologically distinct materials at many other sites which suggests there has been little or no periglacial disturbance of it. The sedimentary laminations present in horizon 3 suggest it was derived from soils or sediments lying outwith the basin. It is not clear from the field evidence whether it was derived from pre-existing paleoargillic horizons or if it acquired its paleoargillic characteristics after deposition in the basin.

Horizon 4 shows no evidence of stratification. It has a similar texture to the underlying stratified gravels, but with a higher clay content. It is distinctly redder than horizon 3 and possibly therefore, represents an earlier phase of interglacial weathering.

5.2.10 Rockford Common Gravel Pit (SU173084)

This site is located in a large disused gravel pit on Avon terrace VIII of Sealy (1955), which is probably equivalent to Everard's (1954) 70m stage. In nearly all of the exposed sections no brickearth overlies the gravel, but at one point about 60cm of sandy brickearth lies in a shallow depression about 10m long in the surface of the gravel (Fig.5.6). The brickearth is reddish near its base and reddening continues into the terrace gravel underneath. There is evidence of cryoturbated boundaries between the gravels and brickearth and between the reddened and non-reddened brickearth.

Description

Altitude: 65m

Slope: level

Vegetation: *Pteridium aquilinum*

Horizon	Depth (cm)	
Ah	40-0	Very dark grey and very dark greyish brown (10YR 3/1-2) fine sandy loam; many small flints; structureless; abrupt smooth boundary.
Eb	0-40	Brownish yellow (10YR 6/6) fine sandy loam; few small flints; structureless; clear irregular boundary.
Bt	40-60	Yellowish red (5YR 4/6) with strong brown 7.5YR 4/6) fine sandy loam; stones as above; structureless; clear wavy boundary
2Bt	60-110	Stratified terrace flint gravel with a yellowish

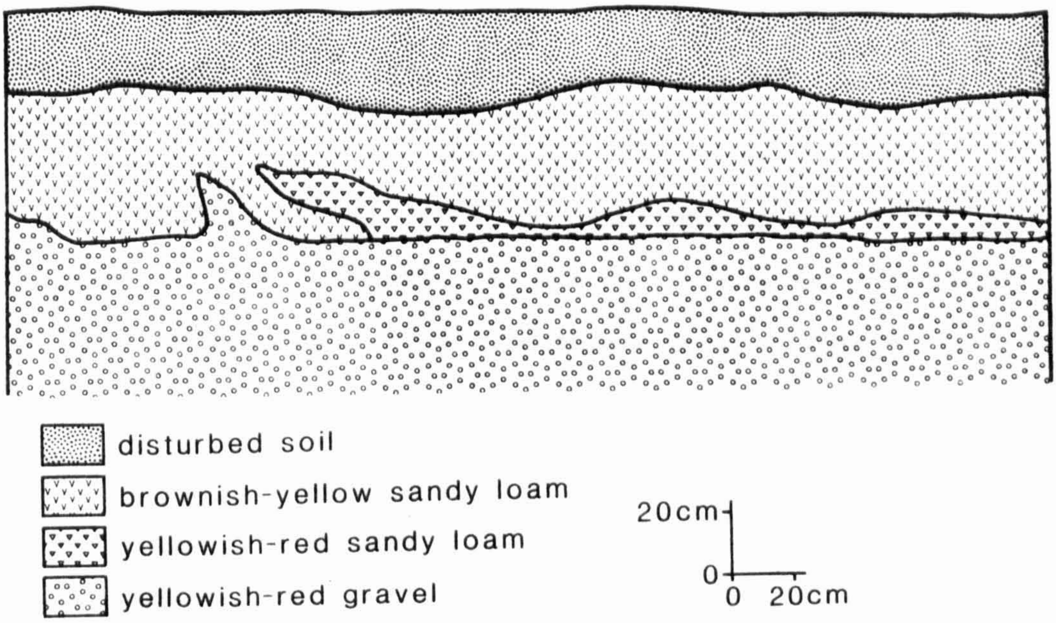


Fig. 5.6 Section through deposits at Rockford Common Gravel Pit

red (5YR 4/6) and strong brown (7.5YR 4/6) sandy clay loam matrix; all flints coated with yellowish red or strong brown clay skins; diffuse smooth boundary.

110-160 + As above except clay skins less common.

Discussion

The Ah horizon has been disturbed and added to, probably during quarrying operations, and qualifies as a thick man-made A horizon. The profile therefore corresponds to soil subgroup 9.12, an earthy man-made humus soil (Avery,1980).

A puzzling feature of the profile is that the paleoargillic Bt horizon is similar in texture to the Eb, yet the Eb horizon has a brownish colour like the upper brickearth. It was therefore not possible to differentiate the Eb horizon as upper or lower brickearth on the field evidence. The Bt horizon is discontinuous and its surface is irregular which suggests it may have been eroded prior to deposition of the material forming the Eb horizon.

The 2Bt horizon in the terrace gravel shows an unusually high degree of pedogenetic alteration; thick reddish clay skins are present to at least 1m below the gravel surface. Its colour is identical to the Bt horizon, so the two may have been weathered contemporaneously.

5.2.11 Holbury Gravel Pit (SU 426049)

This site lies on the 46m terrace on the edge of Beaulieu Heath (east). Extensive deposits of thick lower brickearth are exposed in sections in a disused gravel pit. Upper brickearth formerly overlay this, but it was removed prior to gravel extraction and is mounded to one side. The site is remarkable because one face of the gravel pit appears to show two separate layers of lower brickearth (Fig.5.7). Within the upper (silty clay) layer there are extremely flinty pockets with a silty clay matrix. These resemble festoons of gravel but they are not directly connected to the gravels underlying the lower (clay loam)

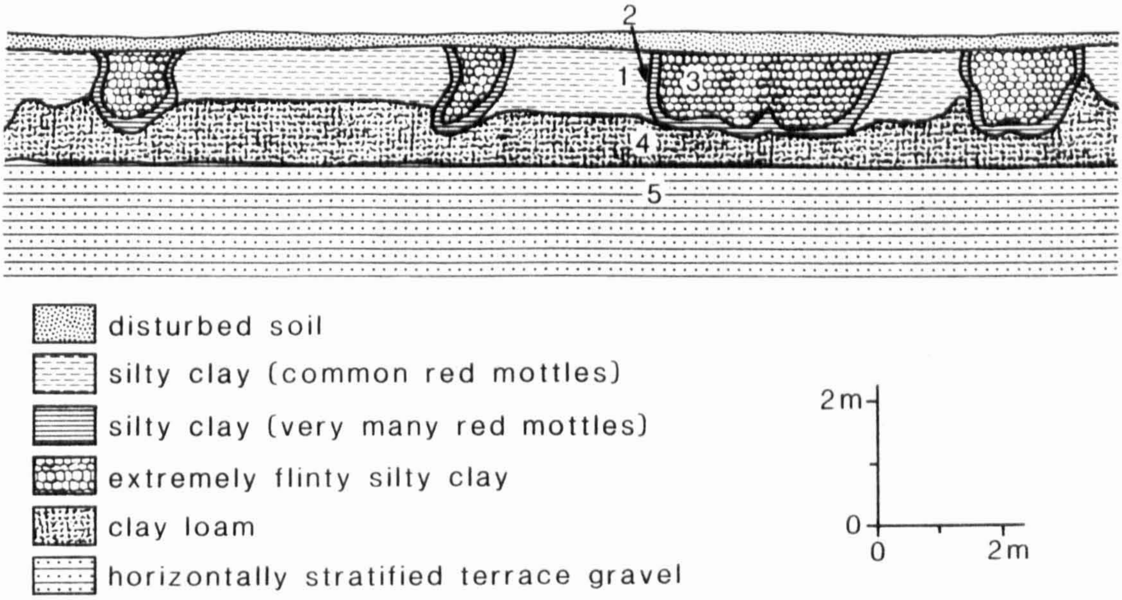


Fig. 5.7 Section through lower brickearths and gravel at Holbury Gravel Pit.

deposit. The junction between the upper and lower deposits is contorted, suggesting that some cryoturbation has occurred.

Description

Altitude: 37m O.D.

Slope: 0.5°

The numbers below refer to the lithological/pedological units marked in Fig. 5.7

Unit depth (cm)

(1) 0-110 Light grey (5Y 7/1) silty clay with common prominent fine to coarse strong brown (7.5YR 5/8) to red (10R 4/6) mottles with clear edges; mottles associated mainly with stonier facies and pockets of finer structure; few small to medium flints; moderate very fine to medium angular blocky; few light grey (5Y 6/1) sandy inclusions between peds; abrupt wavy or irregular boundary to (4)

(2) 4-12cm Thick 'rind' of silty clay separating units (1) and (3); light grey (5Y 7/1) with very many prominent coarse red (10R 4/6) mottles; stones as above; strong very fine and fine angular blocky structure.

(3) Strong brown (7.5YR 5/8) flint gravel with silty clay matrix mottled red (10R 4/6), strong brown (7.5YR 5/8) and light grey (7.5YR 7/1).

(4) 110-180 Strong brown (7.5YR 5/8) with light yellowish brown (2.5Y 6/4) clay loam; few small medium flints; moderate medium angular blocky structure; clear smooth boundary.

(5) 180 + Horizontally stratified gravel with a clay rich matrix in uppermost 10cm continuing few red (10R 4/6) mottles.

Discussion

Both the upper (silty clay) and the lower (clay loam) deposits conform to the definitions of paleoargillic horizons (Avery,1980). The upper deposit has evidence of a far greater degree of weathering than the lower. The intensity of red mottling within it is similar to that found in lower brickearth on other parts of the 46m terrace, for example in the Beaulieu Heath profile. The red mottling is most pronounced in disturbed, possibly cryoturbated, areas (especially unit (2)) where the structure is fine or very fine angular blocky. Material with a sandy loam texture occupies space between peds, but these spaces are not vertical fissures as in the Beaulieu Heath profile. It may be that prior to disturbance by cryoturbation vertical fissures were present in the upper deposit and these were penetrated by the sandy loam material.

The lower (clay loam) deposit has a less disturbed appearance than the upper. It also might be less weathered as it has colours similar to those found in supposed Ipswichian soils (Chartres,1980). The top 10cm of the underlying gravel however, has matrix texture and colours, very similar to the upper (silty clay) deposit.

Thus at Holbury Gravel Pit there appear to be two lower brickearths, the upper of which could be older than the lower. The colours suggest that the upper is equivalent to the Beaulieu Heath profile (possibly at least Hoxnian age) and the lower is equivalent to the Lepe Cliff, Thorns Farm and Ocknell Plain profiles (possibly weathered only during and since the Ipswichian).

5.2.12 Hordle Cliff (SZ 269921)

This site is a cliff exposure in the 21m terrace. About 1 to 1.5m of upper brickearth overlies gravel on most of the terrace remnant, but at the described site a pocket of lower brickearth about 10m long and 50cm thick lies in the surface of the gravel (Fig.5.8). The lower brickearth here is one of the few deposits observed on the terraces at 46m O.D. or lower to the west of the Lymington River, as on most of these

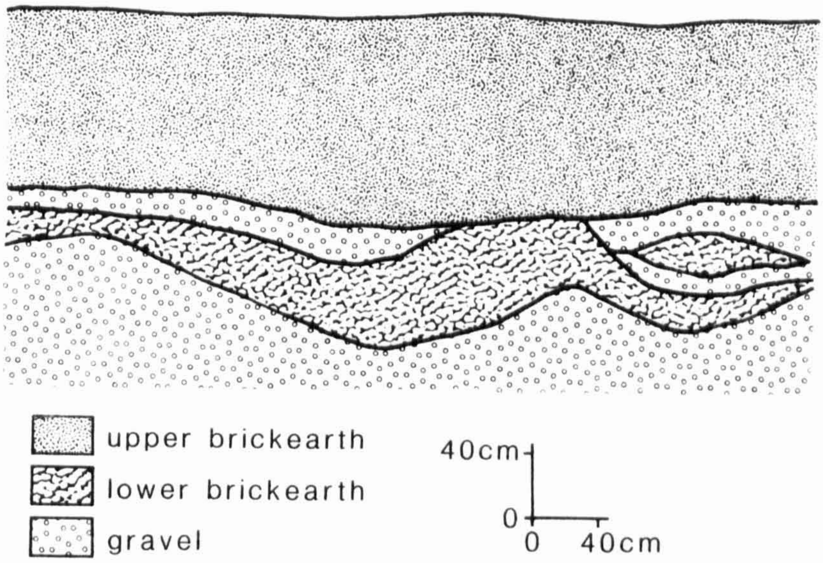


Fig. 5.8 Section through deposits at Hordle Cliff.

terraces lower brickearth appears to have been removed by erosion. This lower brickearth was described and sampled as a comparison with the more extensive deposits found on equivalent terraces at or below 46m to the east of the Lymington River.

Description

Altitude:	24m O.D.
Slope	Level
Deposit Depth (cm)	
Upper Brickearth	0-125 Silt loam becoming more sandy with depth; abrupt irregular boundary.
Lower Brickearth	125-170 Strong brown (7.5YR 5/6-8) clay loam with common coarse distinct yellowish red (5YR 5/8) mottles; few small and medium flints; moderate fine, medium and coarse subangular blocky with pale yellow (2.5Y 7/4) colours on ped faces; clear wavy boundary.
	170 + Terrace Gravel.

Discussion

The lower brickearth conforms to the definition of a paleoargillic horizon (Avery,1980). Both the lower brickearth and upper parts of the terrace gravel are contorted and interdigitated, probabably by cryoturbation. One effect of the cryoturbation is that the lower brickearth now occupies a depression in the gravel, and this has probably protected it from erosion.

The overall colour of the lower brickearth is similar to that at Lepe Cliff, Thorns Farm, Ocknell Plain and Holbury Gravel Pit (clay loam horizon), but it has coarse reddish mottles which these sites do not have. Thus on field evidence its weathering characteristics are intermediate between those of the lower brickearth at these sites and at Beaulieu Heath, Holbury Gravel Pit (silty clay) and Tanner's Lane.

5.2.13 Wootton Heath (SZ 241986)

This site, which lies within one of the areas of brickearth mapped by the Institute of Geological Sciences, lies on another fragment of the same 56m terrace on which the Wilverly Plain profile was described. The lower brickearth is better preserved than at Wilverly. The profile was described mainly because it seems on field evidence to be developed entirely in lower brickearth. Upper brickearth is present locally on this terrace fragment but at the profile site it may have been washed completely off the relatively inpermeable lower brickearth. Even today, shallow rills can be seen after rain on the stock-puddled surface of the brickearth, washing away material from the A horizons of the soil.

Description

Altitude: 61m
Slope: level
Micro Relief: Slightly undulating stock-puddled surface with few rills.
Vegetation: *Erica tetralix*; *Molinia caerulea*; *Calluna vulgaris*

Horizon	Depth (cm)	
Ahg	0-26	Very dark greyish brown (10YR 3/2) silty clay loam with common to many medium and coarse distinct to prominent brown (10YR 5/3), strong brown (7.5YR 5/8) and light olive grey 5Y 6/2) mottles with sharp to diffuse edges; few small subrounded and subangular flints; massive; moderately firm soil strength; slightly sticky; slightly plastic; abundant fine and medium fibrous and woody roots; sharp wavy boundary.
Btgl	26-52	Reddish yellow (7.5YR 6/8) with light grey (5Y 7/2) silty clay loam; few very fine to fine prominent red (2.5YR 5/6) mottles with sharp edges; common stones as above; moderate medium prismatic

with light grey (5Y 7/2) on faces; moderately weak soil strength; moderately sticky; very plastic; common fine fibrous roots; smooth diffuse boundary.

Btg2 52-92 As above except stone content increases to at least 50%, obscuring structure.

92 + Terrace gravel.

Discussion

The profile corresponds to soil subgroup 8.41, a typical argillic gley, and the Btg horizon is paleoargillic. No evidence could be found for a lithological discontinuity within the profile and there were no features, such as a stone line, to suggest that upper brickearth is present.

In terms of matrix colour, texture and mottling, the lower brickearth in the Btg horizons is very similar to that at Lepe Cliff and Ocknell Plain, although the greyish colours suggest it is more gleyed. It may therefore, have a similar age to those sites.

Unlike most soils described with upper brickearth overlying lower brickearth, there is no E horizon. A former E horizon could have been removed during erosion of the upper brickearth, which implies that the upper parts of the profile are formed in former subsoil horizons.

5.2.14 Redistribution of Upper Brickearth on the 56m Terrace

During the field survey, weakly stratified colluvium was found to be widespread in the footslopes and floors of valleys incised in the 56m terrace remnant between Wilverly Plain and Spy Holms (SU246015). The colluvium has similar characteristics to upper brickearth on the terrace surface, from which it may be derived. In the central parts of some valleys the colluvium contains a buried Ah horizon that marks a former ground surface.

The distribution of the colluvium and buried soil was mapped at a scale of 1:10,000 by detailed ground survey and air-photo interpretation. Their distribution is shown in Figs 5.9 and 5.10.

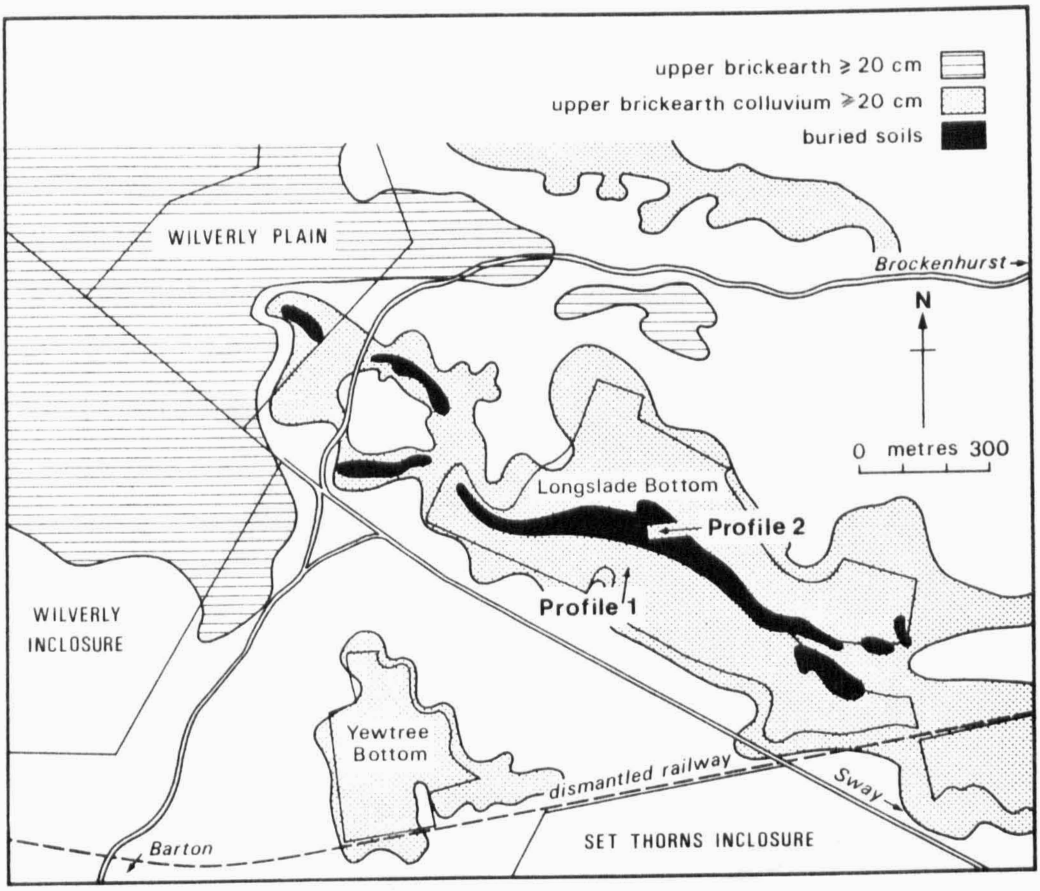


Fig. 5.9 Distribution of upper brickearth, upper brickearth colluvium and buried soils near Wilverly Plain.

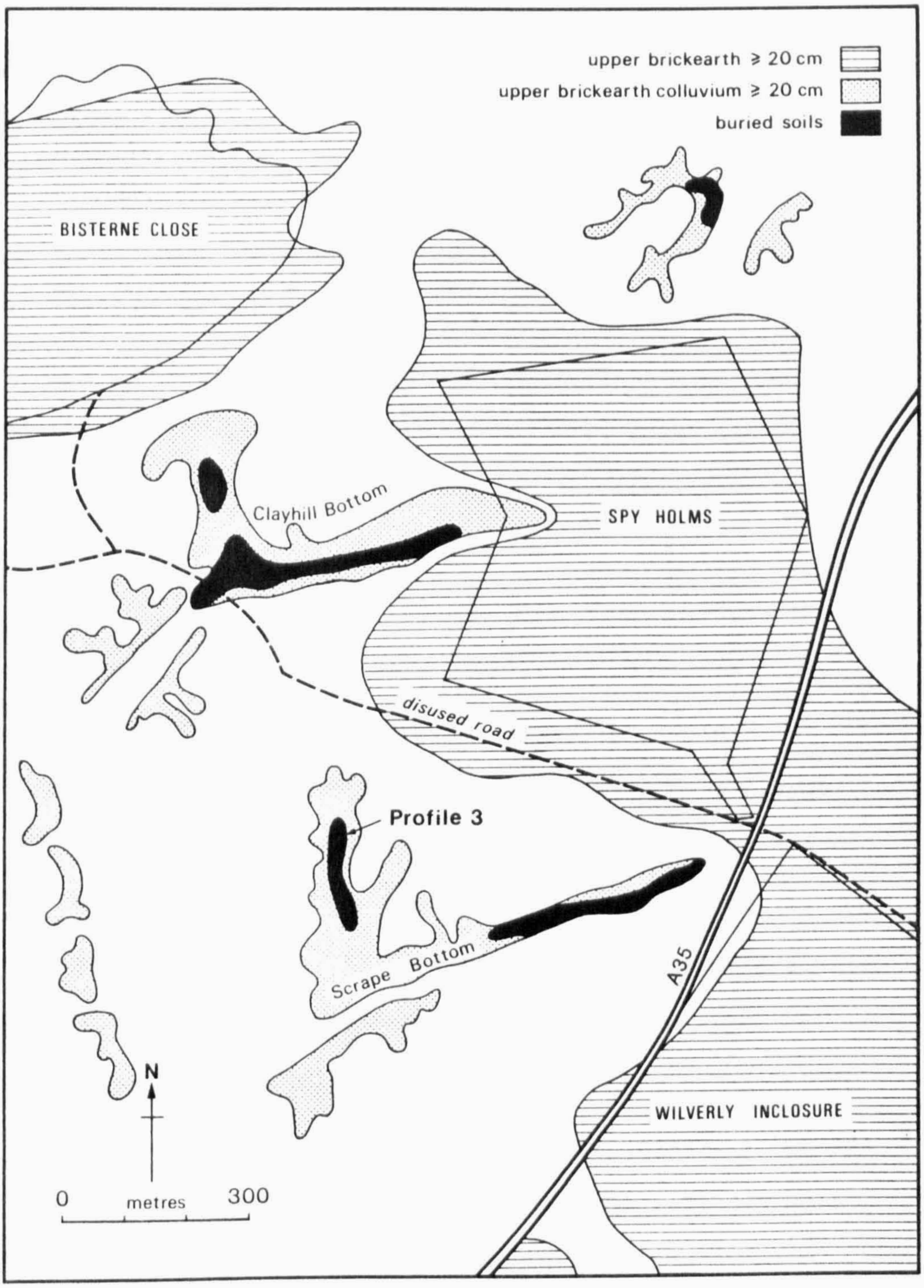


Fig. 5.10 Distribution of upper brickearth, upper brickearth colluvium and buried soils near Spy Holms.

The colluvium is thickest on the lower slopes and floor of the largest valley, Longslade Bottom, where upper brickearth has been almost completely eroded from the two narrow spurs of the 56m terrace that flank the valley. The colluvium also thickens towards the valley mouth (points 1-6, Fig 5.11). The buried soil on the valley floor is variable in thickness and in places is absent, suggesting that erosion occurred prior to burial. Where the overburden is thin (point 2, Fig 5.11) the buried soil may be absent, perhaps because it has been mixed with the colluvium by recent cultivation (Browning, 1951).

Sharp textural discontinuities are common in the soils. These are mainly caused by varying proportions of fine sand in the sediments and shows that the source of materials changed during deposition of the colluvium Most horizons are sandy loams or sandy silt loams suggesting derivation from the upper brickearth, but loamy sands, resembling the Barton Sands, are present and become increasingly more common towards the mouth of the valley suggesting that the Barton Sands that underlie the colluvium in some places (e.g. point 9, Fig 5.11) were an increasingly important contributor to the colluvium towards the valley mouth.

The colours of the colluvium and buried soil become more gleyed both downslope and towards the valley mouth, indicating poorer drainage. Generally, the Ah horizons at the colluvium surface and in the buried soil have the same Munsell hue and value, but the buried soil is nearly always 1 unit of chroma darker and feels greasier.

Three profiles were described; 1. on the side slopes of Longslade Bottom; 2. on the valley floor, exhibiting a buried soil and 3. in Scrape Bottom, also with a buried soil (Figs 5.9 and 5.10). The last two were chosen to see whether pollen analysis and micromorphology would indicate a similar age and mode of formation for the colluvium and buried soils on the east and west side of the 56m terrace fragment.

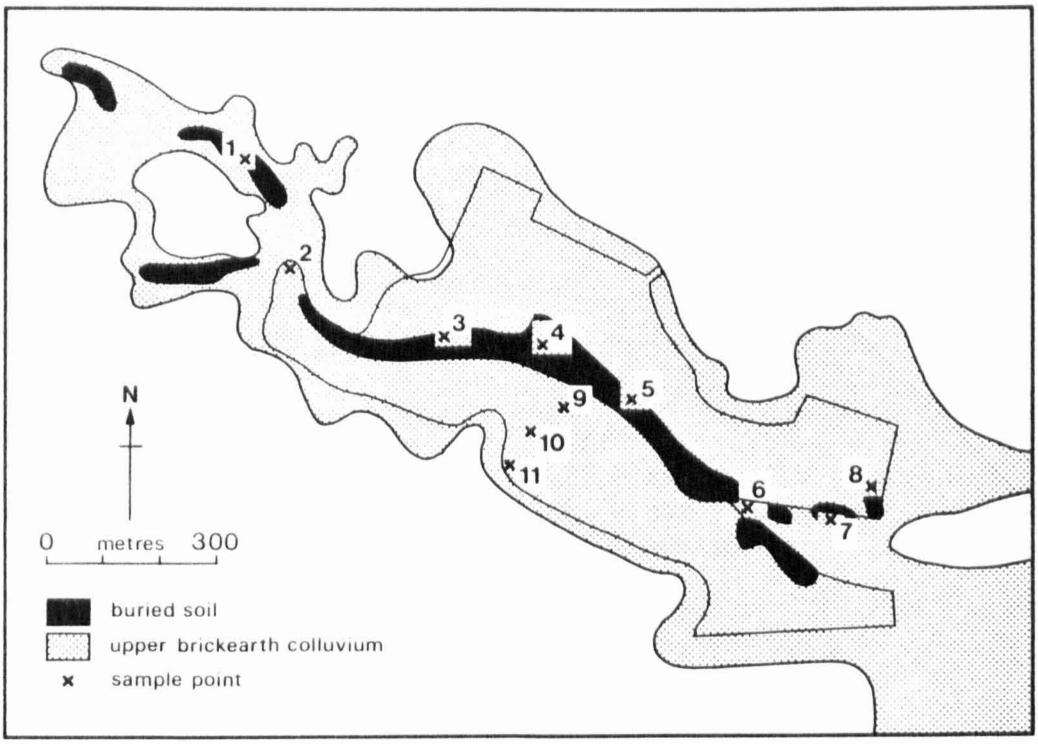


Fig. 5.11 Some characteristics of upper brickearth colluvium and buried soils in Longslade Bottom. (See over for soil descriptions at sample points.)

1 0-14cm 10YR 3/2 SZL
14-28cm 10YR 3/1 SZL (buried soil)
28+cm gravel

2 0-18cm 10yr 3/2 SZL
18+cm gravel

3 0-17cm 10YR 3/2 SZL
17-35cm 10YR 4/2 SZL
35-63cm 10YR 3/2 SZL (buried soil)
63+cm gravel

4 0-57cm 10YR 4/2 SZL
57-67cm 5Y 2.5/2 SZL (buried soil)
67+cm gravel

5 0-40cm 5Y 2.5/1-2 SZL to SL
40-60cm 2.5Y 4/2 SL
60-70cm 5Y 2.5/1 gritty SZL (buried soil)
70+cm gravel

6 0-38cm 5Y 2.5/2 SZL
38-60cm 5Y 2.5/1 SZL (buried soil)
60-122cm 2.5Y 4/2 SZL
122+cm gravel

KEY:
SZL - sandy silt loam
SL - sandy loam
LS - loamy sand

7 0-10cm 5Y 2.5/2 SZL
10-16cm 5Y 2.5/1 SL (buried soil)
16-33cm 10YR 5/3 LS
33+cm gravel with LS matrix

8 0-31cm 5Y 2.5/2 SL
31-43cm 5Y 2.5/1 SZL (buried soil)
43+cm gravel

9 0-28cm 10YR 3/2 SZL
28-50cm 10YR 6/6 SL
50-200cm+ LS Barton Sands

10 0-32cm 10YR 3/2 stony SL
32+cm gravel

11 0-28cm 10YR 5/2 stony SZL
28+cm gravel

Fig. 5.11 (cont.)

Descriptions:

Profile 1: Longslade Bottom (SU263006)

Altitude: 45m O.D.

Slope: 4.5°, north east

Vegetation and Land use: Permanent grazing

Horizon Depth (cm)

Ap 0-22/26 Very dark greyish brown (10YR 3/2) sandy silt loam; few small angular and subangular flints; moderate fine (becoming medium and coarse with depth) subangular blocky; moderately firm soil strength; slightly sticky; very plastic; semi deformable; abundant very fine fibrous roots; common earthworm channels; clear wavy boundary.

Eb/Bw(g) 22/26-51/52 Yellowish brown (10YR 5/4) sandy silt loam with few very fine distinct strong brown (7.5YR 5/8) mottles with sharp edges; stones as above, except two pockets with many flints; weak coarse subangular blocky; moderately weak soil strength; slightly sticky; moderately plastic; semi-deformable common very fine fibrous roots; common earthworm channels coated with very dark greyish brown (10YR 3/2) organans; clear smooth boundary.

2Bw(g) 51/2 - 60+ Brownish yellow (10YR 6/6) and yellowish brown (10YR 5/6) sandy loam with common fine distinct strong brown (7.5YR 5/8) mottles with clear edges; many flints as above; moderate coarse angular blocky; moderately weak soil strength; slightly sticky; very plastic; semi-deformable; few very fine fibrous roots; few earthworm channels, 10% of which are coated with organans as above.

Profile 2: Longslade Bottom (SU 262008)

Altitude: 40m O.D.

Slope: 1-5°, south west, concave

Erosion/Deposition: Dry stream bed 15m away.

Vegetation/Land Use: Permanent grass grazing.

Horizon Depth (cm)

Apg	0-30/32 Very dark greyish brown (10YR 3/2) sandy silt loam with common very fine and fine distinct strong brown (7.5YR 4/6) mottles; stoneless; moderate medium coarse subangular blocky; moderately weak ped and soil strength; not sticky; moderately plastic; semi-deformable; many very fine fibrous roots; common earthworm channels; clear smooth boundary.
Ahg	30/32-46/50 Dark greyish brown (10YR 4/2) sandy silt loam with horizontal yellowish brown (10YR 5/6-8) bands at 42 and 50cm; common fine and medium distinct strong brown (7.5YR 4-5/6) mottles with clear edges associated mainly with vertical root channels; stoneless; weak medium subangular blocky; very weak ped and soil strength; slightly sticky; moderately plastic; semi-deformable; common roots as above; earthworm channels as above; abrupt wavy boundary.
Bw(g)	46/50-56 Yellowish brown and brown (10YR 5/4-3) sandy silt loam; mottles as above; stoneless; structureless; very weak soil strength; slightly sticky; not plastic; semi-deformable; common very fine fibrous roots; abrupt smooth boundary.
bAhg	56-69/73 Very dark grey (10YR 3/1) sandy silt loam with few bleached sand grains; few very fine distinct strong brown (7.5YR 5/6) mottles; stoneless; massive; very weak soil strength; slightly sticky;

moderately plastic; semi-deformable; few very fine fibrous roots; abrupt wavy boundary.

2bBg 69/73-82 + Light olive grey (5Y 6/2) flint gravel with coarse sandy loam matrix; common prominent coarse strong brown (7.5YR 5/6) mottles.

Profile 3 Scrape Bottom (SU235018)

Altitude: 55m O.D.

Slope: 3.5°south, straight

Vegetation: Various grasses; *Calluna vulgaris*; *Ulex europeaus*; *Pteridium aquilinum.*

Land Use: Rough pasture

Horizon Depth (cm)

F,H 0-5 Very dark greyish brown (10YR 3/2); abrupt smooth boundary

Ah 5-17 Very dark greyish brown (10YR 3/2) humose clay loam; few small subangular flints; weak fine granular becoming moderate medium subangular blocky at 9cm; moderately weak soil strength; slightly sticky; moderately plastic; semi-deformable; common very fine to medium fibrous and woody roots; smooth clear boundary.

2Ahg/Bh 17-27 Dark brown (7.5 YR 3/2) sandy silt loam with common fine distinct strong brown (7.5YR 4/6) mottles with clear edges; stones as above; moderate coarse subangular blocky; moderately firm soil strength; slightly sticky; moderately plastic; brittle; common very fine to fine fibrous roots; few ferruginous coats on root holes; smooth sharp boundary.

3bAhg	27-43 Black (10YR 2/1) humose clay loam; stones as above; strong coarse subangular blocky; moderately weak soil strength; slightly sticky; moderately plastic; semi-deformable; few roots as above; smooth clear boundary.
3bEb/Bw(g)	43-69 Dark brown to brown (10YR 4/3) clay loam with common fine to medium distinct strong brown (7.5YR 5/8 and 4/6) mottles with clear edges; stones as above; moderate coarse subangular blocky with common black (10YR 2/1) organans on faces; moderately weak soil strength; slightly sticky; moderately plastic; semi-deformable; roots as above; smooth clear boundary.
4bBh/Bw(g)	59-65 Yellowish brown (10YR 5/6) sandy laom with common medium distinct and prominent strong brown (7.5YR 5/8) and yellowish red (5YR 4/6) mottles with clear edges; abundant stones as above; moderate coarse angular blocky with common organans (as above) and sesquane on ped faces; moderately weak soil strength; slightly sticky; moderately plastic; brittle; roots as above.

Discussion

Profile 1 corresponds to soil subgroup 5.43, a gleyic brown earth, and has a Bw horizon typical of weakly expressed colluvial soils (Avery,1980). The upper part of profile 2 also qualifies as a gleyic brown earth, and the buried profile corresponds to soil subgroup 8.31, a typical cambic gley soil (Avery,1980). Classification of profile 3 is problematical because in the subsurface horizons of both the buried and the overlying soils there is evidence of translocation of organic matter, iron and aluminium which has caused weak cementation, but the Bh characteristics are not well enough expressed to allow the designation of a Bh horizon. The buried profile has therefore been classed as a gleyic brown earth, albeit with weak podzolic features. The overlying colluvium has no distinct E, B or C horizon so is regarded as a deep Ah horizon (Avery, 1980).

In profile 2, weak stratification in the colluvium is evident from horizontally trending gleyic features especially at 42 and 50cm, and by a thin, lighter coloured Bw(g) horizon which was presumably derived from less organic soil horizons further up slope. Stratification is less marked in profile 3, but there are a few horizontal lines of coarse sand that were presumably derived from the Plateau Gravel. In both profiles 2 and 3 the depth and dark colour of the Ap and Ah horizons are conspicuous, a common feature in colluvial soils (Avery, 1980). Profile 1 shows no stratification, but this may have been obscured (and in the Ap horizon of profile 2) by mixing during cultivation.

All three profiles differ from upper brickearth soils on relatively stable terrace surfaces (e.g. Wilverly Plain, section 5.5.2) in having no Bt horizon. Soils developed in late Flandrian colluvium derived from loess in the Netherlands (Bolt et al., 1980) and Luxembourg (Kwaad and Mucher, 1976; 1979) also lack Bt horizons.

5.3 Summary and Conclusions

The 17 soil profiles described in this chapter illustrate the diversity present in the brickearth and brickearth-derived soils in the study area. In addition to the soil subgroups on brickearth described by Fisher (1975; Chapter 2), this work has identified a stagnogley podzol (paleoargillic), a typical paleoargillic brown earth, a typical argillic gley (paleoargillic) and a paleoargillic stagnogley soil. In the upper brickearth-derived colluvium a gleyic brown earth and a typical cambic gley soil were recognised.

The morphology of the four upper brickearth profiles is very similar to Hamble and Hook soils described elsewhere in southern England.

However, the increase in fine sand content with depth noted in three of the four profiles (and at many other sites) is unusual and indicates that the upper brickearth may have a different depositional history to similar deposits elsewhere in Britain

The profiles developed partly or wholly in lower brickearth are more varied, perhaps reflecting their longer pedogenic history. However, the field evidence suggests that the lower brickearth can be divided into two groups based on matrix and mottle colours: 1) greyish horizons with common coarse reddish mottles, and 2) strong brown horizons in which fine red mottles are rare or absent (table 5.2) Only the Hordle Cliff deposit is an exception to this classification as it has both a strong brown colour and common coarse red mottles.

Table 5.2.

Subdivision of lower brickearth deposits based on field evidence

Sites with greyish matrix and coarse red mottles	Sites with strong brown matrix and rare or no fine red mottles
Beaulieu Heath	Lepe Cliff
Tanners Lane	Thorns Farm
Holbury Gravel Pit (upper deposit)	Ocknell Plain
	Rockford Common
	Holbury Gravel Pit (lower deposit)
	Wootton Heath

CHAPTER 6

THERMOLUMINESCENCE DATING OF THE UPPER BRICKEARTH.

6.1 Introduction

The evidence from the general field survey and the Sturt Pond, Chilling Copse, Hook Gravel Pit and Wilverly Plain selected profiles indicates that the field characteristics of the upper brickearth are fairly constant on all terrace levels, and its predominately brownish colour suggests it has not been weathered in a pre-Devensian period. This may mean that the upper brickearth on all terraces could have a similar origin and that it was deposited over a relatively restricted time period. In order to test the latter point, the opportunity was taken to have two samples of upper brickearth dated by the thermoluminescence (TL) technique recently developed by Dr. A.G. Wintle, Cambridge University. This technique has been used widely to date archeological implements (Fleming, 1979) but has only recently been applied to sediments. The principles behind the method can be summarised as follows: "the TL dating of any sedimentary deposit, whether marine or terrestrial, is based on the assumption that exposure to sunlight during the weathering and transport of detrital grains is sufficient to remove most of their previously acquired TL signal. The TL signal in a mineral is due to the untrapping of electrical charges in the crystal when it is heated, the trapped charges having been produced by ionization due to the decay of natural radioactive elements in the sediment. The most common TL sensitive minerals are quartz and feldspar and these are the dominant minerals present in loess" (Wintle, 1981; p.479). The method has been applied previously to pre-Devensian loesses in the Soviet Union (Shelkoplyas, 1974) and in Hungary (Borsy, et al.,1979).

6.2. Dating

The two samples of upper brickearth chosen for dating came from the 46m terrace on Barton Cliff (SZ236929) and the 5m terrace at Sturt Pond (see section 5.2.1). These sites were chosen because of the probable large difference in the ages of the respective terraces. If the upper brickearth was a fluvial deposit associated with the aggradation of these terraces (as was suggested by Keen, 1980) a large difference between the ages of the two samples would be expected.

At the Barton site about 2m of upper brickearth lies directly on the gravel and at Sturt Pond about 1.2m also lies directly on gravel. At both sites a sample block of upper brickearth approximately 0.03m^3 was taken from the basal 0.5m of the section after cutting back at least 0.25m. This procedure minimised the possibility that the samples had been exposed to sunlight since deposition.

The results are shown in Table 6.1. For comparison, 4 dates obtained by Wintle for samples of loess from elsewhere in England are also shown. Both samples of upper brickearth are dated to the Late Devensian period. Although there is an apparent difference of 4,300 years between the two dates, the experimental error of ±20% means that they do not have significantly different ages (Wintle, 1981). In conjunction with the field data, this is strong evidence that the upper brickearth is all of Late Devensian age. As the 5m terrace is unlikely to be younger than the Late Ipswichian/Early Devensian transition (Brown et al., 1975) and the 46m terrace is unlikely to be younger than the Middle Pleistocene (Roe, 1975), the upper brickearth at the two sites (and elsewhere) was probably deposited long after the terraces were aggraded. As the Late Devensian sea level was well below that of the present (Dyer, 1975) and there is no evidence that sea levels in the study area since the Late Devensian were significantly higher than at present, these TL dates suggest it is unlikely that any of the upper brickearth in its primary position can be a marine or fluvial deposit. Only an aeolian origin can explain its deposition over such a wide range of levels in the landscape during the Late Devensian.

The four samples of loess analysed by Wintle also gave Late Devensian dates, confirming the age inferred for them by Catt (1978). Taking into account the experimental error, these dates cannot be separated from those

TABLE 6.1

Thermoluminescence dates for upper brickearth and loess (after Wintle, 1981)

Location	Deposit	TL age (years B.P.)
1. Barton Cliff (Hampshire)	upper brickearth	18,800 ± 20%
2. Sturt Pond (Hampshire)	upper brickearth	14,500 ± 20%
3. Pegwell Bay (Kent)	loess	14,800 ± 20%
4. Lizard Peninsula (Cornwall)	loess	15,900 ± 20%
5. St. Agnes (Scilly Isles)	loess	18,600 ± 20%
6. St. Mary's (Scilly Isles	loess	18,600 ± 20%

for the upper brickearth, and the similar ages of the upper brickearth and the loess is further supporting evidence that the upper brickearth could be aeolian .

CHAPTER 7.

POLLEN ANALYSIS OF THE COLLUVIUM AND BURIED SOILS.

7.1 Introduction

In order to help date the periods of colluviation and burial of the soils in the valleys around the 46m terrace, pollen diagrams were constructed for the soil profiles described in Longslade Bottom (profile 2, section 5.2.14) and Scrape Bottom (profile 3, section 5.2.14). The pollen analyses and most of the sample preparation and interpretation of results were carried out by Dr. K.S. Eide, Institute of Archaeology, London.

As far as is known, pollen analysis of colluvium has not previously been attempted in Britain, but it has been used successfully in dating loess-derived colluvium in Luxembourg (Kwaad and Mucher, 1977; 1979). Studying the effectiveness of pollen analysis in dating slope deposits, Riezbos and Slotboom (1974) found that pollen diagrams of colluvium in Luxembourg showed considerable agreement with those from nearby alluvial deposits and peat, and concluded that the degree of post-depositional disturbance of the pollen was similar in both types of deposits. Thus the analyses presented here should provide a reliable history of the colluvium.

7.2 Methods.

Soil samples were extracted at 5cm intervals from the base of the soil pits to the present surface. Sub-samples were subjected to sodium hydroxide digestion, hydrofluoric acid treatment and acetolysis to extract the pollen, according to the methods of Dimbleby (1961) and Smith (1966). The samples from 55 to 75cm inclusive in the Longslade profile and all the samples from the Scrape Bottom profile still retained a large amount of quartz after these treatments, and this was removed by flotation in a bromoform/acetone mixture (Moore and Webb, 1978). A minimum number of 300 grains were counted from each sample, but those at 55, 65 and 70cm depth in the Longslade profile contained too little pollen for interpretation.

7.3 Results and Discussion

7.3.1 Profile 2, Longslade Bottom.

The pollen frequencies are shown in Fig 7.1. The diagram is divided into two pollen assemblage zones (P.A.Z.) (Cushing,1967), the Gramineae - Corylus P.A.Z.1 and the Gramineae -Calluna P.A.Z2. P.A.Z.1 corresponds to the buried soil.

a) P.A.Z.1

The absolute pollen frequency (A.P.F.) rises to a peak at 60cm approximately coincident with the buried surface identified in the field at 56cm. The absence of Ulmus indicates that the vegetation was post elm-decline, which has been radiocarbon dated to 2900 years B.C. on the Isle of Wight (Tomalin and Scaife,1980). The absence of Pinus indicates that the soil was buried before the 18th century, when this species was introduced to the New Forest and became an important component in pollen diagrams for the area (Tubbs and Dimbleby,1965). The presence of Tilia suggests an early Sub-atlantic date (Tubbs and Dimbleby,1965), and this is supported by the presence of Carpinus which first became consistently common in pollen diagrams in southern England around the Late Bronze Age/early Iron Age transition at 550 B.C. (Pennington,1974)

The arboreal pollen content is 19.2 - 20.5%, and this is below the level that has been taken to indicate that woodland was within 100m of the site (Tinsley and Smith,1974), particularly since the abundant pollen producer Corylus is dominant (Moore and Webb,1978). The high Gramineae/low arboreal assemblage in conjunction with dominant Corylus strongly suggests human interference in the vegetation (Havinga, 1974). The presence of Cerealia type pollen and arable herbs such as Compositae liguliflorae and Cruciferae shows that cereal cultivation was

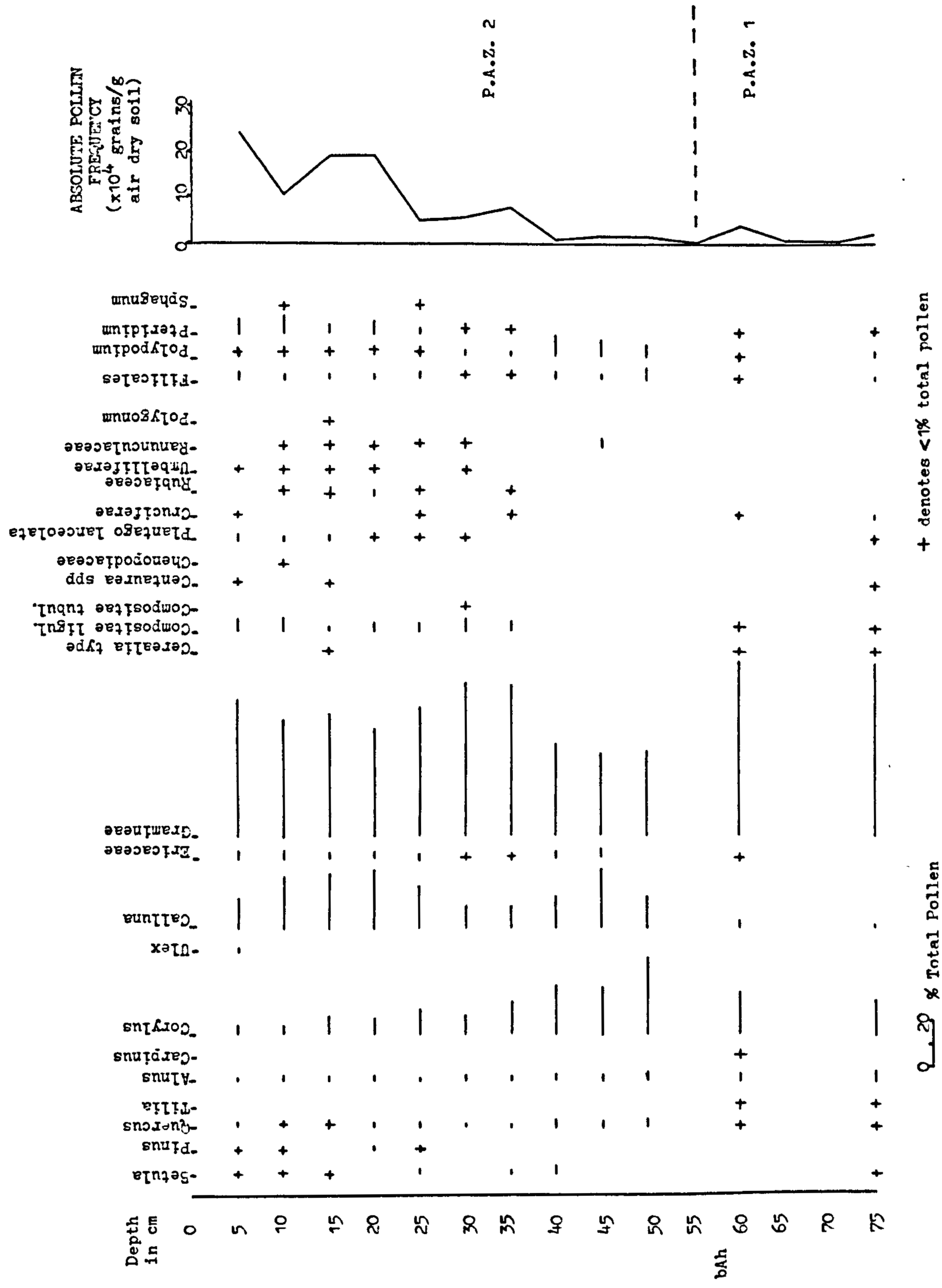


Fig. 7.1 Pollen diagram for profile 2, Longslade Bottom.

practised nearby. Local pastoral agriculture is also indicated in the herb spectrum, particularly by the presence of *Plantago lanceolata* and *Centaurea* spp., excluding *Centaurea cyanus* (Salisbury, 1961).

b) P.A.Z.2

The decline in A.P.F. between 5-10 cm represents the normal reduction in pollen content away from the present surface. A second peak between 15-20cm may be due to inversion of the soil surface by recent cultivation (Browning, 1951). A third small peak in A.P.F. at 35cm is beyond the zone of recent cultivation and may represent a former surface (a temporary standstill in colluviation), though there was no field indication of this.

The arboreal pollen content has a range of 7.5 - 17.7% between 5-35cm depth and a range of 22.8 - 41.1% between 40-50cm depth. The high values between 40-50cm are indicative of a wooded site. This could mean that woodland became re-established on the site at the onset of colluviation in P.A.Z.2, or more probably that this phase of colluviation stemmed from the expansion of agriculture into wooded land further upslope, so that arboreal pollen-rich soil was washed onto the valley bottom. As *Corylus* is the main arboreal component it is possible that this was secondary woodland.

Between 5-35cm, a second phase of colluviation is suggested by the low arboreal pollen content and the presence of a variety of arable and pastoral herb pollen. This indicates that the colluvium accumulated while Longslade Bottom had an open vegetation and agriculture was practised. The herbs present indicative of arable agriculture include *Compositae* spp., *Cruciferae*, *Rubiaceae*, *Umbelliferae*, *Chenopodiaceae* and *Polygonum*. Pastoralism is suggested by the presence of *Plantago lanceolata*, *Centaurea spp* (excluding *Centaurea cyanus*) and *Ranunculaceae*.

Pinus is present only in the top 25cm, so at least 30cm of colluvium had accumulated by the 18th century. It is not possible to say how much colluvium has accumulated since that time as the Pinus pollen will have been mixed into the top 25cm of the profile by recent cultivation.

7.3.2 Profile 3, Scrape Bottom

The pollen diagram for this profile is shown in Fig 7.2. It is divided into two pollen assemblage zones, the Gramineae - Calluna P.A.Z.1 and the Gramineae - Calluna P.A.Z.2

a) P.A.Z.1

The peak in A.P.F. at 25-35cm confirms the field identification of a buried soil surface. P.A.Z.1 comprises all of the buried profile.

The absence of Ulmus and Pinus and the presence of Carpinus and Tilia provides the same evidence for dating as in P.A.Z.1 of the Longslade Bottom profile, and also suggests a Late Bronze Age/early Iron Age transition date. The dominance of Corylus in the arboreal pollen suggests secondary woodland was present nearby. However, as at Longslade, an open vegetation on the site is implied by the low arboreal pollen content (11.4-19.3%) and the presence of Cerealia pollen and agricultural herbs provides ample evidence of agriculture on site. Arable herbs present include Compositae liguliflorae, Cruciferae, Rubiaceae and Chenopodiaceae. Herbs associated with pastoralism include Plantago lanceolata, Succisa, Centaurea spp. (excluding Centaurea cyanus) Ranunculaceae and Papilionaceae.

b) P.A.Z.2

Values for A.P.F. are low throughout this zone and only rise slightly towards the present surface. These low values are probably due to deposition of pollen-poor colluvium. The absence of subsidiary A.P.F. peaks (in contrast to P.A.Z.2 at Longslade Bottom) may indicate that colluviation occurred in a single phase.

The arboreal pollen content is fairly low (18.4-26.1%) and

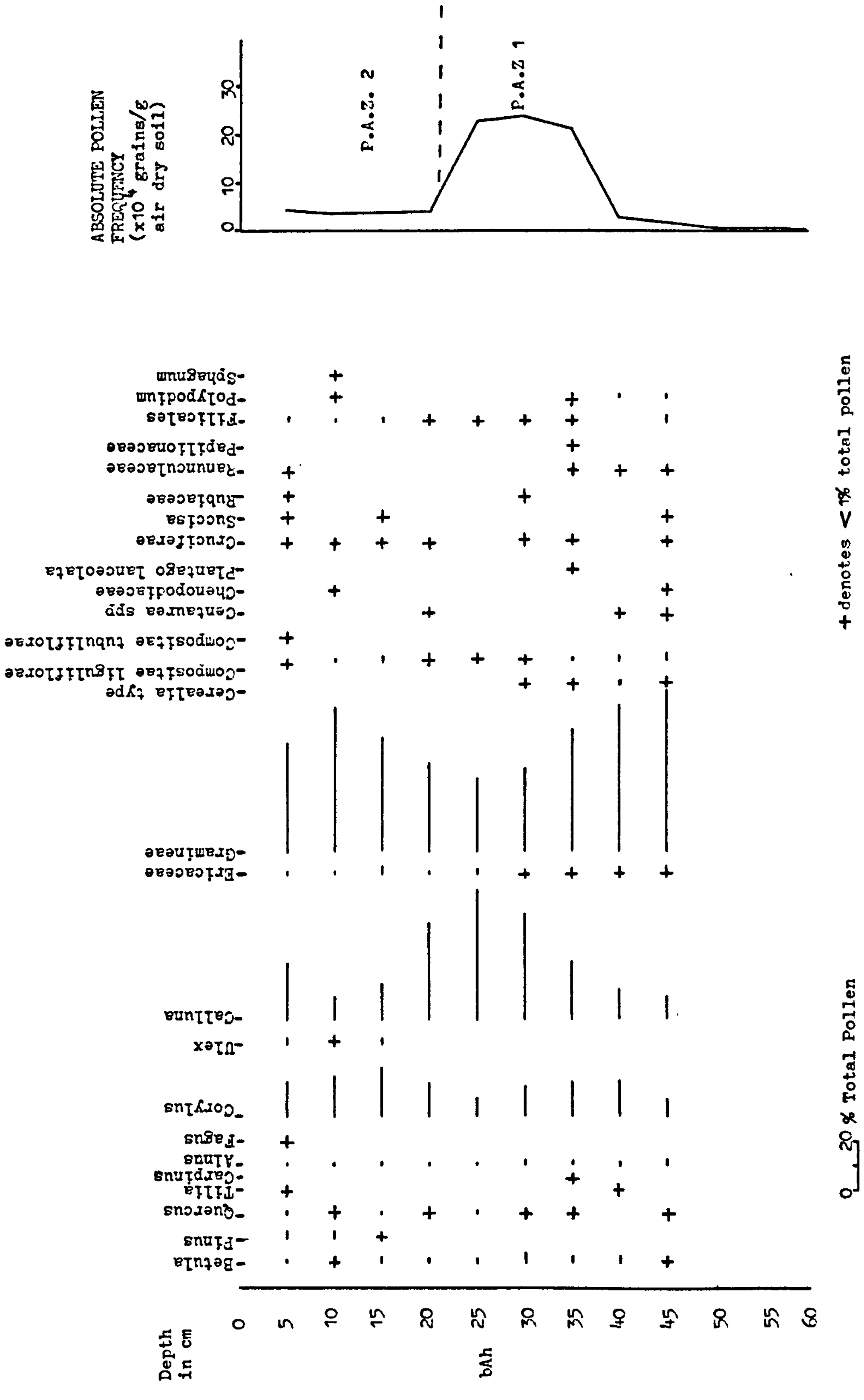


Fig. 7.2 Pollen diagram for profile 3, Scrape Bottom.

indicates an open vegetation. The <u>Calluna</u> content in P.A.Z. 2 (and P.A.Z.1) is higher than in the Longslade Bottom profile and may indicate that the pasture was poorer. There is no <u>Cerealia</u> type pollen but many arable and pastoral herbs are present which suggests agriculture could have been practised nearby. <u>Pinus</u> pollen appears only in the upper 15cm, so at least 12cm of colluvium had accumulated by the 18th century.

7.4. Conclusions

At both sites the buried soils have pollen assemblages that suggest the soils were cultivated during the Late Bronze Age/early Iron Age. Agricultural practices may have initiated colluviation soon afterwards. At Longslade Bottom this occurred in at least two phases but at Scrape Bottom there is evidence for only one. The herb spectra at both sites suggests that arable and pastoral agriculture may have been practised during and after colluviation, but the almost complete absence of <u>Cerealia</u> indicates that cultivation was less intense or practised further from the sites in P.A.Z.1 times.

CHAPTER 8

PARTICLE SIZE DISTRIBUTION

8.1 Introduction and Methods.

The determination of the particle size distribution (p.s.d) is one of the most popular methods of characterising soils and sediments. It is useful in pedology to illustrate the effects of weathering in changing coarser materials into clay and to show the movement of clay in the soil profile by illuviation. In sedimentology, the p.s.d. can often be used in conjunction with stratigraphic and geomorphological information to infer the environment of deposition of a sediment. This is so with loess which shows a characteristic concentration of particles in the silt fraction, and with aeolian sand which peaks in the fine or medium sand fraction. Particle size analysis was therefore an important aspect of this study.

All samples of soil and sediment collected (> 160) were analysed at 1ø intervals between 9 and -1ø (ø = $-\log_2$ grain diameter in mm). This interval was chosen to facilitate comparison because most published analyses of loess and aeolian sands use the ø scale. A few samples were analysed at ½ø intervals over a restricted range, normally between 2-6ø, in addition to 1ø analysis.

A dry sieving and pipette method was used; it is described in detail in Appendix A. The results for each sample are given in Appendix B. As most of the analysed samples were collected within 2m of the surface the clay content has probably been modified by weathering and /or translocation. Therefore, to allow a better comparison between the silt and sand contents of the sediments, the p.s.d's were recalculated on a clay-free basis. The summary statistical parameters mean (m), sorting or standard deviation (So), skewness (Sk) and kurtosis (k) were computed graphically from the clay-free p.s.d's using the Rothamsted Genstat statistical package (Alvey *et al.*, 1977). The mean values were calculated according

McCammon's 97% efficiency method and sorting according to his 87% efficiency method (McCammon, 1962b). Skewness was calculated using Warren's (1974) formula and Kurtosis according to Folk and Ward (1957).

8.2. Particle Size Distribution of Upper Brickearth

This section describes the p.s.d's of the samples of upper brickearth selected in the topsoil survey by stratified random point sampling (section 4.2.3.) and compares them with sediments from elsewhere thought to have an aeolian origin.

The 71 samples of upper brickearth have a wide range of p.s.d's. Silt contents range from 22.5 to 69.6% (samples 36 and 5), sand contents range from 18.1 to 69.1% (samples 31 and 8) and clay contents range from 4.4. to 22.5% (samples 35 and 31). The upper brickearth forms a continuum between these extremes of p.s.d., but to illustrate the variation present arbitrary subdivisions have been made of samples with more than 60% silt (Fig. 8.1), 40-60% silt (Fig 8.2) and less than 40% silt (Fig 8.3), all on a clay-free basis. Of the 71 samples, 28% occurred in category 1, 28% in category 2, and 44% in category 3.

Figs8.1 to 83 show that most samples are unimodal at 1φ resolution and that secondary peaks are relatively minor. A decrease in silt content is accompanied by a gradual shift in the modal diameter from about 6-5φ to 4-3φ or more rarely 3-2φ. This suggests that most samples of upper brickearth are not a mixture of two sediments (which would probably give a bimodal p.s.d.), but a single sediment whose mode varies over a fairly wide range. For the twelve examples, mean size ranges from 4.89 to 3.27φ and sorting from 1.72 to 2.32φ i.e. between poorly sorted and very poorly sorted using the classes of Folk and Ward (1957). The siltiest samples are very slightly negatively skewed and the sandiest samples are slightly positively skewed (-0.08 to + 0.27). Kurtosis values vary between

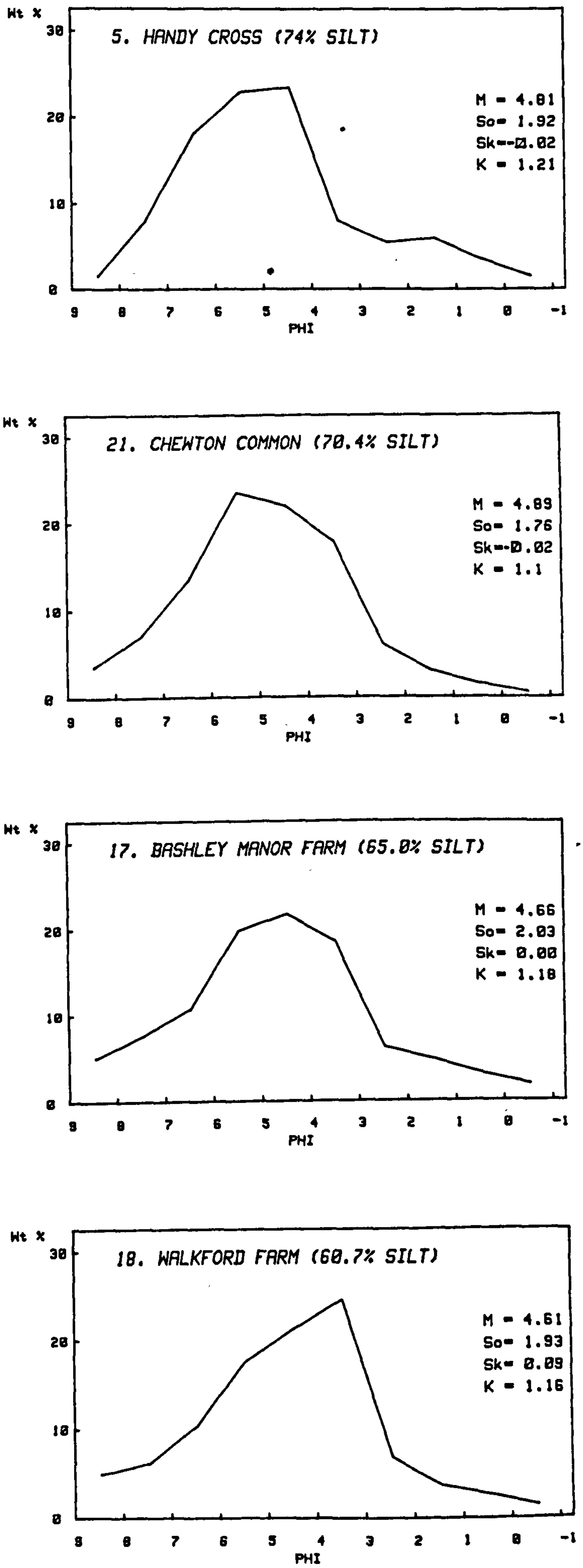


Fig. 8.1 Upper brickearth samples containing more than 60% silt.

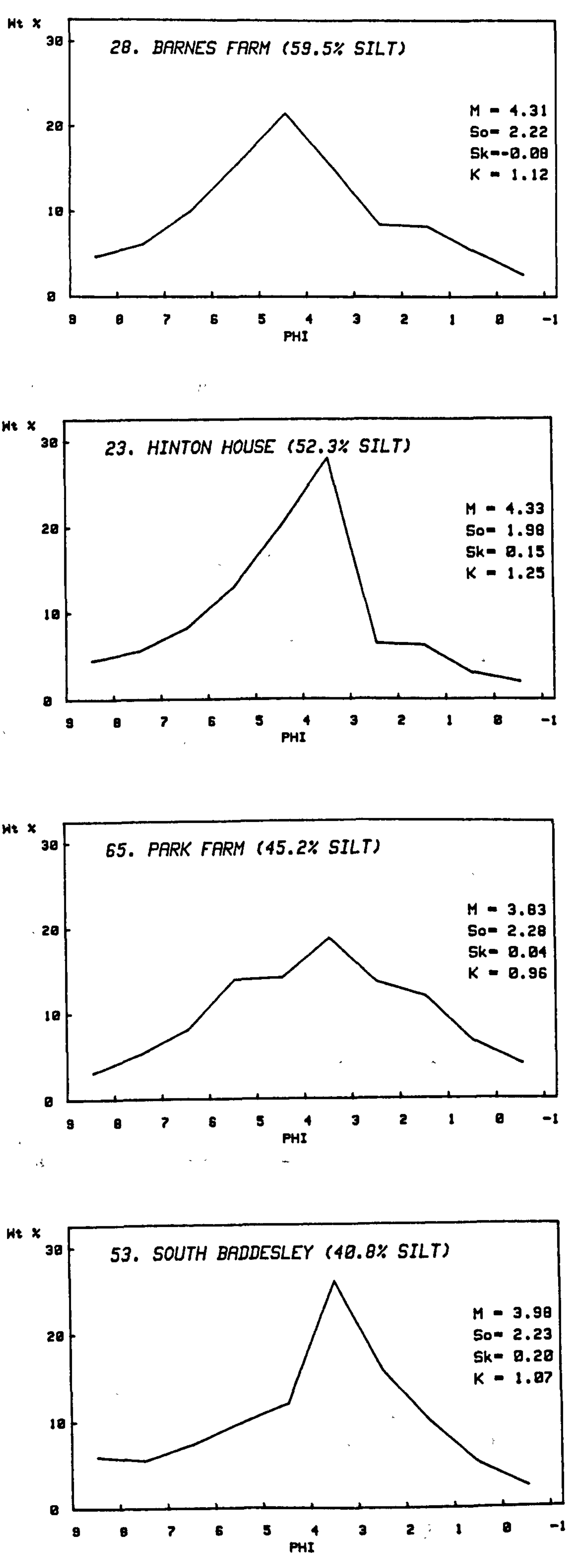


Fig. 8.2 Upper brickearth samples containing 40 to 60% silt.

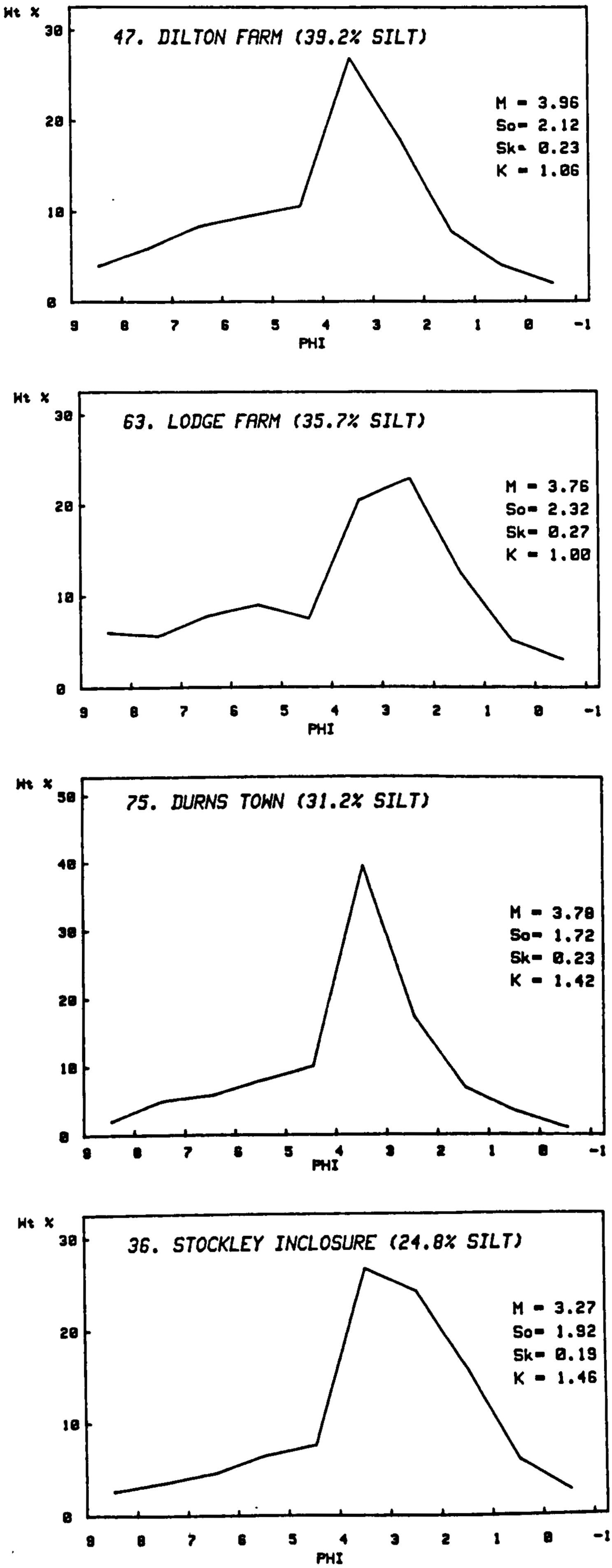


Fig. 8.3 Upper brickearth samples containing less than 40% silt

0.96 and 1.46, i.e. mesokurtic to leptokurtic. The near-normal values for skewness and kurtosis may also indicate that most of the upper brickearth was sorted as a single sediment, because Folk and Ward (1957) suggest that non-normal values for these parameters indicate mixing of sediments. Table 8.1 gives the range and mean of the 4 statistical parameters for all 71 samples of upper brickearth. Bivariate scattergrams (Briggs 1977) were constructed for the various combinations of the parameters, but in no case were distinct subgroups of point clusters evident; the upper brickearth forms a continuum of textures between the extreme values of each parameter.

The siltiest samples of upper brickearth resemble loess from many other parts of England (Fig 8.4.), but generally contain about 10% more very fine sand in the 4-3ϕ range. For comparison, the loess of Pegwell Bay, Kent is shown; it is far siltier than most other English loess deposits and closely resembles much Continental loess (Fig. 8.5). The appreciable quantity of sand in even the siltiest samples of upper brickearth suggests that it might be classified as sandy loess; but the p.s.d.'s do not conform precisely with the description of sandy loess given by the INQUA Loess Commission (Fink, 1976); this specifies that sandy loess is either bimodal with peaks in the coarse silt and medium sand fractions or unimodal with equal amounts of coarse silt, fine sand and medium sand (Table 3.1). The sandy loess of Essex fits the first of these descriptions better (Fig 8.4.)

The sandiest samples of upper brickearth are comparable with the aeolian silty sands of Somerset (Gilbertson and Hawkins, 1978a; Findlay, 1965); these sands contain a little more silt and have a modal size at least 0.5ϕ finer than typical coversand such as is found in Essex and other parts of Britain (Fig 8.6.)

	meansize (ø)	sorting	skewness	kurtosis
mean	4.13	2.01	0.11	1.14
range	2.92 to 5.09	1.66 to 2.44	-0.20 to 0.34	0.83 to 1.57

Table 8.1 Summary statistical parameters for the upper brickearth

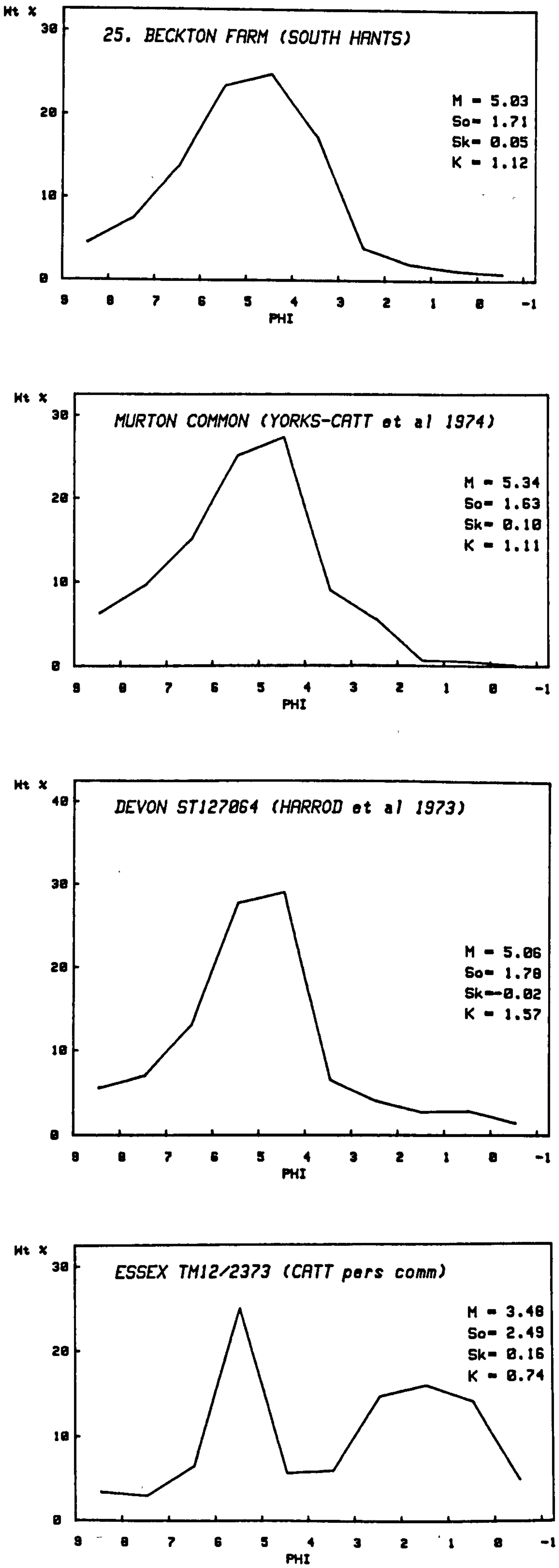
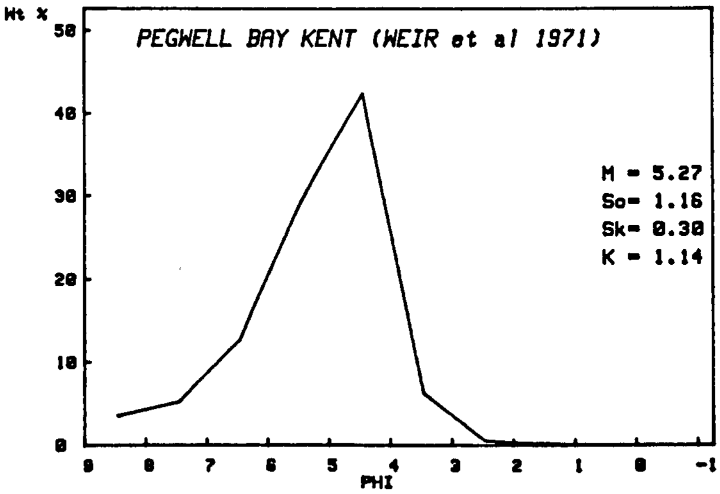


Fig. 8.4 Comparison of upper brickearth with loess.



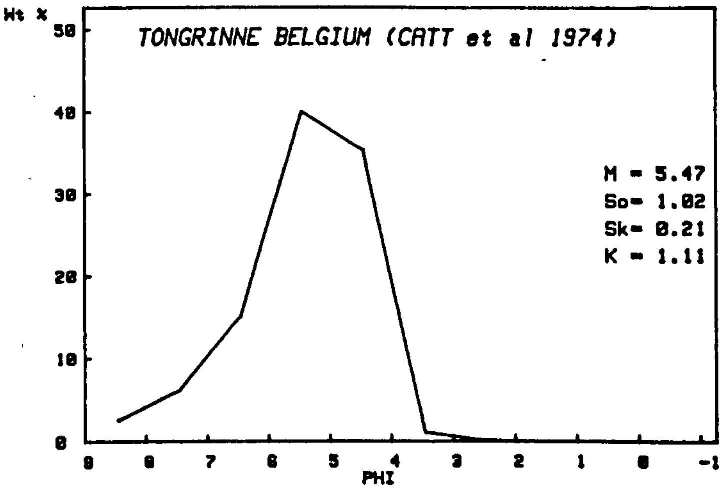


Fig. 8.5 Loess from Kent and Belgium.

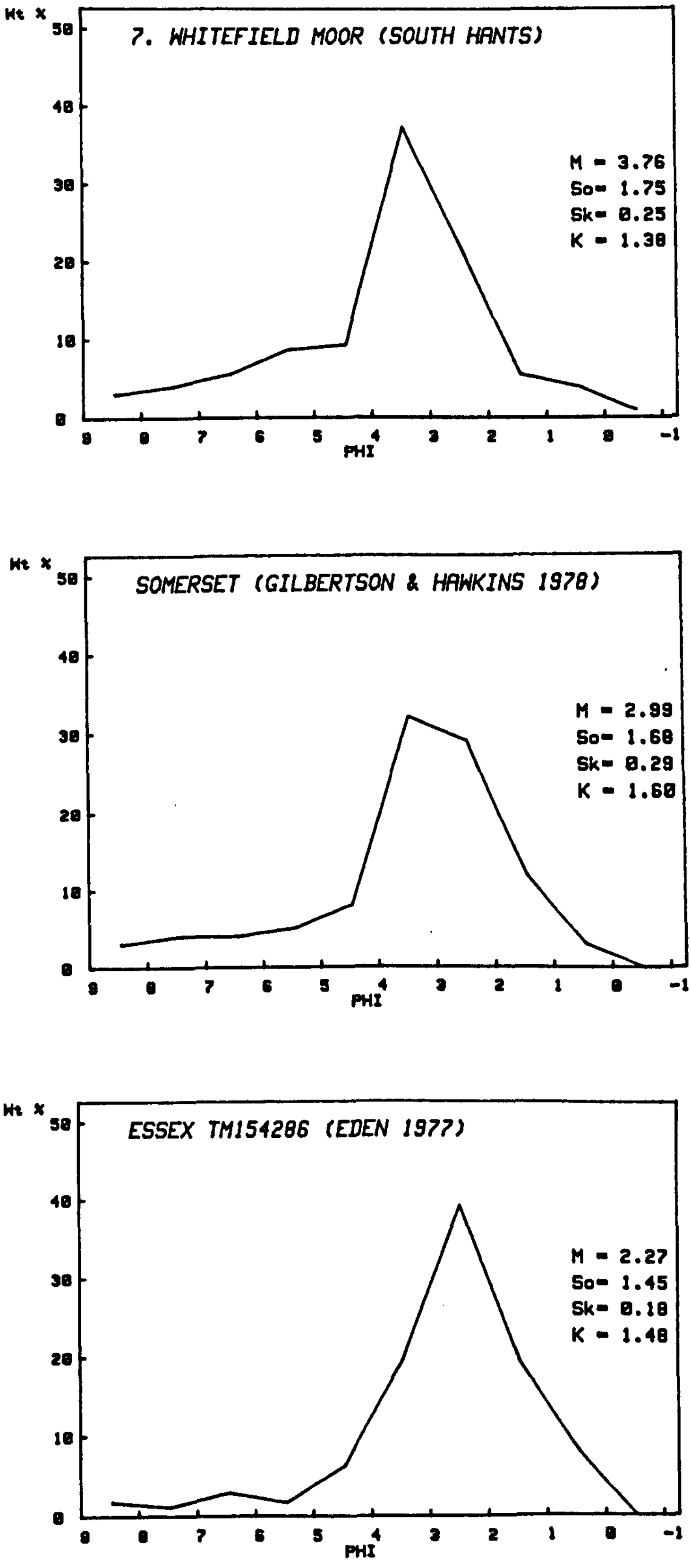


Fig. 8.6 Comparison of sandy upper brickearth with aeolian sand from elsewhere in England.

To investigate whether the textural variations in the upper brickearth have a geographical association, the silt content (clay-free basis) of the 71 topsoil samples and of the A horizons of the described profiles at Ocknell Plain, Wilverly Plain, Tanners Lane, Thorns Farm, Chilling Copse, Hook Gravel Pit and Lepe Cliff (Table 5.1) were plotted on a map (Fig 8.7). In the area enclosed by the broken line (which approximates to the 40% silt isarithm) the topsoils have a much lower silt content (mean = 34.7%) than the rest of the area (mean = 60%). This may be taken to indicate that a geographical association exists, but comparison of Fig 8.7 with Fig 8.8 shows that the variation in silt content may also be related to the thickness of the upper brickearth, and the thickness does vary geographically, as discussed in section 4.3.1.

In Fig. 8.9a,b the silt content of the topsoils is plotted against thickness of the brickearth. For those samples from sites where upper brickearth overlies gravel, there seems to be a positive correlation of topsoil silt content and upper brickearth thickness, but those samples from sites where upper brickearth overlies lower brickearth deviate from the main distribution. The strength of association between the two variables was measured using Spearman's rank correlation method (Norcliffe, 1977), omitting the data from sites where upper brickearth overlies lower brickearth. A correlation coefficient (r_s) of 0.66 was obtained which suggests a positive relationship does exist. The statistical significance of the relationship was assessed using the Student's 't' test (Norcliffe, 1977). Adopting a one-tailed test at a significance level of 0.01, the value of t (5.74) exceeds the critical value, so the relationship between topsoil silt content and upper brickearth thickness is significant with 99% probability

The probable explanation for this relationship is that the

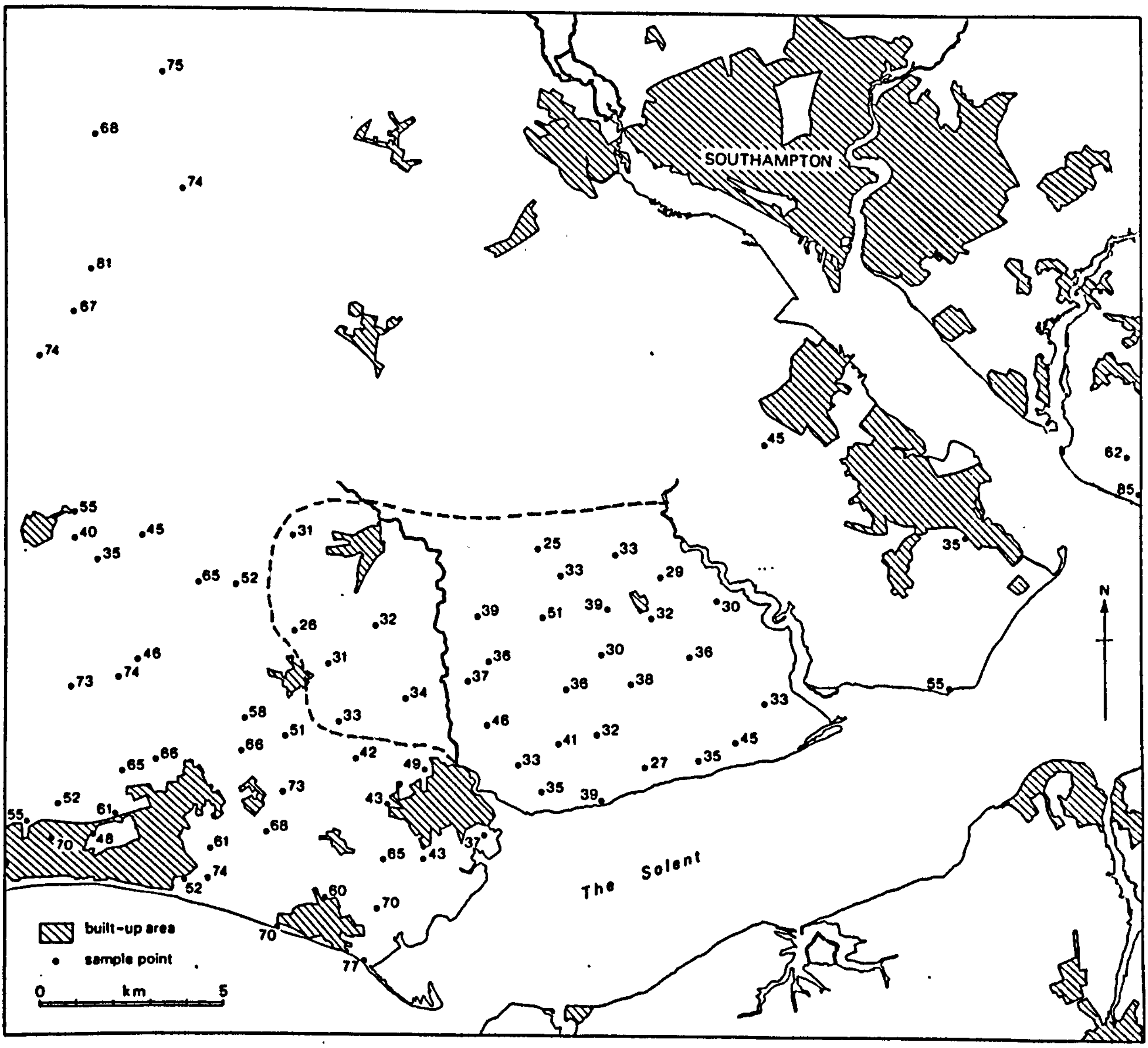


Fig. 8.7 Percentage silt content (clay-free basis) at 20cm depth in the upper brickearth. Dashed line approximates to the 40% isarithm.

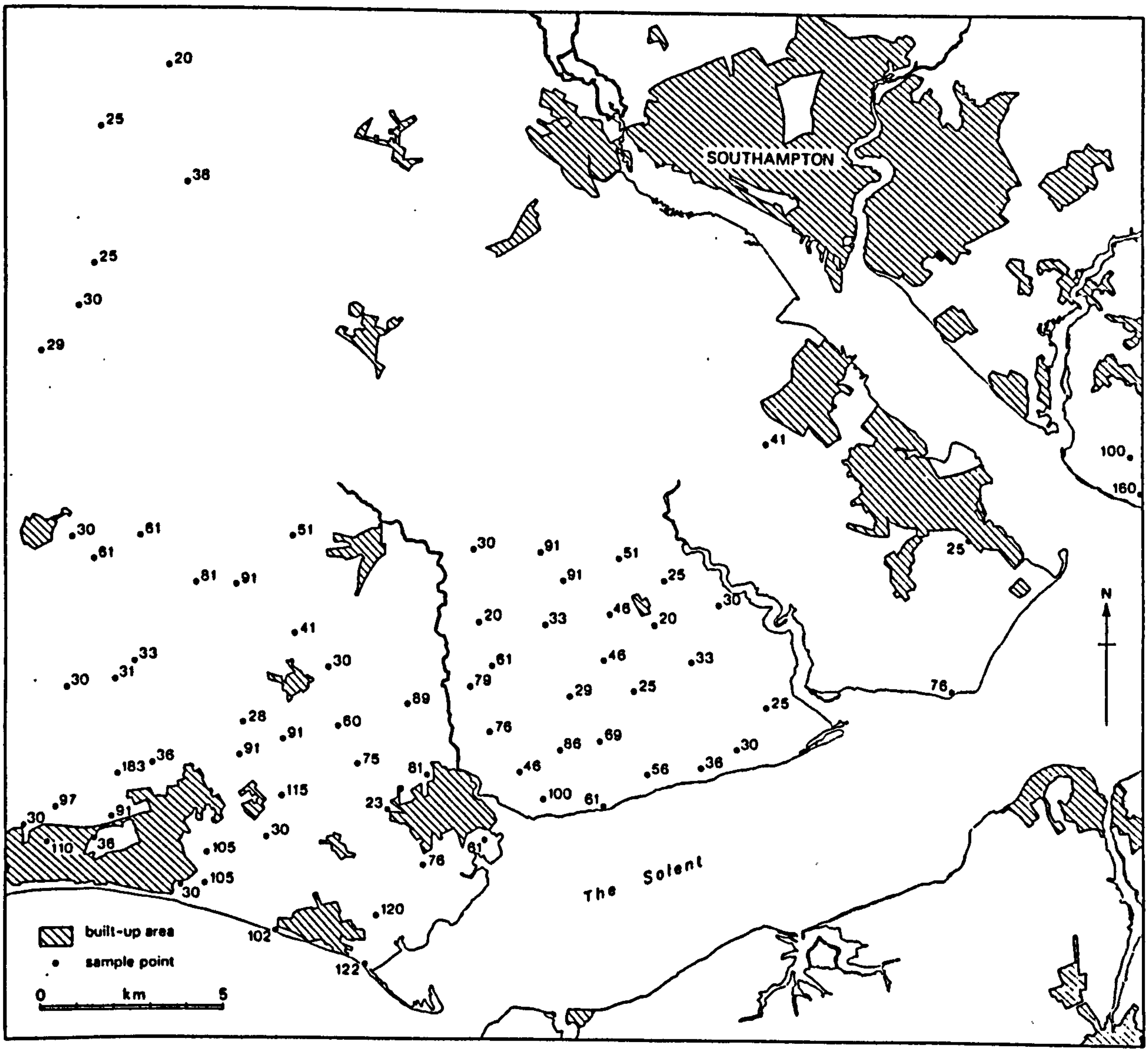


Fig. 8.8 Thickness of upper brickearth (in cm) in the study area.

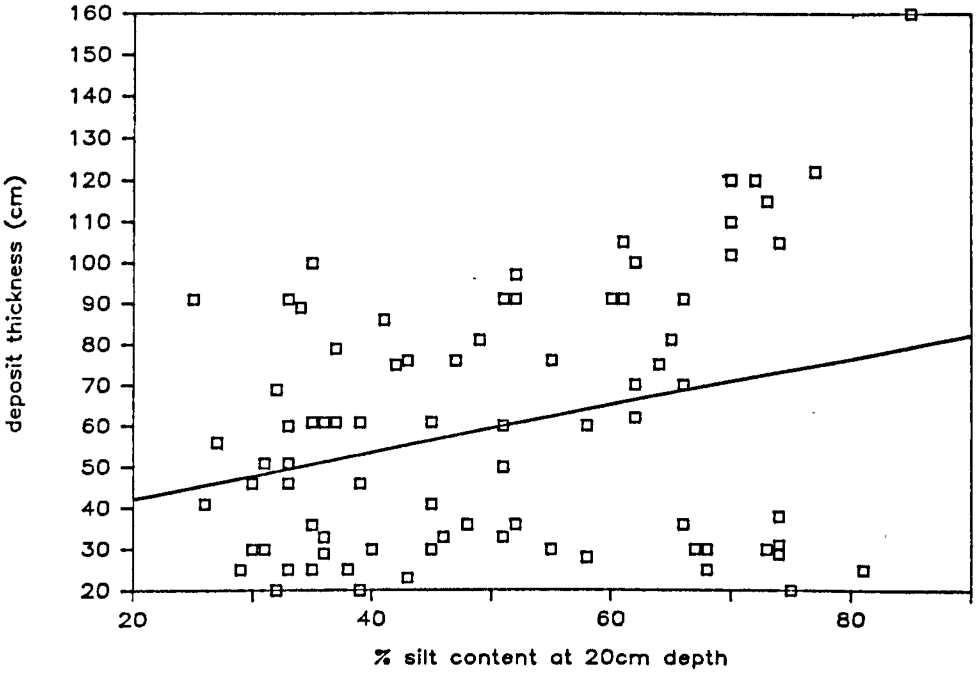


Fig. 8.9a Silt content of upper brickearth topsoil samples plotted against thickness of deposit (lower brickearth sites included)

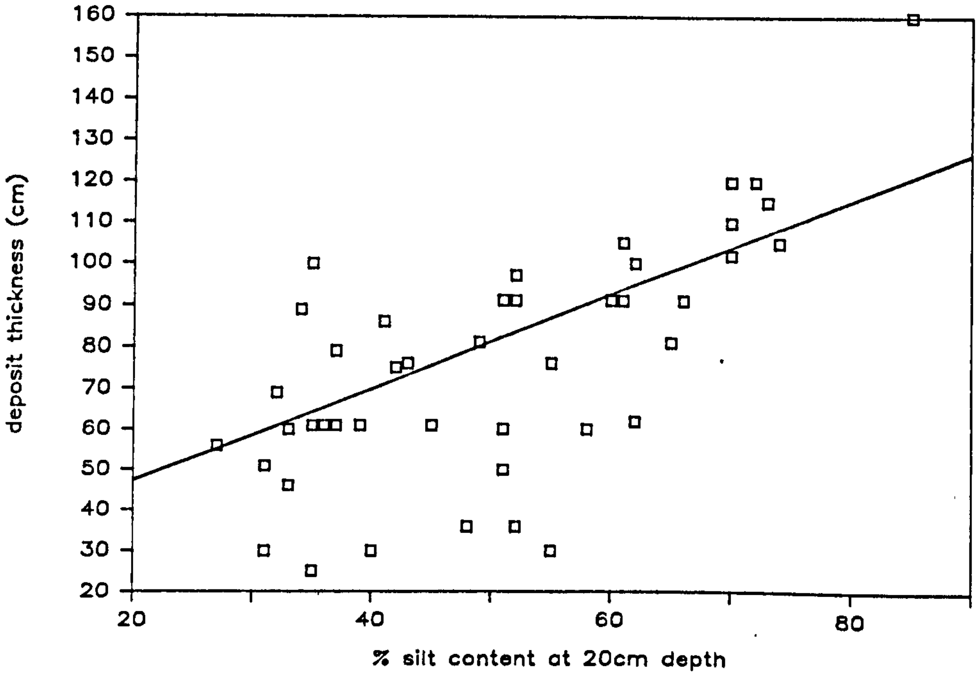


Fig. 8.9b Silt content of upper brickearth topsoil samples plotted against thickness of deposit (lower brickearth sites excluded).

upper brickearth increases in silt content (and decreases in sand content) upwards in the profile, so that the deepest, least eroded, soils have the greatest topsoil silt content. The fact that the relationship is demonstrable with data collected over a wide area emphasises the homogeneity of the upper brickearth and suggests that the relative amounts of silt and sand being deposited at any one time must have been fairly constant over the whole area.

The reason why some thin upper brickearths over lower brickearth deviate from the main distribution is unclear, but it could be that silt rich lower brickearth has been mixed with upper brickearth or that sandy upper brickearth was not deposited at these sites, or that some sandy upper brickearth was eroded before the siltier material was deposited. Most of the deviant sites occur on the high (> 56m) terraces.

8.3. Particle Size Distribution of Local Older Sediments.

As it is likely that older local sediments have contributed material to the brickearth, the p.s.d's of samples of Plateau Gravel and Tertiary Sand were determined for comparison. It was not possible to sample all of the many Tertiary beds, so attention was focussed on those beds that have fine sandy textures and which are the most extensive near the surface in the study area.

8.3.1 Plateau Gravel.

All the samples examined have a prominent peak at 2-1φ in the sand fraction and one, at Lepe Cliff, has secondary peak at 0 to-1φ (Figs 8.10 and 8.11). In unaltered gravel the silt content is always negligible, but in samples 125 and 140, which were taken from near the brickearth/gravel boundary, silt is more important, presumably due to mixing of the two sediments. The clay content of the unaltered gravels is 3.6 - 7.4% but in samples 125 and 140 it increases to 15.3 - 28.6% The dominant sand fraction of the upper brickearth, 4-3φ is a minor constituent in the gravels, amounting to

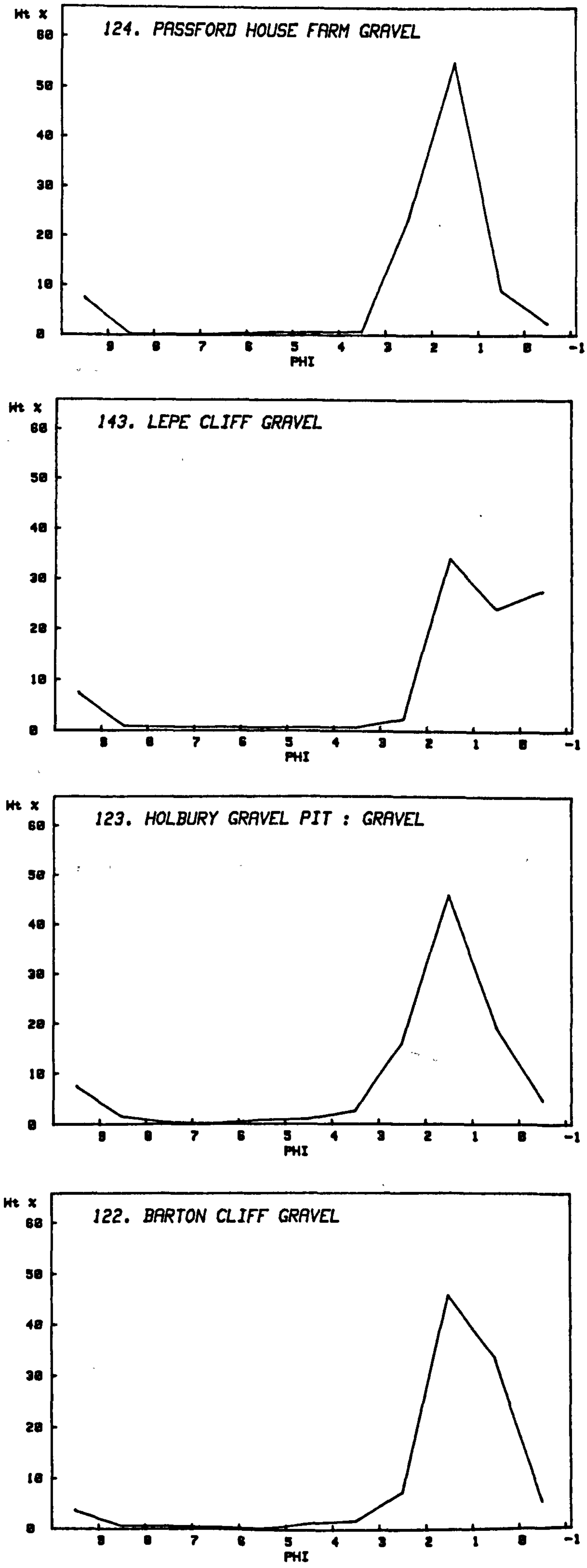


Fig. 8.10 Examples of Plateau Gravel.

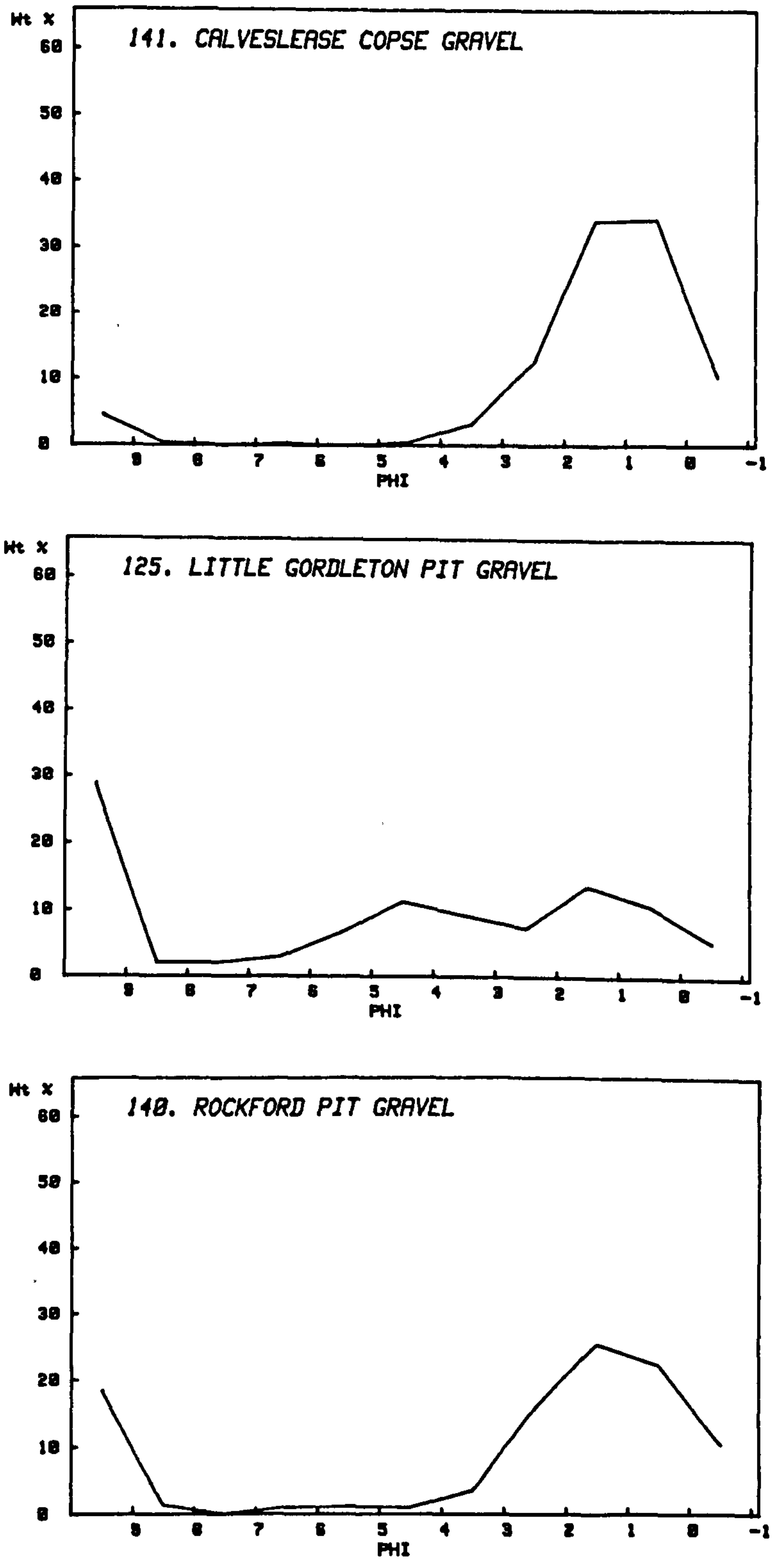


Fig. 8.11 Examples of Plateau Gravel

0.7 - 3.2% of the unaltered samples.

8.3.2 Tertiary sands.

The silt content of the three Barton Sand samples and two Bracklesham Sand samples is 1.2 - 3.8% and the clay content 0.9 - 4.7%. The sample of Headon Beds sand is finer than the others in that it has 12.9% silt (maximum in the 5-4∅ fraction) and 17.5% clay (Figs. 8.12 and 8.13). Two of the Barton Sand samples and the Headon Beds sand peak strongly at 4-3∅, the main sand fraction in the upper brickearth. The other Barton Sand sample and the two Bracklesham Sand samples peak at 3-2∅ and the Headon Beds sand also has a large content of sand in this fraction.

8.4. The Sites Selected for Detailed Study.

In this section the main textural variations found in the upper and lower brickearth at the principal sites (Table 5.1) are discussed.

8.4.1. Sturt Pond.

The clay content in the profile varies from 15.8% in the Eb horizon to a maximum of 25.2% in the Bt horizon, which is probably attributable to translocation between these horizons (Fig 8.14). On a clay free basis silt content is lowest (71.5%), in the A horizon, increasing to a maximum of 84.7% in the Eb horizon then declining to 73.1% in the Bt horizon. All three horizons are thus in the siltiest class of upper brickearth. There is a broad 6-4∅ modal diameter in the A and Eb horizons, but this narrows to 6-5∅ in the Bt horizon.

8.4.2 Wilverly Plain.

The clay content in the profile varies from a value of 16.9% in the Eb(g) horizon to a maximum of 22.7% in the Btg horizon, which suggests that, as in the Sturt Pond profile, clay has been

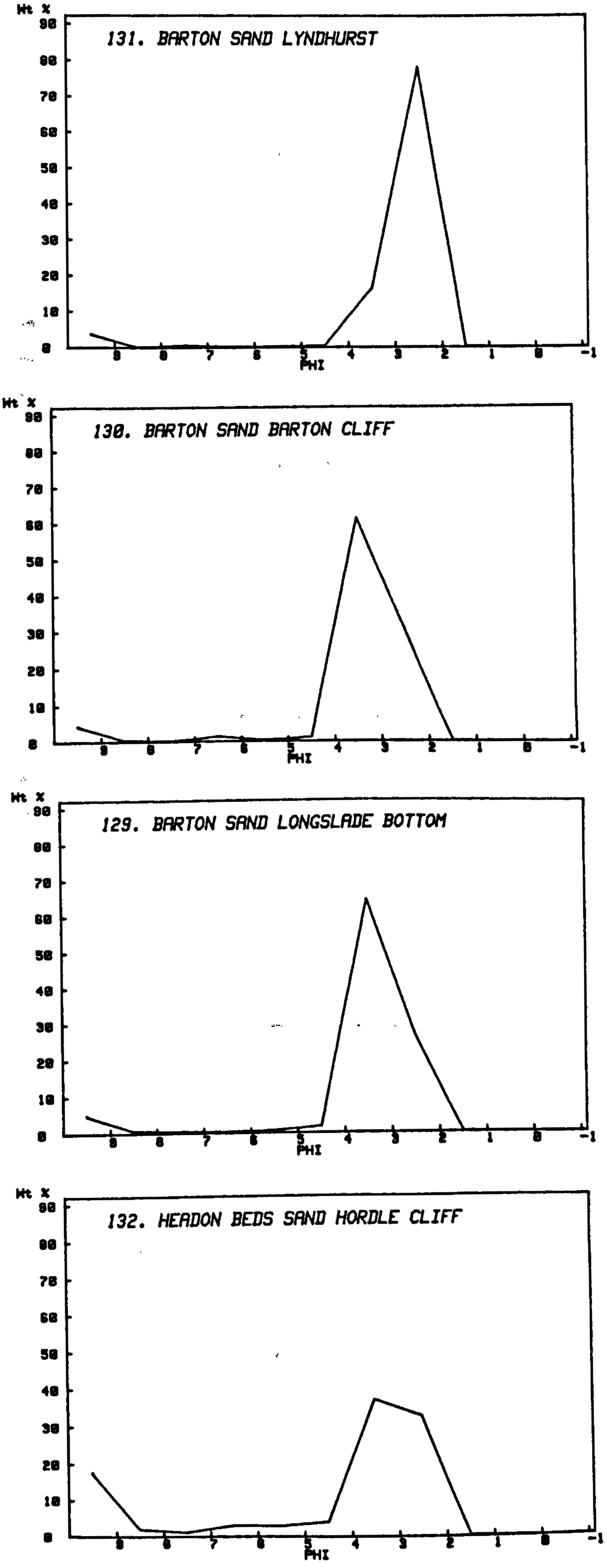


Fig. 8.12 Examples of Headon Beds and Barton Sand.

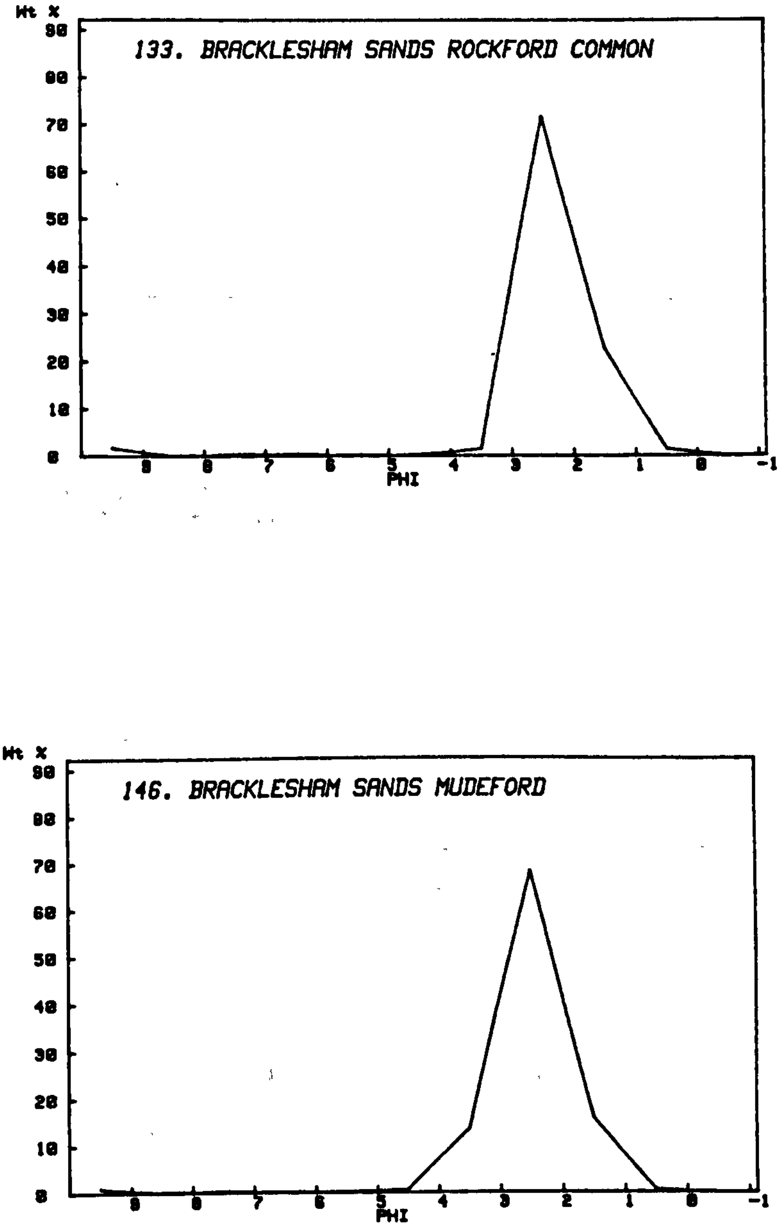


Fig. 8.13 Examples of Bracklesham Sand.

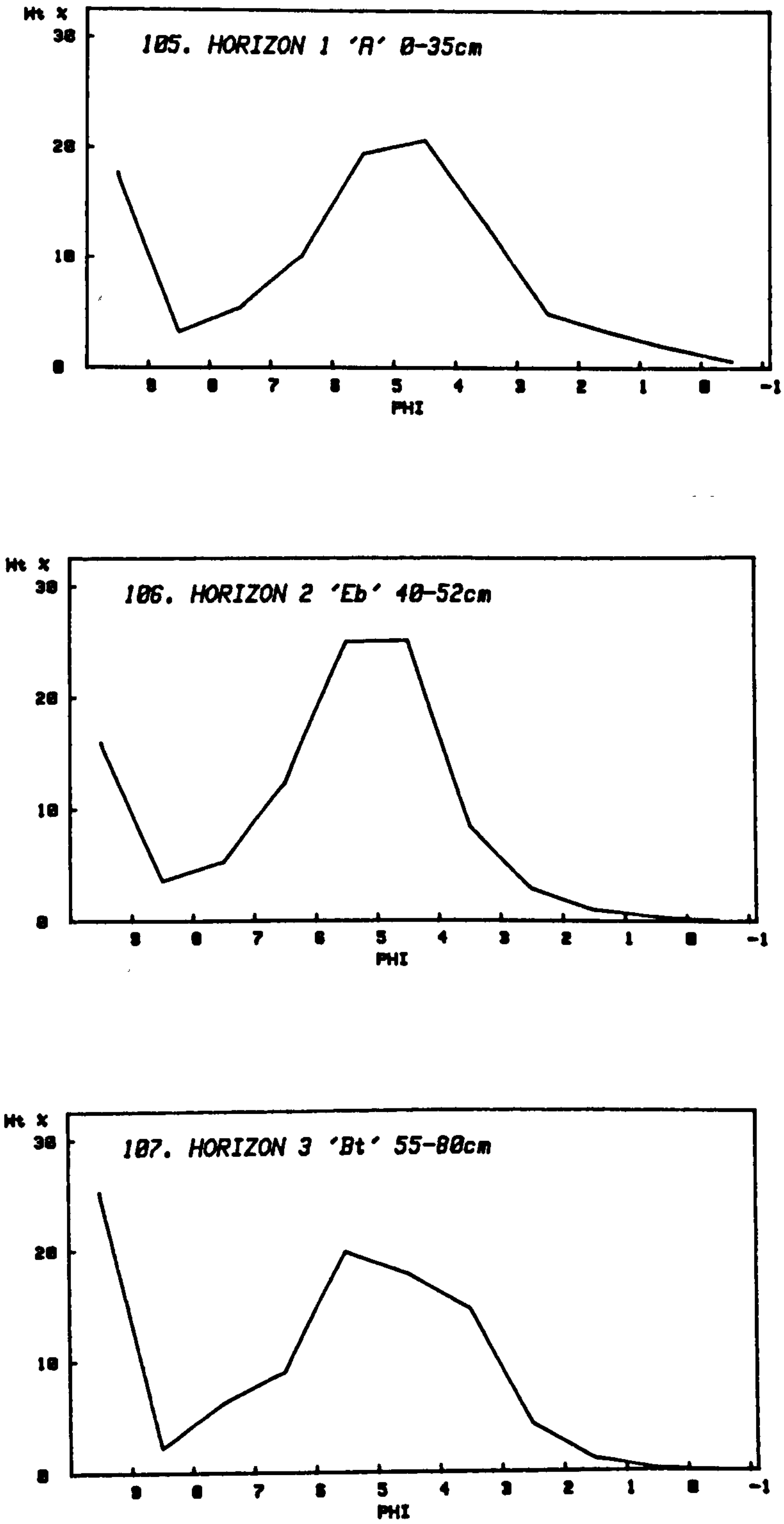


Fig. 8.14 Horizons in the Sturt Pond profile.

translocated between the E and B horizons. The sand content (on a clay-free basis) increases steadily with depth; it is 35% in horizon 1, 37.7% in horizon 2, 45.3% in horizon 3 and 78.1% in horizon 4 (Fig.8.15). The large increase in sand content between horizons 3 and 4 marks the lithological discontinuity referred to in the profile description (section 5.2.2). Thus the upper brickearth here changes in character from the siltiest class (more than 60% silt) to the sandiest class (less than 40% silt) in vertical sequence, confirming the trend suggested by the topsoil survey.

In horizons 1 and 2 there is a broad mode between 6-3ø, just peaking at 5-4ø. In horizon 3 there are two peaks at 6-5ø and 4-3ø which is unusual for the upper brickearth and suggests a mixture of two sediments. In horizon 4 there is a single prominent sand peak at 4-3ø.

8.4.3 Chilling Copse and Hook Gravel Pit.

In The Chilling Copse profile (Fig. 8.16) clay content is at a minimum of 16.6% in the Eb horizon and peaks at 23.3% in the Bt horizon. At Hook (Fig. 8.17) clay content is at a maximum of 23% in the 2Eb/Bt horizon which emphasises the transitional nature of the horizon.

In terms of total silt content (clay-free basis), horizons 1 to 3 at Chilling are very similar with silt contents ranging from 85.2% at 0-16cm to 88.3% at 39-49cm. This very slight fall in silt content towards the surface within the very silty upper horizons reverses the normal trend for the upper brickearth and is similar in magnitude to that between horizons 2 and 1 at Sturt Pond. The Chilling profile is the thickest that has been described and, true to the general trend, its upper horizons contain the most silt. Horizon 3 contains only about 5% less silt than the loess of

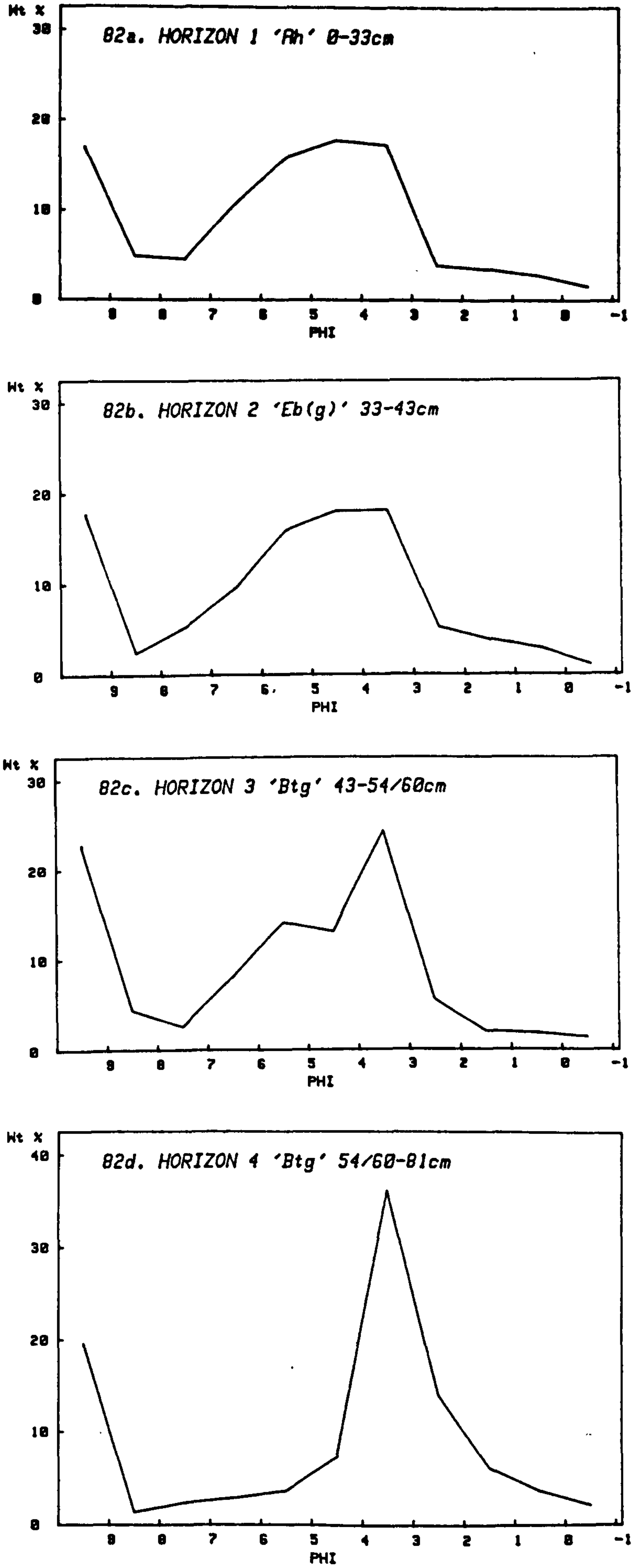


Fig. 8.15 Horizons in the Wilverly Plain Profile.

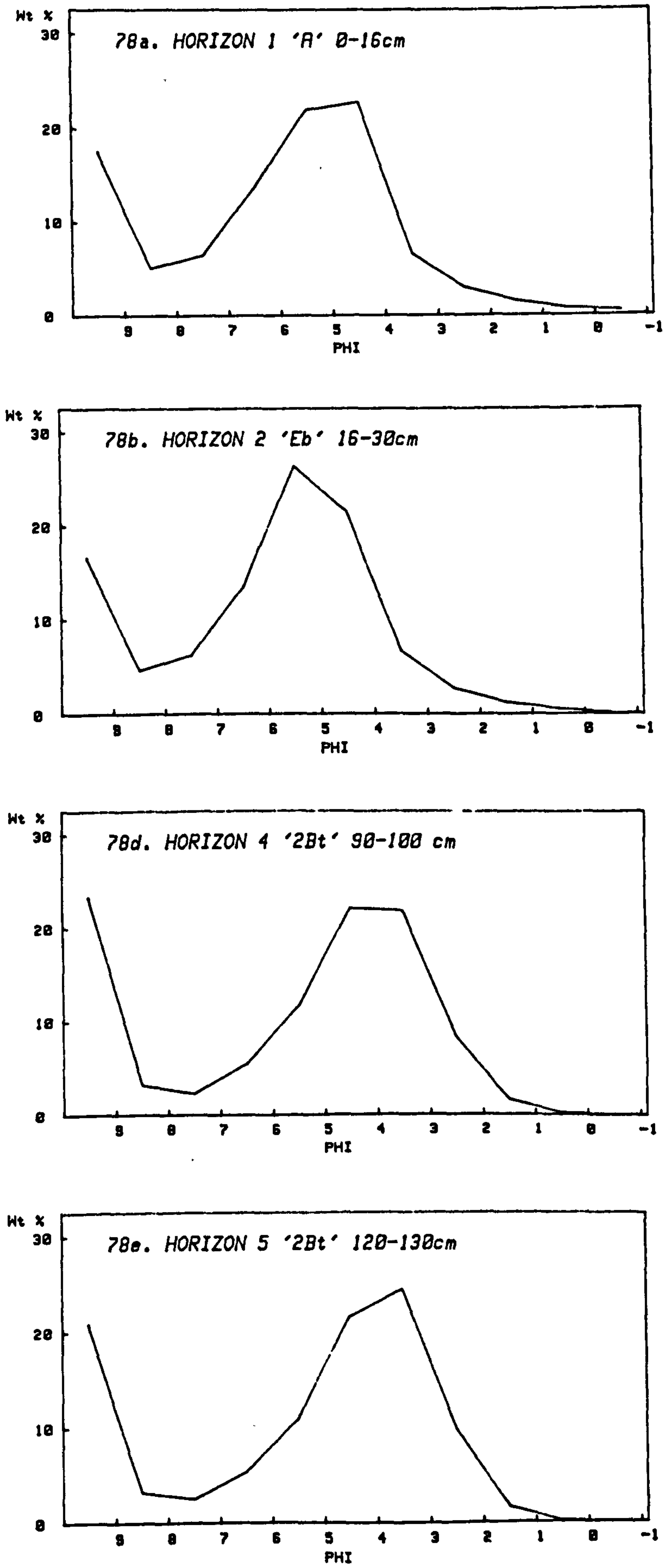


Fig. 8.16 Horizons in the Chilling Copse profile

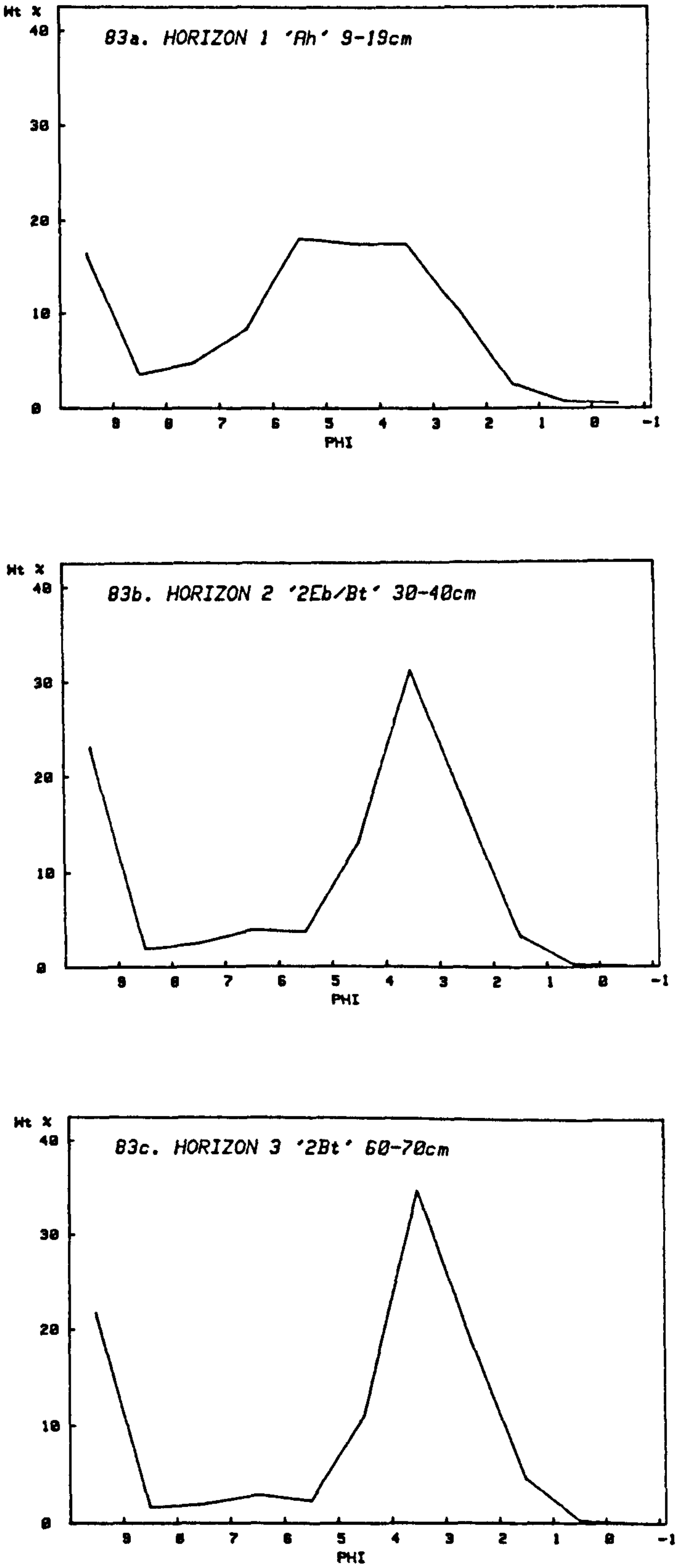


Fig. 8.17 Horizons in the Hook Gravel Pit profile.

Pegwell Bay, Kent (Fig. 8.5), and the p.s.d. of this horizon would allow its classification as typical loess (Fink, 1976). There is a shift in the modal size from 5-40 in horizon 1 to 6-50 in horizons 2 and 3, a similar trend to that found in the Sturt Pond and Wilverly Plain profiles. Horizons 4 and 5 contain about four times as much fine sand (4-20) than the horizons above, and they peak at 4-30.

All three horizons of the Hook profile are quite sandy. Horizon 1 has a similar p.s.d. to horizons 4 and 5 at Chilling, though it contains more 6-50 silt. Horizons 2 and 3 resemble each other, containing 67.4% and 74.8% sand respectively (clay free basis), and they are similar to aeolian silty sand (Fig. 8.6.). These horizons also resemble horizon 4 in the Wilverly Plain profile, but contain slightly more 5-40 and 3-20 sand. The main sand peak is at 4-30 throughout the profile, as at Sturt Pond, Wilverly Plain and Chilling Copse.

8.4.4 Beaulieu Heath.

The sand content (clay free basis) of the upper brickearth increases from 47.1% to 61.2% between horizons 2 and 3 and falls slightly to 59% in horizon 4 (Fig. 8.18). In these three horizons there is a main peak at 4-30 in the sand fraction and a secondary silt peak at 6-50 Thus the upper brickearth here is bimodal with the same peaks as in horizon 3 at Wilverly PLain.

In the lower brickearth clay content increases with depth from 23.6% in horizon 5 to 41.1% in horizon 8 (Fig. 8.19). The sand content (clay free basis) is variable, rising from 56.2% in horizon 5 to 72.2% in horizon 6 (where sandy loam pockets were noted

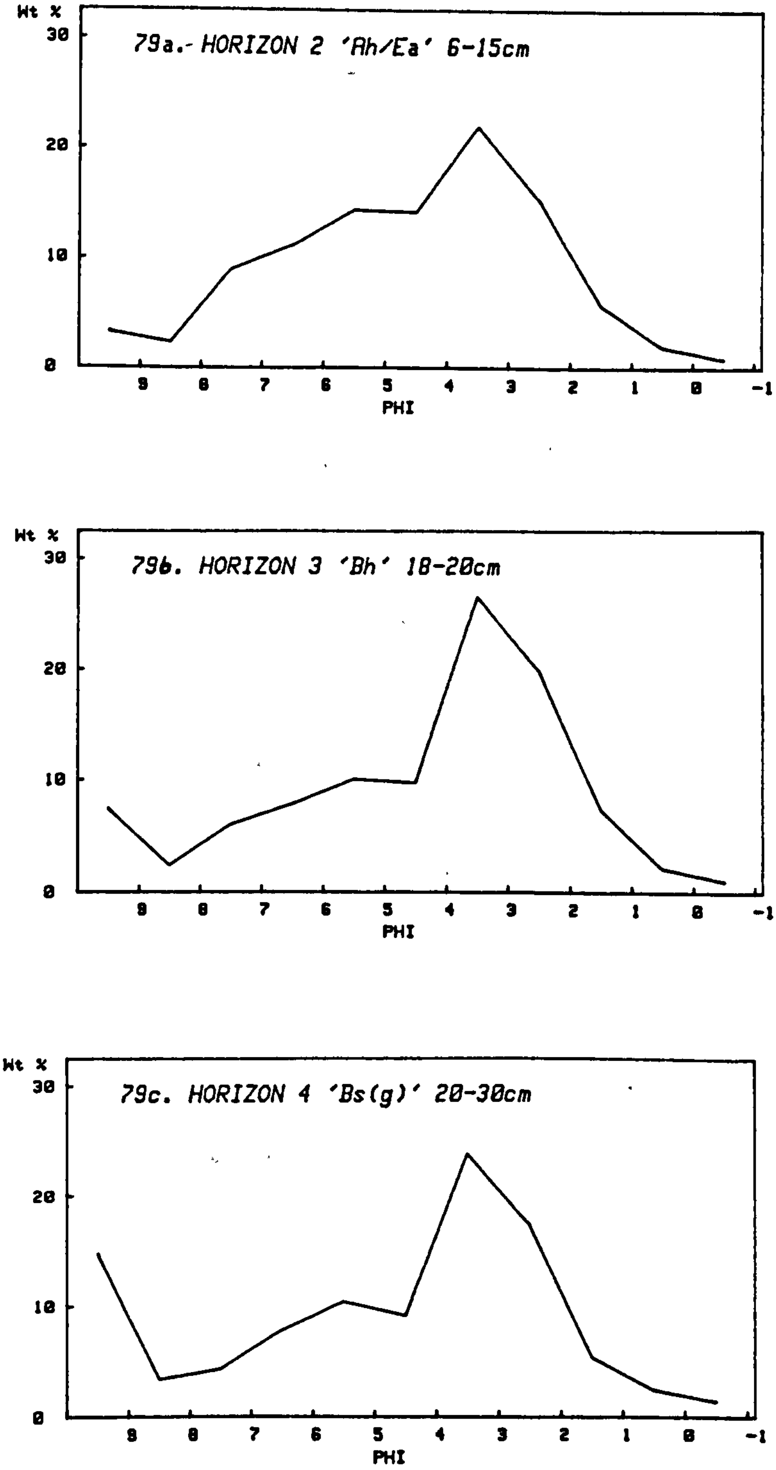


Fig. 8.18 Horizons in the Beaulieu Heath profile.

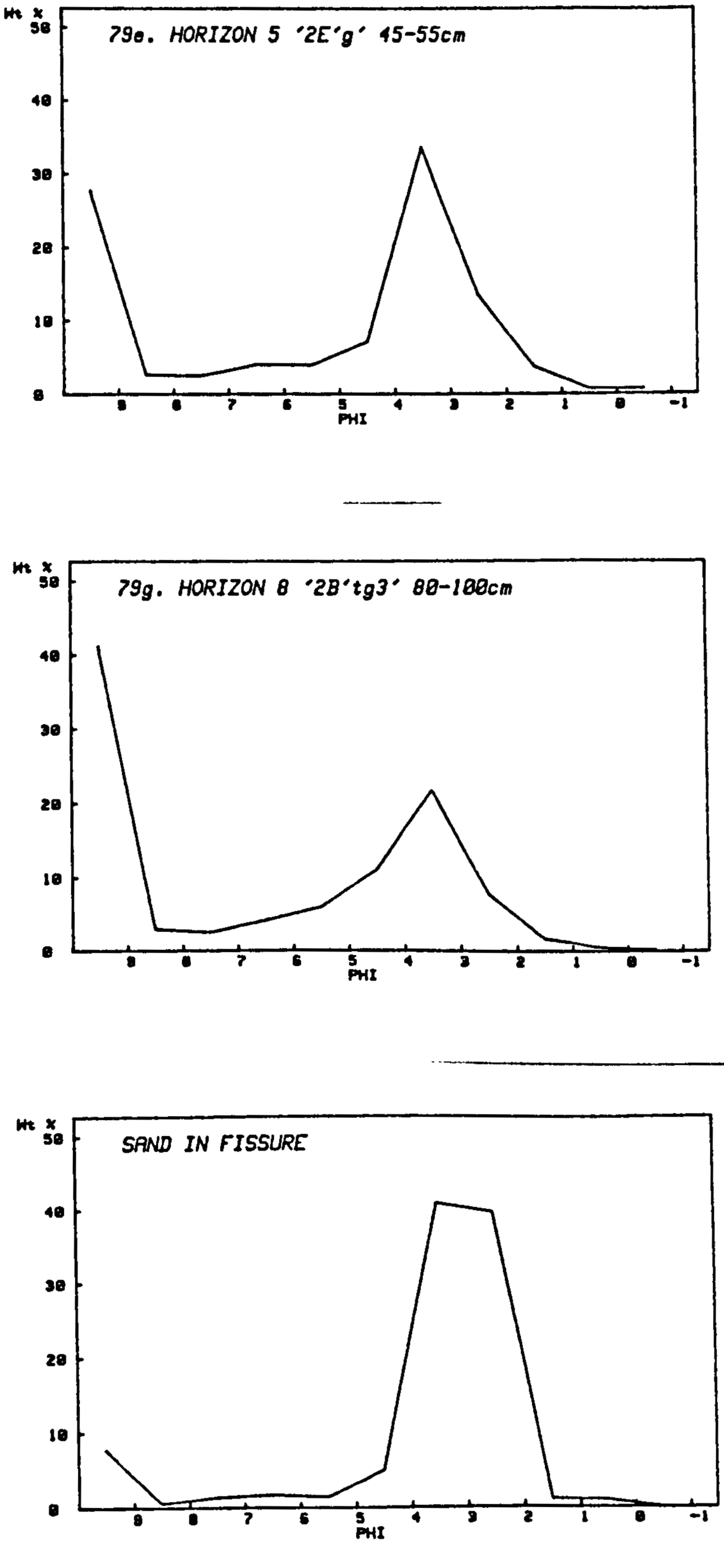


Fig. 8.19 Horizons in the Beaulieu Heath profile

in the field description) and falling again to 54.4% in horizon 8. Throughout these horizons the mode is 4-30, as in the upper brickearth. The p.s.d. of bulked samples from each of the horizons in the lower brickearth here is misleading because they include material from the sandy pockets or sand-filled fissures within the horizons. For this reason sand from a fissure penetrating horizons 7 and 8 was collected and analysed separately. In common with all other horizons in the profile this sand has a large 4-30 peak: the ratio of 4-30/3-20 sand is 1.03, compared with a range of 1.34-1.44 in the upper brickearth and 2.10-2.91 in the bulk samples of lower brickearth. In this respect, therefore, the sand in fissures is different from that in both the upper and lower brickearth but most like that in the upper brickearth. Given that some of this sand is incorporated in the bulk samples of lower brickearth, then because the p.s.d's of the bulk samples show a more than doubled 4-30/3-20 ratio, the main bulk of lower brickearth (freed from this sand) must contain a high proportion of 4-30 sand.

8.4.5. Lepe Cliff

The sand content (clay free basis) increases from 33.1% in horizon 1 to 45.0% in horizon 3 in the upper brickearth, and the samples are unimodal, peaking at 4-30 in the sand fraction. (Fig. 8.20). The upper brickearth thus has similar textural characteristics to that in the Sturt Pond, Wilverly Plain, Chilling Copse and Hook Gravel Pit profiles.

The lower brickearth has a clay content of 37.4% and a very low sand content (clay free basis) of 9.7%. The p.s.d. is bimodal with a major peak at 7-60 in the silt fraction and a minor secondary peak at 2-10 in the sand fraction. The latter is the same as the main peak in the Plateau Gravel (Figs. 8.10 and 8.11) from which the sand could thus have been derived. The silt peak is finer than in

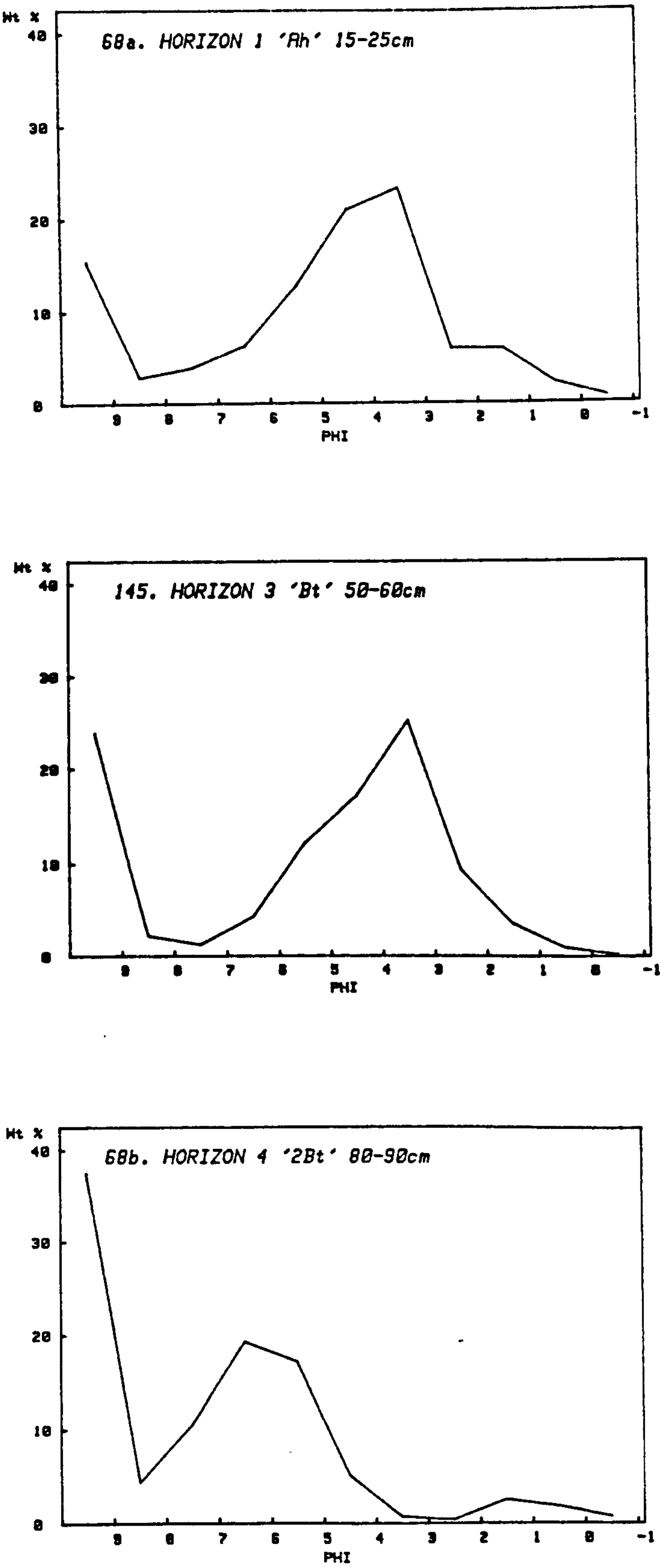


Fig. 8.20 Horizons in the Lepe Cliff profile.

any upper brickearth sample. The total silt content (clay free basis) is 90.3% which suggests the material could be loess.

8.4.6 Thorns Farm

The upper brickearth is very sandy throughout its depth, and sand content rises to a peak of 80.1% (clay free basis) in horizon 4 (Figs 8.21 and 8.22). Horizons 1-4 are unimodal, peaking as usual at 4-30, but horizon 4 is different from the others due to an increase in 3-20 sand. The ratio of 4-30/3-20 sand in horizons 1-3 is 1.88-2.14, but is 1.23 in horizon 4. A large content of 3-20 sand was also found in the material filling fissures in the lower brickearth at Beaulieu Heath, and it is noteworthy that sand from horizon 4 penetrates fissures in the lower brickearth here.

The sample of lower brickearth from horizon 5 at 85-100cm did not include any sand occupying fissures. It has a high clay content of 33.4%, a small silt peak at 7-60 and a larger sand peak at 2-10: The latter peak is probably due to the incorporation of sand from the Plateau Gravel. Although the overall form of the p.s.d. curve is different, the two peaks are at the same position as in the lower brickearth at Lepe Cliff. The lower brickearth sampled at 120-150cm included sandy material occupying a fissure. The clay content, at 26.7% is lower than in the horizon above, and the sample is unimodal, peaking strongly at 4-30, probably due to sand from the fissure.

8.4.7 Tanner's Lane

The sand content (clay free basis) in the upper brickearth increases from 61.5% in horizon 2 to 79.6% in horizon 3, and both horizons have the normal 4-30 sand peak (Fig 8.23). In horizon 2 there is a very small secondary silt peak at 6-50 (in common with horizons 2-4 at Beaulieu Heath and horizon 3 at Wilverly Plain), but this has disappeared in horizon 3.

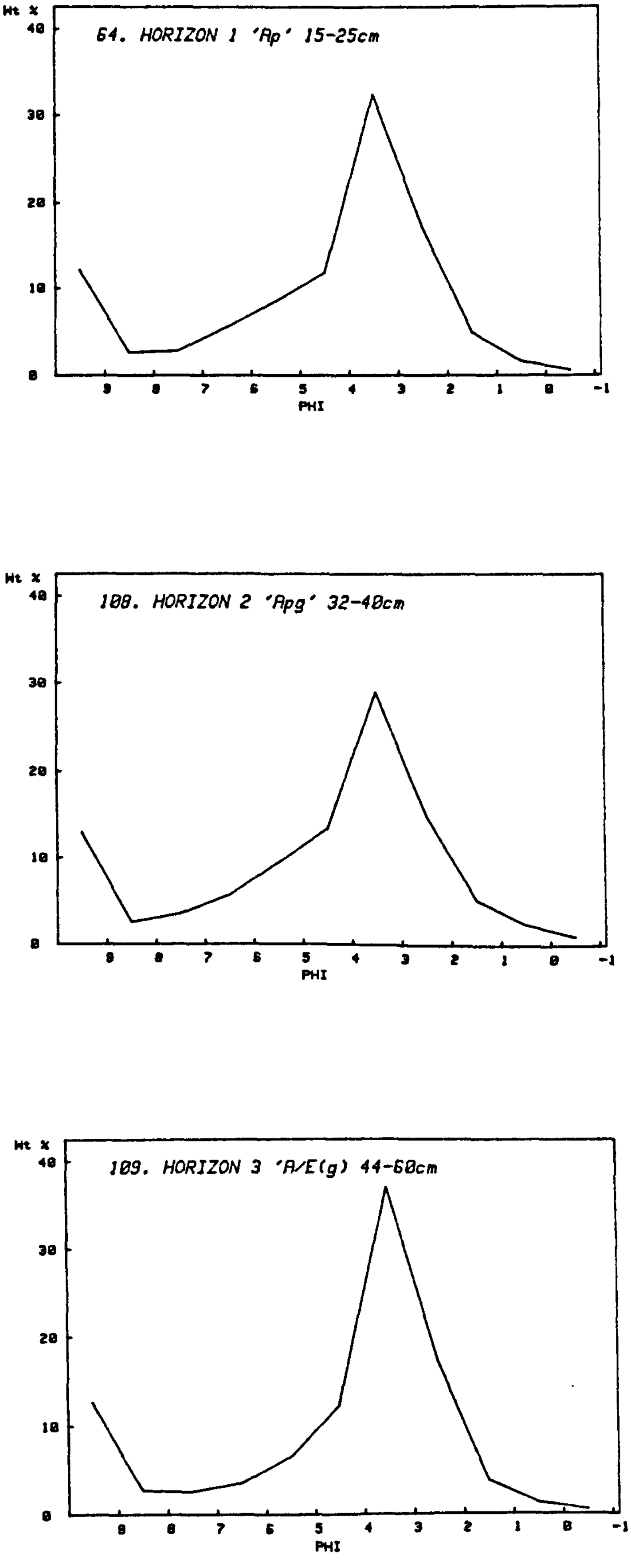
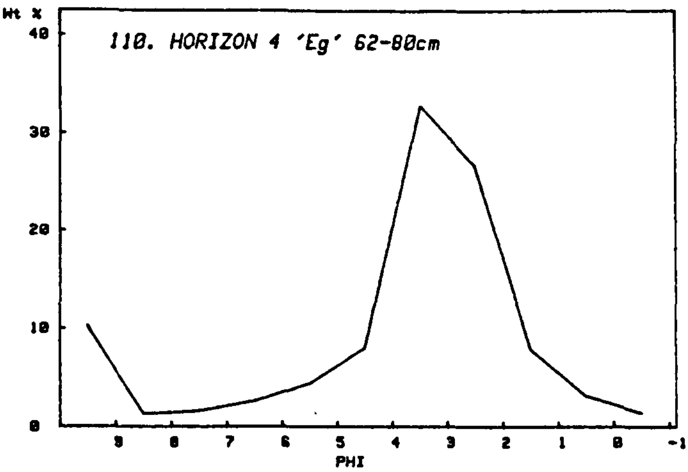
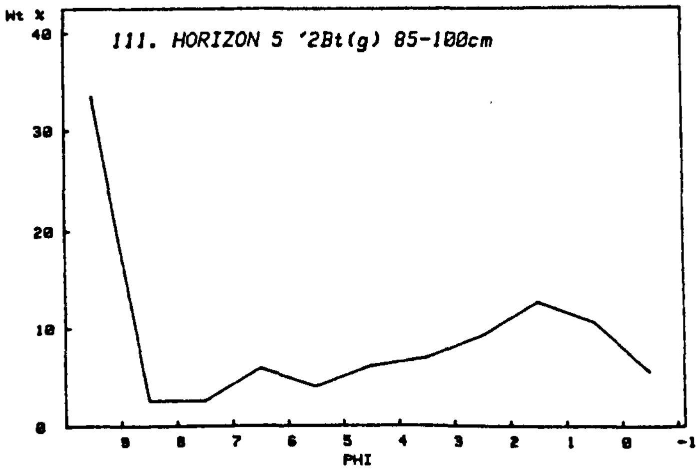


Fig. 8.21 Horizons in the Thorns Farm profile.





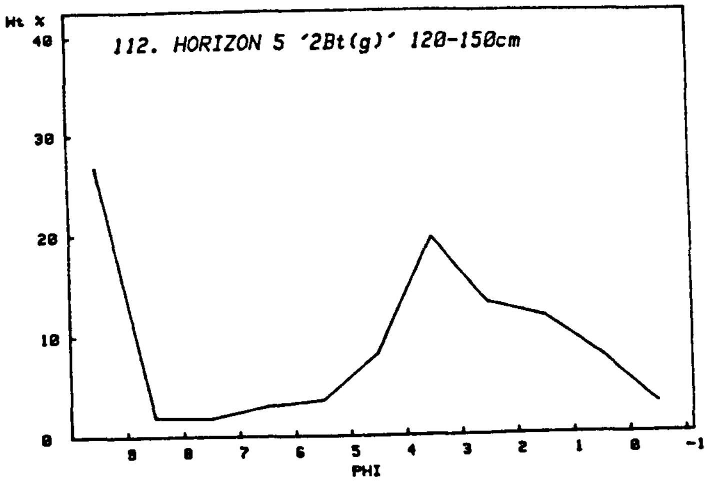


Fig. 8.22 Horizons in the Thorns Farm profile.

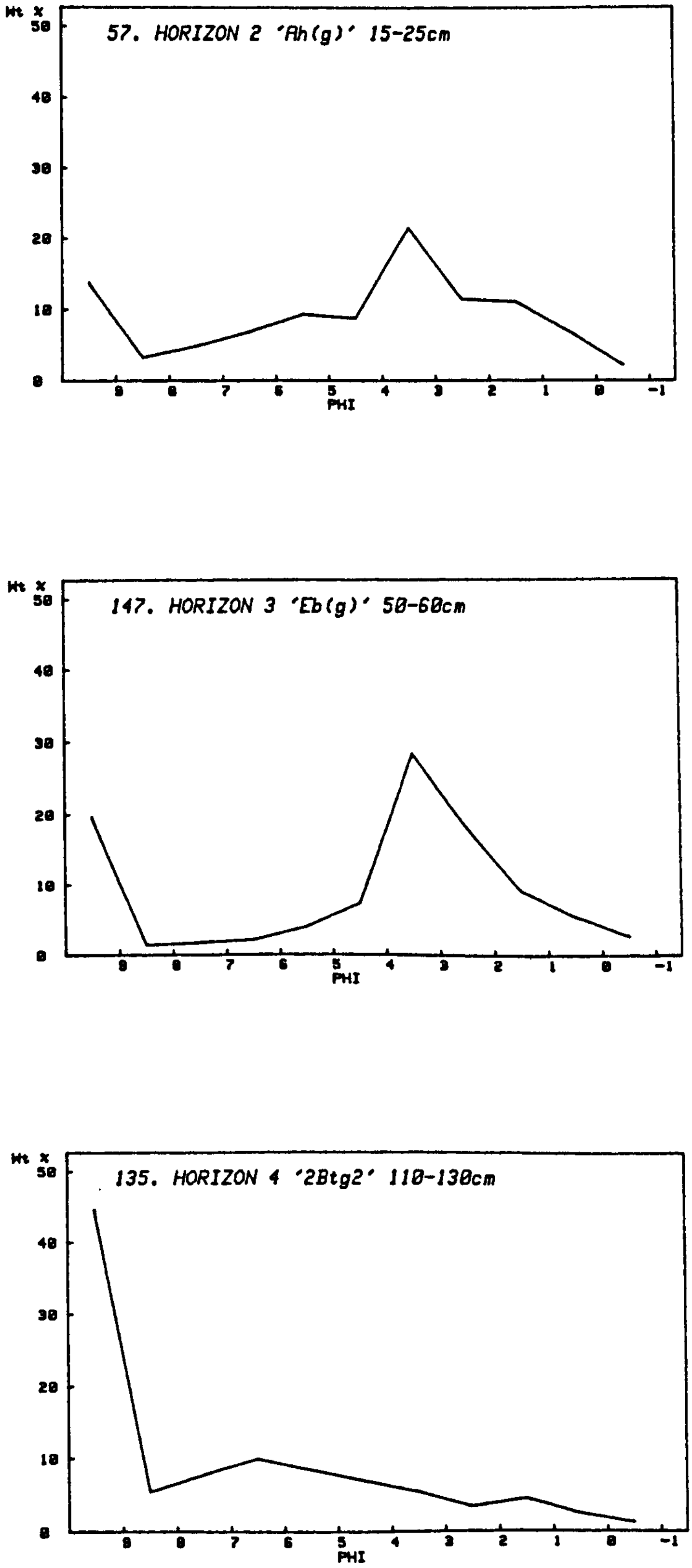


Fig. 8.23 Horizons in the Tanners Lane profile.

The lower brickearth has a very high clay content of 44.5% and has a peak in the silt fraction at 7-60 and in the sand fraction at 2-10, the latter indicating a contribution from the Plateau Gravel.

8.4.8 Ocknell Plain.

The upper brickearth in horizon 3 has a very high silt content of 81.4% (clay free basis) and is unimodal, peaking in the 6-50 range. There is also a large quantity of 5-40 silt and, unusually for the upper brickearth, of 7-60 silt also (Fig. 8.24). In common with other samples of upper brickearth from the high level terraces there is less sand at the junction with the lower brickearth than at most sites on the lower (≤56m) terraces (section 8.2.)

The lower brickearth has a very high clay content of 44.3% in horizon 5 increasing to 48.1% in horizon 6. Both samples are unimodal and peak at 6-50 in the silt fraction. On a clay free basis horizon 5 has 85.1% silt and horizon 6 has 75%, which suggests they could be composed of loess.

8.4.9 Calveslease Copse

Horizons 1 and 2 in the brownish undifferentiated brickearth (section 5.2.9) have almost identical p.s.d's. They are unimodal with a very large peak (57.1% in horizon 1 and 58.9% in horizon 2) in the 4-30 fraction, the main sand peak in most upper brickearth samples. The clay content is quite high for such sandy sediments, 14.9% in horizons 1 and 16.7% in horizon 2 (Figs. 8.25 and 8.26).

Horizon 3 in the strong brown undifferentiated brickearth is texturally very different from the two horizons above. The clay content, 25.3%, is much higher and the modal diamenter, 5-40, is finer, though there is also a relatively large amount of 6-50 silt and 4-30 sand. The overall shape of the distribution

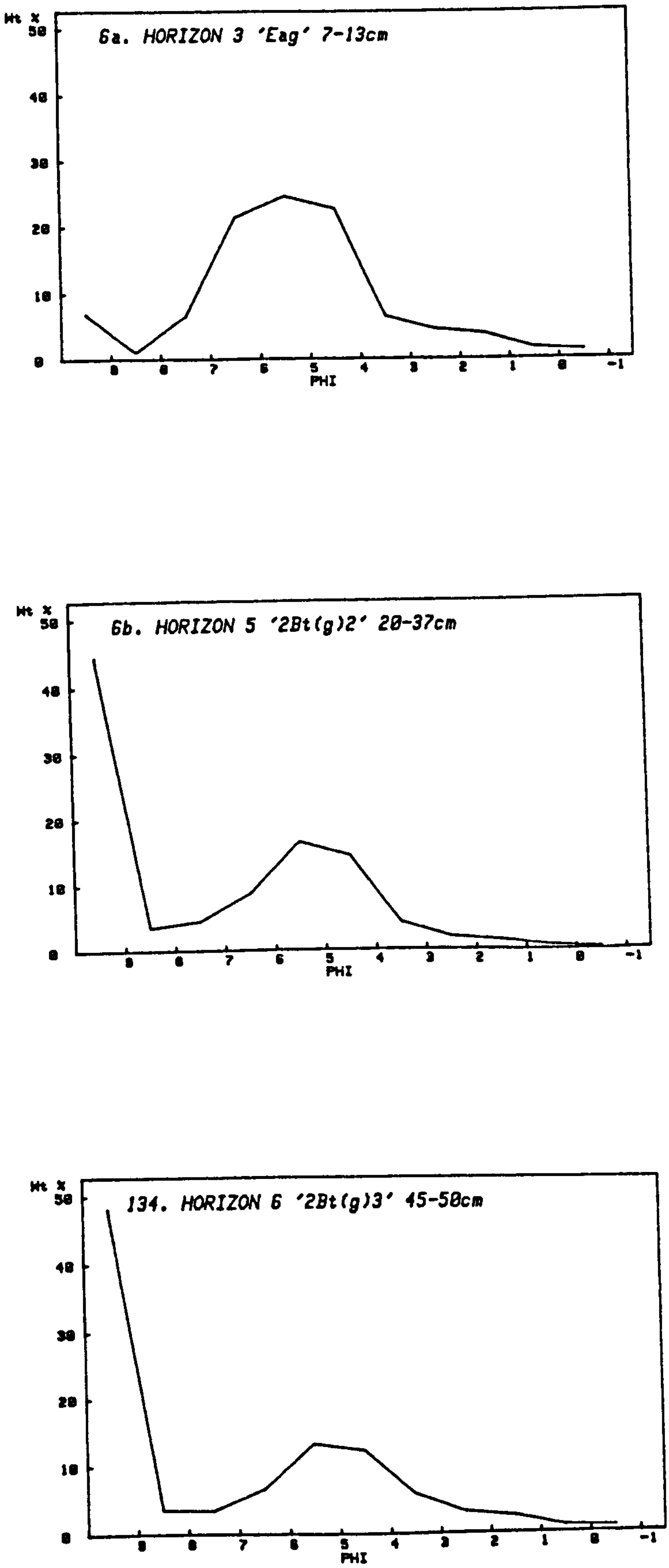


Fig. 8.24 Horizons in the Ocknell Plain profile.

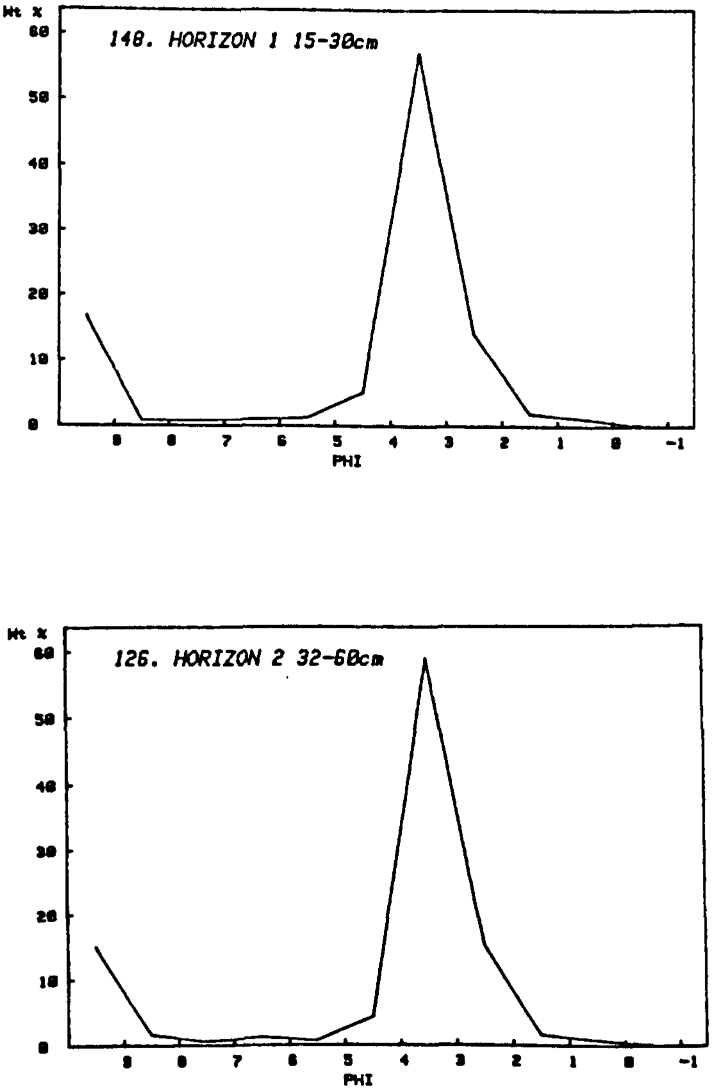


Fig. 8.25 Horizons in the Calveslease Copse profile

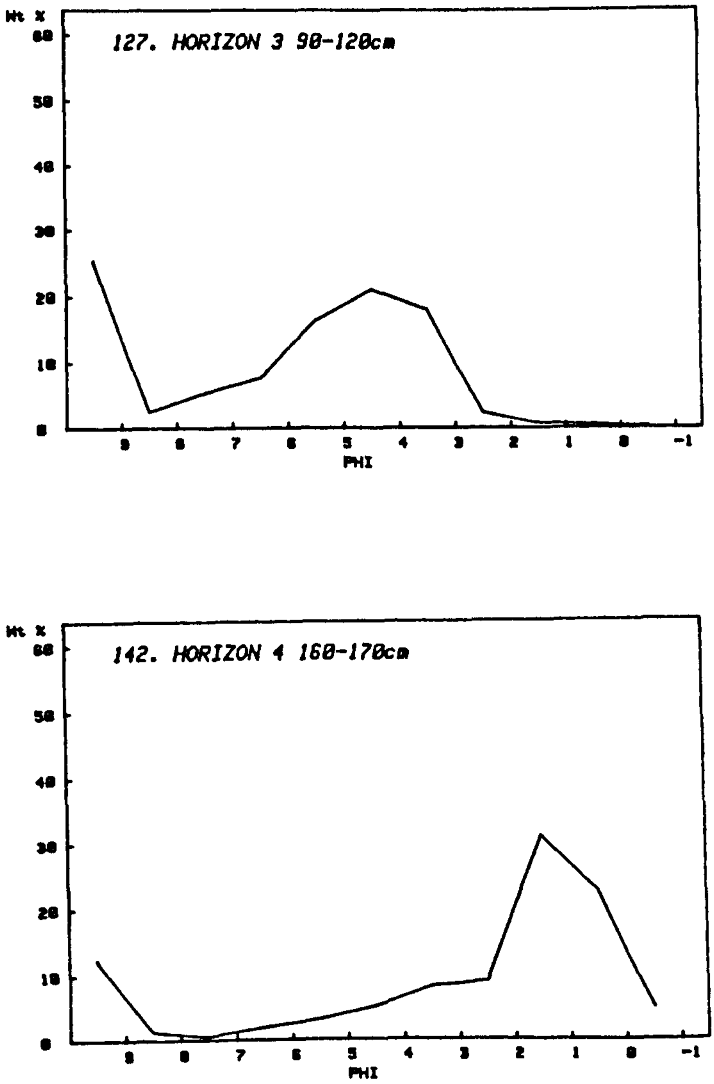


Fig. 8.26. Horizons in the Calveslease Copse profile.

resembles some upper brickearth samples (e.g. Wilverly Plain horizons 1 and 2), but the clay content is slightly higher. The total silt content (clay free basis) is 70.9% which suggests it could be derived from loess.

Horizon 4 consists mainly of medium and coarse sand and peaks in the 2-10 fraction, indicating that it is derived mainly from the Plateau Gravel. However, there is more 4-30 sand, silt and clay than in the Plateau Gravel, which suggests it has been mixed with material from another source.

8.4.10 Rockford Common Gravel Pit.

Horizon 2 in the undifferentiated brickearth and horizon 3 in the lower brickearth have very similarly shaped p.s.d.'s, as indicated in the field description (section 5.2.10).

The main difference between the two is the clay content, which is 6.7% in horizon 2 and 16.5% in horizon 3; this may reflect clay translocation from horizon 2 to 3 (Fig 8.27). Both horizons have a large 3-20 peak and horizon 2 also has a slight shoulder at 5-40. The 3-20 peak is unusual; it was only found in three samples of upper brickearth (samples 10, 34, and 63) and one other sample of lower brickearth (at Hordle Cliff). In each of these samples, the peak was far less pronounced. It is noteworthy that the Bracklesham Sand which underlies the Plateau Gravel at this site, also peaks at 3-20 (Fig. 8.13). Aeolian sand from Essex (Fig. 8.6) has a similar p.s.d. to horizons 2 and 3(although the latter contain slightly more silt), so both horizons could be composed mainly of aeolian sand.

Horizon 4 has the large 2-10 peak typical of Plateau Gravel, but the clay content, at 29.0%, is far larger than usual and reflects the amounts of illuvial clay in the horizon noted in the field description (section 5.2.10).

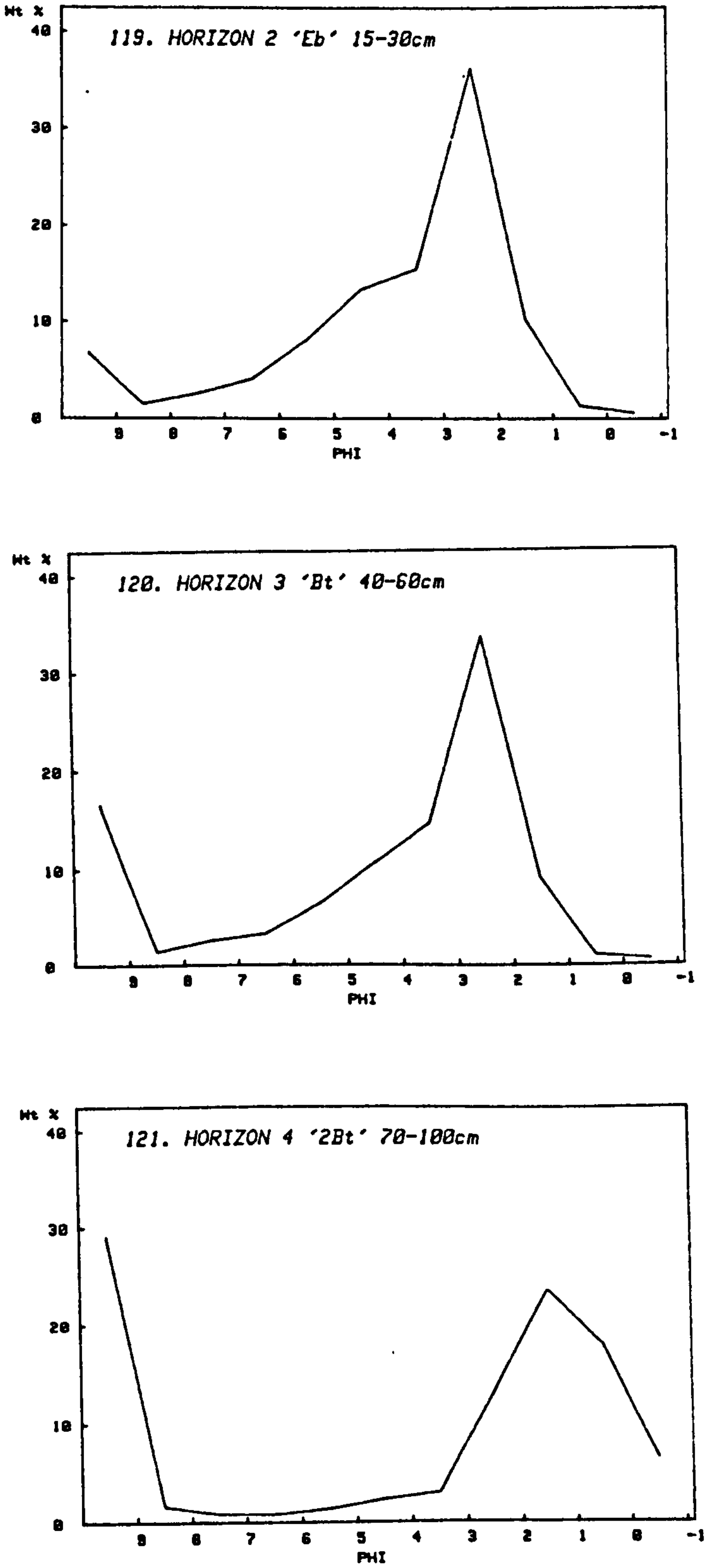


Fig. 8.27 Horizons in the Rockford Common profile.

8.4.11 Holbury Gravel Pit

The lower brickearth in horizon 1 has the very large clay content of 43.0% and is bimodal with a peak at 6-50 and a lesser one at 4-30 (Fig. 8.28). The clay content in horizon 4 is much smaller, at 23.7%. This horizon has two peaks in the silt fraction: a major one at 6-50 and a lesser one at 8-70. The sand content (clay free basis), at 35.0%, is higher than in horizon 1 (20.5%) but the dominant fraction is the same, at 4-30.

8.4.12 Hordle Cliff

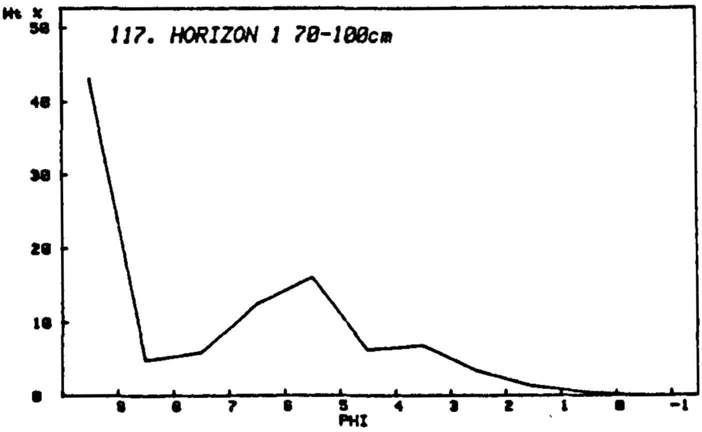
The lower brickearth in horizon 2 has a fairly high clay content of 28.7% and is bimodal with peaks at 5-40 and 3-20 (Fig. 8.29). No other lower brickearth samples with this combination of peaks was found.

8.4.13 Wootton Heath

Horizons 1 and 2 have very similar p.s.d's with a single large peak at 6-50 and fairly high clay contents of 20.7% and 24.3% respectively (Fig. 8.30). The similarity between the two suggests there is little or no upper brickearth contained in horizon 1. The form of the silt distribution and the peak at 6-50 in the two horizons is very similar to the lower brickearth at Ocknell Plain and the silt content (clay free basis) is about the same, so this lower brickearth could also be loess. In horizon 3 the clay content increases to 28.1% and the sand increases (clay free basis) to 41.9%, causing a shift in the modal diameter to 4-30. This is similar to the trend found in the lower brickearth at Thorns Farm, where the increase in sand is known to be due to the incorporation of sand in fissures.

8.4.14 The Colluvium around the 56m Terrace

a) Profile 1 (Longslade Bottom)



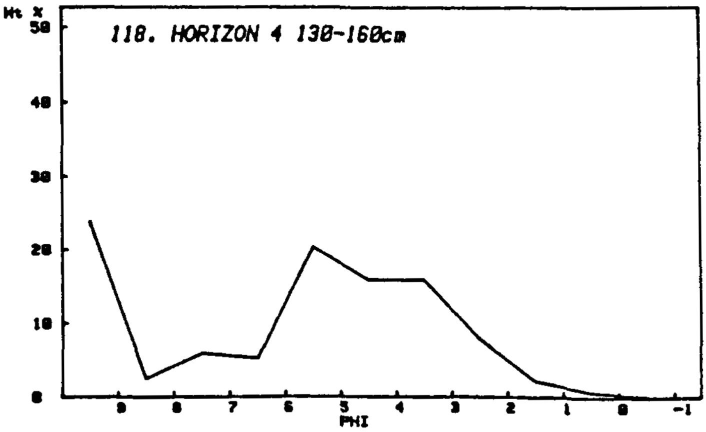


Fig. 8.28 Horizons in the Holbury Gravel Pit profile.

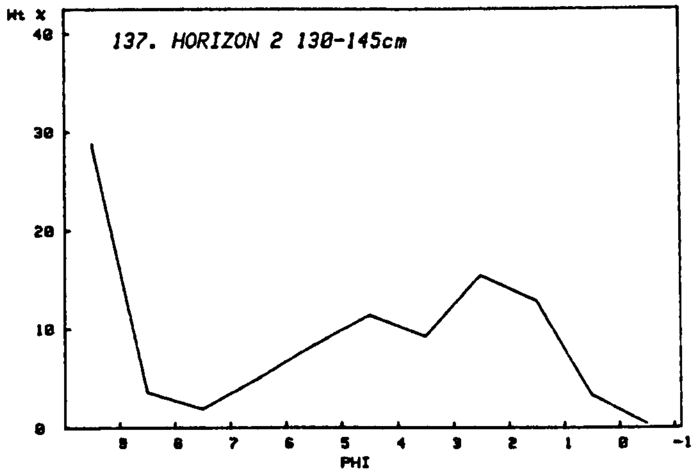


Fig. 8.29 Horizon 2 in the Hordle Cliff profile.

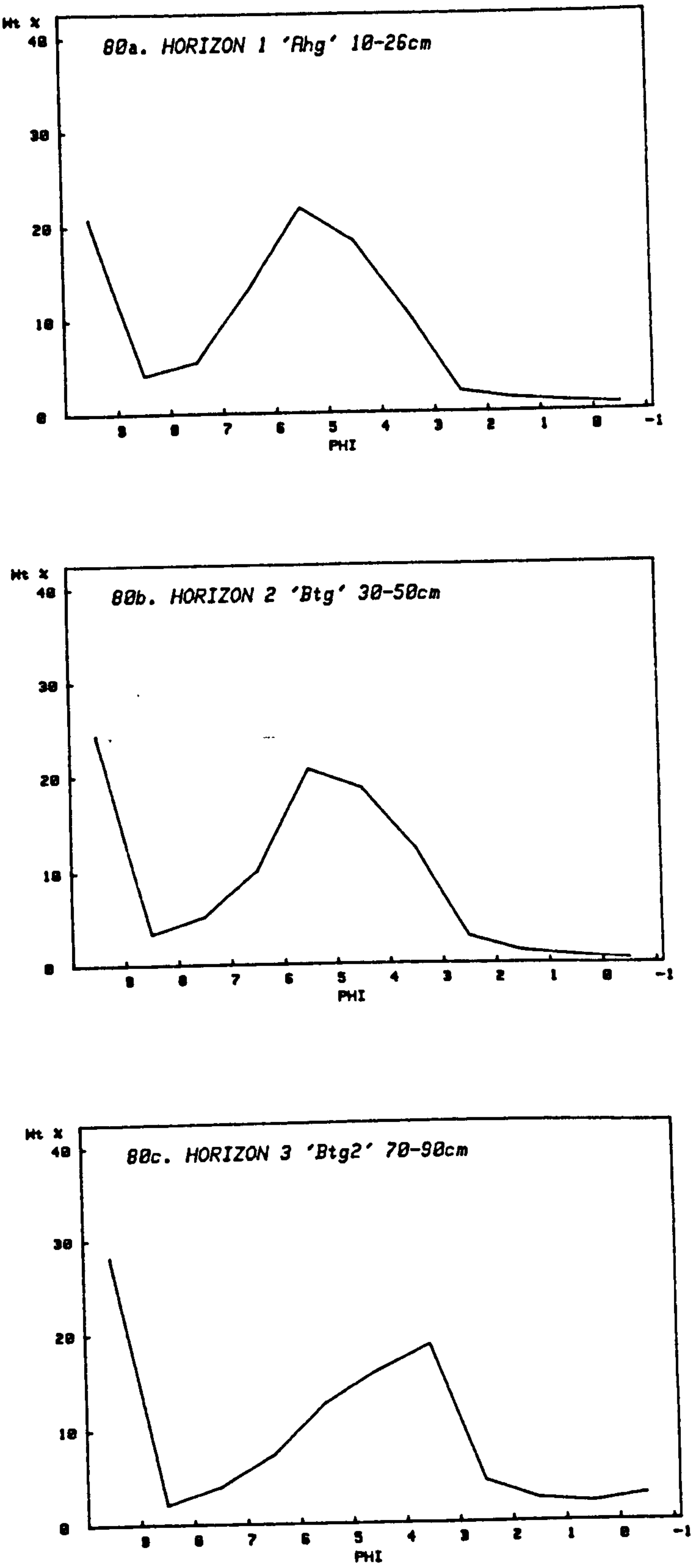


Fig. 8.30 Horizons in the Wootton Heath profile.

All three horizons are sandy and sand content increases with depth from 48.3% in horizon 1 to 77.8% in horizon 3 (clay free basis). All three horizons peak at 4-30 (Fig. 8.31), in common with the Barton Sands which underlie this site (Fig. 8.12) and many upper brickearth samples. The coarse sand content also increases with depth, probably due to an increasing influence of material from the Plateau Gravel. The clay content is 15.4% in horizons 1 and 3 and 12.2% in horizon 2, supporting the field identification of weak Eb characteristics in horizon 2. The overall shape of the p.s.d's is rather like the moderately sandy upper brickearth, from which they could be mainly derived.

b) Profile 2 (Longslade Bottom)

Horizons 1 and 2 are very similar to horizons 1 and 2 in profile 1, which suggests a common source. Horizon 3 has a slightly increased 5-40 silt content and has less coarse sand (Fig. 8.32) which probably indicates a derivation from siltier upper brickearth. Horizon 4 resembles horizons 1 and 2 but has a greater coarse sand content which suggests, that like the basal horizon of profile 1, there is a significant contribution from the Plateau Gravel.

c) Profile 3 (Scrape Bottom)

The sand content increases with depth from 31.2% in horizon 2 to 59.5% in horizon 7 (clay free basis). In horizon 2 there is a silt peak at 6-50 but this diminishes with depth. In contrast, the main sand peak, at 4-30, is established in horizon 3 and becomes more prominent with depth (Fig. 8.33). These trends are not interupted over the colluvium/buried soil junction which suggests that the source of the sediments was not changed significantly after the buried soil developed. The form of the p.s.d. curve in horizon 2 resembles that in horizon 2 of the nearby

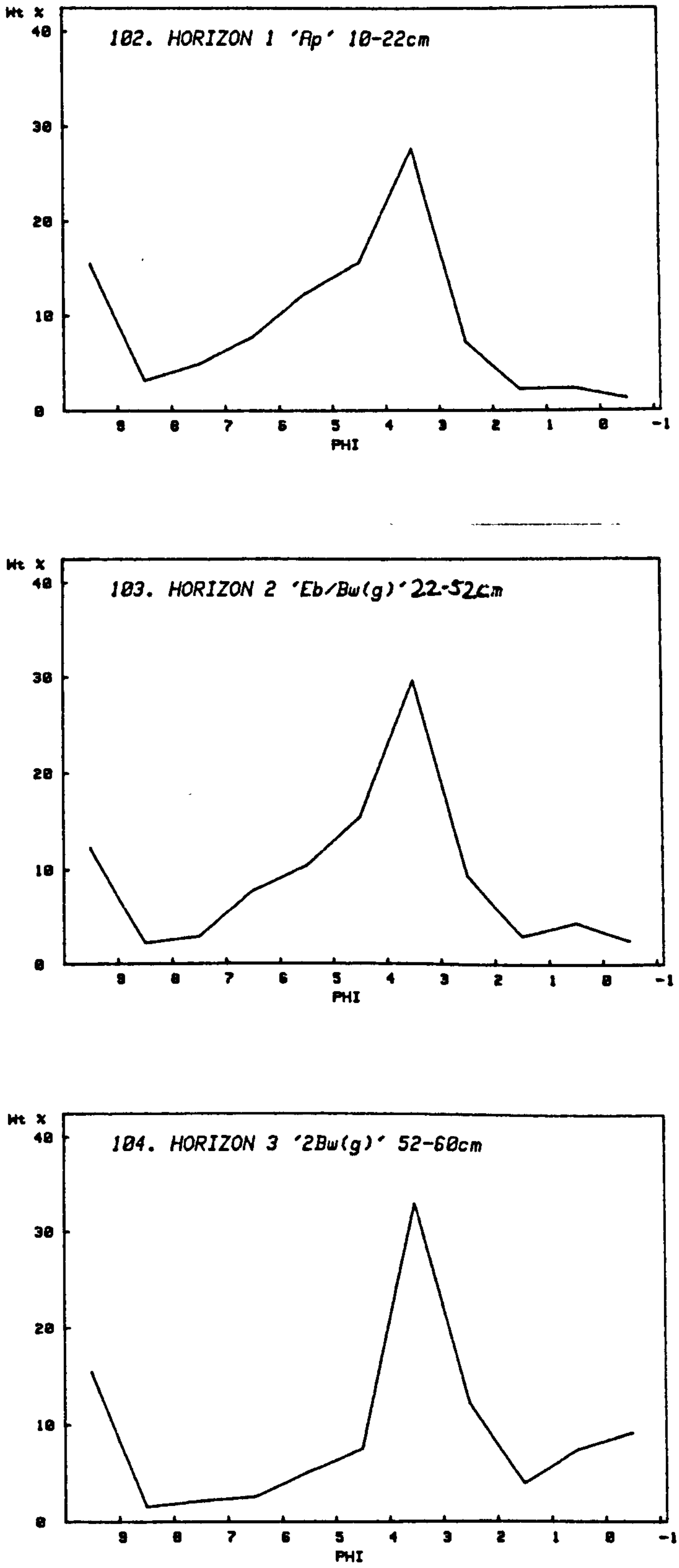


Fig. 8.31 Horizons in profile 1 Longslade Bottom.

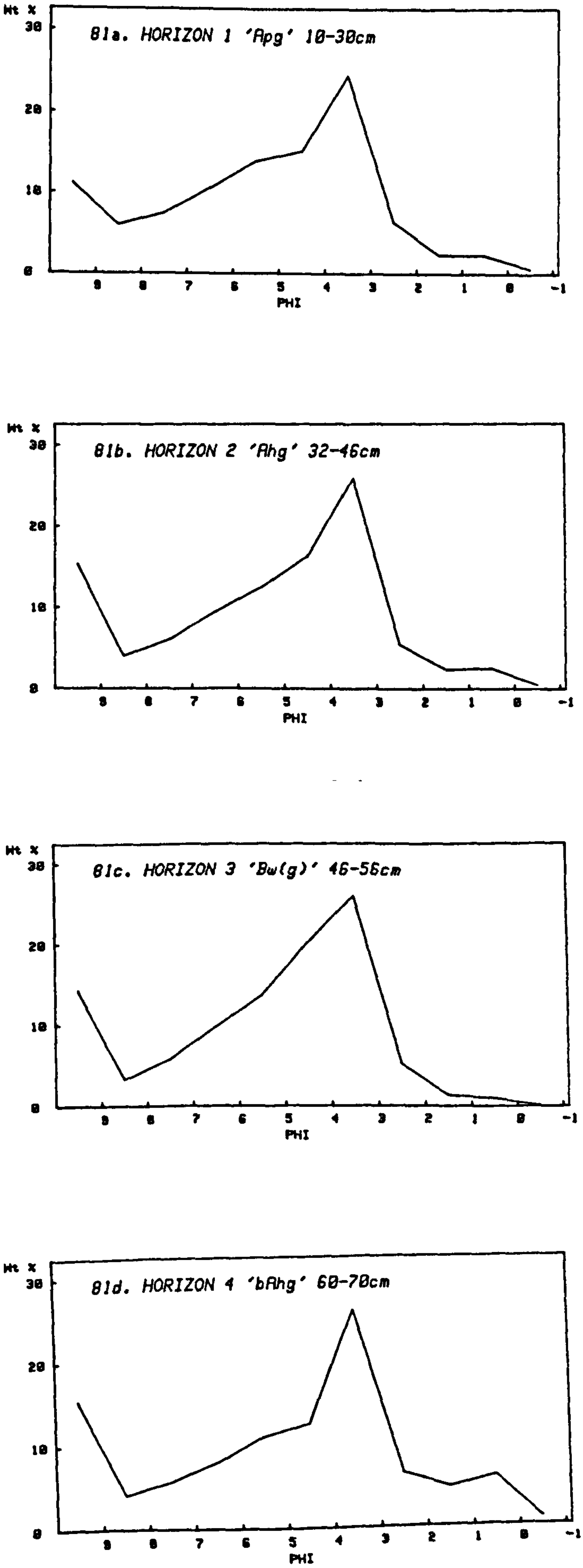
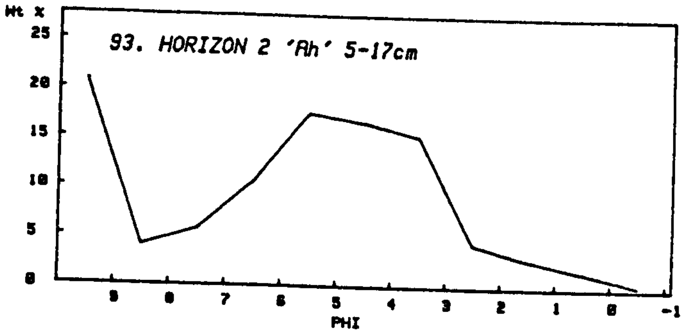
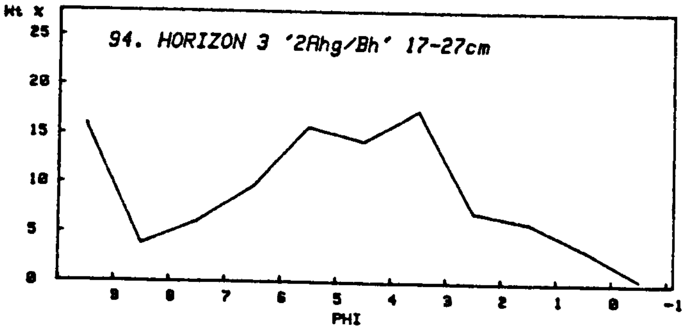


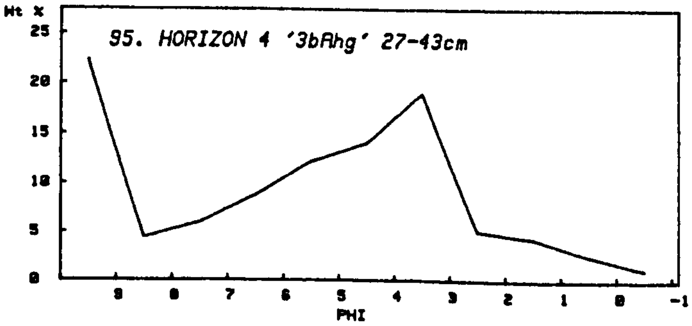
Fig. 8.32 Horizons in profile 2 Longslade Bottom.



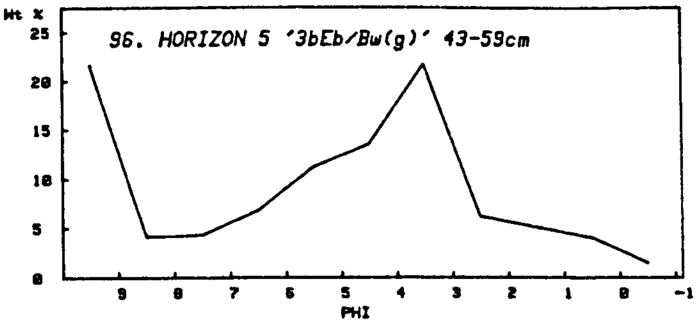
93. HORIZON 2 'Ah' 5-17cm



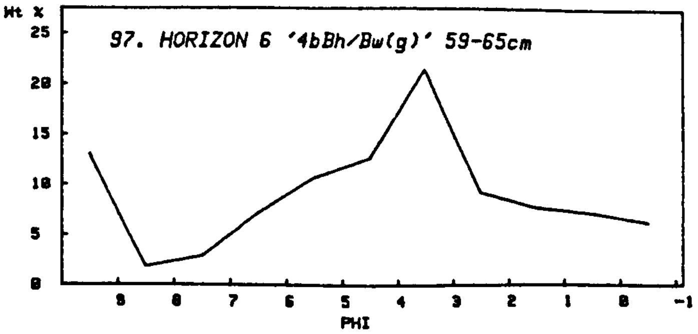
94. HORIZON 3 '2Ahg/Bh' 17-27cm



95. HORIZON 4 '3bAhg' 27-43cm



96. HORIZON 5 '3bEb/Bw(g)' 43-59cm



97. HORIZON 6 '4bBh/Bw(g)' 59-65cm

Fig. 8.33 Horizons in profile 3, Scrape Bottom.

Wilverly Plain profile (Fig,8.15) and horizon 3 resembles horizon 3 at Wilverly which suggests the two horizons could be derived from upper brickearth of this character. The other three horizons also have p.s.d's resembling upper brickearth but they lack precise textural equivalents in the Wilverly profile. As in profiles 1 and 2 the coarse sand content is at a maximum in the basal horizon, suggesting a contribution from the gravels.

8.5. Detailed(¼0) Particle size Distributions.

8.5.1 Introduction

The particle size analyses of selected samples of upper brickearth were repeated at ¼0 resolution over a restricted range (mainly 6-20) to give a more accurate estimate of the position of the silt and sand modes than the 10 analyses could provide. To test whether the modes change in vertical sequence, four samples were analysed from the thickest upper brickearth profile at Chilling Copse, as well as three from the Hook Gravel Pit profile and two each from the Sturt Pond and Wilverly Plain profiles. Two topsoil samples with a high silt content were also analysed: sample 29, Hollybush Farm and sample 21, Chewton Common. The very silty upper brickearth in the Ocknell Plain profile was analysed to compare it with samples from the lower terraces. Lower brickearth samples from the Ocknell Plain and Lepe Cliff profiles were analysed for comparison with each other as they have very similar field characteristics. Four samples of very sandy brickearths - from horizon 4 in the upper brickearth at Thorns Farm, sand from a fissure in the Beaulieu Heath profile, and the undifferentiated brickearths from horizon 2 at Calveslease Copse and horizon 2 at Rockford Common - were analysed to compare their peaks with each other and with the sand fraction of less sandy upper brickearth. Three samples of Tertiary sand which the 10 analyses indicated were most likely to have contributed to the upper brickearth were also analysed - Barton Sands from Barton Cliff and Longslade Bottom and Headon Beds sand from Hordle Cliff. No Plateau Gravel samples were analysed because the 10 analyses suggests relatively little fine sand in the brickearth can have come from this source.

8 .5.2. Results

In the Chilling Copse profile (Fig. 8.34), horizon 1 has a single prominent silt peak at 26-31µm and two minor sand peaks at 125-150µm and 180-210µm. In horizon 3 the 26-31µm peak is still dominant but there is more coarser silt and a secondary 63-75µm peak has appeared in the sand fraction. In horizon 4, this 63-75µm peak is now dominant; although the 26-31µm peak is still present there is now almost as much silt in each of the four 31-63µm fractions. In horizon 5 the form and position of the sand peaks is almost identical to horizon 4 but the silt curve has changed markedly: the 26-31µm peak has been replaced by two peaks at 31-37µm and 44-53µm.

In horizon 1 of the Hook Gravel Pit profile the position of the peaks is identical to those in horizon 5 at Chilling Copse although the relative proportions of material in each peak is slightly different (Fig. 8.35). In particular the 63-75µm peak is less prominent and the 125-150 peak is more so. In horizon 2 the 125-150µm peak has become dominant and the silt content has diminished relative to the sand so that no distinct silt peaks are evident.

In the Wilverly Plain profile (Fig. 8.36a) horizon 2 has an almost identical series of peaks to horizon 1 at Hook Gravel Pit and horizon 5 at Chilling Copse. The only difference is that there is a 105-125µm peak instead of one at 125-150µm, although there is an almost equal amount of sand in both fractions. In horizon 4 no distinct peaks are visible in the silt fraction as in horizon 3 at

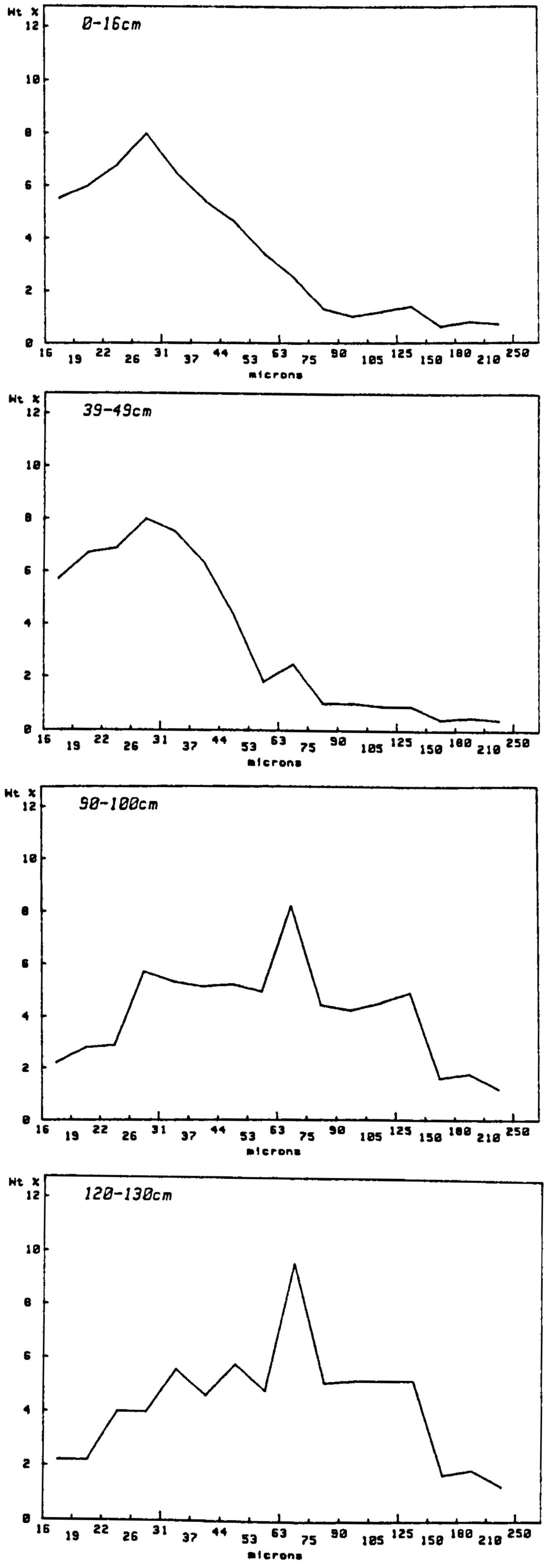


Fig. 8.34 ¼ phi analysis of horizons in the Chilling Copse profile

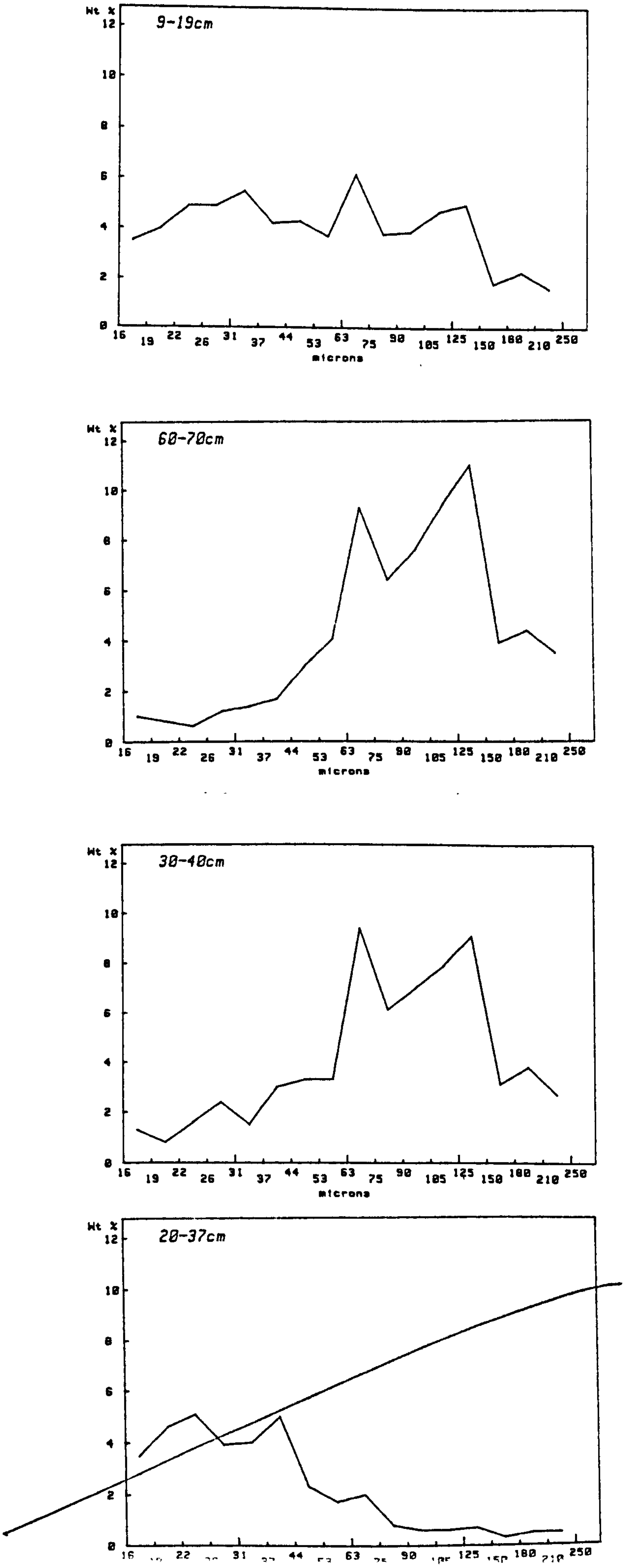


Fig. 8.35 ¼ phi analysis of horizons in Hook Gravel Pit profile.

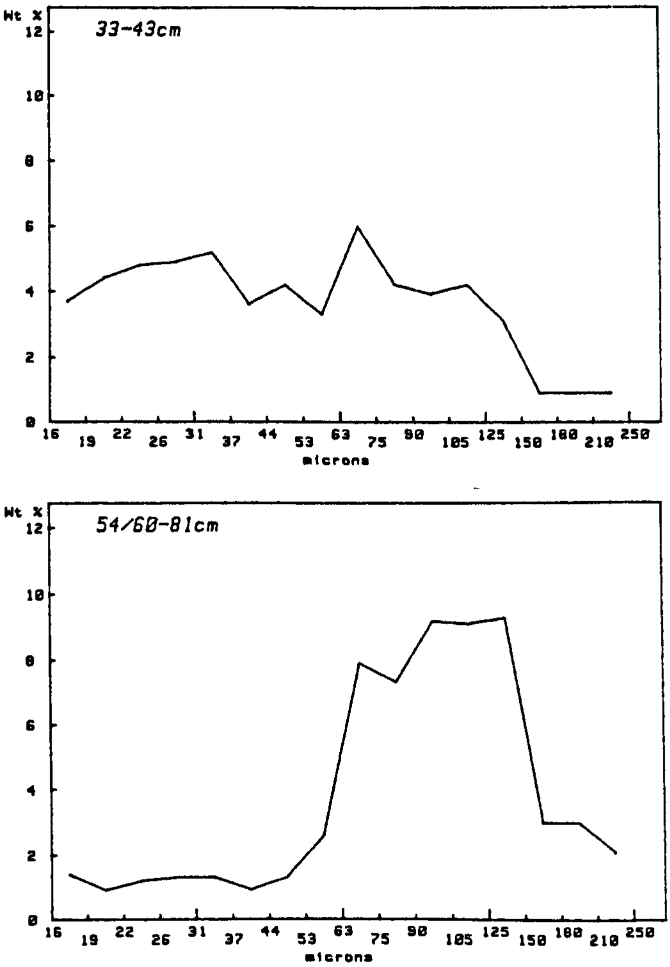


Fig. 8.36a ¼ phi analysis of horizons in the Wilverly Plain Profile.

Hook Gravel Pit. In the sand fraction the 63-75µm peak is now secondary to others at 125-150µm and 90-105µm; the first two of these are the same as in horizon 3 at Hook Gravel Pit.

At Sturt Pond, horizon 1 is most like horizon 3 at Chilling Copse, but the sand content is greater and the silt peak is slightly finer at 22-26µm (Fig. 8.36b). In horizon 3 the silt curve has flattened (as in horizon 4 at Chilling) so that no distinct peak is visible, and the 63-75µm sand peak is amplified.

The Hollybush Farm sample has a similar form and identical set of peaks to horizon 1 at Sturt Pond (Fig. 8.37a). The Chewton Common sample has an identical set of peaks to horizon 4 at Chilling Copse, but the form of the curve differs slightly because there is a substantial fine 'tail' to the 63-75µm peak in the 53-63µm fraction.

The upper brickearth in horizon 3 of the Ocknell Plain profile has a prominent 26-31µm peak and minor 125-150µm peak as in horizon 3 at Chilling Copse, but the fine sand 63-75µm peak is absent and is replaced by a very coarse silt 53-63µm peak that is not present in any other upper brickearth samples, although the 53-63µm 'tail' in the Chewton Common sample may have a similar origin (Fig. 8.37b). The lower brickearth at this site is very different from the upper brickearth and has silt peaks of equal size at 22-26µm and 37-44µm and a secondary 63-75µm sand peak (Fig. 8.37b).

The lower brickearth at Lepe Cliff (Fig. 8.37a) is different from that at Ocknell Plain and has a minor 53-63µm peak and a very fine dominant 13-16µm peak.

The sand found in fissures at Beaulieu Heath has three peaks - 63-75µm, 125-150µm, and 180-210µm - at the same position as in most upper brickearth samples (Fig. 8.38). However, the 125-150µm and 180-210µm peaks are much larger and the 63-75µm much smaller than in the nearest upper brickearth equivalent, horizon 3 at Hook Gravel Pit. It is noteworthy though, that the trend

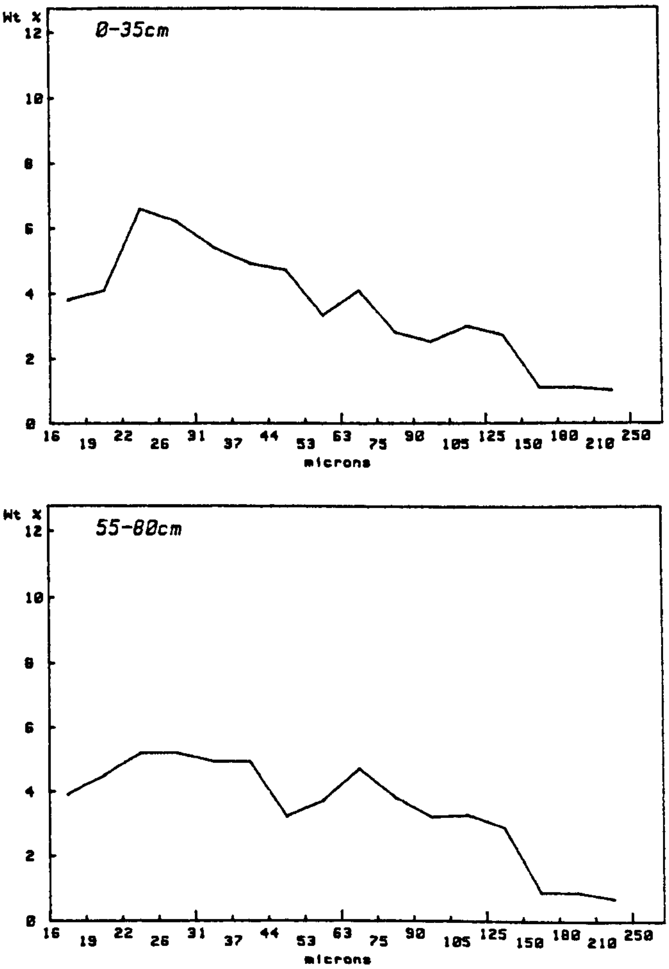


Fig. 8.36b ¼ phi analysis of horizons in the Sturt Pond profile.

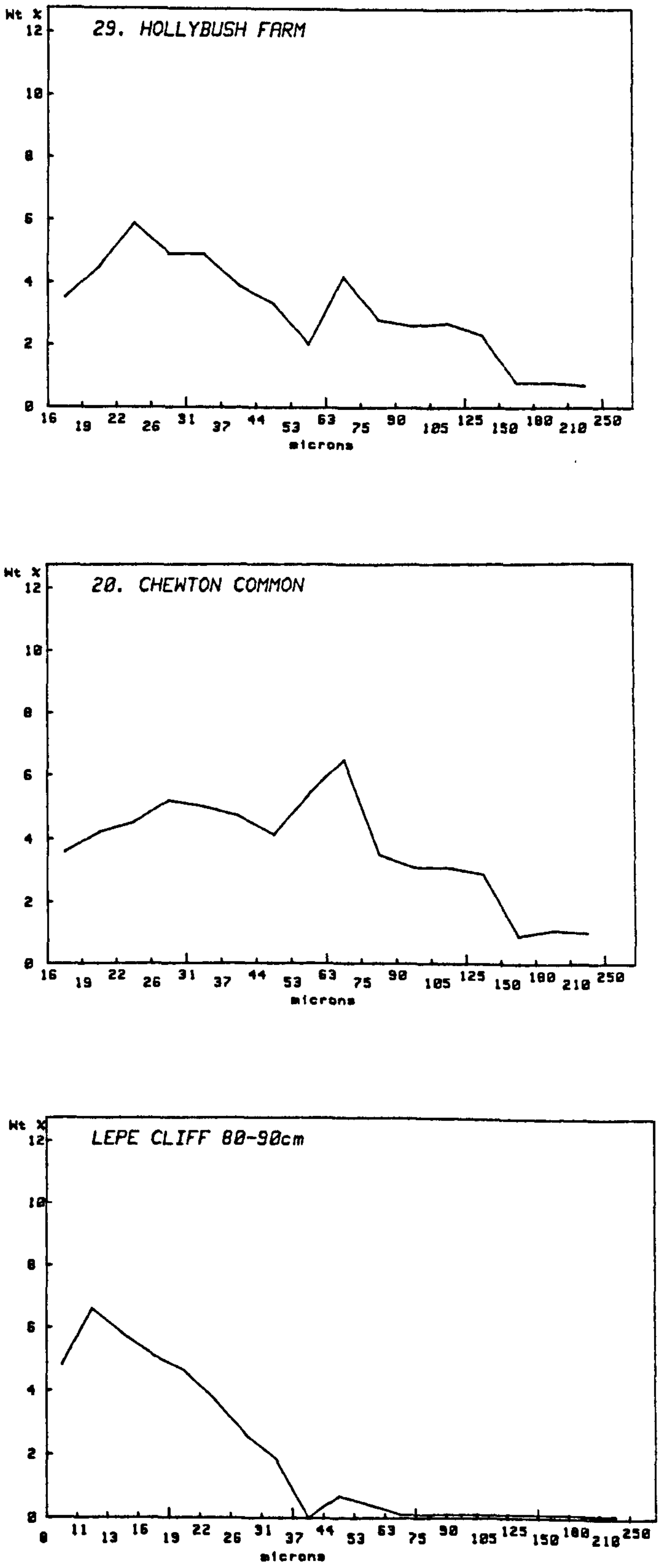


Fig. 8.37a ¼ phi analysis of some upper brickearth samples.

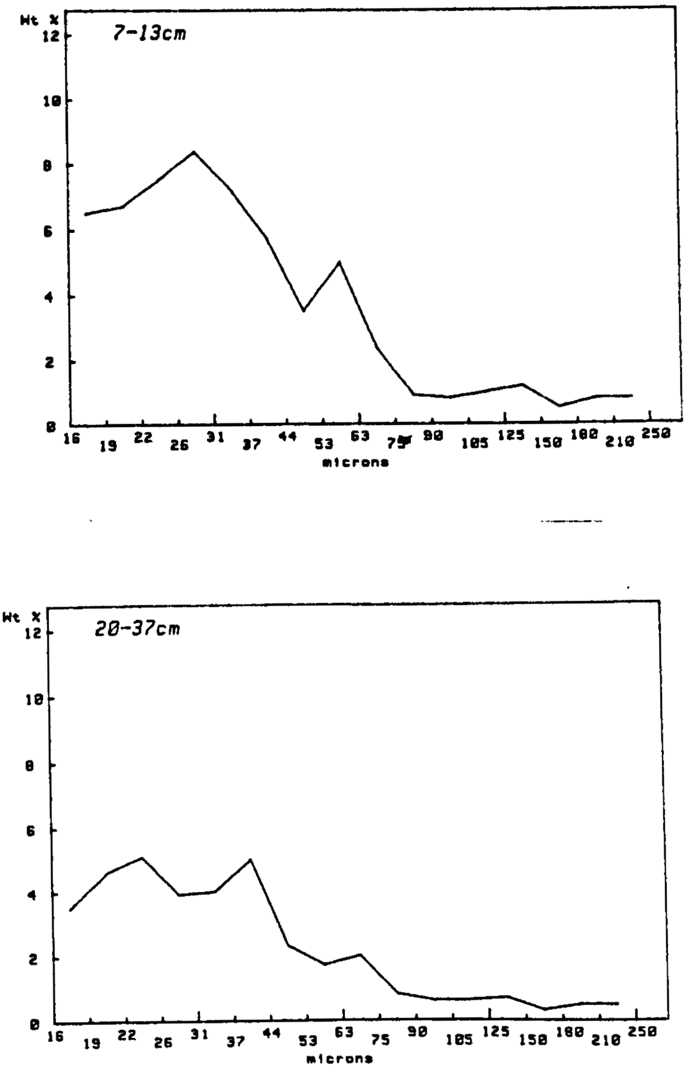


Fig. 8.37b $\frac{1}{4}$ phi analysis of horizons in the Ocknell Plain profile.

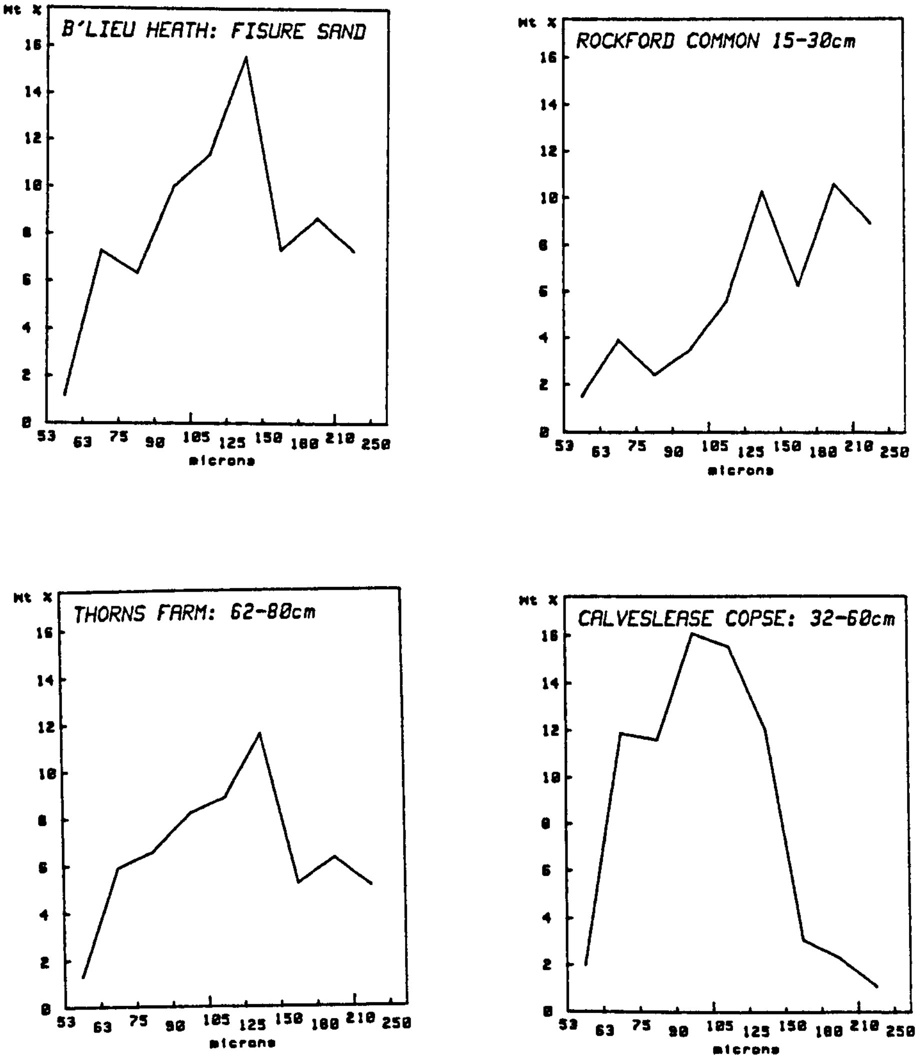


Fig. 8.38 ¼ phi analysis of selected sandy brickearth samples.

towards the base of the Hook Gravel Pit and Wilverly Plain profiles was for the 63-75μm peak to diminish and the 125-150μm and 180-210μm peaks to rise. In the very sandy upper brickearth in horizon 4 at Thorns Farm the 63-75μm peak is not present - perhaps as a continuation of this trend - and the 125-150μm and 180-210μm peaks are well defined. The same three peaks are present at Rockford Common, horizon 2, but the 180-210μm peak is dominant, unlike any other sample. Horizon 2 at Calveslease Copse has the 63-75μm peak, but the dominant peak is at 90-105μm which has only been found elsewhere in horizon 4 at Wilverly Plain.

Only the Headon Beds sand of the three Tertiary Sands analysed has a 63-75μm peak, and the dominant peak is at 105-125μm in this sample (Fig 8.39). The two Barton Sands samples are unimodal; one peaks at 105-125μm and the other at 90-105μm. The latter sample was collected near the Wilverly Plain profile, horizon 4 of which also has, unusually for the upper brickearth, a 90-105μm peak.

8.6 Summary and Conclusions

The upper brickearth varies in particle size distribution from that of typical loess, to aeolian sand. The majority of samples are unimodal at 10 resolution and have approximately normal profile distributions which suggests that the various size components were deposited contemporaneously by a single sorting agent - probably the wind.

The silt content of the topsoils is positively correlated with the total thickness of the upper brickearth. Samples taken vertically through thick sections in upper brickearth show that this is due to an increasing sand content with depth. Other more subtle changes in the relative proportions of the various size fractions occur with depth and many of these are repeated in profiles separated

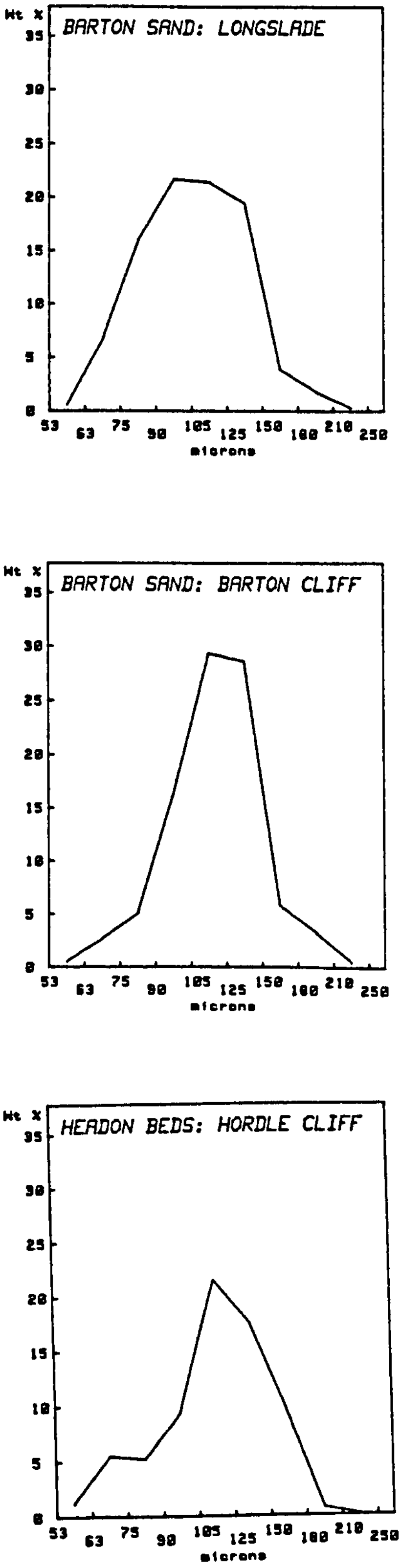


Fig. 8.39 $\frac{1}{4}$ phi analysis of Tertiary sand samples.

by quite large distances. An almost complete range of changes can be followed through the thickest described profile, at Chilling Copse and the lower two horizons at Hook Gravel Pit. The changes found in the lowermost horizons at Hook may also be present at Chilling, but unfortunately the lowermost 30cm of the Chilling profile was not sampled. In summary, the main changes found at 1Ø resolution were as follows: 1) The modal size in the silt fraction shifts from 5-4Ø to 6-5Ø with depth in the siltier (> 40% silt) upper brickearth. 2) The 4-3Ø sand fraction increases in prominence with depth. 3) A decrease in the ratio of 4-3/3-2Ø sand was found at the base of the upper brickearth at Thorns Farm and this is repeated in the sand in fissures in the Beaulieu Heath profile, which may thus be derived from upper brickearth.

At ¼Ø resolution the upper brickearth is shown to be polymodal. Nearly every sample shows the same three peaks in the sand fraction, at 63-75µm, 125-150µm and 180-210µm. With depth, the 63-75µm peak at first increases in prominence but is then exceeded by the 125-150µm peak. In the Wilverly Plain profile there are also peaks at 90-105µm and 105-125µm.

In the silt fractions, the very silty samples all have a single peak at either 26-31µm or 22-26µm - except at Ocknell Plain where there is an additional 53-63µm peak. With depth (in moderately silty samples) this peak diminishes and is eventually replaced by two at 31-37 and 44-53µm. No silt peaks are resolved in the sandy basal horizons of the upper brickearth. The 26-31µm peak is consistent with the known westward decrease in the modal size of Late Devensian loess due to the winnowing effect of easterly periglacial winds (Catt, 1977), but the 22-26µm peak is perhaps slightly finer than expected.

The lower brickearth as exemplified, for example, by the deposits at Tanners Lane and Thorns Farm usually has a much higher clay content than the upper brickearth. However, there are few consistent trends in its particle size distribution and this is probably because the constituent sediments have a diverse origin. and post-depositional history. Some samples, especially those from Ocknell Plain, Lepe Cliff, and Wootton Heath, have as large a silt content (clay free basis) as typical loess.

Of the possible local source sediments, the Tertiary Sands seem on the basis of p.s.d., likely to have been the most important contributor to the upper brickearth. The ¼0 sand modes in the upper and lower brickearths may be a reflection of common modes in local source sediments, as 63-75, 90-105, and 105-125µm peaks were found in the three Tertiary sand samples analysed. However, it was not possible to determine whether all of the brickearth modes occur in older sediments.

CHAPTER 9

MINERALOGICAL STUDIES

9.1 General Introduction and Methods.

As outlined in Chapter 3, mineralogical techniques have been used extensively in Britain and abroad to identify and characterise loess and other aeolian sediments. Apart from some clay mineralogy (Fisher,1975) there has been no detailed mineralogical work on the brickearth of South Hampshire. It was therefore decided to make a detailed mineralogical study to use with particle size analyses in determining the provenance of the brickearth.

In general, clay mineralogy is a less useful indicator of the provenance of a sediment than the mineralogy of the coarser (2μm to 2mm) fractions because clays are more susceptible to weathering and diagenesis and fewer mineral species are identifiable (Catt and Weir,1976). Attention was thus focussed on the silt and sand fractions of the brickearth. The particle size range of the fractions to be studied can have an important influence on results because a large range may include materials of different particle size classes derived from more than one source and because some minerals occur preferentially within certain size ranges. Ideally, the mineralogy of each of the main size classes identified from particle size analysis (Chapter 8) would have been studied but time did not permit this, so two ranges encompassing the main silt and sand peaks in the brickearth were selected, 6-4ϕ and 4-2ϕ. The separation is thus into the fraction most able to be carried far by wind (6-4ϕ) and a fraction largely beyond aeolian transport in suspension (4-2ϕ).

The two fractions were separated into light and heavy minerals for analysis, as described in Appendix C. Because of its platy habit, some chlorite grains tended to float in bromoform causing incomplete separation from the light minerals. Also, in some samples (mainly in the 4-2φ fraction) chlorite grains tended to split into individual plates when being spread on glass slides for counting. Counts of this mineral are therefore less reliable than the others, but they have nevertheless been retained in the data sets because of the suggested geographical variation of chlorite in Late Devensian loess in England (Catt,1978). Collophane was recognised in many samples, but was not included in the mineral counts because it may have been added to agricultural topsoils in bone fertilizers. At least 1000 grains were counted for each of the non-opaque light and heavy fractions in both the 4-2φ and 6-4φ ranges.

The results for each fraction are tabulated as parts per thousand. The level of accuracy of these counts can be gauged from the standard error which is calculable for each mineral species as follows:-

$$\text{S.E.} = \sqrt{\frac{p\% \,.\, q\%}{n}}$$

where p% = estimated percentage of a mineral, q % = estimated percentage of other minerals (i.e., 100-p%) and n = number of grains counted (Gregory, 1963). Thus in a count of 1000 grains, the true content of a mineral estimated to comprise 60.0% of the sample is within the limits 56.9% to 63.1% with 95% probability (± 2 σ). As a percentage of the estimated content of a mineral, the standard error increases with scarcity (Dryden,1931).

A similarity analysis of the mineralogical data was made by multivariate methods using the Rothamsted Genstat statistical package. (Alvey *at al.*,1977). Each mineral was given equal weight by adjusting the amounts to a scale from 0 to 1 corresponding to the percentage range of the mineral in all samples. Similarities between all pairs of samples were then calculated by the formula:

$$S_{ij} = 1 - \frac{\sum_{k=1}^{pl} \left| X_{ik} - X_{jk} \right|}{pl}$$

where S is the similarity between samples i and j in mineral K, Xik is the adjusted value for mineral K in sample i and pl is the total number of minerals. The matrix was used for principal co-ordinates analysis (Gower,1966) in which the distances in multidimensional space between samples are presented two-dimensionally using co-ordinates in the dimensions accounting for the greatest variability.

The results of the mineralogical studies are presented in two parts; part 1 concerns the fine sand (4-2Ø) fraction and part 2 concerns the coarse silt (6-4Ø) fraction.

PART 1

The Mineralogy of The Fine Sand Fraction

9.2. The Upper Brickearth

This section describes the fine sand mineralogy of selected samples from the topsoil survey (Chapter 4) and compares them with samples of Tertiary Sand and Plateau Gravel. Seventeen topsoil samples were selected to give a fairly even spread over the mapped area of the upper brickearth (Fig 9.1), and an additional sample from a Bt horizon at Barton Cliff was also analysed (Sample 73).

Qualitatively, all the samples are very similar, the only differences being in the presence or absence of some minor minerals (Table 9.1a,b).The mineral suites are dominated by quartz (85.7-95.2%) with lesser amounts of alkali feldspar (0.9-9.9%) and flint (1.3-4.4%) and minor amounts of muscovite, glauconite and heavy minerals. The heavy fraction is composed mainly of tourmaline and zircon with lesser amounts of rutile (yellow, brown and red), epidote, staurolite, kyanite zoisite, clinozoisite, garnet (pink and colourless) and chlorite and minor amounts of hornblende (brown and green), tremolite (including actinolite), anatase, brookite, andalusite, monazite, biotite, sphene, spinel and vivianite,

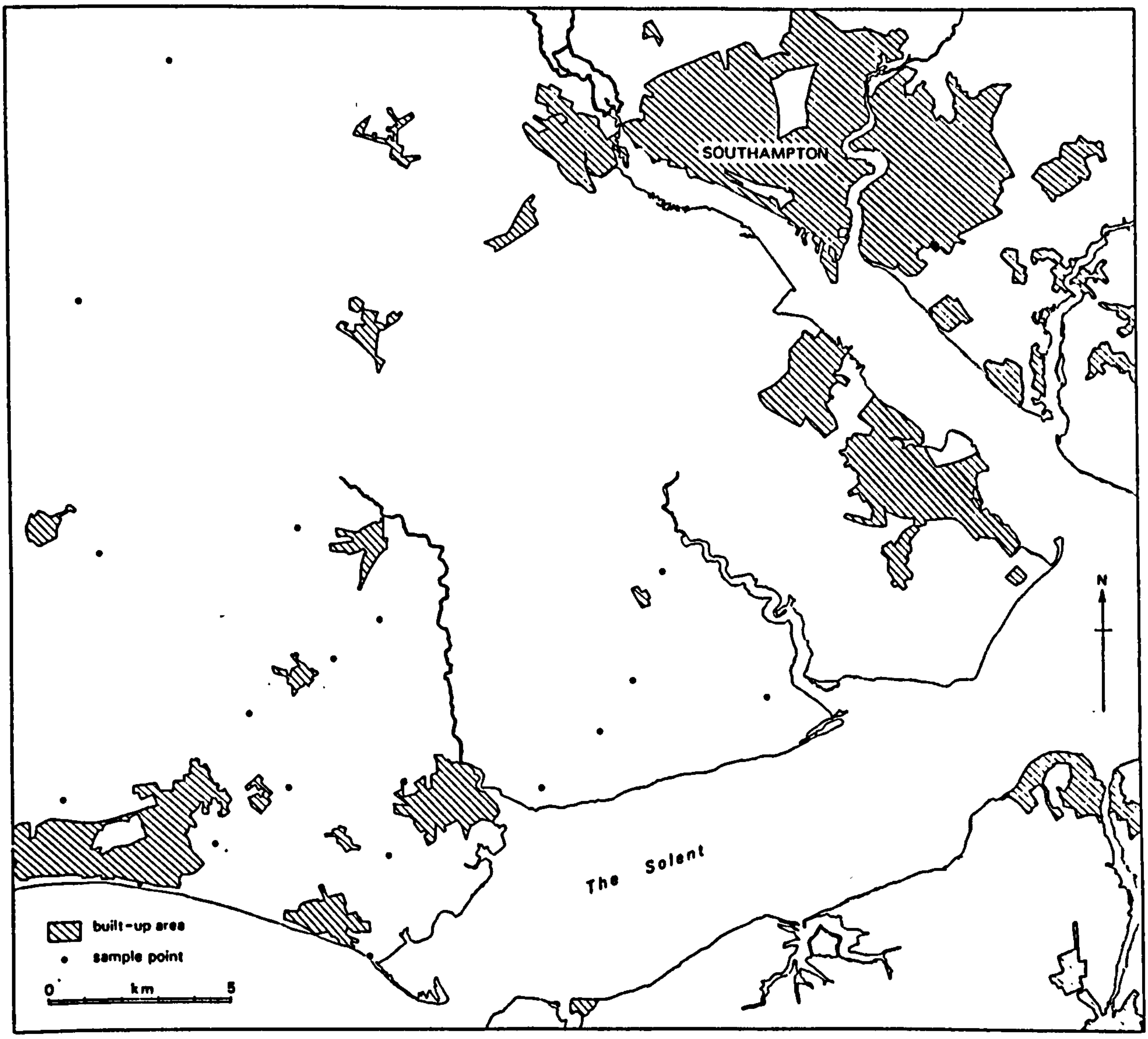


Fig. 9.1 Location of sites from the topsoil survey chosen for mineralogical analysis.

sample number:	M1	7	10	4	23	24	29	31	37	52
Light minerals										
quartz	914	907	927	952	913	885	907	917	907	921
alkali feldspar	62	72	52	9	66	99	69	70	76	47
flint	23	20	21	39	20	15	24	13	16	31
muscovite	-	1	-	-	1	1	-	-	-	-
glauconite	1	-	-	-	-	-	-	-	1	1
Heavy minerals										
tourmaline	364	359	225	402	418	369	438	396	335	356
zircon	261	263	454	354	187	239	158	209	253	287
brown rutile	18	19	14	27	11	10	15	16	20	21
yellow rutile	54	40	96	40	54	51	49	37	63	66
red rutile	8	9	7	10	8	11	5	7	9	10
pink garnet	1	3	-	1	1	-	1	-	3	1
colourless garnet	25	22	21	2	37	21	27	32	34	32
green hornblende	2	-	-	-	-	3	-	-	1	1
brown hornblende	-	-	-	-	-	-	-	1	-	-
kyanite	34	33	32	40	33	17	34	37	42	27
staurolite	45	50	35	34	48	38	56	27	46	36
clinozoisite	35	36	15	13	48	47	33	37	47	40
zoisite	23	36	15	3	24	23	29	21	33	18
epidote	91	112	82	60	98	111	99	95	90	90
anatase	4	4	-	3	2	6	2	8	5	5
brookite	1	1	1	3	1	2	1	3	2	1
andalusite	1	3	-	-	1	-	-	3	-	1
monazite	1	1	-	1	-	-	-	1	-	2
chlorite	31	9	3	4	27	49	52	68	16	4
biotite	-	-	-	-	-	1	1	1	-	-
tremolite	1	-	-	-	2	2	-	1	1	-
sphene	-	-	-	3	-	-	-	-	-	2
spinel	-	-	-	-	-	-	1	-	-	-
vivianite	-	-	-	-	-	-	-	-	-	-
corundum	-	-	-	-	-	-	-	-	-	-
silliminite	-	-	-	-	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Key:
M1 Mean of 18 upper brickearth samples

Table 9.1a 4-20 Mineralogy of upper brickearth topsoil samples

sample number:	54	58	61	66	70	71	73	74	75
Light minerals									
quartz	932	924	922	914	916	914	857	905	924
alkali feldspar	44	56	65	61	52	66	87	66	52
flint	23	18	13	22	31	19	44	26	22
muscovite	-	-	-	-	1	-	3	1	-
glauconite	1	2	-	3	-	1	9	2	2
Heavy minerals									
tourmaline	345	335	326	272	383	356	342	459	425
zircon	261	326	263	383	312	268	108	163	224
brown rutile	30	28	25	22	18	21	7	12	16
yellow rutile	46	57	52	82	53	63	39	37	43
red rutile	7	8	10	8	7	2	10	2	7
pink garnet	1	1	1	-	1	-	-	-	-
colourless garnet	35	26	25	26	10	27	17	23	32
green hornblende	-	1	2	7	6	-	4	-	1
brown hornblende	-	1	1	2	-	-	-	-	-
kyanite	37	41	27	30	53	47	33	24	24
staurolite	62	40	59	46	50	51	58	50	32
clinozoisite	31	15	59	28	18	35	54	40	41
zoisite	21	13	27	19	11	27	50	31	19
epidote	100	95	82	60	56	91	112	106	90
anatase	5	1	2	6	3	4	3	8	6
brookite	1	1	1	2	1	1	-	1	1
andalusite	-	-	5	-	-	-	-	-	1
monazite	-	1	1	1	-	-	1	-	-
chlorite	18	9	32	6	15	7	162	40	34
biotite	-	-	-	-	1	-	-	-	3
tremolite	-	-	-	-	-	-	-	1	1
sphene	-	1	-	-	1	-	-	-	-
spinel	-	-	-	-	1	-	-	-	-
vivianite	-	-	-	-	-	-	-	1	-
corundum	-	-	-	-	-	-	-	-	-
silliminite	-	-	-	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.1b 4-20 Mineralogy of upper brickearth topsoil samples

The relative proportions of the minerals vary quite widely among the samples, especially feldspar, zircon, rutile, garnet zoisite, clinozoisite, epidote and chlorite. As many of these minerals weather in soils and weathering is normally greatest near the soil surface (Brewer,1964), some of the variation in their relative quantities could be due to the effects of weathering. Sturdy et al. (1979) and Avery et al. (1982) considered that the most easily weatherable minerals in loess soils (excluding those that do not occur in the upper brickearth) were muscovite, glauconite, chlorite, biotite, hornblende and tremolite. These minerals are not present in sufficient quantities in the 4-20 fraction of the upper brickearth to make them useful in a weathering index. However, the largest amounts are found in sample 73 from a Bt horizon which suggests that they may be depleted by weathering in the samples from surficial horizons. Other less easily weatherable minerals - feldspar, garnet, zoisite, clinozoisite and epidote - seem to be present generally in the smallest amounts in the samples taken from the A or Ea horizons of thin podzolised soils and are commonest in the A horizons of thick argillic brown earth profiles. Thus they may have been more strongly weathered in the podzolised soils. Little is known about the weatherability of these minerals in British soils but Eden(1980) thought weathering accounted for the loss of garnet in some Essex loess samples, and R.M. Bateman (pers. comm.) has detected weathering of all five minerals in podzols developed in Late Devensian coversand.

To show the relationship graphically, the sum of the five minerals in each topsoil sample has been plotted against clay content in Fig. 9.2. Data from the A or E horizons of the Lepe Cliff, Ocknell Plain, Beaulieu Heath, Sturt Pond, Wilverly Plain and Thorns Farm soil profiles are included. Clay content is used as a rough index of soil type as amounts of clay are lowest in the surface horizons of podzols

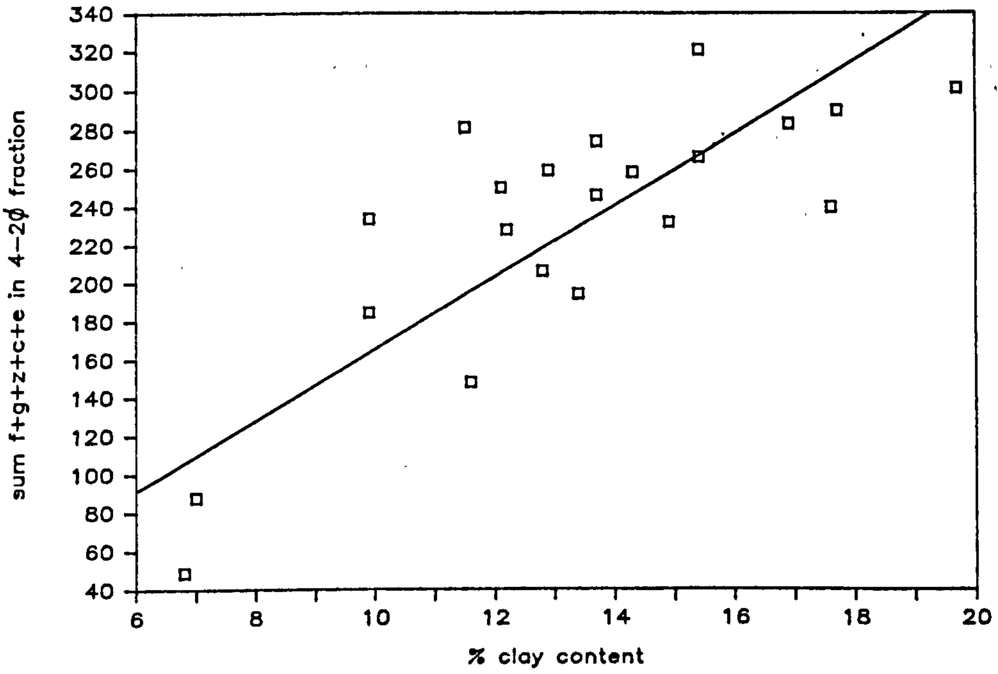


Fig. 9.2 Sum of feldspar, garnet, zoisite, clinozoisite and epidote contents in the 4-2ϕ fraction in the upper brickearth topsoil samples plotted against clay content

and highest in the argillic brown earths. The clay contents have the advantage over soil classification categories in being scalar quantities.

Correlation between the two variables was measured by Spearman's rank method and gave a value of $r_s = 0.71$.

The corresponding Student's t test value of $T = 4.45$ exceeds the critical value at the 0.01 significance level, so the correlation can be accepted with 99% probability.

Weathering is highly unlikely to account for the variability in amounts of zircon and rutile in the samples because these are generally regarded as amongst the most resistant minerals (Pettijohn, 1941). However, it was found that there is a strong relationship between the fine sand particle size distribution and the amounts of zircon and rutile in the samples. In Figs. 9.3 and 9.4, the amounts of zircon and rutile respectively are plotted against the the percentage of 4-3ϕ/4-2ϕ sand for all the analysed samples of upper brickearth (including those from the selected profiles). For the zircon distribution, a high negative correlation of $r_s = -0.88$ was found using Spearman's rank method. For rutile the correlation was less strong $r_s = -0.56$, but this may be due to the fact that rutile is only about 25% as common as zircon in the samples and the probable error in the estimates of its content is therefore correspondingly higher. The computed values of t for both distributions exceed the critical values at the 0.01 significance level so there is less than a 1% probability that either of the two correlations occurred by chance.

Thus high values of rutile and zircon in the 4-2ϕ fraction are associated with high values of 3-2ϕ sand relative to 4-3ϕ sand. However, during the mineralogical analysis it was found that an estimated 80-90% of zircon and rutile grains are infact between 63-100µm in diameter, i.e. they occur mainly in the 4-3ϕ fraction. This

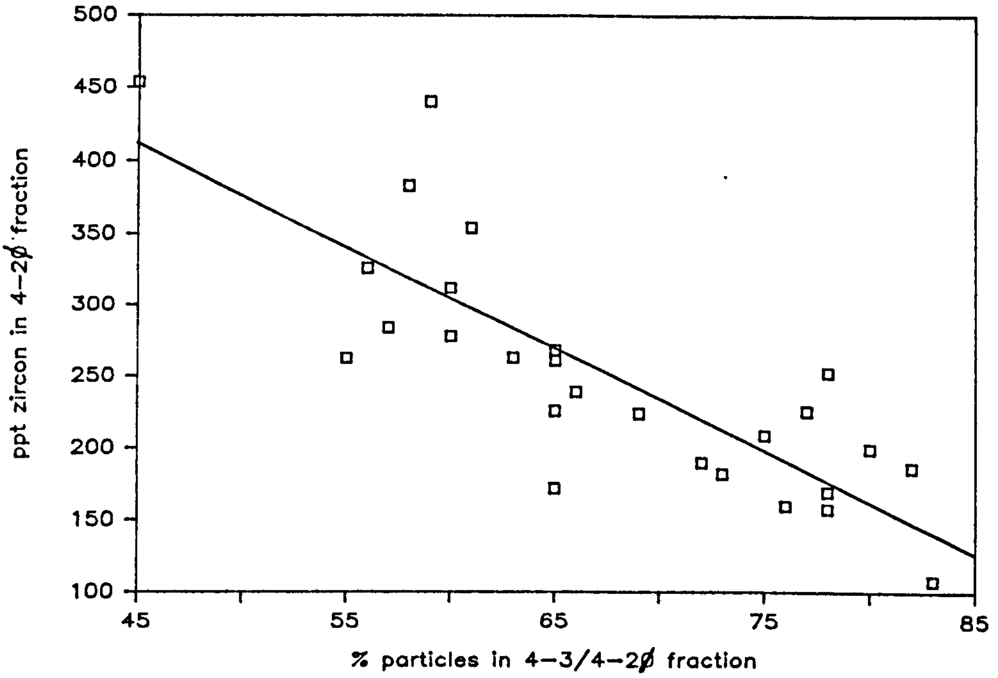


Fig. 9.3 Plot of zircon content against percentage of 4-3/4-20 sand for upper brickearth topsoil samples.

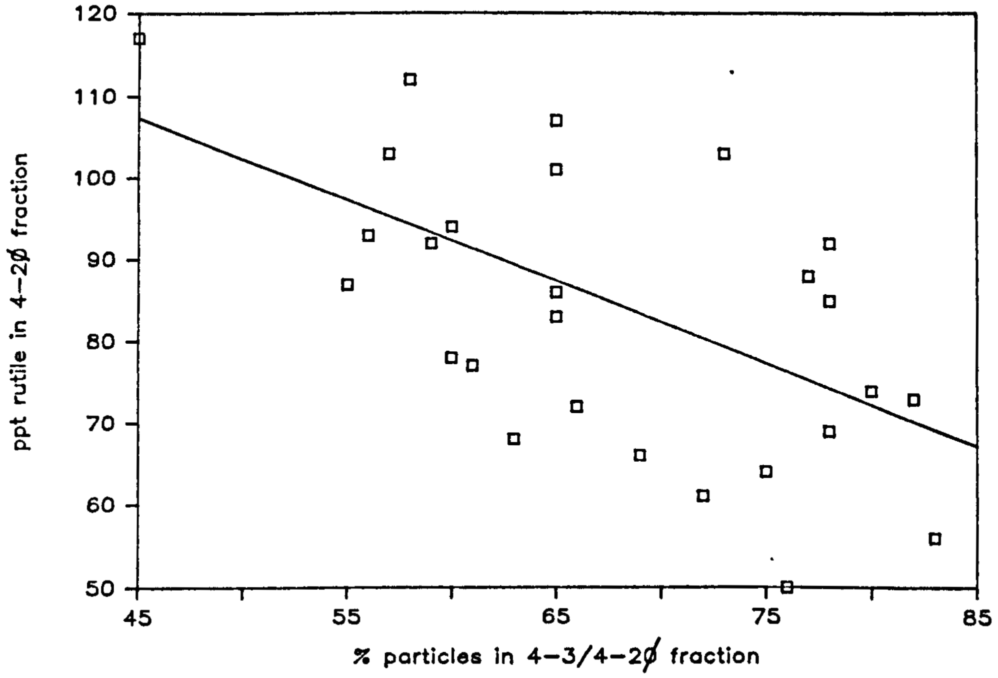


Fig. 9.4 Plot of rutile content against percentage of 4-3/4-2Ø sand for upper brickearth topsoil samples.

discrepancy is probably due to the phenomenon of hydraulic equivalence whereby, because the specific gravity of zircon (s.g. = 4.7) and rutile (s.g. = 4.2) greatly exceeds that of quartz (s.g = 2.65), the natural processes of sorting in a quartz-rich sediment results in zircon and rutile grains being associated with a particle size peak nearly double their true equivalent diameter.

As much of the mineralogical variation in the fine sand fraction of the upper brickearth can thus be explained by weathering and textural differences, it is likely that the 4-2ø fraction has common sources over the whole study area. To help assess what proportion of material has been contributed by local older sediments, six samples of Tertiary Sand and four samples of Plateau Gravel were analysed (Table 9. 2a,b).

The mineral assemblage in both groups of sediment is very like that in the upper brickearth; one grain of corundum, in the Barton Sands sample 130, was the only mineral found that is not present in the upper brickearth. However, in all samples the relative quantities of the minerals is different from the upper brickearth to a greater or lesser degree. The samples most closely resembling the upper brickearth are the Barton Sands from Longslade Bottom and Barton Cliff and the Headon Beds Sand from Hordle Cliff (samples 129, 130 and 132). These are the same three samples that most closely resemble the particle size distribution of the sand fraction in the upper brickearth. (Chapter 8). All three have alkali feldspar contents (7.1 - 8.7%) comparable with the least weathered brickearth samples. However, the zircon and rutile contents are far lower and garnet is completely absent. Epidote is less common in samples 129 and 132, and only one grain of hornblende was found, in sample 129. All three samples have a high clorite content (14.7 - 57.7%).

sample number:	130	132	133	129	131	146
Light minerals						
quartz	895	916	993	894	956	991
alkali feldspar	87	71	-	84	44	-
flint	17	13	7	19	-	9
muscovite	-	-	-	-	-	-
glauconite	1	-	-	3	-	-
Heavy minerals						
tourmaline	561	242	898	558	334	446
zircon	11	23	54	67	317	363
brown rutile	2	7	5	7	63	31
yellow rutile	10	12	7	27	98	36
red rutile	1	2	2	3	4	2
pink garnet	-	-	-	-	-	-
colourless garnet	-	-	1	-	1	7
green hornblende	-	-	-	1	-	-
brown hornblende	-	-	-	-	1	-
kyanite	70	40	15	82	43	34
staurolite	46	29	14	60	102	60
clinozoisite	25	18	-	14	4	5
zoisite	17	18	-	15	2	-
epidote	64	29	-	9	17	6
anatase	6	3	1	10	5	-
brookite	-	-	2	1	1	1
andalusite	-	-	-	-	4	3
monazite	-	-	-	-	1	-
chlorite	185	577	1	147	3	6
biotite	1	-	1	-	-	-
tremolite	-	-	-	-	-	-
sphene	-	-	-	-	-	-
spinel	-	-	-	-	-	-
vivianite	-	-	-	-	-	-
corundum	1	-	-	-	-	-
silliminite	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.2a 4-20 Mineralogy of Tertiary Sands

sample number:	124	122	123	143	M1	M2	M3
Light minerals							
quartz	977	931	952	853	902	980	928
alkali feldspar	12	53	30	30	81	15	31
flint	9	16	18	117	16	5	40
muscovite	-	-	-	-	-	-	1
glauconite	2	-	-	-	1	-	-
Heavy minerals							
tourmaline	615	364	382	624	455	559	495
zircon	276	518	479	129	34	245	351
brown rutile	43	17	15	5	5	33	20
yellow rutile	7	20	43	18	16	47	22
red rutile	5	4	6	-	2	3	4
pink garnet	-	-	-	1	-	-	-
colourless garnet	-	2	1	9	-	3	3
green hornblende	-	-	1	-	-	-	-
brown hornblende	-	-	-	-	-	-	-
kyanite	23	17	20	18	64	31	20
staurolite	18	16	20	36	45	59	23
clinozoisite	2	4	2	18	19	3	7
zoisite	-	7	2	11	17	1	5
epidote	3	8	3	39	34	8	13
anatase	-	1	2	1	6	2	1
brookite	-	1	3	1	-	1	1
andalusite	-	7	3	12	-	2	6
monazite	-	-	-	1	-	-	-
chlorite	8	12	17	76	303	3	28
biotite	-	-	-	-	-	-	-
tremolite	-	-	-	1	-	-	-
sphene	-	-	-	-	-	-	-
spinel	-	-	-	-	-	-	-
vivianite	-	2	1	-	-	-	1
corundum	-	-	-	-	-	-	-
silliminite	-	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Key:
M1 Mean of 3 fine Tertiary Sands, samples 129, 130, 132
M2 Mean of 3 coarse Tertiary Sands, samples 131, 133, 146
M3 Mean of 4 Plateau Gravels, samples 122, 123, 124, 143

Table 9.2b 4-20 Mineralogy of Tertiary Sands and Plateau Gravel

The Barton Sands sample from Lyndhurst and the two Bracklesham Sand samples (samples 131, 133 and 146), which are coarser textured than the other Tertiary sands, resemble the upper brickearth less than they do. Compared with the least weathered upper brickearth samples, the feldspar content is very low (0-4.4%) and so is garnet, hornblende, chlorite and epidote. In sample 133, the tourmaline content is extremely high and the staurolite content is very high in sample 131.

The four Plateau Gravel samples have a similar mineralogical composition to the coarser textured Tertiary sands. They are deficient in feldspar (1.2-5.3%) compared to the least weathered upper brickearth and have extremely low amounts of all weatherable heavy minerals with the exception of chlorite, which is fairly common in sample 143.

From these analyses it seems that the upper brickearth has more garnet, hornblende, clinozoisite, zoisite and epidote in the 4-2Ø fraction than could be provided from any of the examples of possible source sediments. However, in more comprehensive studies of the mineralogical composition of the Tertiary Strata of the Hampshire Basin, Walder(1964), Blondeau and Pomerol(1968) and Morton (1980) have noted high frequencies of all these materials in some beds; garnet in particular is often very common. Therefore despite the results found in this work, it is still possible that the amounts of these minerals found in the upper brickearth could have been derived entirely from the Tertiary strata. It is noteworthy though, that these five minerals are also common in the coarse silt fraction of loess in southern England, so their presence in the fine sand fraction of the upper brickearth could represent the coarse 'tail' of far travelled silt and could thus be derived in part from outwith the Hampshire Basin. A similar mineralogical enrichment of the fine sand fractions of loess from elsewhere in England was discussed in chapter 3.

9.3 The Selected Profiles

Mineralogical analyses were made for selected samples from most of the soil profiles studied. This was done primarily to establish the mineralogical characteristics of the Lower brickearth, but also to compare the upper and lower brickearth at the sites. The results are shown in Table 9.3 a-c.

9.3.1 Sturt Pond, Wilverly Plain, Chilling Copse and Hook Gravel Pit (samples 105, 107, 82b, 78c and 83c).

These four profiles, developed entirely in upper brickearth, are discussed together because of their similarity.

Two samples were analysed from the Sturt Pond profile, from horizons 1 and 3. In terms of the total weatherable minerals content, horizon 1 is similar to the surface horizons of other argillic brown earths e.g. samples 24 and 29, but chlorite and epidote are slightly less common. Horizon 3 has a higher total weatherable minerals content than horizon 1, as would be expected, but feldspar, zoisite and clinozoisite are less common. Like horizon 1, the chlorite and epidote contents are less than in comparable horizons elsewhere (e.g. Bt horizons at Barton Cliff , sample 73; Chilling Copse, sample 78c and Hook Gravel Pit, sample 83c). The garnet content of horizon 3 (6.3%) is also exceptionally high. These observations, which are not entirely explained by the weathering or textural variations described in the last section, suggest that there are local variations in the mineralogical composition of the 4-2ϕ fraction of the upper brickearth.

Only one sample was analysed from each of the other three sites. Horizon 2 at Wilverly Plain is very similar to horizon 1 at Sturt Pond, but has a lower garnet and higher epidote content.

sample number:	105	107	82b	78c	83c	79a	114	79d
Light minerals								
quartz	906	904	913	862	866	930	896	906
alkali feldspar	65	60	67	100	83	52	75	71
flint	29	35	18	38	46	18	29	23
muscovite	-	1	-	-	2	-	-	-
glauconite	-	-	2	-	3	-	-	-
Heavy minerals								
tourmaline	410	252	389	239	267	403	371	363
zircon	190	226	170	182	172	284	285	206
brown rutile	18	5	15	21	19	30	33	19
yellow rutile	41	81	63	79	76	61	61	43
red rutile	2	2	7	3	12	12	5	2
pink garnet	1	3	-	2	1	-	-	-
colourless garnet	33	60	15	25	28	9	10	4
green hornblende	-	1	-	6	-	2	-	-
brown hornblende	-	-	-	-	-	-	-	-
kyanite	80	68	50	70	102	35	67	57
staurolite	51	60	51	56	61	50	67	65
clinozoisite	43	33	57	11	38	24	20	28
zoisite	26	20	29	29	36	17	12	23
epidote	72	90	122	114	104	62	41	62
anatase	6	8	6	6	1	2	8	8
brookite	4	2	3	1	-	2	-	1
andalusite	2	1	-	3	3	1	2	2
monazite	-	-	-	-	-	-	-	-
chlorite	20	85	21	144	77	6	17	115
biotite	-	1	-	9	3	-	-	-
tremolite	-	2	2	-	-	-	1	2
sphene	-	-	-	-	-	-	-	-
spinel	-	-	-	-	-	-	-	-
vivianite	1	-	-	-	-	-	-	-
corundum	-	-	-	-	-	-	-	-
silliminite	-	-	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.3a 4-20 Mineralogy of selected samples from the soil profiles

sample number:	68a	68b	64	110	111	112	6a	6b
Light minerals								
quartz	907	886	921	893	875	890	931	948
alkali feldspar	69	34	58	74	79	76	12	5
flint	18	80	17	33	46	34	57	47
muscovite	3	-	-	-	-	-	-	-
glauconite	3	-	4	-	-	-	-	-
Heavy minerals								
tourmaline	342	406	352	419	293	380	327	384
zircon	200	236	226	159	405	244	440	404
brown rutile	24	11	20	16	11	20	35	18
yellow rutile	44	40	66	41	60	53	54	76
red rutile	6	2	15	3	3	3	3	4
pink garnet	1	-	-	4	1	-	-	-
colourless garnet	31	8	40	32	8	11	4	-
green hornblende	1	-	-	-	-	-	-	-
brown hornblende	-	-	-	-	-	-	-	-
kyanite	51	32	39	49	37	65	48	48
staurolite	50	40	51	42	65	52	42	41
clinozoisite	42	17	30	36	21	22	8	2
zoisite	37	16	20	25	11	16	7	3
epidote	141	43	102	70	57	88	18	2
anatase	5	3	9	6	10	7	2	3
brookite	-	3	-	-	3	4	-	3
andalusite	-	3	1	1	6	4	1	3
monazite	1	-	-	-	-	-	-	-
chlorite	24	140	27	92	9	29	8	8
biotite	-	-	-	4	-	-	-	-
tremolite	-	-	2	1	-	2	1	-
sphene	-	-	-	-	-	-	-	-
spinel	-	-	-	-	-	-	-	-
vivianite	-	-	-	-	-	-	2	1
corundum	-	-	-	-	-	-	-	-
silliminite	-	-	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.3b 4-20 Mineralogy of selected samples from the soil profiles

sample number:	126	127	119	120	121	117	118
Light minerals							
quartz	872	913	945	923	854	908	896
alkali feldspar	89	62	30	23	12	63	74
flint	39	25	25	54	34	29	30
muscovite	-	-	-	-	-	-	-
glauconite	-	-	-	-	-	-	-
Heavy minerals							
tourmaline	394	431	327	325	183	190	291
zircon	126	108	305	243	564	433	321
brown rutile	22	17	28	25	22	61	17
yellow rutile	47	52	45	50	29	117	80
red rutile	2	1	4	2	4	5	3
pink garnet	-	-	-	-	-	1	-
colourless garnet	11	4	20	7	2	2	3
green hornblende	-	-	-	-	-	1	-
brown hornblende	-	-	-	-	-	-	-
kyanite	44	56	26	38	28	50	68
staurolite	72	59	69	58	30	64	58
clinozoisite	35	35	5	2	1	9	34
zoisite	22	23	5	5	2	9	18
epidote	91	97	25	10	11	42	77
anatase	4	2	7	10	6	8	7
brookite	1	1	1	1	2	3	4
andalusite	1	1	1	2	4	4	2
monazite	-	-	-	-	-	-	-
chlorite	128	113	131	223	129	1	11
biotite	-	-	-	-	3	-	-
tremolite	-	-	-	-	-	-	1
sphene	-	-	-	-	-	-	-
spinel	-	-	-	-	-	-	-
vivianite	-	-	-	-	-	-	1
corundum	-	-	-	-	-	-	-
silliminite	-	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.3c 4-20 Mineralogy of selected samples from the soil profiles

The samples from horizon 3 at Chilling Copse and horizon 3 at Hook Gravel Pit are very similar to each other, except that the Chilling sample contains more chlorite. The two samples closely resemble the Bt horizon at Barton Cliff (sample 73).

9.3.2 Beaulieu Heath (Samples 79a, 114, and 79d)

As in the podzolised soils sampled in the topsoil survey (section 9.2) garnet, clinozoisite, zoisite, epidote and chlorite in the upper brickearth in horizon 3 are much smaller than in the surface horizons of the argillic brown earth soils. The sand that fills fissures in the lower brickearth (see field description section 5.2.4) is mineralogically very like that in horizon 3 except that it has slightly more feldspar and chlorite and less epidote. It could therefore be derived from the same source as the upper brickearth. The 4-2ø fraction of the lower brickearth in horizon 6 is also like the other two samples, the main difference being that it contains far more chlorite.

9.3.3. Lepe Cliff (Samples 68 a and b)

The upper brickearth in horizon 1 has a similar mineralogical composition to the surface horizon of argillic brown earths except that the epidote content (14.1%) is very high. The lower brickearth in horizon 3 has the same mineral assemblage as the upper brickearth but has much lower amounts of all weatherable minerals except chlorite. This suggests that the 4-2ø fraction of the lower brickearth was weathered prior to the deposition of the upper brickearth or that its mineral assemblage was originally deficient in weatherable species.

The Plateau Gravel underlying the lower brickearth at this site (sample 143) is also unusually rich in chlorite so the two sediments may have been mixed.

9.3.4. Thorns Farm (samples 64, 110, 111 and 112.)

The quantitative distribution of minerals in the upper brickearth in horizon 1 is similar to that in the surface horizons of the argillic brown earths (section 9.3.1). In horizon 4 there is a higher feldspar and chlorite content but lower amounts of epidote. These changes are similar to those found in the Beaulieu Heath profile between horizon 3 and the sand in a fissure.

In the lower brickearth in horizon 5 (55-100cm) the feldspar content is fairly high (7.9%), but other weatherable minerals - garnet, zoisite, clinozoisite, epidote and chlorite are far less common than in the upper brickearth. At 100-120cm in horizon 5 all these weatherable minerals are more common than at 55-100cm. This may be due to the inclusion of fine sand of a similar texture (and possibly origin) to horizon 4 in the horizon, as indicated by the particle size analysis results (section 8.4.6).

9.3.5 Ocknell Plain (samples 6 a and b)

The upper brickearth is podzolised and horizon 3 has an extremely low total of weatherable minerals. The lower brickearth in horizon 5 has a similar mineralogical composition but the total of weatherable minerals is even smaller.

9.3.6 Calveslease Copse (samples 126 and 127)

The undifferentiated brickearths in horizons 2 and 3 have very similar mineralogical compositions, but horizon 3 has slightly lower amounts of some weatherable minerals, namely feldspar, garnet and chlorite. In both samples the mineral distribution is like the moderately weathered upper brickearth samples.

9.3.7 Rockford Common Gravel Pit (samples 119.120 and 121)

Horizons 2 and 3 have similar mineral assemblages. Apart from chlorite, the weatherable minerals content is low but horizon 2 has the most feldspar, garnet and epidote. This is against the normal trend for weathering to increase towards the surface and suggests that horizon 2 has had an addition of less weathered material from a different source. Horizon 4 has a fairly typical distribution of minerals for the Plateau Gravel, but the chlorite content is very high, in common with sample 143 from Lepe Cliff.

9.3.8 Holbury Gravel Pit (samples 117 and 118)

The lower brickearth samples from horizons 2 and 4 have similar mineral assemblages, but horizon 4 has slightly larger amounts of all weatherable minerals. In common with most other lower brickearth samples, both horizons have much lower amounts of weatherable minerals than the least weathered upper brickearth samples.

9.4. Principal Co-ordinates Analysis

Because of the doubt over the reliability of determining chlorite contents, this mineral was excluded from the data sets used in principal co-ordinates analysis.

The principal co-ordinates analysis yielded two two-dimensional plots, PC1: PC2 and PC1: PC3, which separated most of the upper brickearth samples from the other sediments. Table 9.4 lists the percentage variability accounted for and the main minerals related to each of the three vectors PC1, PC2 and PC3. PC1 is the most important and is influenced mainly by the five moderately weatherable minerals used in the weathering index (Fig. 9.2), PC2 is mainly related to amounts of three readily weatherable minerals, tremolite, muscovite and hornblende and two minerals that probably do not weather in soils - anatase and brookite. All five are present only in minor amounts in the samples. The five main minerals influencing PC3 are all relatively resistant and the two most important minerals, kyanite and staurolite - are quite common in all samples. The true content of these two minerals is therefore much more accurately estimated than any of the five minerals

TABLE 9.4

Principal Co-Ordinate Vectors and the Minerals Related to Them: South Hampshire Sediments 4-20 Mineralogy

Vector:	PC1	PC2	PC3
% of total variability accounted for.	28.2	12.7	10.4
Minerals related to vector in order of importance:	Clinozoisite(-) Epidote (-) Zoisite(-) Feldspar(-) Garnet(-)	Tremolite(+) Muscovite(-) Anatase(+) Brookite(+) Sphene(-)	Kyanite(+) Staurolite(+) Anatase(+) Monazite(-) Sphene(-)

influencing PC2. For this reason PC3 may provide a more reliable differentiation of the sediments, despite the fact that it accounts for slightly less of the total variance than PC2.

The PC1: PC2 plot (Fig 9.5) concentrates all but two of the upper brickearth samples in a single grouping to the left that is interspersed with five samples of other sediments. The other sediments are two undifferentiated brickearth samples from Calveslease Copse (samples 126 and 127) and the fine-grained Tertiary sands from Longslade Bottom, Barton Cliff and Hordle Cliff (samples 129, 130 and 132). The main grouping of upper brickearth samples is not particularly closely knit because there is an almost equal variation among the samples on both vectors. To the right of the main upper brickearth sector comes a less clearly differentiated group composed mainly of other sediments. Six samples of lower brickearth (samples 111, 112, 79d, 118, 117 and 68b), two samples of undifferentiated brickearth (samples 114 and 119), one sample of Plateau Gravel (sample 143), and a Tertiary Sand sample (sample 131) come nearest to the upper brickearth sector. Beyond these, further to the right on PC1 come two outlying upper brickearth samples from Ocknell Plain and Bratley Plain (samples 6a and 4. These are both from podzols and are the most strongly weathered upper brickearth samples. Further right, with PC1 values of 0.24 - 0.32, are four samples of Plateau Gravel (samples 121, 122, 123 and 124), two coarse grained Bracklesham Sand samples (samples 133 and 146) and one lower brickearth sample from Ocknell Plain (sample 6b), and these resemble the upper brickearth least.

The plot of PC1: PC3 (Fig. 9.6) concentrates the upper brickearth samples in a tighter group because there is less variation in PC3 values compared with PC2. Most of the variance is now on PC1 and, considering the minerals mainly influencing this

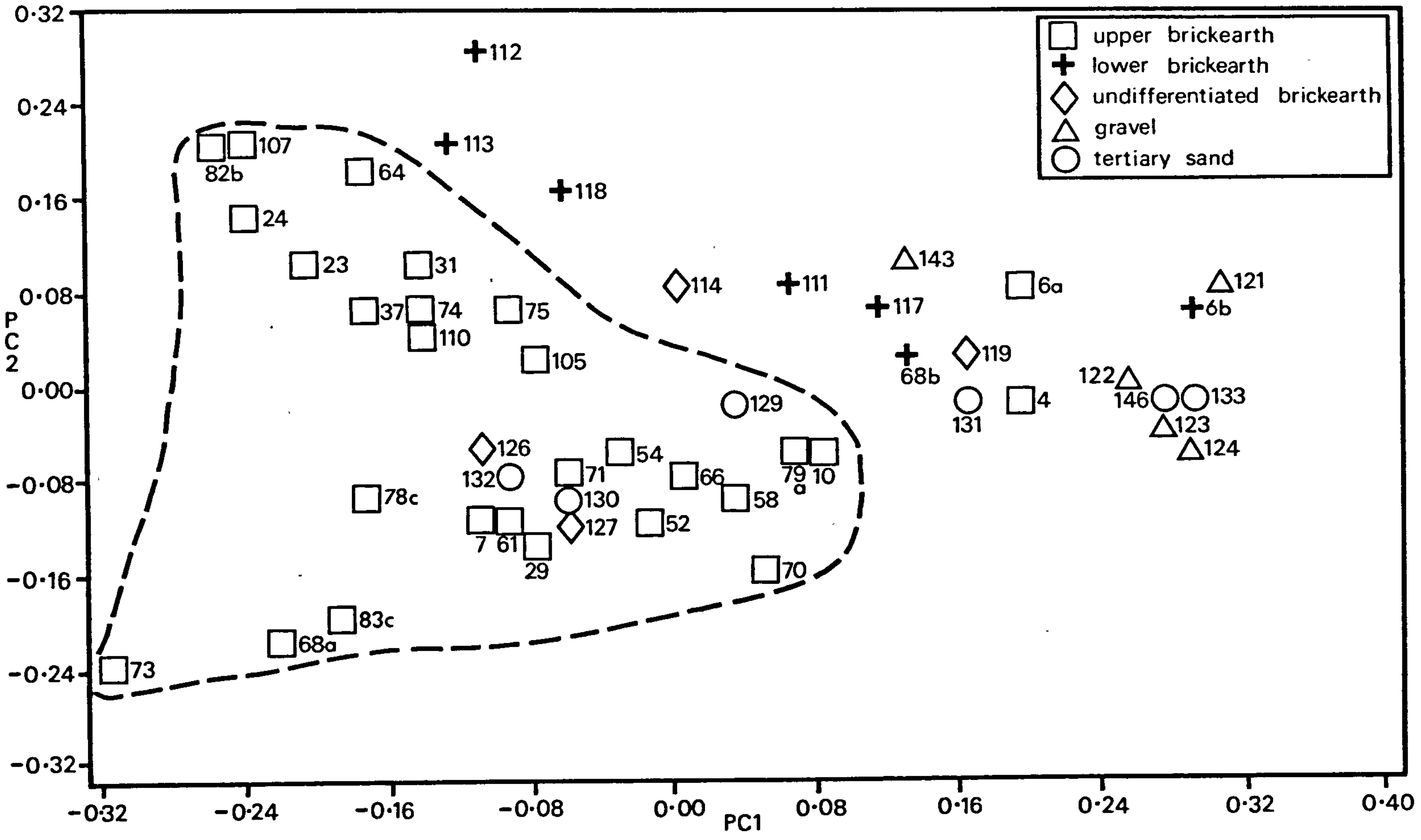


Fig. 9.5 Principal co-ordinates plot PC1 : PC2 for mineralogy of the 2-4ϕ fraction of all south Hampshire sediments.

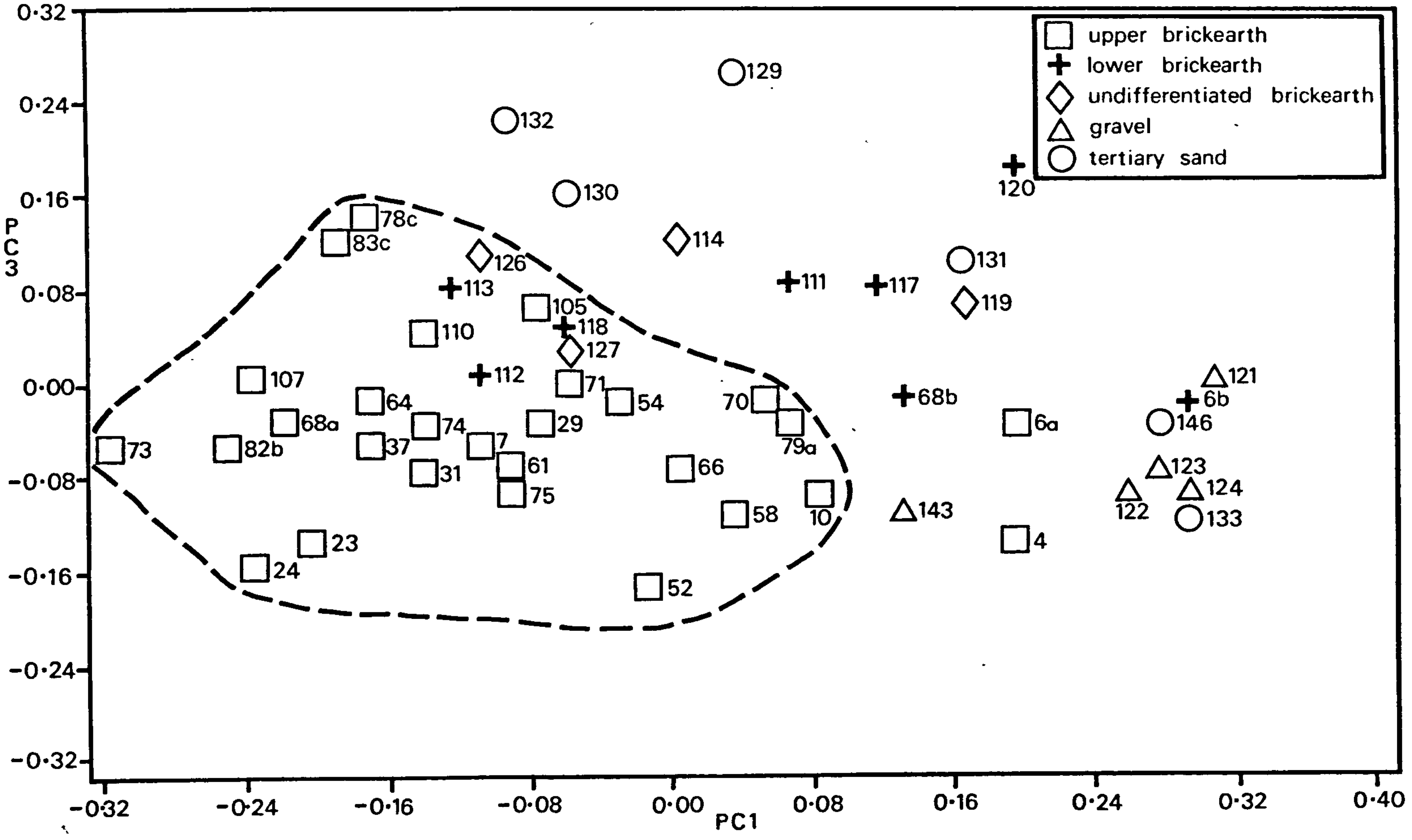


Fig 9.6 Principal co-ordinates plot PC1 : PC3 for mineralogy of the 2-4ø fraction of all south Hampshire sediments.

vector, is probably due to weathering. This plot removes the three fine-grained Tertiary sands (samples 129, 130 and 132) from the upper brickearth sector, but three samples of lower brickearth (samples 112, 118 and 79d), which were formerly outside replace them. Apart from this the main trends are little changed: the fine grained Tertiary sand, three samples of lower brickearth (samples 111, 117 and 68b), one Plateau Gravel sample (sample 143) and one undifferentiated brickearth sample (sample 114) come closest to the upper brickearth sector. Further right come the two highly weathered upper brickearth samples, one undifferentiated brickearth sample (sample 119), one Tertiary sand sample (sample 131) and one lower brickearth sample (sample 120). As in the PC1: PC2 plot, four Plateau Gravel samples, two Bracklesham Sand samples and the lower brickearth from Ocknell Plain least resemble the upper brickearth .

9.5 Summary and Conclusion of the 4-20 Mineralogical Analysis

Detailed study of the fine sand mineralogy of the upper brickearth shows that although the samples are quite variable, much of the variation can probably be explained by post-depositional weathering and original variations in the particle size distribution of the 4-20 fraction. Taking these two factors into account, the mineralogy is remarkably constant over the study area and suggests a common source for the 4-20 fraction. Some small, unexplained, local variations in the mineralogy also occur.

The lower brickearth generally has fewer weatherable minerals than the least weathered upper brickearth, which indicates that it was either weathered prior to the deposition of the upper brickearth or was originally deficient in these minerals. However, in some samples, where particle size analysis indicated the presence of 4-20 sand of a similar particle size distribution to the upper brickearth, the weatherable minerals total is higher suggesting that mixing with fresh material has occurred.

Because all the sediments studied have similar mineral suites, it is difficult to completely exclude any as possible source sediments for the 4-2ϕ upper fraction of the brickearth. However, the samples most closely approximating to the mineralogical composition in the upper brickearth are the fine-grained Tertiary sands. The coarse-grained Tertiary sands and the Plateau Gravel seem likely to have contributed only minor amounts of material to the upper brickearth. This confirms the findings of the particle size analysis. The least weathered upper brickearth samples were relatively rich in weatherable minerals that are characteristically abundant in the coarse silt (6-4ϕ) fraction of loess in southern England; these minerals could have been added to the 4-2ϕ fraction of the upper brickearth as the coarse tail of loess.

The results of the principal co-ordinates analysis support these conclusions; it identified weatherable minerals as the main source of variation between the brickearths and other sediments and demonstrated that the least weathered upper brickearths are mineralogically alike and distinct from the other sediments.

PART 2

The Mineralogy Of The Coarse Silt Fraction

9.6 The Upper Brickearth.

This section describes the mineralogy of the 6-40 fraction of sixteen topsoil samples of upper brickearth, one sample (73), from a Bt horizon and examples of possible source sediments. The samples are the same as those whose 4-20 mineralogy was examined in Part 1 except that sample 31 is excluded (Table 9.5a,b).

The mineral species present in the coarse silt fractions of the upper brickearth samples are almost the same as in the 4-20 fraction, but the relative quantities of most minerals are different. The assemblage is dominated by quartz (79.5-93.4%), with lesser amounts of alkali feldspar (4.1-15.0%) and flint (2.2-5.4%) and minor amounts of muscovite, glauconite and heavy minerals. The heavy mineral assemblage is generally dominated by zircon and epidote with lesser amounts of tourmaline, rutile (red, yellow and brown) and chlorite, small amounts of tremolite (with actinolite), hornblende (green and brown), garnet (pink and colourless), zoisite (including clinozoisite), anatase and brookite and traces of andalusite, biotite, sphene and silliminite.

As in the 4-20 fraction, the between-sample variability of some minerals is quite large, especially that of the weatherable minerals - feldspar, muscovite, garnet, hornblende, zoisite, chlorite and tremolite. Zircon and epidote are less variable in amount than they are in the 4-20 fraction, but epidote may nevertheless be weathered in the podzolised soils (e.g. samples 4 and 70). There are sufficient amounts of easily weatherable minerals (muscovite, glauconite, hornblende, tremolite, chlorite and biotite) in the samples to use them as a measure of weathering. Figure 9.7 shows the sum of these six minerals in all the topsoil samples of upper brickearth (including samples from the soil profiles) plotted

sample number:	24	7	75	71	58	29	23	73	61
Light minerals									
quartz	819	844	863	872	863	795	831	800	855
alkali feldspar	136	129	112	95	102	150	108	136	109
flint	26	23	23	32	30	49	54	49	30
muscovite	19	3	2	1	5	5	6	15	5
glauconite	-	1	-	-	-	1	1	-	1
Heavy minerals									
tourmaline	38	95	114	146	89	104	103	88	85
zircon	316	353	328	341	295	353	328	350	299
brown rutile	6	8	15	12	7	7	6	3	2
yellow rutile	76	97	119	107	91	66	41	83	55
red rutile	1	1	3	5	2	-	2	1	-
pink garnet	-	1	-	2	-	-	-	-	-
colourless garnet	17	7	15	19	17	8	20	18	20
green hornblende	12	8	10	8	15	32	29	33	28
brown hornblende	-	-	-	-	-	-	-	-	-
kyanite	13	9	8	14	9	3	8	5	7
staurolite	8	3	12	9	5	1	4	1	2
zoisite	18	20	21	23	27	16	14	11	20
epidote	243	277	290	254	283	277	278	235	359
anatase	24	24	14	14	15	11	16	12	10
brookite	7	7	5	4	10	5	6	3	1
andalusite	-	1	1	1	-	-	-	-	-
chlorite	210	25	19	16	80	85	112	129	70
tremolite	10	62	25	25	55	32	33	28	42
biotite	1	-	-	-	-	-	-	-	-
silliminite	-	2	1	-	-	-	-	-	-
sphene	-	-	-	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.5a 6-40 Mineralogy of upper brickearth topsoil samples

sample number:	74	54	70	66	52	10	37	4
Light minerals								
quartz	812	854	868	815	841	912	828	934
alkali feldspar	128	101	75	127	121	62	147	41
flint	47	43	50	54	37	23	23	22
muscovite	9	-	7	2	1	3	2	3
glauconite	4	2	-	2	-	-	-	-
Heavy minerals								
tourmaline	63	53	126	105	73	121	89	96
zircon	307	398	474	245	261	355	229	507
brown rutile	8	10	22	13	6	11	12	20
yellow rutile	52	70	99	74	77	131	52	133
red rutile	2	2	3	1	1	1	-	2
pink garnet	-	-	-	-	-	2	-	-
colourless garnet	8	9	4	17	20	14	25	3
green hornblende	34	33	4	41	34	21	38	-
brown hornblende	-	3	-	3	2	-	-	-
kyanite	1	1	13	4	1	4	5	5
staurolite	-	2	6	1	-	8	1	1
zoisite	22	21	6	19	17	14	18	1
epidote	307	311	194	341	374	271	414	183
anatase	12	13	14	23	24	20	20	33
brookite	3	3	5	5	3	8	1	9
andalusite	-	-	1	-	-	-	-	-
chlorite	130	41	3	66	68	3	61	2
tremolite	51	30	26	42	39	16	34	4
biotite	-	-	-	-	-	-	-	-
silliminite	-	-	-	-	-	-	1	-
sphene	-	-	-	-	-	-	-	1

quantities expressed as parts per thousand of the respective fractions

Table 9.5b 6-40 Mineralogy of upper brickearth topsoil samples

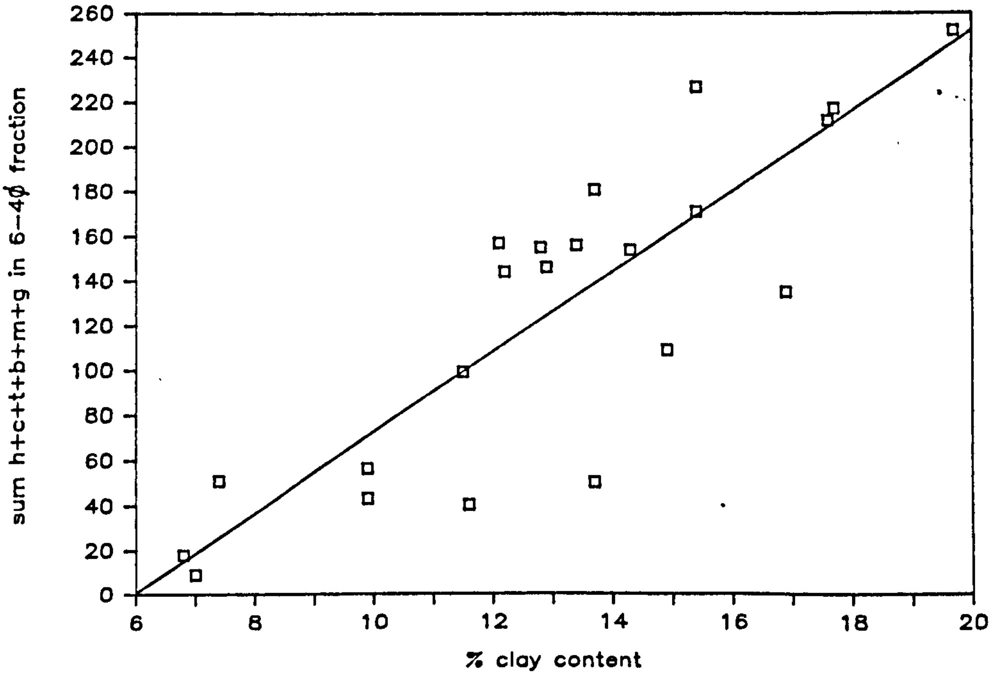


Fig. 9.7 Sum of muscovite, glauconite, hornblende, tremolite, chlorite and biotite contents in the 6-4ϕ fraction in the upper brickearth topsoil samples plotted against clay content.

against clay content. A Spearman's rank correlation co-efficient of $r_s = 0.79$ was obtained for this relationship, which is significant at the 99% level. The moderately weatherable minerals index used for the 4-2ø fraction (feldspar + garnet + zoisite + clinozoisite + epidote) is less strongly correlated with clay content: $r_s = 0.50$ (Fig 9.8). The computed t value for this value of r_s only just exceeds the critical value at the 99% level. However, removing epidote from the index (Fig 9.9) increases the correlation to $r_s = 0.63$.

Thus, in the coarse silt fraction of the upper brickearth far larger amounts of easily weatherable minerals are present than in the 4-2ø fraction and the moderately weatherable minerals, especially epidote, seem to be less affected by weathering. These differences may be due to the 6-4ø fraction originally having greater amounts of weatherable minerals than the 4-2ø fraction. The coarse silt fraction of known Late Devensian loess deposits from elswhere in England and Belgium are characteristically rich in certain weatherable minerals - hornblende, tremolite, chlorite, epidote and garnet - compared with their fine sand fractions and the pre-Devensian deposits on which they rest (Weir et al., 1971; Catt et al., 1971; Juvigné, 1978, Chartres , 1980). To assess what proportion of the 6-4ø fraction of the upper brickearth was derived from subjacent deposits, the 6-4ø mineralogy of five Tertiary sediments and four Plateau Gravel samples was examined.

The five Tertiary sands (Table 9.6a) have at most one fifth the amount of chlorite and tremolite and one quarter the amount of hornblende of the least weathered upper brickearth samples. Epidote and garnet are only about half as common as in the upper brickearth in four of the five samples; sample 131 has as much garnet and sample 133 has as much epidote. The amounts of other

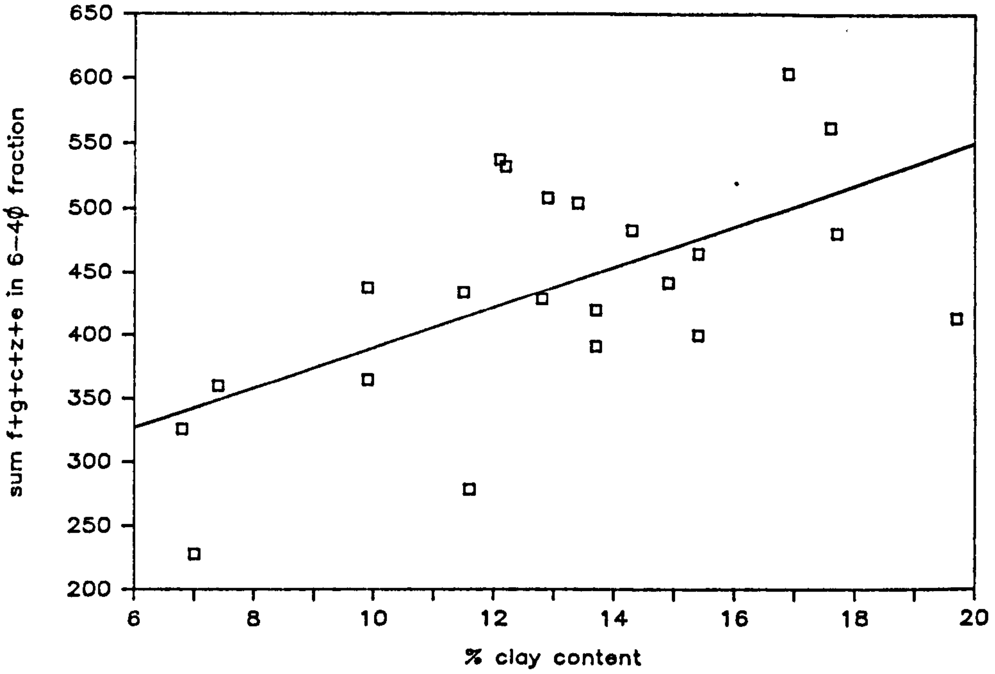


Fig. 9.8 Sum of feldspar, garnet, zoisite, clinozoisite and epidote contents in the 6-40 fraction in the upper brickearth topsoil samples plotted against clay content.

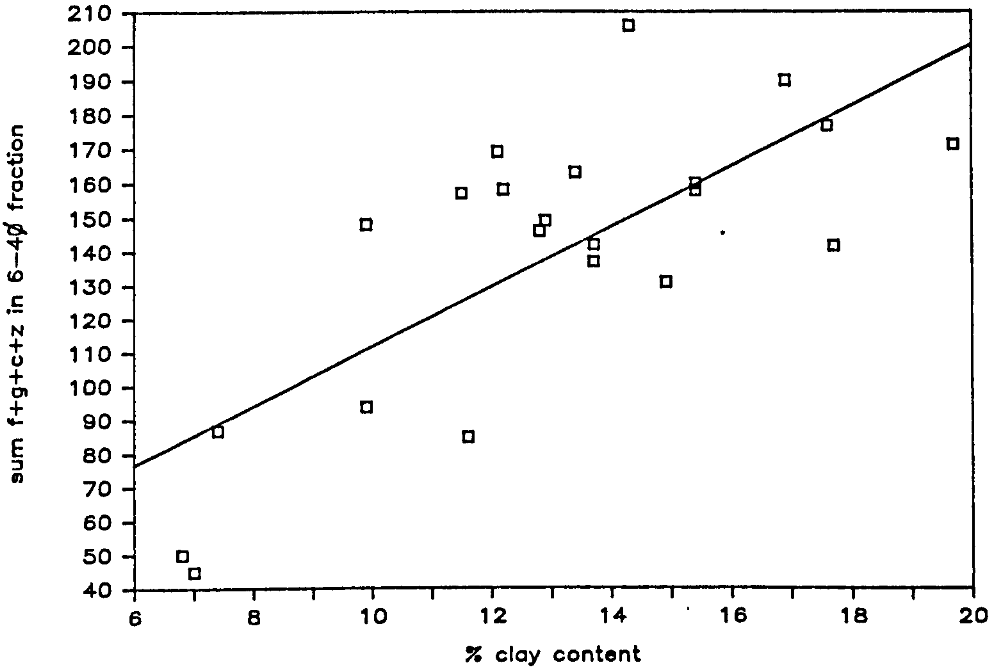


Fig. 9.9 Sum of feldspar, garnet, zoisite and clinozoisite contents in the 6-40 fraction in the upper brickearth topsoil samples plotted against clay content.

sample number:	129	130	131	132	133	146
Light minerals						
quartz	548	845	673	895	908	920
alkali feldspar	270	106	263	70	34	5
flint	89	42	26	27	56	67
muscovite	7	3	4	8	2	8
glauconite	86	4	34	-	-	-
Heavy minerals						
tourmaline	63	115	108	109	306	183
zircon	616	603	493	476	241	524
brown rutile	28	8	12	22	2	6
yellow rutile	131	142	96	192	96	129
red rutile	2	-	-	1	-	2
pink garnet	-	-	4	-	1	-
colourless garnet	11	1	17	6	10	8
green hornblende	1	1	6	1	8	-
brown hornblende	-	-	-	-	1	-
kyanite	5	8	6	7	1	2
staurolite	15	6	6	9	3	3
zoisite	2	2	16	6	15	7
epidote	96	84	179	133	252	94
anatase	9	18	22	19	16	19
brookite	3	8	2	9	9	14
andalusite	-	-	-	-	-	-
chlorite	12	4	27	8	31	9
tremolite	6	-	5	2	5	-
biotite	-	-	1	-	-	-
silliminite	-	-	-	-	-	-
sphene	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.6a 6-40 Mineralogy of Tertiary Sands minerals are often very variable. For example, relative to the upper brickearth, two of the Barton Sands samples (129 and 131) have extremely high feldspar contents, while the two Bracklesham Sands samples have very small amounts of this mineral. No other mineralogical analyses of the coarse silt fraction of the Tertiary Strata in the Hampshire Basin are known to have been published, but on the basis of this fairly limited evidence it seems unlikely that the Tertiary Sands are the major source of 6-40 silt in the upper brickearth.

In contrast to the trends found in the 4-20 analyses (section 9.2), the four Plateau Gravel samples are more like the upper brickearth than are the Tertiary Sands (Table 9.6b). Samples 122 and 143 contain similar amounts of most of the minerals present in the upper brickearth but samples 123 and 124 contain less than half the weatherable minerals content of the upper brickearth. The flint content of all four samples is, however, far higher (1.5 to 7 times) than in the upper brickearth. This suggests that the gravels also are not a major source for the 6-40 fraction of the upper brickearth, especially considering the extremely low total silt content of the gravels.

9.7 Sites for Detailed Study.

The results for each of the sites are presented in Table 9.7a-c.

9.7.1 Sturt Pond, Wilverly Plain, Chilling Copse and Hook Gravel Pit (samples 105, 107, 82b, 78c and 83c)

Horizon 1 of the Sturt Pond profile has slightly fewer weatherable minerals than horizon 3 in the light fraction, as would be expected, but has more epidote, chlorite, zoisite and hornblende in the heavy fraction. This suggests that there were small original mineralogical differences between the two horizons and the effects of weathering have been insufficient to mask these.

sample number:	122	123	124	143
Light minerals				
quartz	748	761	597	781
alkali feldspar	78	52	50	121
flint	168	178	348	89
muscovite	6	9	5	8
glauconite	-	-	-	1
Heavy minerals				
tourmaline	174	161	265	155
zircon	166	474	247	147
brown rutile	1	13	3	1
yellow rutile	61	138	83	84
red rutile	-	1	-	1
pink garnet	-	-	-	-
colourless garnet	7	4	6	10
green hornblende	33	-	17	47
brown hornblende	2	-	-	2
kyanite	2	5	1	3
staurolite	4	3	6	5
zoisite	20	7	25	10
epidote	288	146	236	347
anatase	14	28	34	11
brookite	7	13	5	3
andalusite	-	-	-	-
chlorite	204	8	59	145
tremolite	17	1	12	29
biotite	-	-	1	-
silliminite	-	-	-	-
sphene	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.6b 6-4Ø Mineralogy of Plateau Gravel

sample number:	105	107	82b	78c	83c	79a	114	113
Light minerals								
quartz	807	781	854	791	788	900	861	865
alkali feldspar	131	134	105	179	100	67	103	100
flint	55	51	37	21	92	30	25	23
muscovite	5	31	4	9	6	3	11	11
glauconite	2	3	-	-	14	-	-	1
Heavy minerals								
tourmaline	77	49	53	41	54	160	134	55
zircon	171	290	284	250	322	297	290	487
brown rutile	10	10	5	5	4	18	10	10
yellow rutile	85	117	60	100	40	140	113	91
red rutile	2	1	-	-	1	2	-	-
pink garnet	1	1	-	-	-	-	-	-
colourless garnet	34	41	16	25	30	9	8	3
green hornblende	77	59	31	60	19	3	3	7
brown hornblende	-	1	-	3	-	1	-	-
kyanite	2	2	1	9	3	5	3	4
staurolite	-	5	1	6	4	7	4	3
zoisite	11	5	21	20	11	11	13	5
epidote	385	273	339	265	287	273	361	246
anatase	12	19	5	19	11	23	43	20
brookite	5	5	2	3	4	7	6	3
andalusite	-	-	-	-	-	-	-	-
chlorite	110	100	132	173	184	18	7	57
tremolite	18	22	50	20	24	26	5	9
biotite	-	-	-	-	2	-	-	-
silliminite	-	-	-	-	-	-	-	-
sphene	-	-	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.7a 6-40 Mineralogy of selected samples from the soil profiles

sample number:	68a	68b	64	110	112	135	6a	6b
Light minerals								
quartz	812	883	823	764	851	836	928	904
alkali feldspar	128	64	128	174	117	131	40	47
flint	49	47	45	41	30	22	31	42
muscovite	10	6	3	14	2	11	1	7
glauconite	1	-	1	7	-	-	-	-
Heavy minerals								
tourmaline	45	174	98	57	122	129	121	87
zircon	346	241	218	326	262	321	358	356
brown rutile	16	5	1	12	2	9	12	8
yellow rutile	125	147	95	100	71	125	148	142
red rutile	4	-	1	-	1	-	-	3
pink garnet	3	-	-	-	-	-	-	-
colourless garnet	17	3	24	34	16	27	6	3
green hornblende	36	1	43	49	8	18	2	2
brown hornblende	2	-	2	1	-	1	-	-
kyanite	3	4	4	7	2	6	4	5
staurolite	4	2	1	4	1	5	3	1
zoisite	12	25	16	14	11	9	4	11
epidote	240	317	368	285	422	264	276	317
anatase	22	24	19	19	37	29	40	30
brookite	3	5	4	1	11	3	8	9
andalusite	-	-	-	-	-	-	-	-
chlorite	104	27	77	73	18	45	12	23
tremolite	18	25	31	18	16	9	3	3
biotite	-	-	-	-	-	-	-	-
silliminite	-	-	1	-	-	-	-	-
sphene	-	-	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.7b 6-40 Mineralogy of selected samples from the soil profiles

sample number:	126	127	119	120	121	117	118
Light minerals							
quartz	802	828	788	805	762	877	841
alkali feldspar	139	112	136	115	54	73	124
flint	32	41	45	46	167	37	29
muscovite	21	19	21	24	7	13	6
glauconite	6	-	10	10	10	-	-
Heavy minerals							
tourmaline	94	100	74	61	189	64	92
zircon	290	321	195	341	323	362	244
brown rutile	16	6	6	4	7	14	3
yellow rutile	104	129	78	134	146	175	162
red rutile	-	-	-	1	-	-	-
pink garnet	-	-	-	-	-	-	-
colourless garnet	34	8	40	11	6	1	3
green hornblende	27	3	72	29	11	2	1
brown hornblende	2	1	2	-	1	-	-
kyanite	6	2	3	-	4	11	5
staurolite	4	4	2	2	2	1	1
zoisite	10	18	8	13	5	3	19
epidote	271	237	277	275	180	309	411
anatase	15	21	20	17	35	22	37
brookite	2	6	1	4	8	4	8
andalusite	-	-	-	-	-	-	-
chlorite	110	133	191	92	78	24	11
tremolite	14	11	31	16	6	6	3
biotite	-	-	-	-	-	-	-
silliminite	1	-	-	-	-	2	-
sphene	-	-	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Table 9.7c 6-40 Mineralogy of selected samples from the soil profiles

As in the 4-20 fraction, the garnet contents of horizons 1 and 3 are exceptionally high for theupper brickearth and the chlorite contents are a little less than in comparable soils (e.g. in samples 24, 73, 74, 82b, 78c and 83c). This suggests that the two fractions have, in part, a common source. The samples from horizon 2 at Wilverly Plain and horizon 3 at Chilling Copse have fairly typical mineral assemblages, although the Chilling sample has the highest feldspar content (17.9%) of any of the analysed upper brickearth samples. The sample from Hook Gravel Pit, horizon 3, is less like the others. It has relatively small amounts of feldspar, rutile and hornblende and a very high flint content. This may relate to textural differences as the sample is one of the sandiest analysed.

9.7.2 Beaulieu Heath (samples 79a, 113 and 114).

The upper brickearth in horizon 3 has few weatherable minerals. The sand in the fissure has slightly more feldspar and muscovite in the light fraction - as would be expected according to normal weathering trends if it had the same source as the upper brickearth. But it has less chlorite and tremolite in the heavy fraction. Otherwise, the two assemblages are similar. The light fraction of the lower brickearth in horizon 6 is almost identical to that of fissure sand, but in the heavy fraction it contains considerably more zircon and chlorite and less tourmaline and epidote Thus no clear distinction between the three sediments is possible.

9.7.3 Lepe Cliff (samples 68 a and b)

The upper brickearth in horizon 1 has fairly large amounts of weatherable minerals and is typical of the A horizons of the argillic brown earths in this study. The lower brickearth in horizon 4 has considerably fewer weatherable minerals and smaller amounts of each individual weatherable species except epidote and tremolite. Thus, as in the 4-20 fraction, there is a suggestion that the lower brickearth was weathered prior to deposition of the upper brickearth or was originally deficient in weatherable species.

9.7.4 Thorns Farm (samples 64, 110 and 112)

The upper brickearth in horizon 1 has a similar content of weatherable minerals to the A horizons of argillic brown earths elsewhere. In horizon 4 there is a significant increase of weatherable minerals in the light fraction, but in the heavy fraction, there is less epidote, chlorite and tremolite and more garnet and hornblende. Thus, normal weathering trends appear to be present in the light fraction, but not in the heavy fraction. This parallels the trends found at Beaulieu Heath (section 9.7.2) between the fissure sand and horizon 3. This may indicate that at both sites there was an originally lower level of weatherable heavy minerals, particularly chlorite and tremolite, in the lowest part of the sandy upper brickearth than in the more silty upper brickearth.

In the lower brickearth in horizon 5 (100-120cm) there are smaller amounts of all weatherable minerals except epidote than in either of the upper brickearth samples, so, as at Lepe Cliff, it is likely that the lower brickearth was originally deficient in weatherable minerals or was weathered prior to deposition of the upper brickearth.

9.7.5 Tanner's Lane (Sample 135)

The lower brickearth in horizon 4 has greater amounts of nearly all weatherable minerals - feldspar, chlorite, muscovite, garnet and hornblende - than the two other lower brickearths sampled on the 5m terrace (Lepe Cliff and Thorns Farm). Nevertheless, it still has far fewer weatherable minerals, particularly hornblende, chlorite and tremolite, than are found in Bt horizons in the upper brickearth.

9.7.6 Ocknell Plain (samples 6 a and b)

The upper brickearth in horizon 3 has an extremely low content of weatherable minerals, as was found in the 4-20 fraction. The mineralogical composition of the lower brickearth in horizon 5 is very similar to the upper brickearth (horizon 3) and in fact contains a slightly greater amount of weatherable minerals. It is not possible, therefore, to attribute the 6-40 fraction of the two sediments to different sources on mineralogical evidence alone. The mineral assemblage in the lower brickearth is very similar to that in the lower brickearth (horizon 4) at Lepe Cliff (section 9.7.3) which also has similar field and textural characteristics.

9.7.7 Calveslease Copse (samples 126 and 127).

The undifferentiated brickearths in horizons 2 and 3 are much less alike in the 6-40 fraction than in the 4-20 fraction. Horizon 2 is richer in all weatherable mineral species except chlorite and zoisite, and resembles many of the upper brickearth samples, particularly the similarly-textured horizon 4 from Thorns Farm. Horizon 3 is like many lower brickearth samples in having small amounts of hornblende and garnet. It generally has lower amounts of all weatherable minerals than would be expected in the Bt horizons in upper brickearth.

9.7.8 Rockford Common Gravel Pit (samples 119,120 and 121)

The differences between the undifferentiated brickearth in horizon 2 and the lower brickearth in horizon 3 found in the 4-20 fraction are more strongly expressed in the 6-40 fraction; in the light fraction horizon 2 has about 2% more feldspar than horizon 3, and in the heavy fraction it contains at least twice the amount of all weatherable minerals except epidote and zoisite. This is further evidence that horizon 2 has a different source from horizon

3 or has received an addition of weatherable minerals. The overall mineral compositon of horizon 2 is like many Bt horizons in the upper brickearth.

Horizon 4 in the underlying Plateau Gravel has a very low total of weatherable minerals and resembles the most weathered other Plateau Gravel samples.

9.7.9 Holbury Gravel Pit (samples 117 and 118)

The lower brickearths in horizons 2 and 4 both have much lower amounts of garnet, hornblende, chlorite and tremolite than the least weathered upper brickearth samples. There is no consistent difference between the samples in the content of weatherable minerals: horizon 2 has more chlorite, tremolite and muscovite and horizon 4 has the most feldspar, zoisite and epidote. The garnet and hornblende content of both samples is extremely low.

9.8 Comparison of the 6-4∅ Mineralogy of the Brickearth with known Loess samples from elsewhere in England

In Table 9.8 the 6-4∅ mineralogy of four samples of Late Devensian loess from West Sussex (J.A. Catt, pers. comm.) is presented. This is the closest area to south Hampshire where substantial Late Devensian loess deposits are found. These samples are compared with the mean composition of four samples of upper brickearth taken from Bt horizons (samples 73, 107, 78c and 83c).

The mineral assemblages in the two groups of sediment are generally quite similar, but there are some significant differences. In the light fraction, flint is about four times more abundant in the upper brickearth and in the heavy fraction the upper brickearth has more zircon, rutile and tourmaline than the West Sussex loess, but less hornblende, garnet, zoisite, epidote and anatase. The chlorite and tremolite content of the two sediments is similar.

sample number:	S1	S2	S3	S4	M1	M2	M3	M4	W1
Light minerals									
quartz	827	821	834	862	835	791	816	893	837
alkali feldspar	127	154	143	114	134	137	130	55	122
flint	20	12	7	11	13	53	32	45	10
muscovite	18	10	9	9	12	15	9	7	16
glauconite	8	3	7	4	6	4	13	-	15
Heavy minerals									
tourmaline	50	38	36	28	38	58	92	130	41
zircon	91	192	150	187	155	302	324	298	244
brown rutile	9	19	16	11	14	6	13	7	13
yellow rutile	20	41	36	43	35	85	83	145	58
red rutile	3	3	5	9	5	1	3	1	-
pink garnet	-	-	-	-	-	-	-	-	-
colourless garnet	50	34	30	31	36	29	23	3	58
green hornblende	75	75	91	88	82	43	42	2	26
brown hornblende	6	7	6	8	7	1	4	-	-
kyanite	2	5	4	4	4	5	4	4	4
staurolite	5	9	6	5	6	4	7	2	5
zoisite	22	17	15	18	18	12	13	18	21
epidote	335	380	400	390	376	264	258	317	292
anatase	20	37	29	25	28	15	23	27	31
brookite	5	3	2	5	4	4	5	7	5
andalusite	-	-	-	-	-	-	-	-	-
chlorite	243	106	145	110	151	147	83	25	182
tremolite	29	25	23	31	27	24	15	14	18
biotite	32	9	6	5	13	-	6	-	2
silliminite	-	-	-	-	-	-	-	-	-
sphene	-	-	-	-	-	-	-	-	-
apatite	3	-	-	-	1	-	-	-	-
augite	-	-	-	2	-	-	-	-	-

quantities expressed as parts per thousand of the respective fractions

Key:
S1-4 Sussex loess
M1 Mean of Sussex loess 1-4
M2 Mean of upper brickearth samples 73, 107, 78c, 83c
M3 Mean of ((S1-4) + (6 Tertiary Sands))/2
M4 Mean of lower brickearth samples 6b and 68b
W1 Wolstonian loess, Red Barns, Hampshire

Table 9.8 Comparison of 6-4φ mineralogy of brickearth with loess from elsewhere in southern England

Thus, the upper brickearth has more resistant minerals and fewer weatherable minerals than the West Sussex loess. This could indicate that the 6-4Ø fraction of the upper brickearth contains far travelled silt of a similar composition to the West Sussex loess mixed with silt derived from the south Hampshire Tertiary strata, which are relatively rich in zircon, tourmaline and rutile. If it is assumed that the 6-4Ø fraction of the upper brickearth is composed entirely of material from these two sources, then a contribution of 50% from each would give the assemblage shown in column 7 of Table 9.8. This assemblage is very similar to the 'mean of 4 upper brickearth Bt horizons', the main differences being that the upper brickearth has very slightly more weatherable minerals and slightly fewer resistant minerals. However, in view of the fact that the Tertiary Strata in the area are dominated by sands and to a lesser extent clays, and the sands analysed have a very low silt content, it seems unlikely that nearly 50% of the coarse silt in the upper brickearth can have been deflated from the Tertiary strata.

Two factors may explain this discrepancy. First, the Tertiary sands contain on average 0.6% of non-opaque heavy minerals in the 6-4Ø fraction compared with 0.2% in the upper brickearth, <0.1% in the loess of West Sussex (Hodgson et al., 1967) and < 0.3% in the loess of Kent where Weir et al. (1971) found five to twenty times more heavy minerals in the Tertiary Thanet Sands. Thus a relatively small contribution of silt from the Tertiary strata might have a disproportionately large effect on the 6-4Ø heavy mineral assemblage of the upper brickearth. Second, the upper brickearth has a much larger fine sand content than previously described Late Devensian loess deposits. Therefore, compared with other loess deposits, a larger proportion of silt-sized heavy minerals associated with locally derived fine sand (by the effect of hydraulic equivalence) is likely to have been added to the 6-4ϕ heavy mineral assemblage of the upper brickearth. For these reasons it is suggested that the total local contribution of silt to the upper brickearth is <20%.

The chlorite content of the 6-4ϕ non-opaque heavy fraction of the upper brickearth averages 14.7% in the Bt horizons. The expected amount of chlorite in loess in this area according to Catt's (1978) map of the westward increase in the amounts of this mineral in the Late Devensian English loess would be about 18-20%. This also suggests that the upper brickearth may be composed of loess mixed with relatively chlorite-deficient silt, as is found in the Tertiary strata.

At least two samples of lower brickearth, sample 68b from Lepe Cliff and sample 6b from Ocknell Plain, have field and textural characteristics that suggest they could be weathered pre-Devensian loess. Little is known about the mineralogical composition and variation of pre-Devensian loesses in England because few sites are known where such material exists, but in general they are reported to contain more zircon, tourmaline, rutile and anatase but less hornblende than Late Devensian loess (Avery <u>et al</u>., 1982). In Belgium, the pre-Vistulian (= pre-Devensian) loesses also have more zircon, rutile and tourmaline and less hornblende and garnet than the Vistulian loesses (Juvigné, 1978).

The two lower brickearth samples have more tourmaline, rutile and anatase than the upper brickearth but contain similar amounts of zircon. They have less hornblende and garnet than the upper brickearth but also have less feldspar and chlorite. In Table 9.8 the mean of the two lower brickearth samples is compared with a sample of Wolstonian loess from Red Barnes near Portchester, Hampshire (J.A. Catt, pers. comm.). The two assemblages are quantitatively very different: the Red Barns loess is actually rather similar to the upper brickearth and contains far more chlorite, hornblende, garnet, glauconite, muscovite and feldspar than the two lower brickearth samples. Thus the two lower brickearth samples cannot be correlated with the Wolstonian loess on this mineralogical evidence. But much depends on the relative amounts of weathering that the sediments have undergone. It is possible that the lower brickearth sampled has remained near the surface for longer than the Red Barns loess and that the mineralogical differences are a result of this.

9.9 Principal Co-ordinates Analysis

A similarity matrix was constructed from the 6-4∅ data for all the analysed sediments from south Hampshire. Table 9.9 lists the percentage variability accounted for and the main minerals related to the first two principal co-ordinates, PC1 and PC2. PC1, the most important vector, is influenced mainly by the presence or absence in the samples of four of the characteristic Late Devensian loess minerals - hornblende, epidote, tremolite and garnet and one resistant mineral - rutile. PC2 is influenced mainly by five relatively resistant minerals - kyanite, staurolite, andalusite, anatase and tourmaline.

PC1: PC2 plot (Fig. 9.10) separates all but five of the upper brickearth samples in a fairly tight group interspersed with only three examples of other sediments. These three are two undifferentiated brickearth samples (samples 119 and 126) from Rockford Common and Calveslease Copse and one Plateau Gravel sample (sample 143) from Lepe Cliff. The Calveslease Copse sample was also placed in the main upper brickearth sector in the principal co-ordinates analysis of the 4-2∅ mineralogy. The five upper brickearth samples outwith the main grouping (samples 4, 6a 10, 70 and 79a all have higher PC1 values because of a relative deficiency

TABLE 9.9

Principal Co-ordinate Vectors and the Minerals related to them: South Hampshire Sediments 6-40 Mineralogy.

Vector:	PC1	PC2
% of total variability accounted for:	28.7	14.5
Minerals related to Vector in order of importance:	Hornblende(-) Epidote(-) Tremolite(-) Rutile(+) Garnet(-)	Kyanite(-) Staurolite(-) Andalusite(-) Anatase(+) Tourmaline(+)

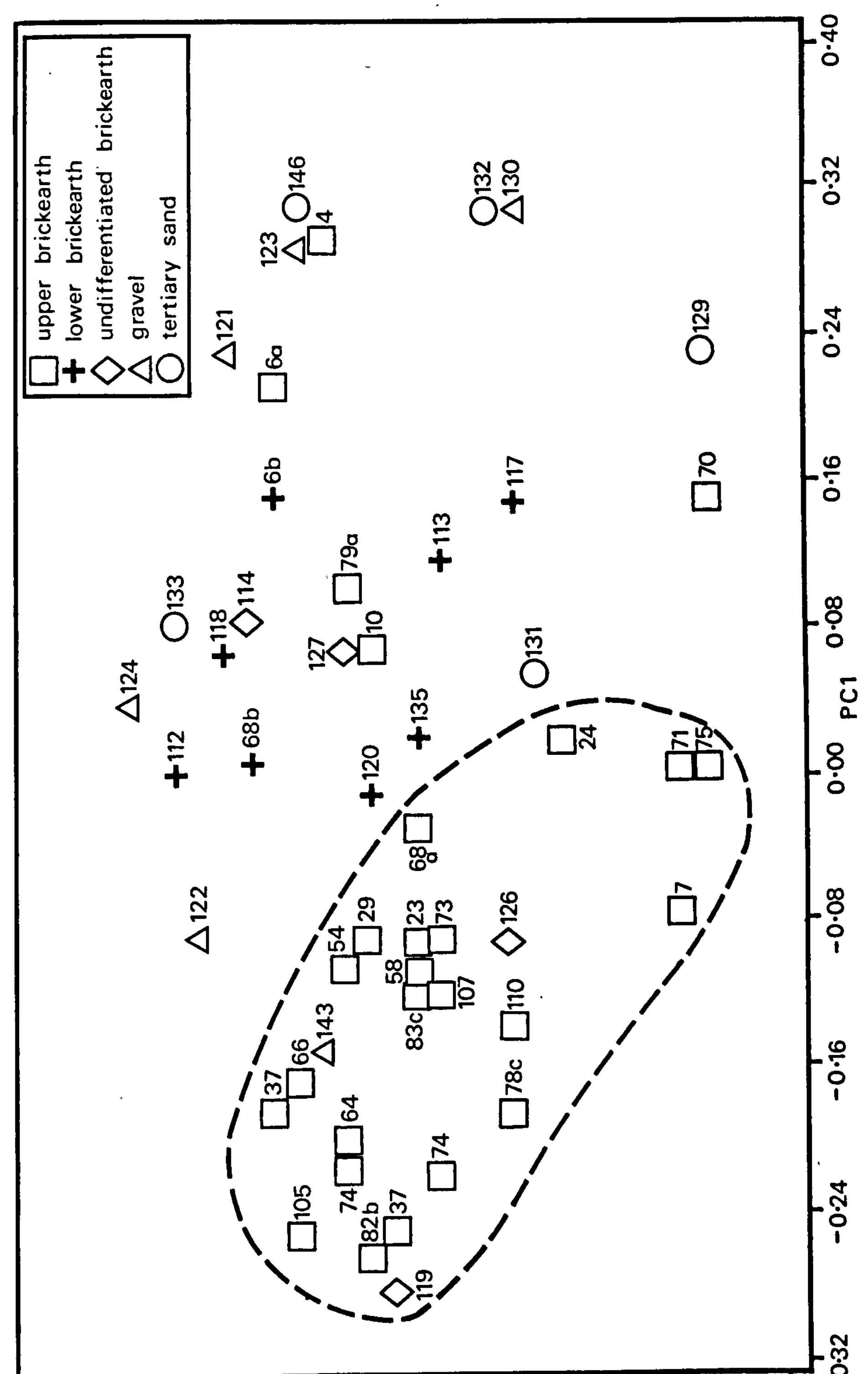


Fig. 9.10 Principal co-ordinates plot PC1 : PC2 for mineralogy of the 6-40 fraction of all south Hampshire sediments.

hornblende, tremolite, epidote and garnet. All five are from podzols, so the deficiency is probably due to weathering.

Nearest the main upper brickearth sector, with PC1 values of -0.08 to 0.16 and PC2 values of -0.10 to 0.20, is a group that includes all eight analysed lower brickearth samples interspersed with two podzolised upper brickearth samples, two undifferentiated upper brickearth samples (samples 127 from Calveslease Copse and sample 114 from Beaulieu Heath), two gravel samples (samples 122 and 124) and two Tertiary Sand samples (samples 131 and 133).

Beyond this sector, with PC1 values of > 0.20 or PC2 values < -0.16, are the remaining three Tertiary Sands (samples 129, 132, and 146) and the remaining three Plateau Gravel samples (samples 121, 123 and 130) interspersed with three, probably extremely weathered, upper brickearth samples (samples 4, 6a and 70). These last samples least resemble the main upper brickearth group.

A second similarity matrix was computed using 6-4ϕ mineralogical data for all the upper brickearth samples analysed, the two possible pre-Devensian loesses from Ocknell Plain and Lepe Cliff, Wolstonian loesses from Northfleet, Kent (J.A. Catt, pers.comm.) and Red Barns, Hampshire, the four examples of West Sussex loess, one sample of Dorset loess (J.A. Catt, pers.comm.) and four samples of Devon loess (Harrod <u>et al</u>., 1973). This was done to show the relationship between the south Hampshire upper brickearth and Late Devensian loess occurring to the west and east and between the possible older loesses from the lower brickearth and known Wolstonian loess.

The variance accounted for and the main minerals influencing PC1 and PC2 are listed in Table 9.10. The plot of PC1: PC2 (Fig. 9.11) completely separates the six groups of sediment involved, showing that each group has its own distinctive mineralogical assemblage; the Late Devensian loesses from different regions have their own local characteristics. The upper brickearth sector does not

TABLE 9.10

Principal Co-ordinate Vectors and the Minerals Related to Them: South Hampshire Brickearth and Loess from elsewhere in Southern England 6-40 Mineralogy.

Vector:	PC1	PC2
% of total variability accounted for:	31.5	19.7
Minerals related to vector in order of importance:	Amphibole(+) Epidote(+) Zircon(-) Rutile(-) Biotite(+)	Staurolite(+) Kyanite(+) Flint(-) Andalusite(+) Anatase(+)

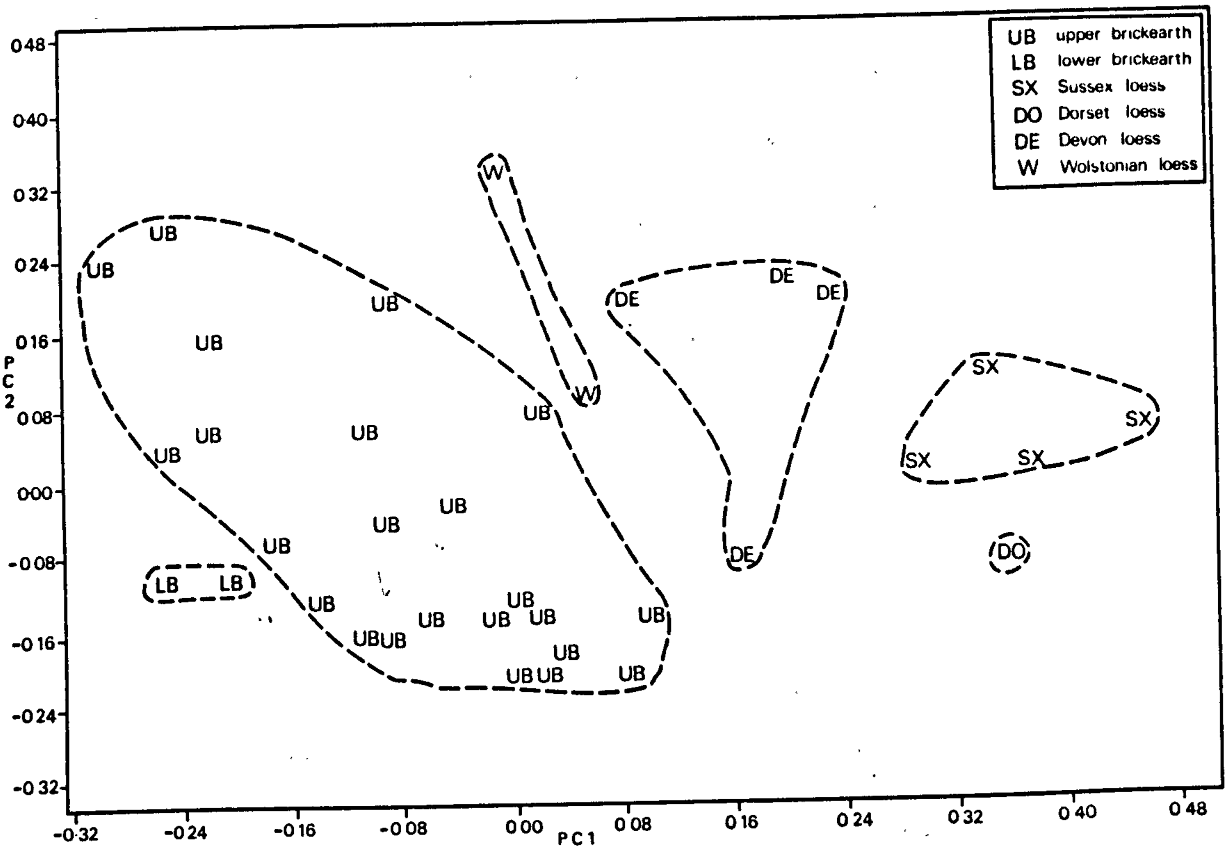


Fig. 9.11 Principal co-ordinates plot PC1 : PC2 for 6-40 mineralogy of the upper and lower brickearth, loess from Sussex, Dorset and Devon and Wolstonian loess.

lie between the loess samples taken from east of south Hampshire (the West Sussex loess) and west (the Dorset and Devon loess) so the mineralogical differences between the upper brickearth and the other loesses are not due solely to westward gradual changes in the mineralogy of the loess. The upper brickearth sector is larger than any of the others which may indicate that the upper brickearth has a more variable mineralogy, but equally it may be because there are more upper brickearth samples and because these were taken from horizons subject to weathering as well as fairly protected horizons.

The two lower brickearth samples have much lower PC1 values than the Wolstonian loesses, which agrees with the observation made earlier that the two groups of sediments are mineralogically dissimilar.

9.10 Summary and Conclusions of the 6-40 Mineralogical Analysis

Much of the variability in the mineralogy of the 6-40 fraction of the upper brickearth can probably be explained by variations in the amount of weathering that has occurred, as in the 4-20 fraction. The mineral assemblages of the 6-40 and 4-20 fractions have much in common and the two probably have in part the same source(s), but the 6-40 fraction has far greater amounts of easily weatherable minerals than the 4-20 fraction. These minerals are characteristically abundant in Late Devensian loess so they probably indicate that far-travelled loess is a major constituent of the upper brickearth, but $<$20% of the 6-40 fraction is probably derived from the local Tertiary strata.

All the lower brickearth samples are fairly similar mineralogically and contain generally lower amounts of weatherable species than the upper brickearth. However, it is difficult to assess their original mineralogical composition, and hence their origin, because the extent of post depositional weathering is not known.

The principal co-ordinate analyses support these conclusions. The main source of variation in the sediments was found to be the variable content of a group of minerals that are characteristic of Late Devensian loess. A relative abundance of these minerals separated the upper brickearth from the lower brickearth, the Tertiary Sands and the Plateau Gravel. However, a comparative lack of them separated the upper brickearth from relatively pure Late Devensian loesses from elsewhere in southern England.

CHAPTER 10

MICROMORPHOLOGICAL STUDIES

10.1 Introduction:

The object of micromorphological analysis was chiefly to distinguish between upper and lower brickearth (especially where this distinction was not clear from field and other laboratory evidence), and to sub-divide the lower brickearth on the basis of the inferred degree of pedological reorganization observed in the thin sections. This can be done partly by deducing the relative order of development of certain pedological features from evidence contained in the thin-sections, but mainly by the assigning of certain pedological features to specific Quaternary periods by reference to similar micromorphological features in soils elsewhere of known age. Many micromorphological features of Flandrian soil profiles are known from soils in southern England (Bullock,1974), but because relatively few dateable pre-Devensian paleosols have been identified the features attributable to the separate interglacial periods are only now being tentatively established (Bullock,1974; Bullock and Murphy, 1979; Sturdy et al., 1979; Chartres, 1980; Avery et al., 1982). The process is problematical because soil forming factors other than time, such as drainage and texture, may account for many of the differences observed between paleoargillic horizons. Therefore, until a framework of Quaternary micromorphology is firmly established, micromorphological comparisons between paleoargillic horizons, such as are made in the following sections, should be treated with caution.

10.2 Methods.

Thin sections were prepared from the samples collected in Kubiena tins by a modified version of the methods of Bascomb and

Bullock (1974), using a crystic resin (SR 1744 9) rather than Autoplax for impregnation and acetone instead of styrene as a thinner. The sections were oriented horizontally unless otherwise stated.

The thin-sections were described using the terminology of Brewer (1964) as a basis, but also adopting the modifications and additions suggested by Bullock and Murphy (1979) concerning the divisions of size and abundance of features. In some sections the amounts of the most important features were estimated by systematic point - counting of about 2000 points on a grid. This provided a reference guide from which to estimate visually (i.e. without counting) the amounts of various features in other thin sections. In the text, the amounts quoted are visual estimates unless they have the suffix p.c. which indicates a point count.

10.3. Descriptive Terminology

It will help to clarify the following descriptions of the microfabrics of the brickearth if the nature and presumed origin of the main features recognised are briefly described first.

a) Plasmic fabrics.

This term concerns the organisation of fine inorganic (mainly clay-sized) soil materials. Sepic plasmic fabrics are characterised by plasma separations - patches of clay with striated orientation - that usually form due to stresses caused by wetting and drying of the soil. Plasma separations tend to be common in old soils (e.g. paleoargillic horizons) giving rise to masepic or omnisepic plasmic fabrics, and absent or rare in young soils (e.g. Flandrian soil horizons) resulting in asepic or insepic plasmic fabrics (Brewer and Sleeman, 1969; Bullock, 1974). However, time is not the only factor influencing the development of plasmic fabrics as the relative amounts of expanding clay minerals in the soil are also important. Thus Flandrian soils rich in expanding clay minerals may have developed masepic plasmic fabrics or may inherit plasma separations from the parent material (Bullock, 1974).

b) Argillans and related clay concentrations

Argillans are concentrations of illuvial clay deposited by percolating water in subsoil voids (Stephen, 1960). They have optical continuity, strong preferred orientation and a laminated appearance. Argillans can have a variety of colours, but nearly all of those found in this study were *ferri-argillans* which are stained yellowish, brownish or reddish due to the incorporation of varying amounts of iron oxides. It is thought that the colours of ferri-argillans may be diagnostic of clay illuviated during certain Quaternary periods. *Yellowish-brown* to *reddish-orange* ferri-argillans are almost universal in Flandrian Bt horizons and are thus considered to be typical of Flandrian clay illuviation. *Reddish* ferri-argillans are found in some paleoargillic horizons. Stratigraphic evidence shows that reddish argillans were extensively formed during at least two interglacials in southern England - the Hoxnian and the Cromerian - but to date there is no conclusive evidence that they were also formed in the Ipswichian. *Egg-yellow* ferri-argillans also occur in paleoargillic horizons, often in conjunction with reddish ferri-argillans. In paleoargillic horizons thought to have been formed only during the Ipswichian the ferri-argillans are often only egg-yellow, though they sometimes occur with yellowish-brown ferri-argillans which were probably deposited later (Bullock, 1974; Bullock and Murphy, 1979; Sturdy *et al.*, 1979; Chartres, 1980; Avery *et al.*, 1982).

Argillans disturbed by pedoturbation such as soil faunal activity or cryoturbation may be dissociated from their voids to form papules (regularly shaped bodies of oriented clay). These are distinguished from papules formed by *in-situ* weathering of mineral grains by the optical similarity of the clay to that found in argillans. Linear clay concentrations may be old ped argillans which have infilled channels. Irregular clay concentrations can be formed by compression of void argillans or by completely infilling irregularly shaped voids. All of these secondary clay concentrations, now embedded in the matrix, may have similar colours (and presumed time of formation) to void argillans.

c) Fossil aggregates

These are rounded aggregates of soil material, the majority of whose constituent skeleton grains have their long-axes oriented at a tangent to the circumference of the aggregate. They may contain papules and irregular clay concentrations, suggesting that they formed after one or more periods of clay illuviation. Fox and Protz(1981) described similar features that are forming at present in the Turbic Cryosols of Canada, and attributed them to cryogenic processes. They coined the fabric term conglomeric to describe this arrangement of soil constituents. The identification of such features in paleoargillic horizons probably indicates a past phase or phases of cryoturbation.

Other aggregates, probably formed in a similar way to the fossil aggregates, were found in the south Hampshire soils: embedded grain matrans are essentially the same as fossil aggregates except that they have a sand grain at their core around which finer soil matrix material has accumulated. Embedded grain argillans are skeleton grains surrounded by clay. They may form by stress reorganisation of fine material around the grains, but most of the features described here are interpreted as having formed by transportation of normal grain argillans, because the argillans are rounded and have a sharp boundary with the surrounding soil matrix. This interpretation is consistent with that given by Bullock and Murphy (1979) for similar features they described in a paleoargillic horizon. In some soils no distinct fossil aggregates were seen (i.e. features with distinct boundaries), but the skeleton grains were arranged in circular or ellipsoidal patterns. Fox and Protz (1981) call this arrangement of soil constituents orbiculic and attribute it also to cryogenic processes.

d)Nodules and segregations

These are concentrations of iron minerals in the soil matrix. Nodules are regularly shaped with a prominent or distinct contrast to and sharp boundary with the adjoining soil matrix. They are commonly found to be transported features. Segregations are synonymous with the mottles described in the field and are irregularly shaped with a clear or diffuse boundary and variable contrast with adjacent soil material (Bullock and Murphy, 1979). The colour of nodules and segregations may be an indicator of certain periods of interglacial soil development in a similar way to argillans. Reddish segregations are commonly present in paleoargillic horizons and are thought to have formed during at least two interglacials, the Hoxnian and Cromerian (Sturdy et al., 1979; Chartres, 1980; Avery et al., 1982). As yet there is no conclusive evidence that they were extensively formed during the Ipswichian. The colour of these features was assessed in reflected light.

10.4 Results.

The full descriptions and analyses of the thin-sections are presented for each site in section 10.4.2. However, most of the micromorphological information that was found useful in assessing the pedological history of the soils came from the Bt horizons and largely concerned the features described in section 10.3. This information is first summarised in section 10.4.1.

10.4.1 Summary of the micromorphological features of the upper and lower brickearth.

The upper brickearth Bt horizons (Table 10.1) are all quite similar. They are pedologically comparatively simple; in each case the plasmic fabric is insepic and the mean total illuvial clay content is fairly low, at 3.3%. This clay is almost universally yellowish-brown, of which an average of about 30% is disrupted. Feruginous segregations occur infrequently (mean=0.3%) and are invariably brown coloured. The mean macro-void area of the horizons, 14. 4%, is comparatively high.

In contrast, the lower brickearth Bt horizons (Table 10.2) are more complex and variable. The plasmic fabrics vary from insepic to omnisepic but are most commonly masepic, suggesting they may have undergone longer periods of soil formation than the upper brickearth. The illuvial clay contents are generally higher (mean=5.1%) and often consist of egg-yellow and red varieties as well as yellowish brown. The mean total disrupted illuvial clay content is slightly higher than in the upper brickearth (39% compared with 31%) but this figure conceals variations between the different varieties of clay. The mean content of disrupted yellowish-brown clay, 18%, is lower than for the same variety of clay in the upper brickearth probably because there is less soil faunal activity in the lower brickearth (see chapter 5). However, the mean content of disrupted egg-yellow clay is 56% and of red clay is 80% . As

	ILLUVIAL CLAY								SEGREGATIONS					AGGREGATES			PLASMIC FABRIC				
Site/Horizon	Total %	Yell Brn % of total	Yell brn % disrupted	Egg yell % of total	Egg yell % disrupted	Red % of total	Red % disrupted	Total % disrupted	Total %	Yell brn. % of total	Brown % of total	Red % of total	Disrupted illuvial clay enclosed	Total %	Disrupted illuvial clay enclosed	Orbiculic orientation	Asepic	Insepic	Masepic	Omnisepic	Macro porosity%
Sturt Pond 3.Bt	2.7	100	52					52	0.1		100							+			16.5
Wilverly Plain 3.Btg	1.6	100	33					33	0.9		100							+			10.0
Chilling Copse 3.Bt	4.0	95	31					33	0.5		100							+			10.2
Hook Gravel Pit 3.2Bt	4.1	100	10					10										+			17.4
Lepe Cliff 3.Bt	4.0	100	25					25										+			18.0

+ denotes presence of feature

Table 10.1 Summary of the micromorphological characteristics of Bt horizons in the upper brickearth

	ILLUVIAL CLAY								SEGREGATIONS					AGGREGATES			PLASMIC FABRIC				
SITE/HORIZON	Total %	Yell.brn % of total	Yell brn % disrupted	Egg yell % of total	Egg yell % disrupted	Red % of total	Red % of disrupted	Total % disrupted	Total %	Yell brn % of total	Brown % of total	Red % of total	Disrupted illuvial clay enclosed	Total %	Disrupted illuvial clay enclosed	Orbiculic orientation,	Asepic	Insepic	Masepic	Omnisepic	Macro porosity %
Beaulieu Heath 7. 2B'tg 2	5.9	75	13	15	60	10	60	25	10.5		52	48	+	10.4	+	+			+		16.1
Lepe Cliff 4. 2Bt	6.6	26	10	74	43			34	0.3		78	22		7.2		+		+	+		11.8
Thorns Farm 5. 2Bt(g)	11.0	52	17	47.9	73	0.1	100	44	14.7		88	10		35.5		+			+		11.8
Tanners Lane 4.2Bt(g)	4.5	11	15	67	80	11	80	64	15		10	90	+	20					+		8.0
Ocknell Plain 6.2Bt(g)3	5.6	60	20	40	80			44	5.3		96	4		5.3		+			+		9.0
Rockford Common 3. Bt	6.3	34	0	66	5o			33	0.1		95	5				+			+		17
Holbury Gravel Pit 1.	2.8	64	22	36	71			40	26	81		19	+	27	+	+				+	8.0
Holbury Gravel Pit 4.	3.2	45	0	55	17			9	1.5	93		7		0.5				+			12.5
Hordle Cliff 2.	3.2	45	8	55	34			22	19	95		5		11	+				+		13.1
Wootton Heath 2. Btgl	2.0	100	75					75	30	95		5						+	+		12

+ denotes presence of feature

TABLE 10.2 Summary of the micromorphological characteristics of Bt horizons in the lower brickearth no process is known which can selectively disrupt different varieties of illuvial clay, these figures suggest that the red and egg-yellow clays in the lower brickearth were deposited then disrupted (probably by cryoturbation) prior to deposition of the yellowish-brown clay.

Feruginous segregations are much more common in the lower brickearth Bt horizons (mean content = 12.2%) than in the upper brickearth, and they are more variable, ranging from yellowish-brown to red. Their relationship to other soil features is also more complex as they sometimes enclose disrupted illuvial clay which suggests they formed after deposition followed by disruption of the clay. Fossil aggregates and orbiculic orientation of sand and silt grains were found only in the lower brickearth. In some horizons the aggregates enclose disrupted illuvial clay, indicating that a period of clay illuviation preceded the cold period. during which the aggregates formed. The lower brickearth horizons have a lower mean macro-void area, 11.9%, than the upper brickearth.

10.4.2 Sampled Profiles

10.4.2.1 Sturt Pond

Micromorphological samples were taken from horizons 1(Ah) at 10-18cm, 2 (Eb) at 38-46cm and 3(Bt) at 78-86cm.

All the illuvial clay in the profile is yellowish-brown, which is consistent with the supposed Flandrian age for soil development in the upper brickearth. The Bt horizon contains 2.7% (p.c.) illuvial clay, about half of which occurs as argillans and half as papules and other clay concentrations (Fig. 10.1). This is a relatively large disrupted/void argillan ratio compared with other Flandrian Bt horizons (Bullock,1974), and is possibly due to the exceptionally high earthworm activity noted in the field description of the profile.

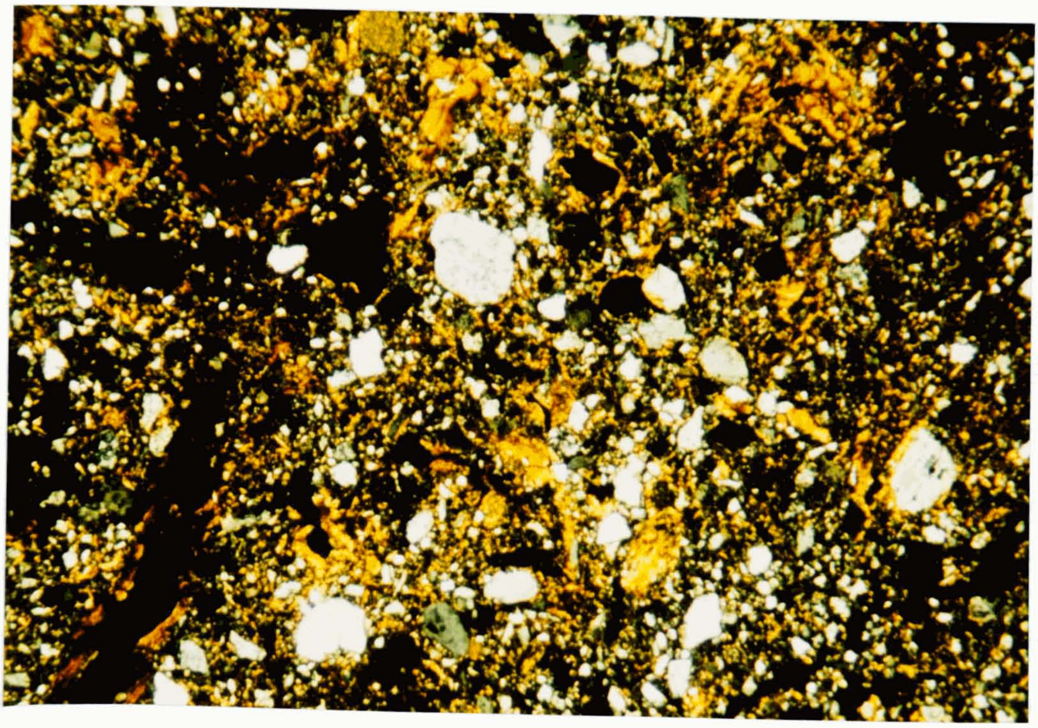


Fig. 10.1 Thin section from horizon 3 (Bt) Sturt Pond.

The yellowish patches are illuviul clay. Note that a high proportion are disrupted and not associated with voids (black areas). Frame length 3mm, cross polarized light.

The Eb horizon contains about 0.5% illuvial clay, and a few intact argillans were also found in the Ah horizon. As argillans are not normally found so near the surface in argillic brown earths, this evidence suggests that the profile was eroded at some time after the onset of clay illuviation.

Typically for a Flandrian soil profile, the Eb and Bt horizons have skel-insepic plasmic fabrics, the stress reorganised plasma occurring preferentially around skeleton grains. The Ah horizon has less reorganization of the plasma, and is silasepic. Organic rich void matrans (organans) attributable to earthworm activity are present throughout the profile. Calcite concentrations in the matrix and on macro-voids (calcitans) were found in the Eb and Bt. This material is probably secondary, and may have been derived from chalking of the adjacent field. Rare ferrans or ferruginous and ferri-manganiferous segregations were found in all three horizons and indicate that drainage is (or was) slightly impeded. The Bt horizon contains 16.5% (p.c.) macro-voids, consisting mainly of metavughs, orthovughs and interpedal planes and it has a moderately developed fine and medium subangular blocky microstructure.

10.4.2.2. Wilverly Plain.

Thin sections were made of samples from horizons 1 (Ah) at 10-18cm, 2 (Eb(g)) at 34-42cm and 3 (Btg) at 44-52cm.

Illuvial clay was found only in the Btg horizon. The total amount, approximately 1.6%, is low for the Btg horizon of a typical argillic gley soil developed in loess. Two-thirds of this occurs as intact argillans and one-third as disturbed clay bodies; these are normal proportions for a Flandrian Bt horizon (Bullock, 1974). All the illuvial clay is yellowish-brown, as in the Sturt Pond profile. The Btg horizon also has an organisation of the plasmic fabric similar to that in the Bt horizon of the Sturt Pond profile, and is in-skelsepic. The Eb(g) and A horizons are dominantly silasepic but have small inclusions of skelsepic plasmic fabric, which indicates that some soil from the Btg horizon may have been mixed into these horizons, possibly by soil fauna.

A few brownish neo-ferrans and ferruginous segregations, indicative of drainage impedance, occur in the Eb(g) and Bt(g) horizons and are slightly more abundant in the Btg horizon. Rare brownish ferruginous nodules occur in all three horizons. One large (600µm diameter) reddish nodule containing small papules was found in the Btg horizon. This is almost certainly a pedorelict derived from an older soil which has been incorporated into the Btg horizon, possibly by faunal activity or cryoturbation.

The Btg horizon has a heterogeneous mix of primary particles with some patches far more sandy than others. This is probably due to the incorporation by faunal activity or cryoturbation of sandier layers from the 2 Btg horizon beneath. The Btg horizon has moderately developed medium and coarse subangular blocky microstructure. It contains about 10% macrovoids, mainly orthovughs, but with subsidiary metavughs , channels and, in the sandier patches, simple packing voids.

10.4.2.3 Chilling Copse

Thin sections were made of samples from horizon 2(Eb) at 16-24cm and horizon 3(Bt) at 47-55cm.

Illuvial clay, representing 4.0% (p.c.) of the total area, was found only in the Bt horizon. This clay is mostly yellowish brown with rare reddish orange bodies, as is normal in Flandrian soils (Chartres,1980). Approximately two-thirds of the illuvial clay occurs as intact argillans and one-third as irregular or linear clay concentrations, the same proportion of disturbed/undisturbed illuvial clay as in the Wilverly Plain profile. Both the Eb and Bt horizons have in-skelsepic plasmic fabrics.

Few brownish ferruginous segregations occur in the Eb and Bt horizons. Ferrans are few in number in the Eb horizon and rare in the Bt horizon. The Bt horizon also contains rare ferruginous nodules.

The total macrovoid area of the Bt horizon (10.2%) is similar to that of the Btg horizon of the Wilverly Plain profile, and consists mainly of metavughs, orthovughs, intrapedal channels and rare skew planes. The microstructure is moderately developed, fine and medium, subangular blocky.

10.4.2.4 Hook Gravel Pit

Thin sections were made of samples from horizons 1(Ah) at 9-17cm, 2 (2Eb/Bt) at 30-38cm and 3 (2Bt) at 61-69cm.

Yellowish brown illuvial clay occurs in both the 2Eb/Bt and 2Bt horizons, confirming the transitional nature of the 2Eb/Bt horizon. The total illuvial clay content of the 2Bt horizon is 4.1%(p.c.). This clay is composed of fine to medium void and grain argillans (in the sandiest parts of the horizon) and rare disturbed illuvial clay bodies. Some of the clay is well oriented and has slightly higher birefringence than most illuvial clay in other upper brickearth profiles. The 2Eb/Bt horizon has about 1.5-2.0% illuvial clay which is about two-thirds intact and one-third disturbed. As in the Sturt Pond profile, the occurrence of illuvial clay at such a shallow depth may indicate that the profile was eroded at some time after the onset of clay illuviation. Both the 2Eb/Bt and 2Bt horizons have in-skelsepic plasmic fabrics, but the 2Eb/Bt horizon also has a few silasepic patches that are probably derived by faunal mixing from the Ah horizon above.

A few pedorelict ferruginous nodules occur in all three horizons, as in the Wilverly Plain profile. The 2Eb/Bt horizon also has rare ferrans which may have formed due to slight drainage impedance caused by illuvial clay accumulation in the underlying 2Bt horizon.

The total macro-void area in the sandy 2Bt horizon, 17.4% (p.c.), is high and consists mainly of metavughs, orthovughs, channels and simple packing voids. The micro-structure is weak, medium and coarse, subangular blocky.

10.4.2.5 Beaulieu Heath

Thin sections were made of samples from horizons 1 and 2 (H/Oh and Ah/Ea) at 2-10cm, horizons 3, 4 and 5 (Bh, Bs(g) and 2E'g) at 18-26cm (vertical), horizon 6 (2B'tgl) at 42-50cm and horizon 7 (2B'tg2) at 65-72cm (vertical and horizontal).

Illuvial clay is present in all the horizons developed in the lower brickearth, the 2E'g, 2 B'tgl and 2 B'tg2 horizons. In the 2E'g horizon both the amount and original colour of this clay were difficult to assess because it is partly obscured by brownish ferruginous segregations. However, the presence of illuvial clay shows that this was not always an E horizon. Point counting gave 5.1% illuvial clay in the 2 B'tgl horizon and 5.9% in the 2B'tg2 horizon, which are higher amounts than in any of the Bt horizons of the profiles developed in upper brickearth. Furthermore, in both horizons ferruginous segregations obscured part of the matrix and some of the abundant stress-reorganized clay that is present may originally have been illuvial, so the total amount of illuvial clay in the horizons was probably underestimated. In both the 2B'tgl and 2B'tg2 horizons about 80% of the illuvial clay is yellowish brown. In the 2B'tg2 horizon the remainder is divided between egg-yellow and red in the proportion 3:2. In both horizons nearly all the yellowish-brown illuvial clay occurs as undisturbed argillans, but the egg-yellow and red clays are about 60% papules and irregular clay concentrations and 40% intact argillans (Fig 10.2) This suggests that the egg-yellow and red illuvial clays were disturbed prior to the deposition of the yellowish brown clays. In this respect the two horizons are similar to paleoargillic horizons described elsewhere that display a high ratio of disturbed to undisturbed egg-yellow and red clays, presumably as a result of cryoturbation after illuviation of the clays (Bullock, 1974).

All three horizons in the lower brickearth display greater re-organization of the plasmic fabric than was found in the upper brickearth profiles; the 2E'g horizon is in -vo-skelsepic and the 2 B'tgl and 2 B'tg2 horizons are skel-masepic. The Ah/Ea, Bh and Bs(g) horizons in the upper brickearth are isotic due to the influence of organic matter and ferruginous segregations.

Fossil aggregates form at least 10% of the soil in the 2 B'tg2 horizon and also occur rarely in the 2B'tgl horizon. They range from 0.4 to 2 mm in diameter but usually lie between 1-1.5mm (Fig 10.3). They often contain papules and irregular clay concentrations which are usually red but also egg-yellow. This suggests that the aggregates formed after one or more periods of interglacial clay illuviation. The aggregates often occur in clusters separated by compound packing voids. Similar concave inter-aggregate voids have been noted elsewhere in sediments subject to cryogenic processes (Van Vliet-Lanoe, 1976). These voids are often partly infilled with red, egg-yellow or yellowish brown argillans (or combinations of these), suggesting that interglacial clay illuviation also occurred after the formation of some of the aggregates and that some of the aggregates and voids have remained stable over long periods (Fig. 10.4). Many aggregates have red or egg-yellow stress reorganised clay "streamers" around their outer edges. Although they are interspersed with some silt or sand grains, the concentration of clay in these rinds is far higher than

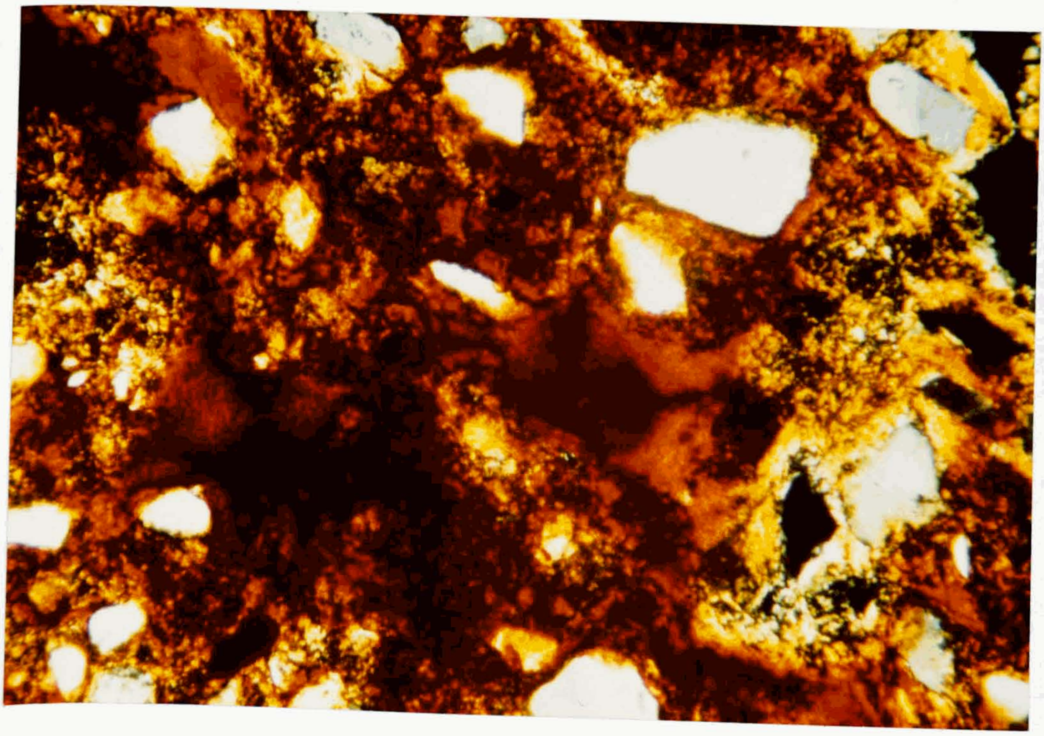


Fig. 10.2 Thin section from horizon 7 (2B'tg2) Beaulieu Heath.
The reddish zones are irregularly shaped bodies of intrapedal illuvial clay. Frame length 790µm, cross polarized light.

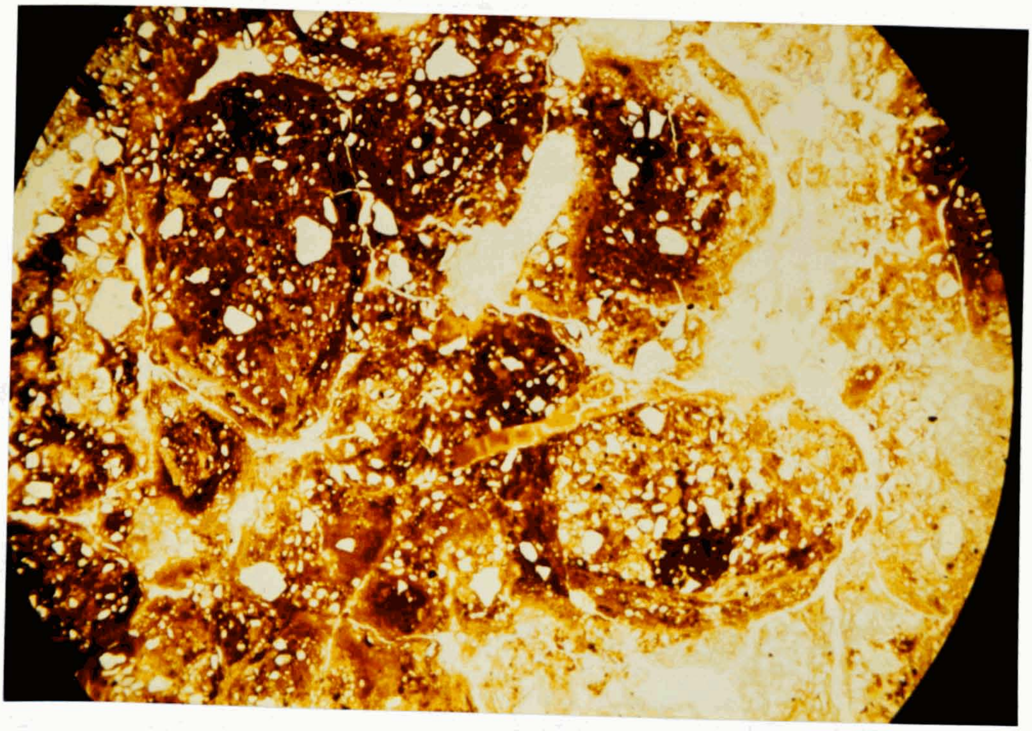


Fig. 10.3 Thin section from horizon 7 (2B'tg2) Beaulieu Heath. A group of large reddish fossil aggregates. Note the smaller aggregates subsumed in the large ones and the partially reddened illuvial clay body between the aggregates near the frame centre. Frame length 9.84mm, plane polarized light.

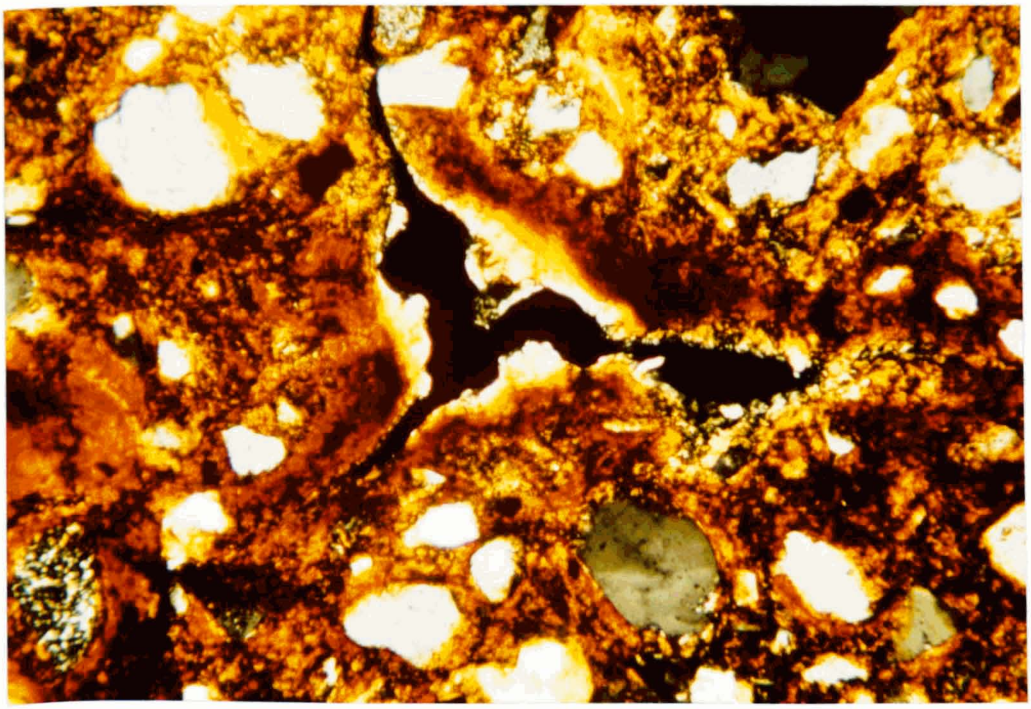


Fig. 10.4 Thin section from horizon 7 (2B'tg2) Beaulieu Heath.
Compound packing void between fossil aggregates, partly filled with a compound red/egg yellow argillan. Frame length 790µm, cross polarized light.

in the matrix, which suggests the clay may originally have been illuvial. If so, the clay is likely to have become oriented around the aggregates as a result of transportation. Rare embedded grain matrans were found in the 2 B'tg2 horizon and rare embedded grain argillans occur in the 2 B'tgl horizon.

A few ferrans and brownish ferruginous segregations were found in the Bh horizon. The Bs(g) horizon consists of a dense mat of horizontally oriented dead roots interspersed with inorganic soil material. The plasma of the soil is coloured orange-brown as a result of dense ferruginous concentration. Brownish ferruginous segregations and a few ferrans occur in the 2E'g horizon. The 2B'tgl horizon contains 9.7% (p.c.) ferruginous segregations and the 2B'tg2 horizon contains 10.5% (p.c.). In both horizons these are brownish and red in the proportions 50: 50. The fossil aggregates in both these horizons are also often red and set in a less red or brownish matrix which suggests that at least some of the aggregates formed from soil that already contained red segregations. Elsewhere, the red segregations appear undisturbed and occur in patches of soil containing papules, irregular clay concentrations and embedded grain argillans. These features suggest that at least some of the rubification occurred after one or more periods of clay illuviation followed by disruption of the argillans.

In contrast to the rubified zones, large areas of the 2B'tgl and 2B'tg2 horizons are dominantly grey, suggesting they lack minerals containing ferric oxide. However, within these areas illuvial clay bodies are often red. This may indicate that the ferric oxide-containing minerals have been removed from the coarser s-matrix but have been retained within the clay bodies (Fig. 10.5).

The sand grains occupying the fissure in the 2B'tg2 horizon

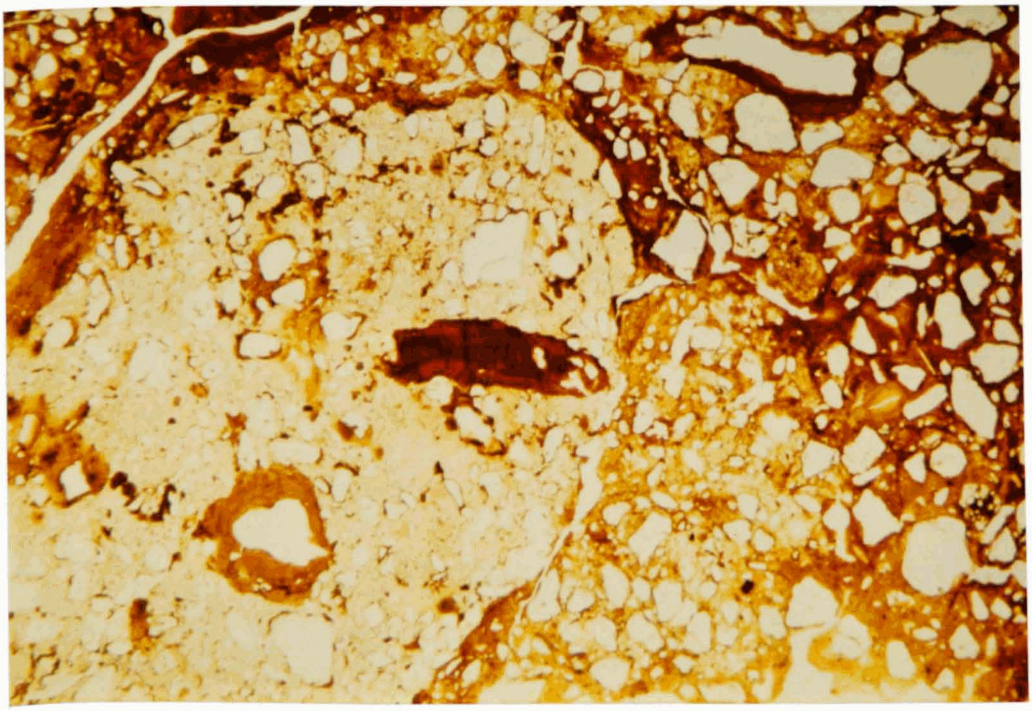


Fig. 10.5. Thin section from horizon 7 (2B'tg2) Beaulieu Heath.

Part of a grey fossil aggregate. Colour is only present in clay bodies, notably the large red papule and the yellowish brown argillan. Frame length 3mm, plane polarized light.

generally have vertically oriented long-axes. The vertical junction between the sand and adjacent soil is clear, but smaller horizontal cracks lead off the main vertical channel, and these are also filled with sand. The sand in the vertical and smaller horizontal fissures is far richer in glauconite than the sand incorporated in the rest of the soil. The 2B'tgl horizon has no sand filled fissures, but the soil contains far more sand mixed into the matrix than in the 2 B'tg2 horizon. Like the sand in the fissures in the 2B'tg2 horizon, this sand is very rich in glauconite which suggests it may have the same source.

Because of its high sand content, the 2B'tgl horizon has the high macrovoid area of 22.5% (p.c.). This falls to 16.1% (p.c.) in the 2B'tg2 horizon. The 2B'tgl horizon has a moderate, fine and medium, subangular blocky microstructure, and the 2B'tg2 horizon has mainly a fine granular microstructure due to the presence of fossil aggregates.

10.4.2.6 Lepe Cliff

Thin sections were made of samples from the upper brickearth in horizon 3 (Bt) at 63-75cm and the lower brickearth in horizon 4 (2Bt) at 100-108cm.

The illuvial clay content is highest in the paleoargillic 2Bt horizon, at 6.6% (p.c.) and is about 4% in the Bt horizon (upper brickearth). As in the other upper brickearth profiles, all the illuvial clay in the Bt horizon is yellowish-brown, and about 75% occurs as undisturbed argillans. In contrast, 74% of the illuvial clay in the 2 Bt horizon is egg-yellow and 26% is yellowish brown (Fig. 10.6). About 90% (p.c.) of the yellowish brown clay is undisturbed argillans whereas only 57% (p.c.) of the egg-yellow clay is undisturbed. As in the Beaulieu Heath profile, this suggests the yellowish-brown clay was deposited in the 2Bt horizon after some disturbance of the egg-yellow clay. The plasmic fabric of the Bt horizon is skel-insepic, but the 2 Bt horizon has more stress

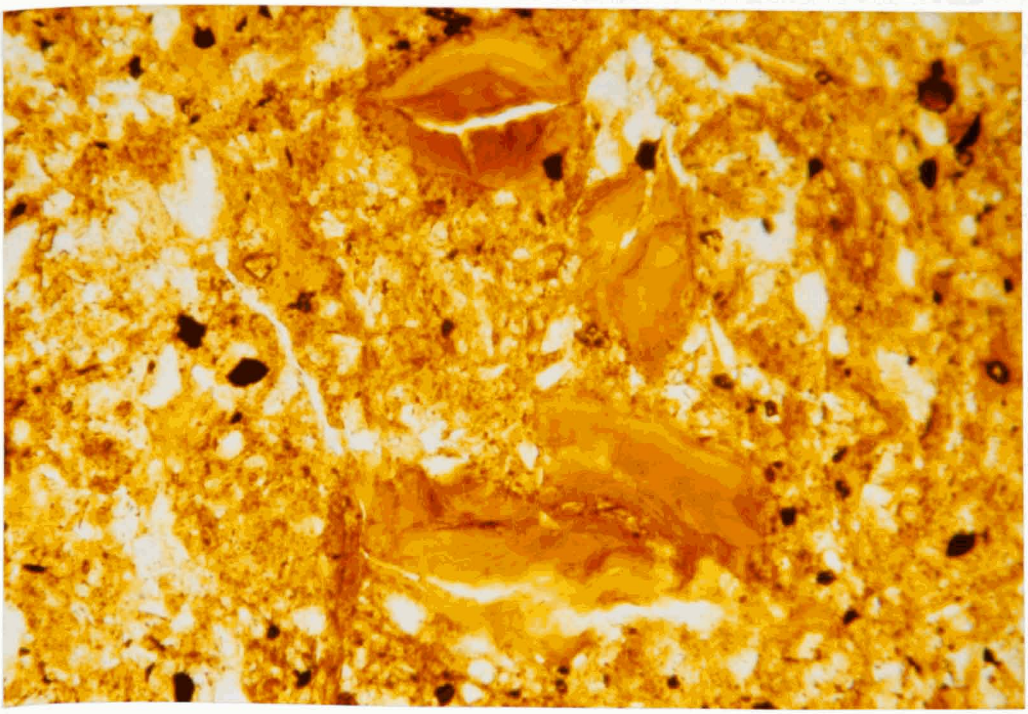


Fig. 10.6 Thin section from horizon 4 (2Bt) Lepe Cliff.
Large papules of egg-yellow clay in a silty matrix. Frame length 790µm, plane polarized light.

reorganized clay and is in-masepic.

Fossil aggregates or patches of soil with orbiculic orientation of skeleton grains form the greater part of the 2Bt horizon in the lower brickearth. These are mainly 0.3-1.5mm in diameter. In contrast to the Beaulieu Heath profile, the aggregates do not contain papules or other disturbed clay bodies, which suggests they formed before the illuviation of the egg-yellow clay. They do however, have similar stress-reorganised clay streamers around their edges (Fig. 10.7). As with the streamers in the Beaulieu Heath profile, these may have originated as illuvial clay.

The Bt horizon has rare ferruginous nodules but no segregations or ferrans. The 2 Bt horizon contains few ferruginous segregations and nodules which are mainly brown, but occasionally red. In common with the Beaulieu Heath profile, grey patches of soil, possibly depleted of iron minerals, occur in the 2Bt horizon. Rare calcitans and secondary calcite concentrations also occur in the 2Bt horizon.

In the Bt horizon macrovoids make-up 18% of the total area, and consist mainly of metavughs, orthovughs and rare interpedal planes. The 2Bt horizon has a lower macrovoid area of 11.8% (p.c.) because the fossil aggregates which make up most of the soil are very densely packed and contain no voids. In this horizon compound packing voids (between fossil aggregates) are dominant with subsidiary orthovughs, metavughs and channels. Both horizons have a moderate fine and medium subangular blocky microstructure

10.4.2.7 Thorns Farm

Thin sections were made from samples taken from the upper brickearth in horizon 1 (Ah) at 22-30cm, horizon 2 (Apg) at 36-44cm, horizon 3 (A/E(g)) at 50-58cm and horizon 4 (Eg) at 68-76cm and from the lower brickearth in horizon 5 (2Bt(g)) at 94-102cm.

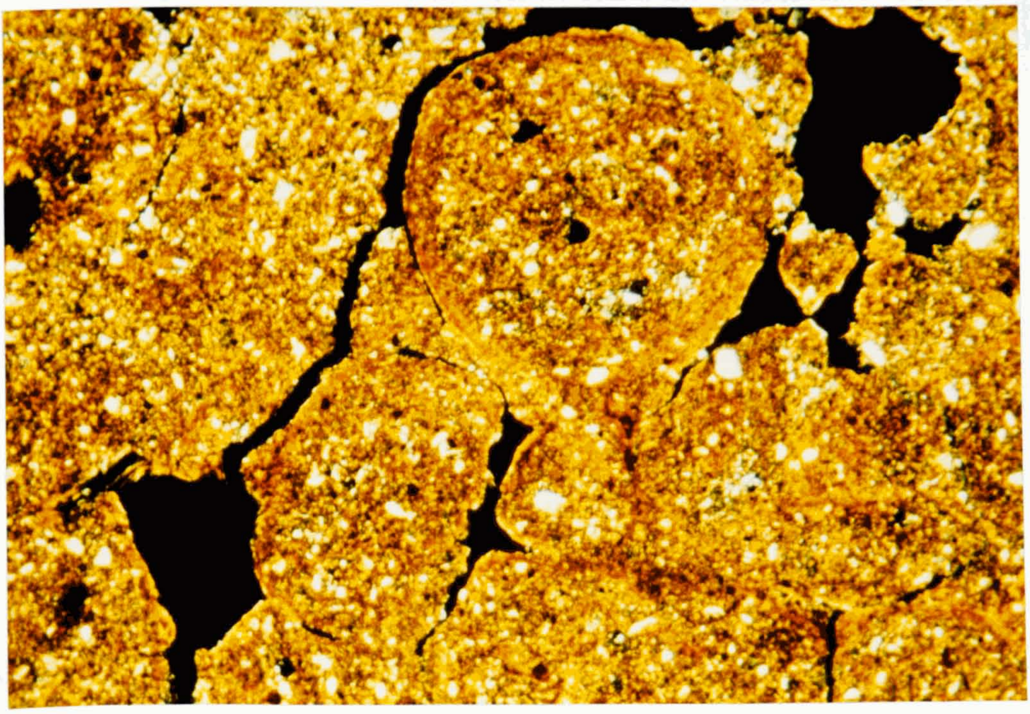


Fig. 10.7 Thin section from horizon 4 (2Bt) Lepe Cliff.

Group of fossil aggregates with stress-reorganised clay streamers at their margins. Frame length 3mm, cross polarized light.

Illuvial clay occurs in all horizons beneath the Ah horizon. In the Apg horizon very rare yellowish brown argillans speckled with organic matter line some voids, and in the A/E(g) and Eg horizons a few undisturbed yellowish brown argillans occur. In both these horizons rare egg-yellow papules and irregular clay concentrations occur within patches of soil containing brown segregations that have probably been derived by mixing from the 2Bt(g) horizon below. The 2Bt(g) horizon in the lower brickearth has a very high illuvial clay content of 11.0%(p.c.), about half of which is egg-yellow and half yellowish brown. Very rare reddish argillans were also found. About one-third of the illuvial clay is obviously disrupted, but much of the remainder completely infills voids, and may also have been subject to stress. Some voids have compound argillans consisting of egg-yellow then yellowish brown clay towards the centre of the void. The plasmic fabric of the 2Bt(g) horizon is skelmasepic, but the soil material in the horizons of the upper brickearth above are less reorganised in that the Ah and Apg horizons are silasepic and the A/E(g) and Eg horizons are in-skelsepic.

Fossil aggregates and embedded grain matrans are extremely common in the 2Bt(g) horizon and form 35.5%(p.c.) of the thin section analysed. Both features are normally 0.2-0.4mm in diameter but occur up to 1.8mm. The 'host' skeleton grains of the embedded grain matrans are not less than 20µm in diameter. Both features have identical thick coats (comprising 30-45%(p.c.) of the total area of the feature) that consist mainly of silt grains whose long-axes are oriented tangentially to the circumference of the aggregate or skeleton grain. These coats are brownish and are a slightly lighter shade (i.e. they have higher value and chroma) than the centre of the aggregates. Some of the larger aggregates contain small aggregates and embedded grain matrans within them. None of the aggregates or embedded grain matrans enclose disrupted illuvial clay, so they probably formed prior to the onset of clay illuviation in the profile. However, they are often embedded within masses of disrupted egg-yellow clay, which suggests they retained their form during one or more periods of illuviation followed by disruption, possibly by cryoturbation (Fig 10.8).

Ferruginous segregations are common in the 2Bt(g) horizon, occupying 14.7%(p.c.) of the matrix. These are almost all brownish in reflected light, but very rarely reddish. Rare black manganiferous segregations also occur. The aggregates and embedded grain matrans are often enclosed by the brownish segregations, suggesting that the segretations formed later. Apart from the brownish segregations likely to have been derived from the 2Bt(g) horizon (mentioned above) the Eg, A/E(g) and Ah horizons contain only rare ferrans.

Both the Eg and 2Bt(g) horizons have heterogeneous mixtures of sand and silt particles. The Eg horizon is dominantly sandy but contains silty patches (with brownish segregations and egg-yellow clay) probably derived from the 2Bt(g) horizon beneath, and silty patches with in-skelsepic plasmic fabric probably derived from the A/E(g) horizon above. The 2Bt(g) horizon is dominantly silty, but concentrations of sand, possibly derived from the overlying Eg horizon, occur in places. In contrast to the sand grains seen elsewhere in the thin section, these grains do not have silty matran coats, and were therefore probably mixed into the horizon after the period of embedded grain matran formation.

The Eg horizon has about 15% void space, mainly orthovughs, interpedal planes, metavughs and simple packing voids. The microstructure is weak, medium and coarse subangular blocky. The 2Bt(g) horizon has 11.8%(p.c.) voids of similar form to those in the

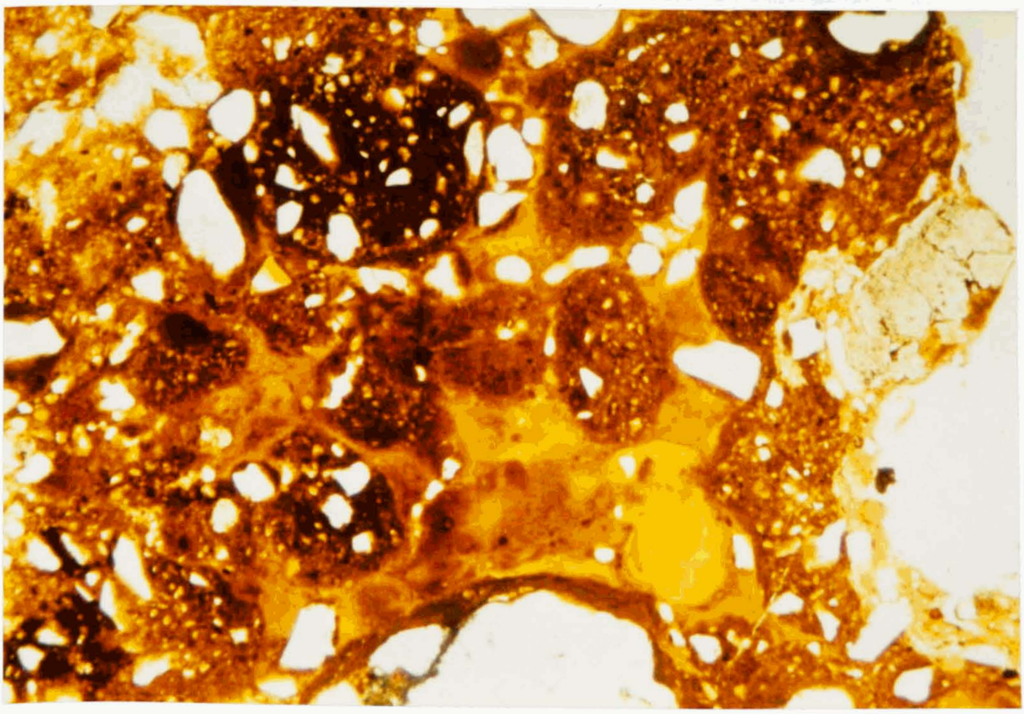


Fig. 10.8 Thin section from horizon 5 (2Bt(g)) Thorns Farm.

A cluster of fossil aggregates embedded in a mass of disrupted illuvial egg-yellow clay. Frame length 3mm, plane polarized light.

horizon above except that compound packing voids also occur between clusters of fossil aggregates and embedded grain matrans.

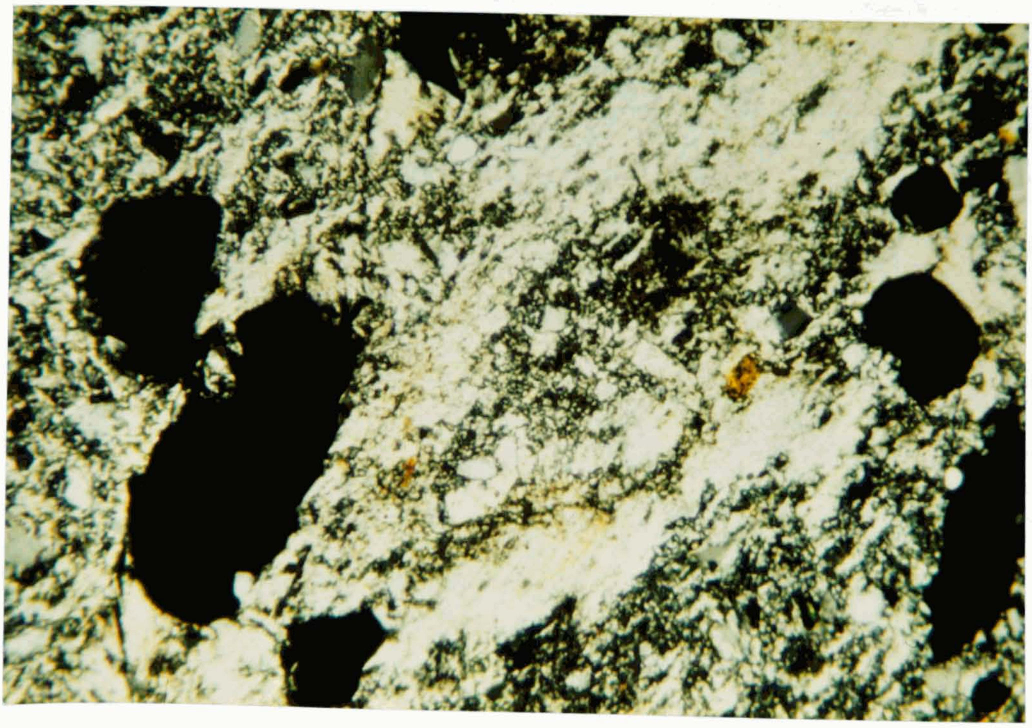
10.4.2.8 Tanners Lane

Vertical thin sections were made of samples taken from horizon 3 (Eb(g) and 2Btg) at 66-74cm and horizon 4 (2Btg2) at 109-117cm.

The 2Btg2 horizon (in the lower brickearth) contains about 4.5% illuvial clay, most of which is egg-yellow. In common with most other lower brickearth horizons, about two-thirds of the illuvial clay is disrupted. In places where disturbed clay bodies are enclosed by red segregations, the clays are also often red. The horizon has a masepic plasmic fabric and much of the stress reorganised clay could originally have been illuvial. The Eb(g) and 2Btg horizon contains about 4% illuvial clay, most of which is yellowish brown and undisturbed, but egg-yellow papules and irregular clay concentrations occur within red segregations. The plasmic fabric is generally skelsepic, as in many Flandrian horizons, but masepic patches occur in proximity to red segregations.

Red ferruginous segregations are common in both horizons. In the 2 Btg2 horizon they often enclose disturbed illuvial clay, which suggests they formed after a period of clay illuviation followed by disruption. In the Eb(g) and 2Btg horizon the segregations are more localised and enclose egg-yellow clay and masepic plasmic fabric. This suggests that the soil in which they are found was mixed into the upper brickearth of the horizon from the 2Btg2 horizon beneath ..

As in other lower brickearth horizons, grey areas of soil occur adjacent to red segregations in the 2Btg2 horizon. These areas contain disturbed illuvial clay bodies of similar dimensions and birefringence to those occuring within the red segregations, but their colour is pale yellow or grey as opposed to egg-yellow or red (Fig 10.9).



<u>Fig. 10.9 Thin section from horizon 4 (2Btg2) Tanners Lane.</u> Grey-coloured masses of intrapedal clay. Frame length 790µm, cross polarized light.

This suggests that these illuvial clays within the greyish zones have lost their colour due to the reduction and removal of iron oxide minerals. If so this suggests that it is not reliable to use colour alone as a guide to the origin of illuvial clay.

The 2Btg2 horizon contains common fossil aggregates ranging in diameter from 0.5-2.5mm. These do not contain papules or irregular clay concentrations, but many contain much stress reorganised clay which originally may have been illuvial in part. Thus, the aggregates may have formed after a period of clay illuviation. Nearly all the undisturbed egg-yellow argillans in the section occur in voids within the aggregates; no argillans were found on structural faces in the section. This suggests that the internal fabric of the aggregates has remained relatively stable since the deposition of at least some of the egg-yellow clay.

The total macro void area of the 2 Btg2 horizon, 8%, is small, in common with most other horizons in the lower brickearth. The voids are mainly metavughs and interpedal channels, with rare skew planes and orthovughs. The microstructure is fine, medium and coarse subangular blocky. The Eb(g) and 2Btg horizon has about 17% macrovoids consisting mainly of simple packing voids and channels and the microstructure is weak coarse subangular blocky.

10.4.2.9 Ocknell Plain

Thin sections were made of samples from horizon 2 (Ah) at 5cm depth in the upper brickearth and from horizons 5 (2Bt(g)2) at 29-37cm and 6 (2Bt(g)3) at 60-68cm in the lower brickearth.

One intact yellowish-brown void argillan was found in the Ah horizon, which suggests that the upper brickearth may have been eroded at some time after the onset of Flandrian clay illuviation. The 2Bt(g)2 horizon contains about 2.5% illuvial clay and this figure rises to 5.6%(p.c.) in the 2Bt(g)3 horizon. In the 2Bt(g)3 horizon, about 40% of this clay is egg-yellow, and 60% is yellowish brown. About 80% of the egg-yellow clay is disturbed, whereas only about 20% of the yellowish-brown is disturbed which again suggests that egg-yellow clay was disrupted prior to the deposition of the yellowish brown clay. In the 2Bt(g)2 horizon nearly all the illuvial clay appears yellowish brown, and about 40% is disturbed. However, this horizon has extensive greyish areas (as in the 2Bt(g)2 horizon of Tanners Lane profile); some of the illuvial clay may originally have been egg-yellow but is now partly depleted of its iron-oxide minerals. The 2Bt(g) 2 horizon has a ma-skel-insepic plasmic fabric, but the 2Bt(g)3 horizon is slightly more reorganised and is skel-vo-masepic. The Ah horizon is isotic.

Fossil aggregates, 0.3-1.5mm in diameter, occupy at least 5.3% of the 2Bt(g)3 horizon. No definite aggregates were seen in the 2Bt(g)2 horizon but orbiculic orientation of skeleton grains occurred in places. In both horizons, however, a large proportion of the voids are arcuate like the compound packing voids found between fossil aggregates at other sites. Thus both horizons may once have had many more aggregates which cannot now be recognised because their boundaries are largely obscure. None of the aggregates contain disrupted illuvial clay so they probably formed prior to the onset of clay illuviation. As at other sites, many of the aggregates have stress-reorganised, possibly originally illuvial, clay around their margins. The 2Bt(g)3 horizon also contains rare embedded grain argillans.

Both the 2Bt(g)2 and 2Bt(g)3 horizons have moderate medium subangular blocky microstructure. The total macrovoid area of the 2Bt(g)2 horizon is about 15%, but this falls to around 9% in the 2Bt(g)3 horizon. In both cases the voids are mainly compound packing voids, metavughs and orthovughs with rare channels and skew planes.

10.4.2.10 Calveslease Copse

Samples for micromorphological analysis were extracted from the undifferentiated brickearth in horizons 1 at 17-25cm, 2 at 52-60cm (vertical) and 3 at 85-93cm (vertical) and 152-160cm (vertical).

Horizon 1 consists largely of loosely packed sand grains many of which are surrounded by tangentially oriented silty coats (embedded grain matrans) or yellowish-brown illuvial clay. Most of the clay is undisturbed (giving the soil an intertextic elementary fabric), but a few rounded embedded grain argillans also occur. Rare, rounded egg-yellow papules (Fig.10.10) and fossil aggregates are present. The papules are surrounded by silt with a colour and masepic plasmic fabric organisation similar to that surrounding the embedded grain matrans and forming the fossil aggregates.

This horizon has probably been formed of material transported to the site. The papules, fossil aggregates and embedded grain matrans probably originated in one or more paleoargillic horizons judging by the plasma organisation and the colour of the illuvial clay. These disrupted paleoargillic horizons probably contained appreciable quantities of silt, some of which now adheres to skeleton grains and papules and some forms the fossil aggregates. As most of the sand grains have no adhering silty coat, there is no evidence that they are derived from a paleoargillic horizon. The sand grains, papules, fossil aggregates and embedded grain matrans all have similar dimensions, so it is likely that they were subject to sorting during transport to the site. In-situ pedogenesis after emplacement of the constituents is shown by the presence of yellowish brown clay that was probably translocated during the Flandrian period.

Horizon 2 has a similar appearance to horizon 1 except that the sand grains are sorted into laminae. The sand grains in each

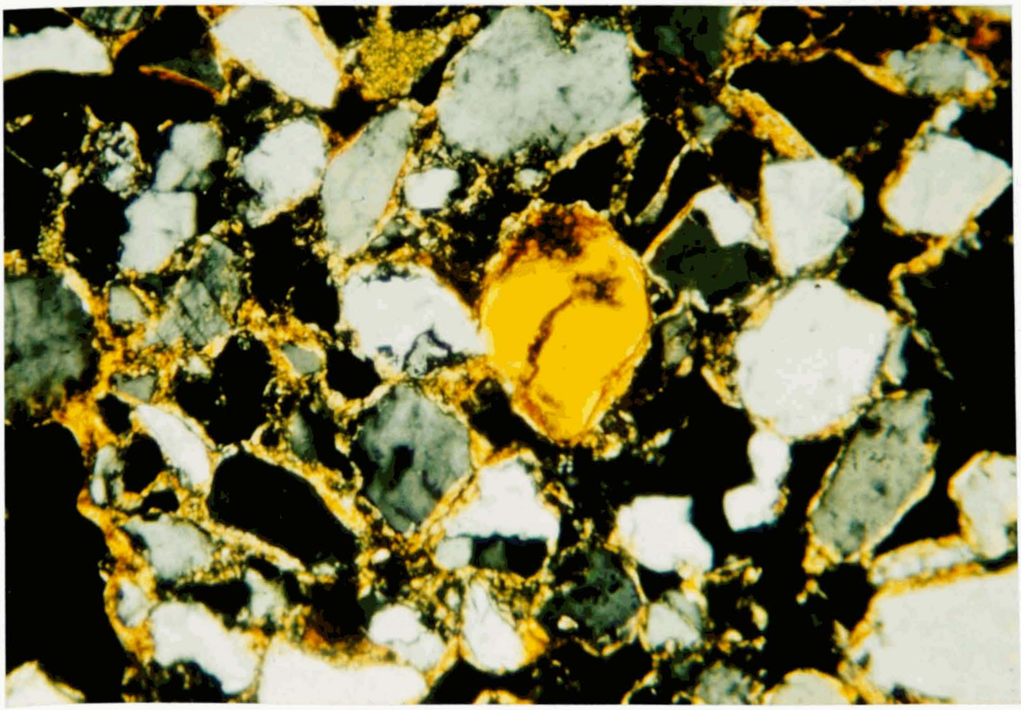


Fig. 10.10 Thin section from horizon 1 at Calveslease Copse. Rounded egg-yellow papule surrounded by silt coat within a mass of similarly coated sorted sand grains. Frame length 790µm, cross polarized light.

lamination have a slightly different average particle size. Embedded grain matrans, fossil aggregates and egg-yellow papules are present, but they are less common than in horizon 1. Undisturbed yellowish brown illuvial clay is about twice as abundant as in horizon 1 and occupies about 4% of the thin section. This clay bridges the voids between sand grains and also lines many of the pseudo-horizontal voids that separate the laminae. The latter voids are also commonly lined with reddish neo-ferrans equivalent to the reddish-brown ped coats recognised in the field. Where the ferrans enclose void argillans the clay is coloured brown. A few blackish and reddish-brown manganiferous and ferruginous segregations also occur. This horizon probably has a similar origin to horizon 1, but the relative scarcity of egg-yellow papules, embedded grain matrans and fossil aggregates suggests that less of the material was derived from a paleoargillic horizon, or that more of these features were destroyed during transport.

Horizon 3 is also composed of well defined laminae; these mainly consist of densely packed silt, but rare sandy layers also occur. The bulk of the horizon is conspicuous for its lack of voids and illuvial clay. Pseudo-horizontal voids between the laminae are almost completely absent at 152-160cm, but occur occasionally at 85-93cm and are lined with yellowish brown argillans. The silty laminae are generally brownish coloured with insepic plasmic fabrics. However, they contain a few reddish fossil aggregates and rounded egg-yellow papules, especially at 152-160cm. The sandy laminae at 152-160cm contain more voids and most of these are filled with disrupted reddish orange and egg-yellow clay. A large vertical channel crosses all the laminae at 152-160cm. It is lined with a thick compound argillan which consists of disrupted egg-yellow clay at the void edge and undisturbed yellowish brown clay towards its centre (Fig. 10.11). This suggests the channel has been open

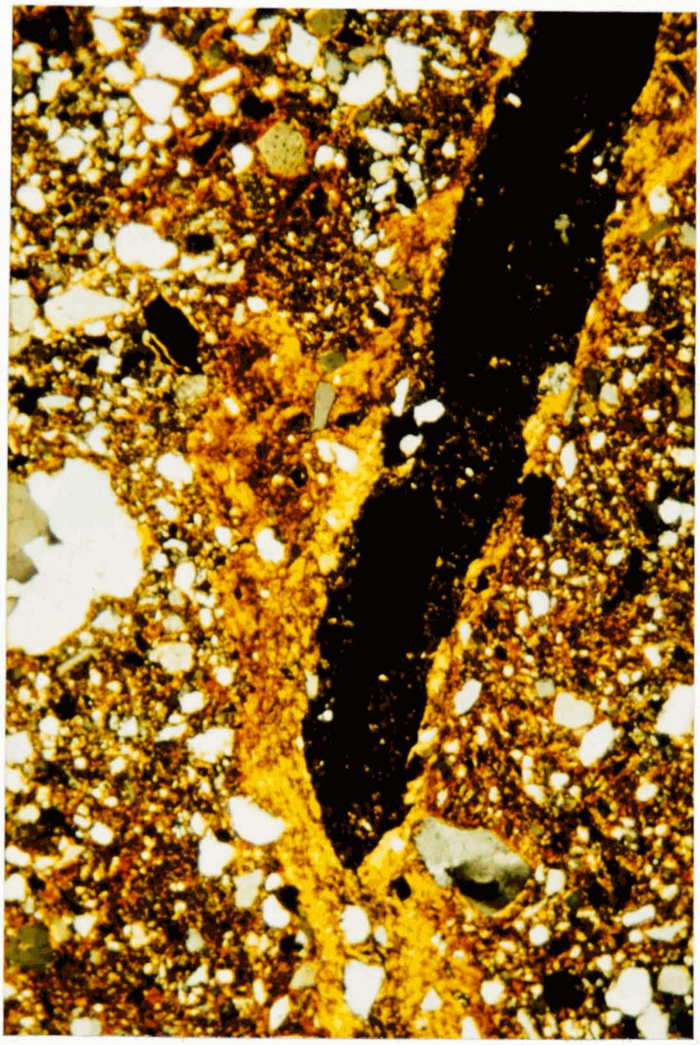


Fig. 10.11 Thin section from horizon 3 (152-160cm) Calveslease Copse. The large vertical channel is lined with a compound argillan of disrupted egg-yellow and undisturbed yellowish-brown clay. Frame length 3mm, cross polarized light.

through two periods of clay illuviation, separated by a period of cryoturbation.

Many of the laminae are broken and displaced vertically, and within some of these there is a weak orbiculic orientation of the silt grains. This suggests that some disturbance, probably cryoturbation, has affected the horizon after emplacement of the laminae. The horizon has a very low macrovoid space of .8% (p.c.) in common with many of the lower brickearth horizons. Like horizons 1 and 2, there is evidence in the fossil aggregates and papules that this horizon was derived at least partly from pre-existing paleoargillic horizons. However, the egg-yellow clay lining the vertical channel and voids between sand grains is evidence of interglacial clay illuviation having occurred <u>in-situ</u>. Moreover, the disturbance of the egg-yellow clay and of many laminae and the formation of circular arrangements of silt grains suggest that cryoturbation affected the soil prior to the deposition of the yellowish brown clay. A puzzling feature of the horizon is the insepic plasmic fabric of most of the laminae: stronger stress reorganisation of the plasma is typical of pre-Devensian pedogenesis.

10.4.2.11 Rockford Common Gravel Pit.

Thin sections were made of samples taken from horizons 2(Eb) at 27-35cm in the undiferentiated brickearth and 3(Bt) at 45-53cm in the lower brickearth.

The Eb horizon is silasepic and contains less than 0.1% yellowish brown argillans in one small patch. In these respects it resembles the upper brickearth. The Bt horizon, in contrast, is skel-masepic and contains 6.3% (p.c.) illuvial clay. About 64% of this is egg-yellow, half of which occurs as disturbed irregular clay concentrations and papules (Fig.10.12). The remainder is yellowish-brown, almost all of which is undisturbed argillans.

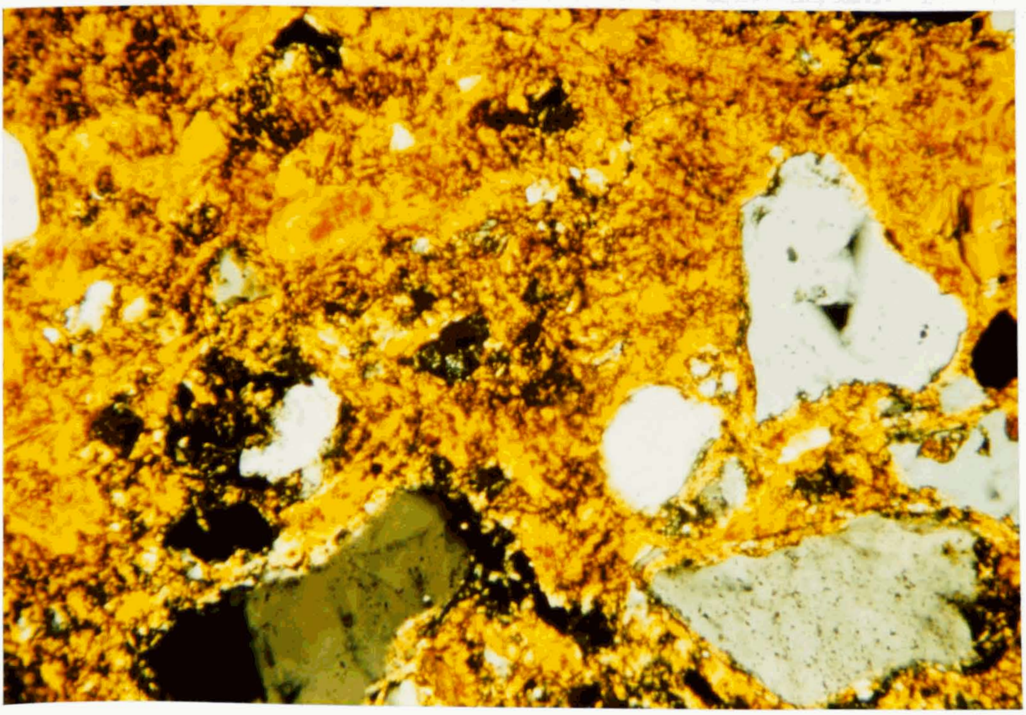


Fig. 10.12 Thin section from horizon 3 (Bt) Rockford Common.

A few grains of quartz embedded within a mass of disrupted egg-yellow clay. Frame length 790μm, cross polarized light.

In places in the Bt horizon the constituent sand grains have an orbiculic orientation up to 3.5mm in diameter and the spaces between the grains are often occupied by papules of egg-yellow clay. This suggests that a period of cryoturbation followed illuviation of the egg-yellow clay. Rare brownish ferruginous segregations and reddish nodules occur in the Bt horizon. The total void area of the Bt horizon is 17%(p.c.) consisting mainly of simple packing voids, orthovughs, metavughs, and channels. The microstructure is fine and medium angular blocky.

10.4.2.12 Holbury Gravel Pit

Samples for micromorphological analysis were taken from the lower brickearth in horizons 1 at 90-98cm and 4 at 130-138 cm.

Horizon 1 is composed mainly of very densely packed silt. Fossil aggregates, 0.35-3.5mm in diameter, form 27% (p.c.) of the section. Some of the larger aggregates are composed of several small ones closely packed together. As at other sites, many of the aggregates have stress reoriented, clay rich rinds, which may originally have been illuvial. No embedded grain matrans were seen. There are local concentrations of sand grains in the section and these often surround the aggregates, but are never incorporated within them (Fig 10.13). This suggests that the sand was mixed into the profile after formation of the aggregates.

The total illuvial clay content of horizon 1 was point counted at 2.8%, but this only included optically continuous clay bodies (i.e. those with a clear extinction pattern). Other, stress reoriented, clay bodies are abundant and give the soil an omnisepic plasmic fabric. Some of this clay may originally have been illuvial. The illuvial clay is about one-third egg-yellow and two-thirds yellowish-brown and pale yellow. About 71% of the egg-yellow clay is disturbed, but about 78% of the yellowish-brown

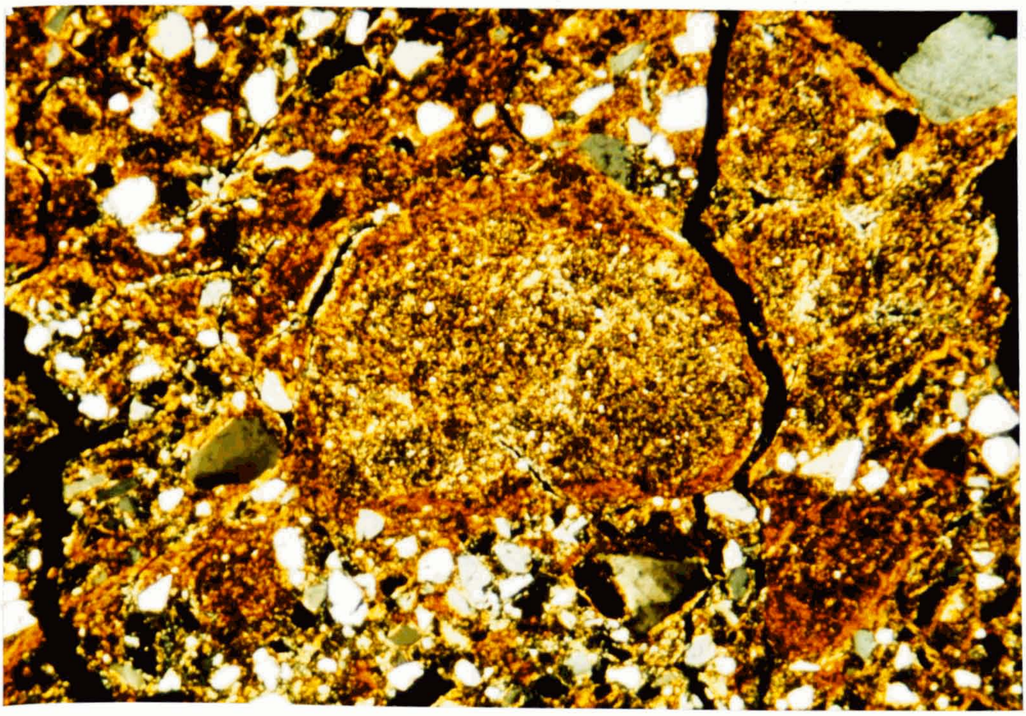


Fig. 10.13 Thin section from horizon 1 Holbury Gravel Pit.

Large silty fossil aggregates with clay-rich rinds surrounded by concentrations of sand grains. Frame length 3mm, cross polarized light.

and pale yellow clay occurs as intact argillans. Some egg-yellow papules and irregular clay concentrations occur within single fossil aggregates and between the secondary fossil aggregates forming larger aggregates. This suggests that some illuvial clay was present before some of the aggregates were formed.

Ferruginous segregations comprise 26% (p.c) of the section and about one-fifth of these are red. The remainder are dominantly yellowish-brown but within these the flecks of clay around many silt grains are red. The reddish segregations sometimes enclose bodies of disrupted illuvial clay, suggesting that rubification occurred after a period of clay illuviation followed by disruption. Pale grey areas of soil form 44%(p.c.) of the section and are generally found between fossil aggregates and adjacent to fissures. As in the Tanners Lane profile (section 10.4.2.8), most of the pale yellow illuvial clay is found in these zones suggesting that the clay might once have been redder or yellower. The total void area of the section is low, at 8% (p.c.) and consists mainly of skew planes with rare orthovughs, metavughs and chambers. The microstructure is medium angular blocky and large fossil aggregates form the centre of most structural units.

Horizon 4 has a strikingly lower level of pedological re-organization than horizon 1. The plasmic fabric is mainly in-skelsepic, with patches of masepic. The total illuvial clay content, at 3.2%(p.c.) is actually higher than in horizon 1, but there is far less stress-reorganized clay. The illuvial clay is about half egg-yellow and half yellowish-brown. All the yellowish brown clay forms undisturbed argillans, and a far greater than normal proportion of the egg-yellow clay is also undisturbed, about 80%(p.c.). Fossil aggregates are very rare (about 0.5%) compared with other lower brickearth horizons, and no embedded grain argillans or matrans were seen. This evidence, in conjunction with the low disrupted/intact egg-yellow clay ratio suggests that cryoturbation has been far less active in this horizon than in other lower brickearth horizons. Ferruginous segregations are also rare, forming about 1.5%(p.c.) of the section. They are dominantly yellowish-brown, but occasionally reddish. The total void area is 12.5%(p.c.), consisting mainly of metavughs and skew planes. The microstructure is fine and medium subangular blocky.

10.4.2.13 Hordle Cliff.

A thin section was made of a sample from horizon 2 at 140-148cm in the lower brickearth.

The section contains 3.2%(p.c.) illuvial clay, about half of which is egg-yellow and half yellowish brown. About 9% of the yellowish-brown clay is disturbed, and only about 34% of the egg-yellow clay is papules and irregular clay concentrations. Rare compound argillans of both colours of clay were found. Fossil aggregates 0.3-1mm in diameter, form 2.4%(p.c.) of the section and these sometimes contain egg-yellow papules. Embedded grain argillans and matrans form 9% (p.c.) of the matrix and sometimes occur within the fossil aggregates. Ferruginous segregations form 19%(p.c.) of the section and the vast majority are yellowish brown though rare red patches occur.

The void area is 13.1% and consists of skew planes, metavughs, orthovughs and compound packing voids. The microstructure is medium and fine subangular blocky.

10.4.2.14 Wootton Heath.

Thin sections were made of samples extracted from horizons 1 (Ahg) at 2-10cm (vertical) and 2 (Btgl) at 28-36cm.

The Ahg horizon is heterogeneous, with patches of organic rich, silasepic soil containing no illuvial clay that are separated by less organic, insepic soil containing a few argillans and disturbed illuvial clay bodies. The insepic patches of soil are very similar to parts of the Btg horizon and are probably derived from it. The horizon contains common brown ferruginous segregations and ferrans.

The Btgl horizon contains about 2% illuvial clay, all of which is yellowish-brown, in contrast to other horizons in the lower brickearth. About one-third of this forms argillans and the remainder occurs as papules and linear irregular clay concentrations, so the disrupted/intact ratio of illuvial clay is similar to that of the egg-yellow clay in other paleoargillic horizons. The plasmic fabric is insepic to masepic. There are many ferruginous segregations which are dominantly yellowish-brown and rarely yellowish-red or red. A few fine brown ferrans line some voids. The void area of the Btgl horizon is about 12% and is composed of metavughs, orthovughs and channels. The microstructure is fine subangular blocky.

10.4.2.15 The colluvial brickearth profiles around the 56m terrace.

a) Profile 1.

Thin sections were made of samples from horizons 1 (Ap) at 8-16cm and 2 (Eb/Bw(g)) at 30-38cm.

In both horizons the soil is heterogeneous with patches of very well sorted silt surrounded by patches of sorted sand. Earthworm casts are present in horizon 1 and often have a different texture from the surrounding soil. Voids in silty patches are commonly partly filled with sand grains. Rare intact yellowish-brown argillans occur in the Eb/Bw(g) horizon. The Ap horizon is isotic and the Eb/Bw(g) horizon is silasepic. A few ferruginous nodules occur in both horizons.

b) Profile 2

Thin sections were made of samples taken from horizon 1 (Apg) at 12-20cm, horizon 2 (Ahg) at 35-43cm, horizon 3 (Bw(g)) at 46-54cm (vertical and horizontal) and horizon 4 (bAhg) at 56-64cm.

The horizontal thin sections of all four horizons display the same textural heterogeneity as profile 1. Earthworm casts were found in the Apg and Ahg horizons. The vertical thin section of the Bw(g) horizon showed the soil to be composed mainly of horizontal and sub-horizontal laminae, sometimes cross-bedded and averaging 1-2mm thick. The laminae are composed alternately of tightly packed very well sorted, silt grains and less well sorted mixtures of sand and silt grains (Fig. 10.14).

Rare undisturbed yellowish-brown argillans occur in the bAhg horizon (the buried soil), but not in any of the horizons above, which suggests that the argillans were present before the bAhg horizon was buried. Rare rounded yellowish brown papules and embedded grain argillans occur in some of the laminae of the Bw(g) horizon, which suggests that part of the material of this horizon was derived from a pre-existing Bt horizon. The Apg and bAhg horizons are isotic and the Ahg and Bw(g) horizons are silasepic. Ferruginous segregations occur throughout the profile and ferruginous nodules are present in all horizons above the buried soil.

c)Profile 3

Thin sections were made of samples from horizon 1 (Ah) at 8-16cm, horizon 2 (2Ahg/Bh) at 18-26cm, horizon 3 (3bAhg) at 31-39 cm and horizon 4 (3bEb/Bw(g)) at 42-50cm.

All four horizons display the heterogeneous separations of particle size classes described in profiles 1 and 2.

Rare undisturbed yellowish-brown argillans occur in the buried soil in the 3bAhg and 3bEb/Bw(g) horizons, but not in the horizons

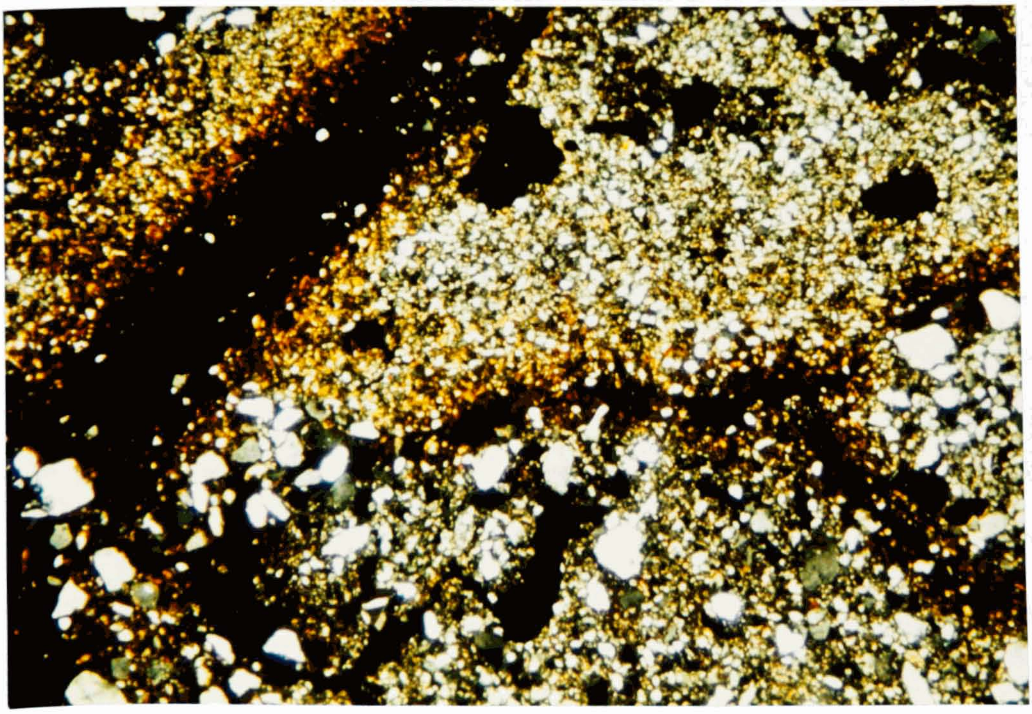


Fig. 10.14 Thin section from horizon 3 (Bw(g)), profile 2 Longslade Bottom.

Cross-bedded laminae of sand and silt grains. Frame length 3mm, cross polarized light.

above. As in profile 2, this may indicate that they were present before the deposition of the overlying colluvium. Rare yellowish-brown papules occur in the Ah horizon, which suggests that this horizon was partly derived from one or more pre-existing Bt horizons All four horizons have silasepic plasmic fabrics. A few ferruginous nodules and ferrans are present in all four horizons and a few ferruginous segregations occur in the 2Ahg/Bh, 3bAhg and 3bEb/Bw(g) horizons.

d) Synthesis

The outstanding micromorphological feature of every horizon in the three colluvial profiles is the heterogeneity due to patches of soil of different texture. The evidence of the additional vertical thin section from the Bw(g) horizon in profile 2 suggests that this is caused by the presence of laminae of different particle size classes. As the buried soils in profiles 2 and 3 also display these characteristics they too are probably formed of colluvium.

Mucher and De Ploey (1977) and Mucher _et al_., (1981) have noted the micromorphological characteristics of loess reworked by experimentally produced colluvial processes; rainsplash, flow without splash and rainwash (i.e. combined splash and flow). Rainsplash produces unsorted, non-laminated sediments. Flow without splash results in well-layered, cross-bedded sediments with excellent sorting. Rainwash forms poorly laminated, poorly sorted sediments with no cross bedding. Similar sedimentary structures have been found in naturally reworked loess (Mucher and De Ploey,1977; Vreeken and Mucher,1981; Mucher and Vreeken,1981).

The well sorted, cross-bedded silt laminae in the Bw(g) horizon of profile 2 may therefore have formed by flow without splash and the less well sorted laminae by rainwash. These processes probably also account for the sorting of particles found in the other thin-sections.

Mucher (1974) described the characteristic micromorphological features of colluvium formed from loess and found common matrans and matri-argillans thought to have formed as a result of intensive cultivation. No such features were found in the three profiles described here, so these soils may never have been intensively cultivated. The presence of argillans in the buried horizons of profiles 2 and 3 suggests that these were formerly Bt horizons, which must have been truncated prior to deposition of the overlying colluvium.

10.5 Discussion and Conclusions.

The micromorphology of the four profiles developed entirely in upper brickearth is similar to that of Flandrian soils developed in loess elsewhere in England. All the illuvial clay found was yellowish-brown or rarely reddish-orange, and in most cases about two-thirds of it was undisturbed. The plasmic fabrics of the Bt horizons were typically in-skelsepic and all the *in-situ* ferruginous concentrations found were brownish coloured. No fossil aggregates, embedded grain matrans or embedded grain argillans were found. Flandrian erosion of the Hook Gravel Pit and Sturt Pond profiles was suggested by the presence of argillans within the uppermost 30cm of the soil.

In contrast, all the horizons in the lower brickearth show a much stronger degree of pedological reorganization. They all display some or all of the following features: egg-yellow or red illuvial clay, of which a high percentage is disrupted; red ferruginous concentrations, masepic or stronger plasmic fabrics; greyish iron depleted zones; fossil aggregates, embedded grain matrans and embedded grain argillans; few macrovoids.

Some of the lower brickearth horizons are clearly pedologically more complex than others. It may be that the horizons described are of several ages, but the descriptive methods used are not precise enough to allow a complete subdivision of the horizons into their respective periods of formation. However, a simple bipartite subdivision can be made between horizons providing evidence of only one phase of interglacial soil formation, and those in which there is evidence of at least two phases of interglacial pedogenesis, separated by a period of cryoturbation.

The first group - the 'younger' lower brickearth - comprises the deposits at Lepe Cliff, Thorns Farm, Ocknell Plain, Holbury Gravel Pit (Horizon 4), Wootton Heath and Hordle Cliff. As only one interglacial phase of pedogenesis is evident in the horizons it is reasonable to suppose that this was the Ipswichian. Fossil aggregates and to a lesser extent embedded grain matrans and orbiculic orientations of skeleton grains are present in all these horizons except at Wootton Heath; in all but two cases they do not contain papules or irregular concentrations of egg-yellow clay, so these cryogenic features probably formed mainly during the Wolstonian cold period. At Hordle Cliff and Rockford Common Gravel Pit, the cryogenic features do contain disrupted egg-yellow clay, which suggests they may have formed during the Devensian. The evidence from all six sites suggests that fossil aggregate formation was far more pronounced during the Wolstonian than the Devensian.

Egg-yellow clay is common in all of the horizons except Wootton Heath, and the ferruginous concentrations present are dominantly brown or yellowish brown. However, red illuvial clay and ferruginous concentrations occur rarely in some horizons, which suggests that red colours were produced by Ipswichian soil formation, albeit not extensively. This agrees with Chartres(1980) evidence from the Kennet/ Valley.

The second group - the 'older' lower brickearth - comprises the deposits at Beaulieu Heath, Tanners Lane and Holbury Gravel Pit (Horizon 1). Evidence for two or more phases of interglacial soil formation in these horizons is provided by the occurrence of red segregations enclosing papules of red or egg-yellow clay, and/or fossil aggregates containing papules of red or egg-yellow clay separated by voids filled with red or egg-yellow clay. These horizons contain common red segregations also, and this is further evidence that they were weathered during the Hoxnian and perhaps earlier interglacial periods, when extensive rubification is known to have occurred (Avery _et al._, 1982).

The micromorphological analyses also indicate the periods of soil formation undergone by the undifferentiated brickearths. Horizon 2 (Eb) of the Rockford Common profile contains similar micromorphological features to Flandrian soils, as do horizons 1 and 2 of the Calveslease Copse profile, although the last two horizons also contain material probably derived from pre-existing paleoargillic horizons. Horizon 3 at Calveslease Copse contains evidence of interglacial pedogenesis _in-situ_, and part of the soil was probably derived from yet earlier paleoargillic horizons.

CHAPTER 11

DISCUSSION AND CONCLUSION.

11.1 Introduction

This chapter draws together evidence from the fieldwork (Chapters 4 and 5) and the various laboratory analyses (Chapters 6 to 10) to help explain the nature, origin and distribution of the brickearth, both at the selected sites and in general for the whole study area. This is done first for each of the selected sites in section 11.2, where the profiles are divided into four groups according to the oldest brickearth present: colluvium, upper brickearth, moderately weathered lower brickearth or strongly weathered lower brickearth. Sections 11.3 and 11.4 summarize the evidence for the age, environment of deposition, weathering and erosion of the upper and lower brickearth respectively in south Hampshire, and section 11.5 shows how this data can be used to infer minimum ages for some of the terrace surfaces. The principal conclusions of the work are presented in section 11.6.

11.2 The Development of the Selected Profiles

11.2.1 Profiles with strongly weathered lower brickearth

11.2.1.1 Beaulieu Heath (see also sections 5.2.4, 8.4.4, 9.3.2, 9.7.2 and 10.4.2.5)

This profile is one of the most complex studied and the sequence of events that formed it is consequently difficult to deduce. Sandy upper brickearth, equivalent to the lower parts of the upper brickearth, forms a thin layer (Ah/Ea, Bh and Bs(g) horizons) over the lower brickearth. The field and micromorphological evidence shows that sand has been mixed into the lower brickearth, either intimately or as discrete fissure fillings and pockets, probably after the interglacial soil characteristics were developed. The granulometric evidence suggests that this sand is upper brickearth (it has almost identical textural characteristics to the Eg horizon at the base of the upper brickearth at Thorns Farm), but the mineralogical evidence fails to confirm this, probably because podsolisation has caused severe weathering of the identifiable characteristic loess minerals and because the mixing of the upper and lower brickearth prevented an uncontaminated comparative sample of lower brickearth being obtained.

The intimate mixing of the upper and lower brickearth in the 2 E'g and 2 B'tg1 horizons could have been achieved by the Late Devensian cryoturbation or by early Flandrian bioturbation. The 2B'tg2 and 2B'tg3 horizons, in which the fissures survive, probably escaped much of this mixing. By implication, therefore, the fissures might originally have extended to the surface through what are now the 2B'tgl and 2E'g horizons. The origin of the fissures is not clear. Their association with a periglacial deposit (the upper brickearth) suggests they could be thermal contraction cracks, which form in periglacial regions when the ground surface freezes and contracts in winter (Embleton and King, 1975). These are often filled with other sediments either immediately after formation or later, after the melting of the ice-veins and wedges that sometimes occupy them. However, the pseudo-polygons which the fissures form in plan in the 2B'tg2 and 2B'tg3 horizons are only 3 to 5 cm, in diameter, and this is much smaller than normal for ice-polygons (Embleton and King, 1975). An alternative possibility is that the fissures originally formed during an interglacial period due to desiccation. Soils with desiccation cracks(vertisols) occur today in regions with a pronounced warm-dry season, such as the Western Mediterranean (Buringh, 1979) and this type of climate is thought to have been responsible for the formation of paleoargillic horizons during interglacials in England and N.W. France (Boulaine in Federoff, 1966;

Catt, 1979). Thus the fissures may have formed during the Ipswichian, but they would have had to survive Early and Middle Devensian cryoturbation in order to receive aeolian sand in the Late Devensian.

The micromorphological evidence suggests that the lower brickearth (2E'g and 2 B'tgl-3 horizons) was subject to pedogenesis during at least two interglacials and is thus probably at least as old as the Hoxnian. The texture of the deposit has been modified during its long post-depositional history by weathering, clay illuviation and mixing with other deposits such as the upper brickearth. Consequently its original nature is obscure and it is not possible to decide how it was deposited.

11.2.1.2 Tanners Lane (see also sections 5.2.7, 8.4.7, 9.7.5, and 10.4.2.8)

A thin layer of sandy upper brickearth (Ah(g) and Eb(g) horizons) overlies the lower brickearth (2Btgl-4 horizons) here; as at Beaulieu Heath, the field and micromorphological evidence shows that the two deposits are mixed near their junction, probably by cryoturbation, and sand-filled fissures are present in the lower brickearth. The micromorphological evidence of at least two phases of interglacial pedogenesis in the lower brickearth suggests the deposit was weathered during the Hoxnian and this agrees with the presence of common coarse red mottles (red segregations in thin section) in most horizons which are thought to be typical of Hoxnian and earlier interglacial pedogenesis (Chartres, 1980; Avery et al., 1982). Although this indicates that the lower brickearth has been weathered over a longer period than the other 5m terrace deposits, at Lepe Cliff and Thorns Farm, the Tanners Lane sediment nevertheless contains more weatherable silt minerals, which implies it must originally have had a much greater content of these minerals. The micromorphology of the 2Btg2 horizon suggests that the greyish appearance of some parts of the horizon is due to removal by weathering of iron oxide minerals. The same process might account for the absence of red mottles in the 2Btg3 horizon.

The main indicator of the origin of the lower brickearth is its content of smooth, rounded flint pebbles. These cannot have been introduced to the sediment from the underlying terrace gravel by cryoturbation because the terrace gravel here (as elsewhere) is composed of subangular flints. The pebbles were probably an original constituent of the deposit. Similar pebbly clays often occur within marine or estuarine sediments, such as those deposited in Southampton Water during the Flandrian (Hodson and West, 1972). Thus the lower brickearth here might be an estuarine or marine sediment; its time of deposition can only be estimated (from the micromorphological evidence) as Hoxnian or earlier.

11.2.1.3 Holbury Gravel Pit (see also sections 5.2.11, 9.3.8, 9.7.9, and 10.4.2.12)

This site is notable as the only one described with two layers of lower brickearth, one strongly weathered and the other moderately weathered. The two layers are clearly separable on field, granulometric and micromorphological evidence. The upper deposit (horizon 1) has common coarse red mottles, a very high clay content and evidence of more than one phase of interglacial soil development, whereas the lower deposit (horizon 4) has no red mottles, a moderately high clay content and micromorphological evidence of only one phase of interglacial pedogenesis. This suggests that normal stratigraphical relationships at the site are reversed, and the upper deposit is the older.

The field and micromorphological characteristics of the upper deposit are similar to those of the lower brickearth at Tanners Lane and Beaulieu Heath, and suggest that the material is at least as old as the Hoxnian. Sand appears to have been mixed into the horizon after the periods of interglacial pedogenesis and, as at Beaulieu Heath and Tanners Lane, this sand could have come from the upper brickearth. There is insufficient evidence of the original characteristics of the deposit to indicate its original mode of deposition.

The lower deposit has similar field colours and micromorphological characteristics to the lower brickearth at Lepe Cliff (section 11.2.2.1), Thorns Farm and Ocknell Plain (section 11.2.2.3) and like those sites it was probably weathered during the Ipswichian interglacial. However, the burial of the lower deposit by the upper may have altered the course of pedogenesis compared with other sites,so that the correlations with other sites can only be regarded as tentative. There is no positive evidence that the horizon was cryoturbated before illuviation of the egg-yellow clays, so unlike the other sites, it is possible that the material was deposited early in the Ipswichian. The complex (tri-modal) particle size distribution of the deposit suggests it is a mixed sediment, so it is not possible to determine its original mode of deposition.

A horizon equivalent to the older, upper deposit probably originally lay directly on the terrace gravel at this site; a similar red mottled horizon does so today in other parts of the gravel pit, and at the described site the colour and texture of the uppermost 10cm of gravel suggests a former presence of reddish lower brickearth. When this deposit was eroded (possibly by gelifluction in a pre-Ipswichian cold period), the almost bare gravel surface would have been free for deposition of the material now represented by the lower deposit. Subsequent gelifluction (probably during the Devensian) probably then moved the upper deposit material from another part of the terrace surface, where it had survived the earlier erosion, onto the surface of the lower deposit. This sequence of events is illustrated in Fig 11.1. The micromorphological evidence that the lower deposit is less disturbed by cryoturbation than many similar horizons elsewhere, may mean it was buried by the upper deposit beyond the depth of seasonal thaw in the Devensian period.

The equivalents of the red-mottled deposit resting on the gravel surface elsewhere in the gravel pit are penetrated from below by festoons of gravel. This suggests the flinty pockets in the upper deposit could have originated as festoons when the upper deposit lay on the gravel surface (Figs. 11.1 and 5.7).

11.2.2 Profiles with moderately weathered lower brickearth

11.2.2.1 Lepe Cliff (see also sections 5.2.5, 8.4.5, 9.3.3, 9.7.3, and 10.4.2.6)

The lower brickearth (2Bt horizon) at this site is clearly distinguishable from the upper brickearth (Ah, Eb and Bt horizons) on colour differences, granulometric evidence of a lower sand and a higher clay content, mineralogical evidence of a relative deficiency of weatherable minerals and micromorphological evidence of interglacial pedogenesis prior to a periglacial period.

The disturbed appearance of the lower brickearth noted in the field is probably due to cryoturbation, and this process would have disturbed the egg-yellow argillans seen in thin section. This cryoturbation probably occurred during the Devensian, but unlike the Beaulieu Heath profile (section 11.2.1.1) there is no evidence that the upper and lower brickearths have been mixed; the intact stone-line separating the two deposits suggests that at this site a period of sheet erosion preceded deposition of the upper brickearth.

As there is evidence of only one phase of interglacial clay illuviation in the lower brickearth, this probably occurred during the Ipswichian. However, the presence of fossil aggregates indicate

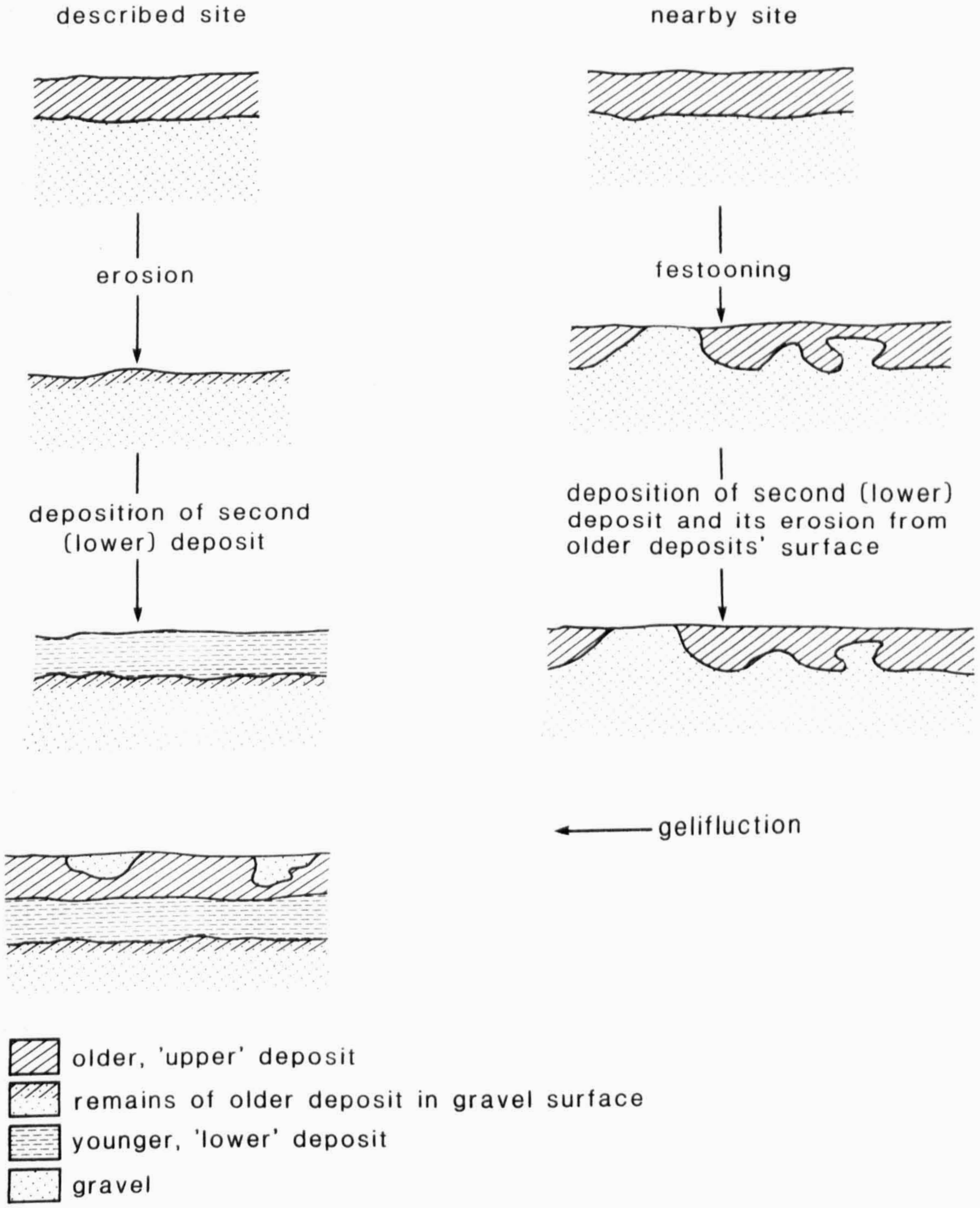


Fig. 11.1 Possible sequence of events producing the brickearth stratigraphy at Holbury Gravel Pit.

that the deposit could have been subject to cryoturbation before that, so it was probably deposited during the Wolstonian. The clay-free particle size distribution of the lower brickearth suggests the deposit could be loess; it conforms to Fink's (1976) definition of clayey loess (Table 3.1). The deposit is rich in clay compared with Late Devensian loess probably because that fraction has been augmented by Ipswichian weathering and clay illuviation.

11.2.2.2 Thorns Farm. (see also sections 5.2.6, 8.4.6, 9.3.4 9.7.4. and 10.4.2.7)

The lower brickearth (2Bt(g) horizon) here has similar field characteristics to that at Lepe Cliff, except that like the Beaulieu Heath, Tanners Lane and Holbury Gravel Pit profiles, the evidence suggests the upper and lower brickearths are mixed, probably by cryoturbation, and sand from the upper brickearth penetrates the lower brickearth in fissures. The arguments relating to the origin of the fissures in the Beaulieu Heath profile are equally relevant here. Despite the mixing of the two sediments, the granulometric, mineralogical and micromorphological evidence clearly distinguishes the upper and lower brickearth. The lower brickearth contains fewer weatherable minerals and has evidence of one period of interglacial (probably Ipswichian) pedogenesis that was both preceded and followed by periods of cryoturbation. It is therefore likely to have been deposited during the Wolstonian. As the lower brickearth is mixed with upper brickearth and to a lesser extent Plateau Gravel, it is difficult to assess its original particle size distribution and origin. However, the abundant embedded grain matrans in the 2Bt(g) horizon seem to have been present prior to the period of interglacial pedogenesis. The sand grains which form the core of these features might have been deposited with the lower brickearth during the Wolstonian, which suggests that the deposit was originally sandier than the Lepe Cliff lower brickearth.

11.2.2.3 Ocknell Plain (see also sections 5.2.8, 8.4.8, 9.3.5, 9.7.6 and 10.4.2.9)

Although the upper and lower brickearth seem clearly separated at this site by a stone-line, the mineralogical and granulometric evidence is less clear-cut. Unlike other sites, the upper brickearth is extremely silty at its junction with the lower brickearth and its particle size distributions measured at either 1φ or ¼φ intervals, have no exact equivalents in the upper brickearth elsewhere, although they do distinguish it from the lower brickearth in the profile. This indicates either local variation in the characteristics of the upper brickearth or modification of the deposit by mixing with the lower brickearth. Sandy upper brickearth was probably originally deposited at the site, as it is present nearby, at Rockford Common Gravel Pit. Its absence may be explained by erosion, possibly by the same sheet wash process that formed the stone line. The upper and lower brickearths are mineralogically quite similar, but this is probably because the amounts of weatherable species in the upper brickearth have been rapidly depleted by Flandrian podsolisation.

The lower brickearth has similar field characteristics to that at Lepe Cliff and Thorns Farm, and, as at those sites, the micromorphological evidence suggests it was subject to pedogenesis during only one interglacial period (probably the Ipswichian) with cryoturbation both before and afterwards. It was therefore probably deposited during the Wolstonian. In common with the Lepe Cliff lower brickearth, the deposit conforms to Fink's (1976) definition of clayey loess; they both have very similar coarse silt mineral suites, but their ¼φ particle size distributions differ which suggests they do not have exactly the same origin. Fluvial or marine processes could not have deposited the Ocknell Plain lower brickearth on the 113m terrace during the Wolstonian period because Late Pleistocene glacial sea levels are thought to have been well below Ordnance Datum (West, 1977). The aeolian origin indicated for the deposit by its texture is thus supported by its position on the 113m terrace.

11.2.2.4 Calveslease Copse (see also sections 5.2.9, 8.4.9, 9.3.6, 9.7.7 and 10.4.2.10)

The undifferentiated brickearths in horizons 1 and 2 have almost identical particle size distributions, which suggests they have the same source. Their overall brownish (10YR hues) colour is suggestive of Flandrian pedogenesis, but the reddish-brown (5 YR 4/4) colour of ped coats in horizon 2 is not. However, this may be due to its high sand content: rubification is known to proceed quickest in sandy soils, and similar reddish colours have been found elsewhere in sandy soils on Devensian and younger sediments (Ameryckx 1960; Federoff,1966; Bullock,1974). Moreover, there is no micromorphological evidence of <u>in-situ</u> interglacial pedogenesis. The mineralogical composition of horizon 2 closely resembles upper brickearth and its particle size distribution is similar to horizon 4 of the Wilverly Plain profile. These facts suggest horizons 1 and 2 are derived mainly from upper brickearth.

Micromorphology suggests that horizon 3 has undergone one period of interglacial pedogenesis, probably during the Ipswichian. This is supported by its colour and coarse silt mineralogy which are similar to other lower brickearth deposits. However, its fine sand mineralogy is very similar to that of horizon 2 (and upper brickearth) indicating that some sand from horizon 2 has been incorporated into the horizon. As there is no field evidence of a cryoturbated boundary between horizons 2 and 3, the mixing may have been accomplished by soil fauna.

The particle size distribution of horizon 4 suggests it is derived mainly from the Plateau Gravel. Its red colour suggests it too has undergone interglacial pedogenesis, but because of stoniness, no micromorphological samples could be collected to confirm this.

If the brickearth-filled ground depression at this site is a collapsed pingo (as suggested in section 5.2.9), then it must have been slowly filled over several Quaternary stages. When the ground ice in a pingo melts, the resulting enclosed depression is initially partly filled by slumping of the near-surface horizons that were originally displaced upwards by the ice-lens (West et al., 1974; West, 1977; Fig. 11.2). At Calveslease Copse, the non-stratified horizon 4 could have formed like this. Such an origin could explain why this horizon is distinctly redder than the overlying brickearth and the underlying stratified Plateau Gravel, because it might have been derived from soil weathered during an interglacial prior to formation of the ice mound

After the slumping of horizon 4, the basin began filling with brickearth. The distinct laminations in horizon 3 suggest that this was accomplished by fluvial deposition, and the evidence of one period of in-situ interglacial pedogenesis in the horizon suggests deposition occurred during the Wolstonian and/or early Ipswichian. Although some of the material in horizon 3 was derived from pre-existing paleoargillic horizons, most of the laminae are composed of silt with no evidence of prior pedogenesis. Former pedogenic coats on the silt grains could have been destroyed during fluvial transport, but it is equally likely that the grains are fresh, in which case the silt is likely to have been derived

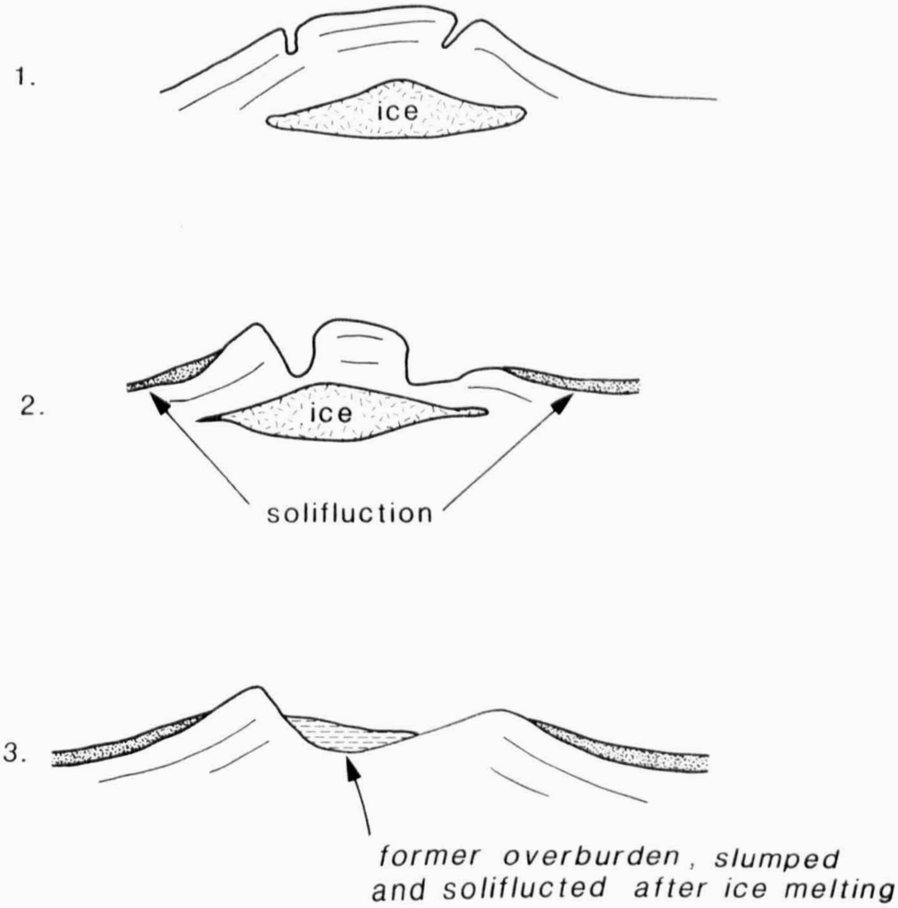


Fig. 11.2 Decay of a pingo (adapted from West, 1977, p.85).

from the same loess sheet that was probably deposited during the Wolstonian at Lepe Cliff and Ocknell Plain.

The final filling of the basin seems also to have been accomplished by fluvial deposition. Sheet erosion of freshly deposited upper brickearth and older paleoargillic horizons on the surrounding land surface probably supplied the sediment. It seems likely that this erosion occurred contemporaneously with the aeolian deposition of the upper brickearth, otherwise the depression would have been filled directly with upper brickearth. The absence of bedding in horizon 1 can probably be explained by subsequent cryoturbation or bioturbation.

11.2.2.5. Rockford Common Gravel Pit (see also sections 5.2.10, 8.4.10 9.3.7, 9.7.8, and 10.4.2.11)

The brickearths in horizons 2 and 3 were not differentiated (into upper and lower types) in section 5.2.10 because the field distinction between the two was insufficiently clear. However, the accumulated evidence of field colours, micromorphology and mineralogy shows that horizon 2 is upper brickearth and horizon 3 lower brickearth. This is remarkable, because their clay-free particle size distributions are almost identical and suggest that the horizons are both formed from aeolian sand. The micromorphology of horizon 3 suggests it was subject to pedogenesis during only one interglacial period, probably the Ipswichian. The colour of the horizon (yellowish red, 5YR 4/6) is slightly redder than other supposed Ipswichian soils described in the area, but this may be due to its relatively high sand content (as in the Calveslease Copse upper brickearth). The sand was probably deposited during the Wolstonian.

The granulometric and mineralogical evidence suggest that horizon 4 was derived from Plateau Gravel. Its red colour and very high clay content indicate that it has also been weathered during an interglacial period.

The observation that such similar sediments as horizons 2 and 3 were deposited at a single site during separate Quaternary cold stages needs further comment. A possible cause is that similar source sediments were available at both times. The Bracklesham Sands that outcrop nearby could have provided most of the medium and coarse sand in the samples, but the finer fractions must be from other sources. The relative abundance of weatherable minerals in horizon 2 compared with horizon 3 suggests that part of the fine sand and coarse silt was derived from beyond the local area, as has been postulated for the rest of the upper brickearth. A second possibility is that horizon 2 is composed of material derived from horizons equivalent to horizon 3, which was reworked and mixed with a little far travelled silt and sand during the late Devensian by the winds that deposited the rest of the upper brickearth. This is possibly the best explanation for the similarity between the two sediments.

11.2.2.6 Hordle Cliff (See also 5.2.12, 8.4.12 and 10.4.2.13)

The micromorphology and field colours confirm that the pocket of lower brickearth lying in the gravel surface at this site is paleoargillic, and this supports the assertion made in section 4.2.2 that, although lower brickearth is very rare on terraces at 46m O.D. or lower to the west of the Lymington River, it was once more extensive.

The occurrence of common coarse red mottles suggests that the lower brickearth has affinities with the red mottled lower brickearths at Beaulieu Heath, Tanners Lane and Holbury Gravel Pit (older deposit). However, the micromorphological evidence indicates only one period of interglacial weathering has occurred and this correlates it with the lower brickearths at Lepe Cliff, Thorns Farm, Ocknell Plain and elsewhere. In support of this, the main field colour is strong brown (not greyish as in the other red mottled horizons), and the red mottles appear as yellowish brown segregations in thin section (not red as in the other red mottled horizons). Thus the lower brickearth is equated with the horizons elsewhere supposedly weathered only during and since the Ipswichian, but its dissimilarity to those horizons in mottle colour illustrates the danger of using field colours alone to indicate the age of soil horizons.

11.2.2.7 Wootton Heath (see also sections 5.2.13, 8.4.13 and 10.4.2.14

The field, granulometric and micromorphological evidence all suggest that the entire soil profile at this site is developed in lower brickearth. The Btg1 horizon has similar field colours and micromorphological characteristics to the lower brickearth at Lepe Cliff, Ocknell Plain and elsewhere and, as at those sites, it seems to have undergone pedogenesis only during and since the Ipswichian. The particle size distribution of the Btg1 horizon is like that of the Ocknell Plain deposit in particular, and conforms to Fink's (1976) definition of clayey loess (Table 3.1). If it is loess, it was probably deposited in the cold Wolstonian period preceding the Ipswichian. The basal part of the lower brickearth, the Btg2 horizon, contains far more sand than the Btg1 horizon, but the horizon was not analysed mineralogically and micromorphologically, so it is impossible to say whether this is an original feature or due to mixing with another sediment.

11.2.3. Profiles developed entirely in upper brickearth - Sturt Pond, Wilverly Plain, Chilling Copse and Hook Gravel Pit (see also sections 5.2.1-3, 8.4.1-3, 9.3.1, 9.7.1, and 10.4.2.1-4)

All four of these profiles, developed entirely in upper brickearth, have similar field characteristics and vary mainly in the amounts of mottles and organans. Apart from the 2Bt horizon of the Hook Gravel Pit profile, they have brownish matrix colours throughout, as in the loess soils of West Sussex. (Hodgson, 1967) and many other soils weathered only during the Flandrian (Catt, 1979a). The 2Bt horizon at Hook Gravel Pit is slightly redder (7.5YR 6/8 to 5YR 5/8) than those of the others but as in horizon 2 at Calveslease Copse, (section 11.2.2.4) this may be due to its very high sand content. The micromorphological characteristics of each profile are also very similar and show the low complexity of pedological reorganization that is typical of Flandrian soils elsewhere (Bullock, 1974).

The sand content of all four profiles increases with depth. The greatest vertical variation occurs in the thickest profile, Chilling Copse, where the particle size distributions indicate that the sediment changes from typical loess at the surface to aeolian sand at the base. As the vertical sequence of changes in particle size distribution is repeated in all four profiles, the type of aeolian sediment being deposited at any one time during the Late Devensian was probably similar over a wide area. Also, post-depositional disturbance of the sediment, by cryoturbation or bioturbation, cannot have been very great. The very silty upper brickearth that is found at the surface at Chilling Copse is probably absent from the other three profiles because of erosion. The presence of argillans in the Ah horizon at Sturt Pond and the 2Eb/Bt horizon at Hook Gravel Pit shows that some erosion has occurred there since the onset of clay illuviation in the manner to the Australian sequences described by Butler (1959). The second and third colluvial episodes are represented in the colluvium overlying the bAh horizon in the Longslade Bottom profile, but the Scrape Bottom profile has evidence only of a second phase. It is only possible to say that these episodes occurred after the Late Bronze Age/Early Iron Age and it is not known whether the second colluviation was contemporaneous at the two sites. As formation of the colluvium above the buried Ah horizons was contemporaneous with agricultural activity at or near the sites, it is likely that the colluviation was initiated by agricultural practices. Bare cultivated or cleared soil surfaces on the valley slopes were probably eroded by rainsplash and flow without splash, which deposited the colluvium on the lower slopes and valley floors.

11.3 The Origin of the Upper Brickearth

11.3.1 Age and environment of deposition

The Late Devensian age of the upper brickearth given by the thermoluminescence dating (Chapter 6) is supported by micromorphological evidence that the deposit has undergone pedogenesis only during the Flandrian, the field evidence of cryoturbation which shows that it was deposited during or prior to a periglacial period, and its mineralogical affinities with Late Devensian loess elsewhere in England

Upper brickearth in the field area overlies lower brickearth and/or gravels on every terrace level. Such a distribution could not have been achieved by a single episode of marine or fluvial deposition; the only transporting agent that could reasonably account for this distribution is the wind. No evidence was found that the upper brickearth is a floodloam, as suggested by many previous authors (Swanson, 1968; Fisher, 1971; 1975; Keen, 1980); it is likely that this explanation was invoked to explain the high sand content of much of the upper brickearth compared to loess and the association of the deposit with the Plateau Gravel terraces.

Indeed, its particle size distribution is in fact consistent with an aeolian origin; the siltiest parts resemble loess and the sandiest resemble aeolian silty sands. The mineralogical analyses (section 9.8) suggest that at least 80% of the silt and some of the sand in the deposit was derived from outwith the Hampshire Basin, and this exotic component has a mineralogical assemblage similar to that of Late Devensian loess in other parts of England. As most of the Late Devensian loess of England seems to have been derived from glacial outwash in the North Sea Basin (Catt et al., 1971;1974;Eden 1980), that source probably provided the bulk of the exotic material in the upper brickearth. The granulometric (chapter 8) and mineralogical (chapter 9) evidence shows that the local components in the upper brickearth were probably derived from the Tertiary strata. As none of the described upper brickearth deposits actually rests on Tertiary deposits, the components from that source were probably transported by the same winds that carried the far travelled material. This is supported by the 10 particle size analyses, which suggest the upper brickearth was sorted by a single process. Such mixing of components would have been possible in the environmental conditions of the Late Devensian, when the land surface was sparsely vegetated (West,1977) and exposed outcrops of the unconsolidated Tertiary Sands would have been open to wind erosion.

The transition from aeolian sand to loess upwards in profiles in the upper brickearth emphasises the twin sources of the deposit. At the beginning of the Late Devensian aeolian phase, the upper brickearth was composed mainly of reworked local sand with the addition of a little far-travelled material (as represented, for example, by the Eg horizon at Thorns Farm and horizon 2 at Rockford

Common). As accumulation continued, the local sources of sand were perhaps progressively blanketed by it, so that the far travelled components eventually became the dominant constituent (as represented by the Ah horizon at Chilling Copse).

The vertical changes in the dominant peaks in the particle size distributions are less easy to explain. The ¼ Ø peaks in the sand fraction are probably reflections of peaks in the local Tertiary sands, but it is unclear why the 125-150μm peak increases in prominence with depth at the expense of the 63-75μm peak (section 8.5.2). It seems unlikely that there would have been a significant change in the range of source sediments available, so the solution to the problem is likely to be found in the mechanics of deflation and deposition of the sand. One possibility is that mean wind-speeds were greater in the early part of the aeolian phase so that proportionately more 125-150μm sand was deflated then.

The 26-31μm and to a lesser extent the 22-26μm peaks in the siltiest upper brickearth are consistent with the known westward decrease in the modal size of Late Devensian loess due to the winnowing effect of easterly periglacial winds (Catt, 1978). However, the twin peaks at 31-37μm and 44-53μm found in the moderately silty upper brickearth at Wilverly Plain, Hook Gravel Pit and Chilling Copse (section 8.5.2) indicate that there were probably two sources for the silt at that stage. The material peaking at 31-37μm could also have been carried from the North Sea Basin by the easterly winds and might reflect slightly stronger mean windspeeds earlier in the Late Devensian (as is also suggested by the changes in the sand peaks). The 44-53μm peak, however, is far coarser than would be expected according to the gradual westward decrease in the modal size of the

Late Devensian loess, and is therefore likely to represent material from another source. It might have come from silty Tertiary Strata, but this cannot be confirmed as no ¼ 0 analyses were made of the silt fractions of the Tertiary beds. A second possibility is that it represents loess blown from a different direction; although easterly winds probably dominated during the Late Devensian (Lill and Smalley, 1978), minor winds from other directions, especially westerlies blowing over the Irish Sea glacial outwash, could have carried some loess. Catt and Staines (1982) also reported loess in Cornwall and the Scilly Isles with a coarse 40-44μm peak which they thought was likely to have been deflated from the Irish Sea basin to the north and north-west. Clearly, more work is required on this topic to provide firm conclusions on the origin of the coarser silt peaks.

The upper brickearth is probably a continuation of the sheet of aeolian sediments that forms the brickearth of West Sussex (Hodgson, 1967) and the upper brickearth of the Portsmouth area (Palmer and Cooke, 1923). However, the West Sussex brickearth does not display the vertical transition from aeolian sand to loess that is present in south Hampshire. The south Hampshire deposits are atypical in this respect probably because of the presence of an unusually large area of exposed, unconsolidated fine sands of Tertiary age. No other known English loess deposits display the same vertical textural changes. In north-east Essex the Late Devensian loess is underlain by Late Devensian coversand, but the change from sand to loess seems to have been quite sudden and the sediments with silt/sand mixtures are thought to have arisen by post-depositional mixing (Eden,1980). Silt/sand mixtures deposited by the wind contemporaneously are known from Somerset (Gilbertson and Hawkins, 1978) and Norfolk (Catt et al., 1971) but in both cases the relative proportions of the two fractions were not reported as changing with depth.

11.3.2 Distribution and erosion

Except in a few places, the edge of large terrace fragments and over some of the very small terrace fragments, the upper brickearth completely mantles, but is almost exclusively confined to the Plateau Gravel outcrop. Although aeolian sediments are probably deposited fairly evenly throughout the landscape, their unconsolidated nature leaves them open to subsequent erosion. Catt (1977) showed that loess in England has been extensively eroded by fluvial and geliflual processes, particularly from over clayey and sandy substrata. These processes probably explain the absence of the upper brickearth from the Tertiary outcrop.

Moreover, it is clear from the studies of the selected profiles that the upper part of the depositional sequence of the upper brickearth is missing almost everywhere on the terrace sites, particularly where there is an intermediate layer of lower brickearth. Geliflection may account for much of this erosion, but since the head deposits that occur in many valleys have not been examined to ascertain their content of upper brickearth, this cannot be confirmed. The evidence from the Hook Gravel Pit profile (section 11.2.3) suggests that late Flandrian, probably fluvial, erosion was significant; this is supported by the evidence from the colluvial profiles studied (section 11.2.4) which also suggest that agricultural practices may have been partly responsible. Sheet erosion of the upper brickearth during the Late Devensian is indicated by the fluvially reworked upper brickearth in the Calveslease Copse fossil pingo and by the presence of stone lines at the base of the deposit at Ocknell Plain and Lepe Cliff. The relative importance of these three forms of erosion, gelifluction, Late Devensian sheet erosion, and Flandrian fluvial erosion, is not ascertainable on the incomplete evidence available in the New Forest; Catt (1978) suggested that erosion of the Late Devensian loess by Neolithic and later agriculture did not greatly change its general distribution throughout the country.

11.4 The Origin of the Lower Brickearth

11.4.1 Soil development and age

On the basis of the field and micromorphological data, the lower brickearth is clearly divisible into two groups whose characteristics are fairly constant on widely separated sites (tables 5.2. and 11.1) The first group, the 'older' lower brickearth (lower brickearth I) is characterised by greyish matrix colours and coarse red mottling, combined with a very complex microfabric that displays evidence of at least two phases of interglacial pedogenesis separated by periods of disturbance attributable to cryoturbation.

The second group, the 'younger' lower brickearth (lower brickearth II) has mainly strong brown matrix colours and contains reddish, normally very fine, mottles in some profiles only. The microfabrics of these horizons are clearly less complex than those of the lower brickearth I and only one phase of interglacial pedogenesis can be detected in them. The characteristics of the two groups are summarised in Table 11.1. This study has therefore identified three brickearths in South Hampshire, the upper brickearth and two lower brickearths. This compares with the findings of Palmer and Cooke (1923) in the nearby Portsmouth district; they also found three brickearths, the upper, middle, and lower, lying in stratigraphic succession.

Table 11.1

Summary of the characteristics of the lower brickearth

	Site	Dominant matrix colour	Reddest mottle colour and size	Micromorphology
GROUP I (older)	Beaulieu Heath	light grey (5Y 6/1)	coarse, red (2.5YR 5/8)	more than one phase of clay illuviation and/or rubification prior to yellowish-brown (Flandrian) clay illuviation
	Tanners Lane	light olive grey (5Y 6/2)	"	"
	Holbury Gravel Pit * (Horizon 1)	light grey (5Y 6/1)	coarse, red (10R 6/1)	"
GROUP II (younger)	Lepe Cliff	strong brown (7.5YR 5/8)	very fine, dark red (2.5YR 3/6)	one phase of clay illuviation prior to yellowish brown (Flandrian) clay illuviation
	Thorns Farm	"	no red mottles	"
	Ocknell Plain	"	very fine, dark red (2.5 YR 3/6)	
	Rockford Common	yellowish red (5YR 4/6) and strong brown (7.5YR 4/6)	no red mottles	"
	Holbury Gravel Pit (Horizon 4)	strong brown (7.5YR 5/8)	"	"
	Hordle Cliff	strong brown (7.5YR 5/6-8)	coarse, yellowish red (5YR 5/8)	"
	Wootton Heath	reddish yellow (7.5YR 6/8)	fine, red (2.5YR 5/6)	"

As the soils developed in the lower brickearth II have evidence of only one interglacial pedogenetic phase, it is suggested that this occurred during the Ipswichian. However, this conclusion must remain tentative in the absence of absolute dates for the deposition of the brickearth in which the horizons are developed. Clearly it would be of benefit to compare the results of this study with soils developed in material of proven Wolstonian age. However, the agreement in pedological characteristics between the supposed Ipswichian soils of south Hampshire with those of the Kennet Valley (Chartres) 1980), despite wide textural differences, does suggest that the same techniques might be used to recognise soils of similar age elsewhere in southern England.

The older lower brickearth I soils were probably weathered during the Flandrian, Ipswichian, Hoxnian and perhaps earlier interglacials, but their microfabrics are too complex for further subdivision by the simple descriptive micromorphological techniques used in this study. Similarly complex (and reputedly Hoxnian or earlier) horizons were described by Bullock and Murphy (1979) and Chartres (1980) who also found it impossible to separate all the phases of pedogenesis and cryoturbation that the soils had undergone.

The division of the lower brickearth into two groups I (= Hoxnian weathering) and II (= Ipswichian weathering) has been based on relative dating principles. However, the Geological Society's Quaternary sequence (Mitchell et al., 1973) is probably over simplified, and in particular there is some doubt that the Ipswichian represents only one interglacial (Sutcliffe, 1975; 1976) Therefore strict application of relative dating principles could be used to infer that the older lower brickearth I has been weathered only during and since an earlier 'Ipswichian' interglacial. This seems unlikely on current knowledge of Quaternary soils because no studies of Ipswichian deposits elsewhere in southern England have revealed evidence of two periods of clay illuviation, the earlier accompanied by intense rubification, separated by a period of cryoturbation. Such a sequence of events would be required to explain weathering of both the South Hampshire lower brickearths during the Ipswichian only. Although there may have been more than one warm period between the Hoxnian and Flandrian periods, clay illuviation and rubification need not have occurred each time; both these pedological processes seem to require prolonged periods of environmental conditions found only at interglacial maxima. Indeed, Evans (1971) thought the evidence from deep-sea cores indicated only one prolonged fully warm period among the supposed 'Ipswichian' interglacials. Therefore, even if several warm periods are eventually proved for the period now represented by the Wolstonian/Ipswichian, it is still likely that the lower brickearth I is Hoxnian or older.

11.4.2 Mode of deposition.

The original depositional environments responsible for the lower brickearth (I and II) sediments can be inferred in only a few cases because of the extent of post depositional weathering and mixing with other deposits, such as the upper brickearth and the Plateau Gravel. At least three of the younger lower brickearth II deposits, at Lepe Cliff, Ocknell Plain and Wootton Heath, may be composed of loess, and part of the interglacial sediments filling the Calveslease Copse fossil pingo (section 11.2.2.4) may originally have been derived from loess. None of these can be correlated mineralogically with supposed Wolstonian loess described elswhere in England (Catt, pers comm; Avery et al., 1982) but for the mineralogy to be similar, the loess deposits would have to have had similar source materials and weathering histories. The Rockford Common lower brickearth could be Wolstonian aeolian sand.

The presence of these pre-Devensian aeolian sediments in the area suggests that similar environmental conditions prevailed during the Wolstonian and Late Devensian. Interestingly, the middle brickearth of Palmer and Cooke (1923) is also composed of loess and sands. However, re-investigation of the Portsmouth deposits is required before the equivalence of these deposits can be assumed, as Palmer and Cooke's descriptions were not sufficiently detailed.

The lower brickearth I deposit at Tanners Lane is possibly estuarine in origin and some of the other lower brickearths may yet prove to be fluvial or marine sediments. Fine-grained sediments associated with terrace aggradation have been reported in analogous situations elsewhere, such as the Thames Valley, and are therefore likely to have been deposited in south Hampshire as well.

11.4.3 Distribution and erosion

The lower brickearth is less widely distributed than the upper brickearth (Fig. 4.2) probably as a result of the greater erosion it has undergone. Similarly, lower brickearth II deposits are far more widespread than lower brickearth I deposits. It is interesting to note that no sites were found where lower brickearth II overlies lower brickearth I. This is probably because lower brickearth II deposits were easily eroded from the surface of the relatively impermeable clayey, older lower brickearth I deposits in an analagous way to that in which much of the upper brickearth has been eroded from the surface of the lower brickearths. This implies that sheet erosion was responsible for some destruction of the lower brickearth II, and direct evidence of this is to be found in the stone lines at Lepe Cliff and Ocknell Plan (section 4.3.2). Gelifluction is also likely to have been significant in eroding both lower brickearths, however, as shown by the presence of the gelifluctеd horizon 1 at Holbury Gravel Pit (section 11.2.1.3).

11.5 Implications for the Terrace Chronology of South Hampshire

Chartres (1980) studies of soils in the Kennett Valley demonstrated that a sequence of soils exists there, in which the degree of pedological reorganization increases on successively higher (and reputedly older) terraces. The soils thus reflect the age of the surfaces on which they lie. This study suggests, however, that in south Hampshire the situation is more complex. Former mantles of lower brickearth have been partly or completely eroded from some terraces and lower brickearth I and II horizons often co-exist on the same terrace. As a result the soils on some relatively old terraces, for example the 113m terrace at Ocknell Plain, may be younger than the soils on younger terraces, such as the 46m terrace at Beaulieu Heath. This study therefore confirms Fisher's (1975) conclusion that a chronosequence of soils is not recognisable in the area. The soil characteristics only provide a tentative guide to the minimum age of the terrace surfaces (Table 11.2)

This last conclusion has important implications for the dating of the 5m terrace. As outlined in Chapters 2 and 5, this terrace is thought to have formed during the Late Ipswichian/Early Devensian transition (Brown <u>et al</u>., 1975; Keen, 1980) because Ipswichian deposits reputedly underlie it at Lepe Cliff (Reid, 1893; West and Sparks, 1960; Brown <u>et al</u>., 1975). However, lower brickearth II overlies the 5m

Table 11.2

Minimum ages of the terraces from soil evidence

Site	Terrace level	Age of weathering features	Minimum terrace age
Lepe Cliff	5m	Ipswichian	Wolstonian
Tanners Lane	5m	Hoxnian	Anglian (1)
Chilling Copse	11m	Flandrian	Devensian (2)
Hordle Cliff	21m	Ipswichian	Wolstonian
Beaulieu Heath	46m	Hoxnian	Anglian
Wootton Heath	56m	Ipswichian	Wolstonian
Rockford Common	70m	Ipswichian	Wolstonian
Ocknell Plain	113m	Ipswichian	Wolstonian

Notes:

1. the 5m terrace could be composite - see text
2. Lower brickearth was found on the 11m terrace during the field survey, which suggests that the terrace is at least of Wolstonian age.

terrace gravel at Lepe Cliff and Thorns Farm, and at Tanners Lane it is overlain by lower brickearth I. These deposits contain pedological features that almost certainly were formed during the Ipswichian interglacial or earlier; if these features were formed while the lower brickearth deposits were <u>in-situ</u> on the 5m terrace, then the dating of the terrace needs revision. It is possible that the lower brickearths at these sites were transported from a higher terrace to the 5m terrace by gelifluction and that the interglacial pedogenesis occurred on the higher terrace. The continuity of slope necessary for such transportation is present today at Tanners Lane and Thorns Farm, but not at Lepe Cliff where the terrace fragment is bounded by valleys on all landward sides. However, one of the valleys is relatively shallow and could have been formed during the Devensian or Flandrian periods. If the 5m terrace was unbroken during the Devensian, up to its junction with the bluff separating it from the next highest (21m) terrace, gelifluction could have carried soil from the 21m terrace onto the more recent 5m terrace. However, at each site this would require movement of material over a distance of 1-2km on slopes generally less than 1^{o} and often less than 0.5^{o}. Although gelifluction deposits are known to move on 0.5^{o} slopes (Williams, 1968) and to travel up to 2km (Embleton and King, 1965, p.106) it would be exceptional to have a deposit formed at the limits of both slope and distance. Furthermore, the Tanners Lane lower brickearth is unusual in its content of rounded pebbles, and no similar deposits from which it could have been derived occur on any of the higher terraces. Perhaps the most significant relevant piece of evidence is the fact that so many egg-yellow clay bodies occur in all three deposits and apparently undisturbed red segregations occur in the Tanners Lane deposit: it is very unlikely that these features could have survived prolonged transportation in a saturated deposit. Indeed Avery (1980) implies that characteristic features of paleoargillic horizons survive only in material that is either <u>in-situ</u> or has been transported over a short distance.

Thus it seems most likely that the lower brickearths at the three sites developed their paleoargillic characteristics whilst emplaced on the 5m terrace, which implies that the terrace must pre-date the Ipswichian. As the Tanners Lane lower brickearth seems to have been weathered during at least two interglacials, the terrace gravel there may pre-date the Hoxnian. In the Portsmouth area Palmer and Cook (1923) also described upper and middle brickearth overlying a 5m terrace.

Of the supposed Ipswichian estuarine deposits at Lepe Cliff only the pebbly clay undoubtedly underlies the 5m terrace gravels (see Fig. 5.2 Chapter 5). An incorrect dating of the terrace could have been made if the pebbly clay were much older than the Ipswichian organic estuarine deposits which overlie it on the foreshore. These organic deposits could originally have been banked against the terrace gravel. There must have been a break in sedimentation between the deposition of the pebbly clay and the lowermost organic estuarine deposit because the surface of the pebbly clay is eroded. Moreover, unlike the overlying organic deposits, the pebbly clay contains no plant macrofossils or molluscs. Its main link with the Ipswichian sequence is its pollen spectrum which, at the site it was sampled, could have been derived from the overlying organic beds (Moore and Webb, 1978). The range of species present in the spectrum is less than in most of the overlying beds. More detailed studies of the distribution, morphology and fossil content of the pebbly clay must be made before firm conclusions can be drawn about its age,and thus, the age of the overlying gravel. Another scenario which could explain the incorrect dating of the 5m terrace at Lepe is if the organic deposits actually belong to one of the other interglacials thought by Sutcliffe (1975; 1976) and others to have occurred during the Wolstonian-Ipswichian period (see section 11.4.1). Sutcliffe (1975) thought it possible that when two warm periods occurred close together, their botanical successions would be similar, so the periods could not be distinguished on paleobotanical evidence. At Lepe Cliff, the pollen assemblage of the organic deposits might belong to a subsidiary warm period prior to the main 'Ipswichian' interglacial; the gravels between the organic deposits and the lower brickearth II might then have been deposited during the intervening cold period (stage 3c of Evans; 1971). This cold period is part of what is conventionally thought of as the Wolstonian. The suggested Hoxnian age of the pedological features in the Tanners Lane lower brickearth I implies, however, that the underlying 5m terrace gravel there is at least of Anglian age. This casts doubt on the possiblity that the Lepe Cliff 5m terrace could be Wolstonian, but it is conceivable that the 5m terrace is composite and represents two terraces formed during the Anglian and Wolstonian periods respectively; certainly, the Lepe Cliff and Tanners Lane terrace (gravel) surfaces are presently at slightly different levels :+7m and -1m O.D. respectively.

11.6 Summary

In chapters 1 and 2 previous work relating to the origin and age of the south Hampshire brickearth was reviewed, and showed that it was generally thought to be a floodloam, although depositional processes such as aeolian, gelifluction and marine may have contributed to it. No previous work has proposed subdivisions of the deposit, although it has been thought to be composed of sediments of several ages. Its relationship with the most widespread Quaternary brickearth elsewhere in southern England-Late Devensian loess-was not known.

This study has mapped the distribution of the deposit and has shown that it is much more widespread than previously thought. Evidence has been presented which demonstrates that the brickearth is divisible into at least three units - upper brickearth, lower brickearth I and lower brickearth II. The upper brickearth is the most widespread of the three. It is aeolian, largely in-situ and is contemporaneous with the Late Devensian loess elsewhere in England, but is different from the other loess in that a large component is locally derived and that it changes gradually upwards in profiles from aeolian sand to loess. Lower brickearth II is the next most widespread and seems to be composed mainly of aeolian sediments also. It was subject to pedogenesis in the Ipswichian period and was probably deposited during the Wolstonian. Lower brickearth I is the oldest and least widespread; it was weathered during the Hoxnian. Its origin is largely obscure, but at least some could be estuarine.

In clarifying the distribution, origin and age of the brickearth, this study has contributed more generally to the poorly known Quaternary history of south Hampshire. It has identified a variety of erosional and depositional environments that occurred during periglacials and the weathering environments of interglacials. In particular, soil studies have helped towards dating the 5m, and to a lesser extent higher terraces. The work is therefore an example of the valuable contribution that detailed field and petrographic studies of soils can make to Quaternary history in areas where other, more reliable, evidence is scarce.

APPENDIX A

Method of Particle Size Analysis

a) 1Ø Intervals

1) Pretreatment and dispersion

Air-dry and weigh the bulk sample and record the mass (T). Place sample in a Rukuhia soil crusher with a 2mm drum. Record the mass (S) of the stones returned on the drum. The stone content is calculated:

$$\text{Stones} > 2\text{mm } \% = \frac{S}{T} \times 100$$

Weigh a 20-30g subsample of 2mm air-dry soil to 0.0001g and record the mass (M_1). Place in a 600ml beaker and cover with 10-20% Hydrogen Peroxide (H_2O_2) . Some very organic samples require gentle heating to initiate the reaction. Add more H_2O_2 dropwise as the reaction subsides until no further reaction occurs. Let the sample stand for about 4 hours then dilute to 200ml. with de-ionised water and boil until all excess H_2O_2 is removed.

Wash the sample into a shaking bottle with de-ionised water, add 20ml Calgon (Bascomb and Bullock, 1974) and shake overnight.

2) Fractionation

Wash the contents of the bottle, through a 63um sieve on a funnel, into a 1000ml measuring cylinder. Make up the contents to 1000ml with de-ionised water. Dry the sand retained on the 63µm mesh at 105° C, place on a nest of sieves (1000, 500, 250, 125 and 63µm) and shake for 10 minutes. Weigh the material retained on each sieve and that passing the 63um sieve to ± 0.001g and record masses $A_1 \ldots A_6$ respectively

Equalise air and sedimentation tube temperatures in a room where air temperature varies within ± 2°C over the sedimentation period. Homogenise the sample with a stirrer, start the clock and extract a 20ml aliquot immediately using a calibrated pipette on a racking stand. Extract 4 more aliquots at times relevant to the sedimentation of the fractions<31,<16,<8 and<4um at 20cm depth. The $<2\mu m$ fraction is pipetted at 8cm depth to save time. A chart of sedimentation times for these fractions at various temperatures can be constructed using nomographs published by Tanner and Jackson (1947). Transfer the aliquots to crucibles that have been pre-weighed to ±0.0001g and their masses recorded $C_1 \dots C_6$ Dry crucible and aliquot at 105° C, reweigh and record the masses $Z_1 \dots Z_6$

To make a correction for the moisture content of the sample weigh a crucible (C_7) to ± 0.001g, ¾ fill with air-dry soil and weigh again (X_1). Dry overnight at 105° C and re-weigh (X_2). The moisture content is calculated:

$$\text{moisture content } \% = 100 - \left(\frac{X_2 - C_7}{X_1 - C_7} \times 100 \right)$$

The equivalent dry weight of soil in the original sub-sample is calculated:

$$\text{equivalent dry weight } (M_2) = M_1 - \left(\frac{M_1 \text{ x moisture content}}{100} \right)$$

To make a correction for the Calgon content of the suspension pipette 20ml of Calgon into a 1000ml measuring cylinder and make up to 1000ml with de-ionised water. Mix, extract 3 20ml aliquots using the racking pipette, and place into 3 crucibles pre-weighed to ± 0.0001g ($C_8 \dots C_{10}$). Dry at 105° C and re-weigh. ($G_1 \dots G_3$). The Calgon correction is callculated from the mean of the three values :

$$\text{Calgon content } (Y) = G_{1 \dots 3} - C_{8 \dots 10}$$

3) Calculations

The percentage of material in each of the sand fractions is determined:

e.g. $\% \ 63\text{–}125\text{um} = \frac{A_5}{M_2} \times 100$

The percentage coarse silt passing the 63μm sieve after dry sieving is also determined by the above formula and the result is added to the percentage 31–63μm silt calculated from the formulae below

Percentage silt and clay having less than the given equivalent diameters

e.g. $\% < 63\mu m = \left(\frac{Z_1 - C_1 - Y}{M_2} \right) \times 50$

Due to the destruction of organic matter and minor losses of sediment during analysis, the sum of the various fractions is usually between 95 and 100%. Samples within these limits are rounded pro-rata to 100%; those outside the limits should be re-analysed.

b) ¼ Ø intervals

Pretreat and disperse samples as for 1Ø intervals. Wash sample in shaking bottle, through a 63μm sieve, into a 1000ml cylinder as for 1Ø analysis. Dry material returned on the 63μm mesh, place on a nest of sieves (250, 210, 180, 150, 125, 105, 90 and 63μm) and weigh material on each sieve as for 1Ø analysis but returning material passing the 63μm sieve to the suspension

Equalise air and sedimentation tube temperature, homogenise sample and remove 20ml aliquots at 20cm depth at times relevant to the sedimentation of the fractions <52.6, <44.2, <37.2, <31.3, <26.3, <22.1, <18.6, <15.6μm. The sedimentation times can be calculated from the equation:

$$t = \frac{k}{D^2} \times h$$

where t = time (secs), D = particle diameter (cm), h = height of fall (cm) and k is a temperature dependant constant (Tanner and Jackson, 1947). Great care must be taken to disturb the

the suspension as little as possible when lowering and raising the pipette.

Calculations and corrections are made as for 10 analysis.

APPENDIX B

PARTICLE SIZE ANALYSIS RESULTS

The particle size distributions of each of the samples discussed in the text are presented below. The values for mean, sorting, skewness and kurtosis were computed from recalculated clay-free distributions. The location and context of each of the samples can be determined from appendix D.

sample: phi	1	2	3	4	5
0 to -1:	2.3	0.9	2.6	0.9	1.5
1 to 0:	4.0	1.2	4.4	4.2	3.4
2 to 1:	4.8	2.4	6.4	8.8	5.8
3 to 2:	3.8	3.7	4.6	6.5	5.2
4 to 3:	5.8	14.2	11.0	10.0	8.5
5 to 4:	14.7	22.0	21.3	21.5	22.1
6 to 5:	16.6	17.1	13.5	19.4	21.5
7 to 6:	11.9	13.6	14.6	12.4	16.9
8 to 7:	8.9	9.1	9.6	6.8	7.6
9 to 8;	5.7	3.6	2.7	2.7	1.5
>9:	21.5	12.2	9.3	7.0	6.0
mean:	4.9516	4.9622	4.5259	4.5472	4.8061
sorting:	2.2872	1.7846	2.1663	2.0418	1.9182
skewness:	-0.1979	0.0441	-0.1349	-0.1552	-0.1893
kurtosis:	1.1759	1.0362	1.0559	1.0572	1.2087

sample:	6a	6b	7	8	9
phi					
0 to -1:	1.2	0.3	0.8	1.6	0.3
1 to 0:	1.6	0.6	3.5	6.1	1.8
2 to 1:	3.7	1.4	5.0	10.4	4.1
3 to 2:	4.4	1.9	19.1	15.4	6.3
4 to 3:	6.4	4.1	33.0	35.6	27.9
5 to 4:	22.6	14.3	8.2	8.4	17.7
6 to 5:	24.5	16.4	7.7	6.1	11.8
7 to 6:	21.3	8.7	5.0	4.0	7.2
8 to 7:	6.5	4.5	3.5	3.9	4.5
9 to 8;	1.0	13.5	32.7	21.9	3.3
>9:	6.8	44.3	11.5	6.6	15.1
mean:	5.0771	5.3401	3.7643	3.4630	4.4158
sorting:	1.6479	1.6510	1.7472	1.8008	1.7573
skewness:	-0.1797	0.0385	0.2549	0.0938	0.2459
kurtosis:	1.2213	1.2633	1.3759	1.5733	1.1890

sample:	10	11	12	13	14
phi					
0 to -1:	2.5	1.7	1.5	1.7	0.6
1 to 0:	5.6	6.3	3.7	4.1	1.5
2 to 1:	12.9	11.4	10.4	5.8	2.5
3 to 2:	20.9	11.5	8.1	8.1	4.8
4 to 3:	17.0	23.0	15.8	26.2	13.8
5 to 4:	8.9	14.9	18.0	11.5	17.6
6 to 5:	8.6	8.8	14.2	10.4	20.9
7 to 6:	6.3	6.0	8.1	7.0	13.8
8 to 7:	4.7	3.5	4.6	5.0	8.5
9 to 8;	2.7	2.6	3.0	3.8	3.6
>9:	9.9	10.3	12.6	16.4	12.4
mean:	3.5330	3.6927	4.1676	4.1463	5.0719
sorting:	2.1475	2.0501	2.0948	2.0806	1.8014
skewness:	0.2271	0.0599	-0.0448	0.1649	-0.0516
kurtosis:	1.0273	1.0929	1.0140	1.2168	1.0294

sample:	15	16	17	18	19
phi					
0 to -1:	2.6	2.4	1.7	1.3	1.2
1 to 0:	9.1	3.2	2.9	2.4	6.7
2 to 1:	13.4	3.7	4.0	3.2	11.4
3 to 2:	6.0	2.7	5.4	5.9	8.2
4 to 3:	14.2	16.1	15.9	21.2	13.2
5 to 4:	13.3	17.0	18.7	18.5	15.1
6 to 5:	9.6	17.6	17.0	15.4	13.5
7 to 6:	7.5	9.8	9.3	9.0	7.9
8 to 7:	5.0	6.1	6.6	5.5	4.7
9 to 8;	3.5	4.1	4.1	4.1	3.5
>9:	15.8	17.3	14.4	13.5	14.6
mean:	3.7727	4.6890	4.6577	4.6061	4.0448
sorting:	2.4395	2.0841	2.0308	1.9272	2.2631
skewness:	-0.0241	-0.0403	-0.0047	0.0935	-0.0449
kurtosis:	0.8346	1.2591	1.1830	1.1613	0.9013

sample:	20	21	22	23	24
phi					
0 to -1:	3.5	0.6	2.6	1.8	0.5
1 to 0:	7.2	1.6	4.4	2.8	2.0
2 to 1:	10.2	3.1	9.2	5.4	5.2
3 to 2:	8.7	5.9	9.8	5.7	7.7
4 to 3:	14.7	16.9	12.6	25.5	15.1
5 to 4:	13.9	21.0	15.9	17.5	15.1
6 to 5:	9.9	22.6	13.2	11.4	17.0
7 to 6:	7.5	13.0	8.6	7.3	7.6
8 to 7:	4.5	6.7	6.2	4.8	8.7
9 to 8;	4.6	3.6	3.6	4.1	1.4
>9:	15.3	5.0	13.9	13.7	19.7
mean:	3.8999	4.8879	4.1876	4.3272	4.5869
sorting:	2.3976	1.7606	2.2849	1.9785	1.8967
skewness:	0.0232	-0.0151	-0.0483	0.1500	-0.0211
kurtosis:	0.9331	1.1009	0.9539	1.2548	1.0323

sample:	25	26	27	28	29
phi					
0 to -1:	0.8	1.0	2.6	2.4	1.8
1 to 0:	1.1	2.2	2.8	4.4	2.1
2 to 1:	1.6	3.5	3.4	6.8	2.0
3 to 2:	3.3	2.8	2.9	7.0	3.8
4 to 3:	14.3	16.0	14.8	12.5	13.5
5 to 4:	20.4	20.0	17.6	18.1	16.4
6 to 5:	19.4	18.3	17.4	13.2	18.8
7 to 6:	11.3	10.3	10.4	8.2	12.5
8 to 7:	6.4	5.9	6.1	5.1	8.6
9 to 8;	3.7	4.9	4.3	3.9	6.2
>9:	17.7	15.1	17.7	18.4	14.3
mean:	5.0345	4.8607	4.8270	4.3149	5.0861
sorting:	1.7109	1.8938	2.0804	2.2173	2.0295
skewness:	0.0467	0.0221	-0.0500	-0.0785	-0.0498
kurtosis:	1.1154	1.2432	1.2739	1.1164	1.1247

sample:	30	31	32	33	34
phi					
0 to -1:	1.8	0.4	2.0	1.7	1.8
1 to 0:	2.6	0.8	3.5	2.1	3.9
2 to 1:	2.9	1.9	7.3	6.3	11.8
3 to 2:	4.2	3.8	16.8	18.7	27.4
4 to 3:	11.3	11.2	26.4	23.6	17.6
5 to 4:	20.2	20.1	9.0	8.6	7.1
6 to 5:	19.5	20.0	9.8	8.7	8.4
7 to 6:	10.8	9.9	5.7	6.9	8.4
8 to 7:	7.3	5.9	3.7	5.3	6.4
9 to 8;	3.5	3.5	2.7	4.1	0.7
>9:	15.9	22.5	13.1	14.0	6.5
mean:	4.8545	5.0502	3.7835	4.0396	3.5915
sorting:	1.9458	1.6592	1.9713	2.0811	2.0187
skewness:	-0.0741	0.0277	0.1957	0.2973	0.3334
kurtosis:	1.2966	1.2141	1.1339	1.0104	0.9578

sample:	35	36	37	38	39
phi					
0 to -1:	0.7	2.4	1.8	1.4	0.7
1 to 0:	2.0	5.5	1.9	3.0	1.4
2 to 1:	7.7	14.2	2.0	4.4	2.1
3 to 2:	24.6	21.8	6.3	4.4	1.7
4 to 3:	28.9	24.1	22.7	29.1	21.8
5 to 4:	9.2	6.9	14.5	16.8	15.8
6 to 5:	8.8	5.8	15.5	12.3	16.4
7 to 6:	6.3	4.0	9.6	7.4	10.2
8 to 7:	4.8	3.3	5.1	4.8	6.1
9 to 8;	2.6	2.5	3.7	3.5	5.4
>9:	4.4	9.5	16.9	12.9	18.4
mean:	3.8047	3.2661	4.5973	4.3595	4.9514
sorting:	1.7894	1.9225	1.9378	1.8922	1.8484
skewness:	0.3098	0.1909	0.1045	0.2228	0.1169
kurtosis:	1.1193	1.4575	1.1150	1.2643	1.0458

sample:	40	41	42	43	44
phi					
0 to -1:	1.4	0.9	2.2	3.0	2.1
1 to 0:	2.0	4.3	4.0	5.5	4.0
2 to 1:	2.7	9.7	5.3	7.5	6.9
3 to 2:	2.7	10.6	11.6	13.5	6.9
4 to 3:	14.9	20.3	27.4	28.7	27.6
5 to 4:	15.9	11.2	13.0	9.7	12.3
6 to 5:	17.7	9.2	9.9	7.5	6.4
7 to 6:	10.8	6.3	6.8	5.5	11.1
8 to 7:	6.8	4.2	4.3	3.3	3.7
9 to 8;	4.5	3.3	2.9	2.6	2.2
>9:	20.6	20.2	12.6	13.2	16.8
mean:	4.9357	3.9468	3.9807	3.6157	4.0152
sorting:	1.9588	2.1174	1.9910	1.9867	2.0251
skewness:	-0.0317	0.1381	0.1424	0.1044	0.1234
kurtosis:	1.1459	1.0224	1.2579	1.2993	1.2059

sample:	45	46	47	48	49
phi					
0 to -1:	1.0	2.0	1.9	1.1	1.4
1 to 0:	4.4	4.0	3.7	2.1	3.9
2 to 1:	8.5	5.1	7.2	5.4	7.1
3 to 2:	16.4	11.6	16.4	16.6	16.5
4 to 3:	23.4	34.7	24.0	28.6	27.1
5 to 4:	9.2	9.5	9.5	9.0	10.2
6 to 5:	8.6	6.9	8.2	7.7	7.5
7 to 6:	6.9	6.4	7.4	5.8	6.7
8 to 7:	3.8	4.3	5.4	4.4	4.0
9 to 8;	3.4	2.9	3.7	3.3	4.7
>9:	14.4	12.6	12.6	16.0	10.9
mean:	3.8441	3.8678	3.9577	3.9536	3.9286
sorting:	2.0585	1.9047	2.1254	1.8762	2.0551
skewness:	0.2228	0.2052	0.2331	0.2876	0.2542
kurtosis:	1.0700	1.5017	1.0553	1.1895	1.1995

sample:	50	51	52	53	54
phi					
0 to -1:	1.4	4.2	2.2	2.1	1.7
1 to 0:	2.6	10.2	5.4	4.4	3.5
2 to 1:	5.4	13.0	9.3	8.7	8.0
3 to 2:	12.1	12.6	15.9	14.2	16.0
4 to 3:	24.7	18.0	24.0	22.7	30.0
5 to 4:	12.9	8.4	9.0	10.4	7.9
6 to 5:	10.7	7.7	8.8	8.6	6.6
7 to 6:	7.5	5.6	5.8	6.5	5.2
8 to 7:	4.8	3.9	4.1	4.9	3.9
9 to 8;	4.6	3.1	3.3	5.5	2.3
>9:	13.3	13.3	12.2	12.0	14.9
mean:	4.2464	3.3404	3.1855	3.9776	3.6836
sorting:	2.0338	2.3089	2.1020	2.2343	1.8691
skewness:	0.2214	0.1283	0.1612	0.2041	0.2091
kurtosis:	1.1256	0.9601	1.1173	1.0734	1.3366

sample:	55	57	58	59	60
phi					
0 to -1:	0.6	2.2	1.7	1.6	2.6
1 to 0:	1.9	6.9	4.2	3.5	3.7
2 to 1:	5.5	11.1	8.9	8.1	8.5
3 to 2:	17.7	11.4	19.5	11.9	18.8
4 to 3:	19.2	21.5	24.8	27.9	23.7
5 to 4:	11.0	8.8	8.4	8.9	7.5
6 to 5:	13.3	9.3	7.7	9.0	7.4
7 to 6:	8.4	6.9	6.1	6.4	5.5
8 to 7:	8.6	4.9	3.3	4.2	4.0
9 to 8;	4.6	3.3	2.6	3.2	2.9
>9:	9.2	13.7	12.8	15.3	15.4
mean:	4.4180	3.7488	3.6369	3.9140	3.6364
sorting:	2.1044	2.2542	1.9551	2.0237	2.0358
skewness:	0.2234	0.1250	0.2189	0.1956	0.2138
kurtosis:	0.8826	0.9623	1.1716	1.1403	1.1987

sample:	61	62	63	64	65
phi					
0 to -1:	1.3	2.5	2.6	0.6	3.3
1 to 0:	3.4	5.3	4.5	1.6	5.6
2 to 1:	9.5	11.3	10.7	4.9	9.8
3 to 2:	21.5	20.1	19.4	17.2	11.3
4 to 3:	26.3	22.4	17.5	32.4	15.6
5 to 4:	7.2	6.8	6.2	11.8	11.7
6 to 5:	6.8	6.4	7.5	8.5	11.6
7 to 6:	4.7	5.7	6.7	5.5	6.8
8 to 7:	3.5	3.7	4.8	2.8	4.4
9 to 8;	2.9	3.6	5.2	2.6	3.1
>9:	12.9	12.2	14.9	12.1	16.8
mean:	3.6016	3.5173	3.7564	3.8917	3.8292
sorting:	1.8796	2.0802	2.3170	1.6578	2.2758
skewness:	0.2728	0.2302	0.2749	0.2592	0.0390
kurtosis:	1.2997	1.2264	0.9973	1.2583	0.9576

sample:	66	67	68a	68b	69
phi					
0 to -1:	2.7	4.7	0.7	0.7	5.0
1 to 0:	6.5	12.7	2.2	1.8	9.0
2 to 1:	11.5	20.6	5.9	2.5	14.2
3 to 2:	15.7	13.7	5.9	0.4	10.7
4 to 3:	21.7	12.1	23.3	0.7	18.4
5 to 4:	8.7	5.5	21.0	5.1	12.2
6 to 5:	8.4	6.5	12.7	17.2	8.1
7 to 6:	5.1	5.0	6.2	19.3	5.1
8 to 7:	4.1	3.5	3.9	10.5	3.0
9 to 8;	2.2	2.8	2.8	4.4	2.4
>9:	13.4	12.9	15.4	37.4	11.9
mean:	3.4858	2.9247	4.3013	5.8503	3.2986
sorting:	2.0905	2.2692	1.7755	1.6706	2.2156
skewness:	0.1303	0.3373	0.0902	-0.2083	0.0519
kurtosis:	1.0874	1.0116	1.2667	1.6968	0.9522

sample:	70	71	72	73	74
phi					
0 to -1:	1.7	1.0	0.2	0.9	0.6
1 to 0:	2.8	3.1	0.3	1.4	1.9
2 to 1:	7.3	5.8	0.7	2.9	3.2
3 to 2:	14.9	17.3	2.6	5.6	5.6
4 to 3:	22.0	31.8	20.7	28.2	18.1
5 to 4:	11.0	8.1	19.3	19.7	19.7
6 to 5:	11.7	6.6	15.5	11.8	17.4
7 to 6:	8.4	5.5	7.2	6.1	9.0
8 to 7:	5.8	4.3	4.2	2.6	4.9
9 to 8;	2.8	2.8	3.5	2.3	4.2
>9:	11.6	13.7	25.8	18.5	15.4
mean:	4.1091	3.8175	4.8950	4.2995	4.7274
sorting:	2.0716	1.8258	1.5348	1.6042	1.8278
skewness:	0.1913	0.2707	0.2453	0.1991	0.0662
kurtosis:	0.9631	1.3364	0.9937	1.2485	1.1597

sample:	75	76	77	78a	78b
phi					
0 to -1:	1.0	1.1	0.7	0.5	0.1
1 to 0:	3.2	2.9	1.4	0.7	0.5
2 to 1:	6.1	4.8	1.7	1.5	1.2
3 to 2:	15.9	10.1	7.3	3.0	2.7
4 to 3:	35.8	25.9	37.0	6.6	6.7
5 to 4:	9.3	15.1	12.4	22.8	21.5
6 to 5:	7.4	12.1	11.3	22.0	26.4
7 to 6:	5.2	7.6	6.6	13.8	13.5
8 to 7:	4.3	3.6	3.9	6.5	6.2
9 to 8;	1.9	3.7	2.9	5.1	4.6
>9:	9.9	13.2	14.8	17.5	16.6
mean:	3.7833	4.2329	4.3237	5.3496	5.3981
sorting:	1.7243	1.9087	1.6442	1.6159	1.4950
skewness:	0.2289	0.1770	0.4113	0.0762	0.0722
kurtosis:	1.4187	1.1894	1.1302	1.1790	1.1807

sample:	78c	78d	78e	79a	79b
phi					
0 to -1:	0.0	0.0	0.0	0.8	1.0
1 to 0:	0.3	0.2	0.1	1.9	2.1
2 to 1:	0.9	1.6	1.6	5.7	7.3
3 to 2:	2.2	8.3	9.8	15.3	19.8
4 to 3:	5.8	21.8	24.4	22.0	26.5
5 to 4:	22.2	22.1	21.5	14.2	9.7
6 to 5:	23.6	11.7	10.8	14.4	10.0
7 to 6:	13.1	5.5	5.3	11.2	7.8
8 to 7:	6.3	2.3	2.5	9.0	6.0
9 to 8;	3.9	3.2	3.2	2.3	2.4
>9:	21.7	23.3	20.8	3.2	7.4
mean:	5.4141	4.4880	4.4108		3.9906
sorting:	1.4399	1.5301	1.5277		1.9226
skewness:	0.1040	0.1999	0.2442		0.2755
kurtosis:	1.1088	1.1928	1.2121		0.9884

sample:	79c	79d	79e	79f	79g
phi					
0 to -1:	1.4	1.1	0.7	0.2	0.2
1 to 0:	2.4	1.1	0.7	0.5	0.5
2 to 1:	5.3	3.8	3.7	1.9	1.7
3 to 2:	17.4	11.9	13.5	8.6	7.8
4 to 3:	23.8	25.0	33.6	25.0	21.8
5 to 4:	9.1	9.2	7.1	11.5	11.1
6 to 5:	10.4	10.7	3.9	5.6	6.0
7 to 6:	7.8	6.9	4.0	4.0	4.2
8 to 7:	4.3	4.2	2.5	2.8	2.6
9 to 8;	3.4	2.5	2.6	3.0	3.0
>9:	14.7	23.6	27.7	36.9	41.1
mean:	3.9654	4.2147	3.8495	4.2533	
sorting:	1.9993	1.8423	1.5666	1.6483	
skewness:	0.2584	0.2709	0.3172	0.3974	
kurtosis:	1.0068	1.0513	1.8546	1.3534	

sample:	80a	80b	80c	81a	81b
phi					
0 to -1:	0.7	0.5	2.8	0.6	0.5
1 to 0:	1.0	0.8	2.0	2.3	2.5
2 to 1:	1.4	1.3	2.4	2.3	2.4
3 to 2:	2.2	2.9	4.3	6.4	5.4
4 to 3:	10.8	12.4	18.6	24.5	25.9
5 to 4:	18.4	18.6	15.9	15.1	16.2
6 to 5:	21.9	20.6	12.6	13.8	12.4
7 to 6:	13.3	10.0	7.2	10.5	9.4
8 to 7:	5.5	5.2	4.0	7.4	6.0
9 to 8;	4.1	3.4	2.1	6.0	4.0
>9:	20.7	24.3	28.1	11.1	15.3
mean:	5.2129	5.0795	4.3701	4.7919	4.6084
sorting:	1.6652	1.6165	1.9115	2.0009	1.8934
skewness:	-0.0096	0.0286	0.0301	0.1832	0.2065
kurtosis:	1.1448	1.1703	1.2994	0.9939	1.0770

sample:	81c	81d	82a	82b	82c
phi					
0 to -1:	0.1	0.9	1.6	1.1	1.4
1 to 0:	0.9	5.9	2.8	2.9	1.8
2 to 1:	1.3	4.6	3.5	3.8	2.0
3 to 2:	5.2	6.4	3.9	5.2	5.5
4 to 3:	25.9	25.9	17.3	18.1	24.3
5 to 4:	20.1	12.4	17.8	18.0	13.1
6 to 5:	13.5	10.9	15.9	15.9	14.1
7 to 6:	9.7	7.9	10.8	9.6	8.1
8 to 7:	5.8	5.7	4.6	5.3	2.6
9 to 8;	3.3	4.1	4.9	2.4	4.4
>9:	14.2	15.3	16.9	17.7	22.7
mean:	4.7350	4.2522	4.7154	4.5622	4.5395
sorting:	1.6227	2.1101	2.0135	1.8825	1.8788
skewness:	0.2430	0.1572	0.0245	0.0164	0.1982
kurtosis:	0.9827	1.1928	1.2116	1.1437	1.1830

sample:	82d	83a	83b	83c	85
phi					
0 to -1:	2.1	0.5	0.1	0.0	4.6
1 to 0:	3.6	0.7	0.3	0.3	6.6
2 to 1:	6.1	2.5	3.3	4.6	7.2
3 to 2:	14.0	10.3	17.0	18.8	8.1
4 to 3:	37.1	17.5	31.2	34.8	19.1
5 to 4:	7.3	17.5	13.1	11.1	15.2
6 to 5:	3.6	18.1	3.7	2.3	12.1
7 to 6:	2.9	8.3	3.9	2.9	7.5
8 to 7:	2.4	4.7	2.5	1.9	3.3
9 to 8;	1.4	3.5	1.9	1.6	8.6
>9:	19.5	16.4	23.0	21.7	7.7
mean:	3.4307	4.6757	4.8361	3.6262	4.1197
sorting:	1.6008	1.7578	1.4224	1.3223	2.4359
skewness:	0.0419	0.0809	0.2640	0.2084	0.0261
kurtosis:	1.9514	1.0088	1.3671	1.6787	1.1093

sample:	86	87	88	89	90
phi					
0 to -1:	1.2	1.6	1.5	2.4	1.8
1 to 0:	2.5	4.2	4.0	5.6	3.4
2 to 1:	2.9	5.8	4.6	8.6	4.2
3 to 2:	4.9	5.6	5.5	8.0	4.9
4 to 3:	19.6	18.2	14.2	17.0	18.0
5 to 4:	19.9	16.9	17.7	13.6	17.8
6 to 5:	15.5	15.8	16.4	13.9	16.8
7 to 6:	7.8	8.2	10.0	7.7	9.5
8 to 7:	4.8	4.6	4.7	5.0	5.3
9 to 8;	3.1	2.7	3.8	2.4	3.2
>9:	17.8	16.4	17.8	15.8	15.1
mean:	4.5609	4.3232	4.5406	4.0296	4.5284
sorting:	1.8447	2.0015	2.0535	2.1847	1.9863
skewness:	0.0566	-0.0541	-0.0748	-0.0339	-0.0185
kurtosis:	1.2246	1.1795	1.1829	0.9941	1.1995

sample:	91	92	93	94	95
phi					
0 to -1:	2.0	2.1	0.4	0.5	1.2
1 to 0:	3.3	3.1	1.7	3.5	2.6
2 to 1:	2.9	2.4	2.9	6.1	4.4
3 to 2:	5.8	4.2	4.4	7.1	5.1
4 to 3:	18.9	17.2	15.3	17.4	19.0
5 to 4:	19.2	18.2	16.7	14.3	14.1
6 to 5:	16.7	18.0	17.6	15.7	12.2
7 to 6:	8.8	10.3	10.5	9.6	8.8
8 to 7:	4.8	6.3	5.7	6.1	6.0
9 to 8;	3.4	2.9	4.0	3.8	4.4
>9:	14.2	15.2	20.8	15.9	22.2
mean:	4.5055	4.6520	4.8881	4.4266	4.6020
sorting:	1.9372	1.9463	1.8491	2.0672	2.0856
skewness:	0.0055	-0.0390	0.0128	-0.0005	0.0998
kurtosis:	1.2466	1.2349	1.1034	1.0537	1.0932

sample:	96	97	98	102	103
phi					
0 to -1:	1.5	6.3	0.7	1.3	2.5
1 to 0:	4.0	7.2	2.3	2.4	4.4
2 to 1:	5.1	7.7	8.4	2.3	3.0
3 to 2:	6.2	9.2	24.0	7.2	9.4
4 to 3:	21.7	21.4	21.5	27.7	29.7
5 to 4:	13.5	12.6	9.1	15.6	15.5
6 to 5:	11.2	10.7	8.0	12.3	10.4
7 to 6:	6.8	7.2	5.9	7.7	7.8
8 to 7:	4.3	2.9	3.9	4.9	2.9
9 to 8;	4.1	1.8	3.5	3.2	2.2
>9:	21.6	13.0	12.7	15.4	12.2
mean:	4.2691	3.5695	3.8018	4.4014	3.9795
sorting:	2.0831	2.1993	1.9322	1.8494	1.8661
skewness:	0.1104	-0.0466	0.3295	0.2384	0.1007
kurtosis:	1.2287	0.9649	1.0771	1.1766	1.3695

sample:	104	105	106	107	108
phi					
0 to -1:	9.2	0.6	0.1	0.0	1.0
1 to 0:	7.5	1.8	0.4	0.2	2.4
2 to 1:	3.9	3.2	1.0	1.1	5.2
3 to 2:	12.3	4.9	2.9	4.3	15.0
4 to 3:	33.0	13.0	8.5	14.5	29.0
5 to 4:	7.5	20.7	25.1	17.7	13.4
6 to 5:	5.1	19.5	25.0	19.7	9.4
7 to 6:	2.5	10.1	12.3	8.9	5.6
8 to 7:	2.1	5.4	5.3	6.2	3.5
9 to 8:	1.5	3.2	3.6	2.2	2.5
>9	15.4	17.6	15.8	25.2	12.9
mean:	3.0978	4.8295	5.2499	5.0026	3.9517
sorting:	1.9436	1.7735	1.4410	1.5402	1.7724
skewness:	-0.1433	-0.0199	0.1126	0.0481	0.2103
kurtosis:	1.4699	1.2122	1.2011	1.0491	1.2495

sample:	109	110	111	112	113
phi					
0 to -1:	0.5	1.4	5.6	3.0	0.7
1 to 0:	1.3	3.1	10.7	7.8	0.8
2 to 1:	3.8	7.9	12.8	11.6	3.7
3 to 2:	17.2	26.7	9.3	13.0	17.1
4 to 3:	37.0	32.8	7.0	19.6	25.2
5 to 4:	12.2	8.0	6.1	8.1	7.5
6 to 5:	6.5	4.4	4.0	3.5	4.5
7 to 6:	3.6	2.6	5.9	3.0	5.0
8 to 7:	2.6	1.6	2.6	1.8	3.0
9 to 8;	2.7	1.3	2.6	1.9	2.7
>9:	12.6	10.2	33.4	26.7	29.8
mean:	3.8505	3.2804	2.9967	3.0672	3.9039
sorting:	1.5219	1.4663	2.4492	1.9878	1.7241
skewness:	0.2729	0.1265	0.3277	0.0400	0.3548
kurtosis:	1.5275	1.4880	0.8468	1.2093	1.2903

sample:	114	115	116	117	118
phi					
0 to -1:	0.0	1.1	0.7	0.0	0.1
1 to 0:	0.9	3.2	1.9	0.4	0.7
2 to 1:	1.0	4.9	2.8	1.2	2.2
3 to 2:	39.6	10.9	16.2	3.3	7.9
4 to 3:	40.8	18.3	30.3	6.8	15.8
5 to 4:	4.9	9.3	10.4	6.2	15.8
6 to 5:	1.4	9.5	9.1	16.0	20.2
7 to 6:	1.7	7.1	5.1	12.4	5.2
8 to 7:	1.4	6.9	2.8	5.9	5.9
9 to 8;	0.6	6.4	3.0	4.8	2.5
>9:	7.7	22.4	17.7	43.0	23.7
mean:	3.2265	4.4718	3.9936	5.5530	4.7376
sorting:	0.9661	2.3014	1.7309	1.7515	1.6887
skewness:	0.1735	0.2204	0.2942	-0.1052	0.0223
kurtosis:	1.1690	0.9634	1.2351	1.0724	1.0515

sample:	119	120	121	122	123
phi					
0 to -1:	0.6	0.6	6.5	5.3	4.7
1 to 0:	1.3	1.0	18.0	33.3	19.6
2 to 1:	10.2	9.1	23.5	45.6	46.0
3 to 2:	36.2	33.6	13.1	7.4	16.1
4 to 3:	15.4	14.7	3.0	1.7	2.6
5 to 4:	13.3	10.7	2.3	1.3	1.0
6 to 5:	8.1	6.5	1.4	0.2	0.8
7 to 6:	4.1	3.3	0.8	0.4	0.1
8 to 7:	2.6	2.6	0.8	0.6	0.3
9 to 8;	1.5	1.4	1.6	0.6	1.4
>9:	6.7	16.5	29.0	3.6	7.4
mean:	3.4671	3.4290	1.7808	1.2320	1.5429
sorting:	1.6334	1.6128	1.6282	0.9484	1.0700
skewness:	0.4159	0.4282	0.2871	0.0363	0.0965
kurtosis:	1.0585	1.1381	1.3254	1.0435	1.4172

sample:	124	125	126	127	128
phi					
0 to -1:	2.4	5.4	0.1	0.2	1.0
1 to 0:	9.1	10.8	0.8	0.5	2.3
2 to 1:	55.0	13.7	1.6	0.7	4.3
3 to 2:	23.7	7.4	15.3	2.3	11.1
4 to 3:	0.7	9.3	58.9	18.0	41.7
5 to 4:	0.6	11.3	4.3	21.0	9.1
6 to 5:	0.6	6.6	0.7	16.4	6.7
7 to 6:	0.2	2.9	1.2	7.7	3.5
8 to 7:	0.1	2.0	0.6	5.4	2.2
9 to 8;	0.2	2.0	1.6	2.5	2.7
>9:	7.4	28.6	14.9	25.3	15.4
mean:	1.6563	2.9985	3.4209	4.9433	3.7992
sorting:	0.7420	2.2817	0.8557	1.4948	1.5467
skewness:	0.0734	0.1478	-0.0429	0.2062	0.2312
kurtosis:	1.1977	0.8462	1.6152	0.9865	1.9590

sample:	129	130	131	132	133
phi					
0 to -1:	0.0	0.0	0.0	0.0	0.0
1 to 0:	0.0	0.0	0.0	0.1	1.3
2 to 1:	0.1	0.1	0.3	0.2	22.8
3 to 2:	27.0	30.5	78.1	32.5	71.6
4 to 3:	64.3	61.3	16.3	36.8	1.4
5 to 4:	1.7	1.7	0.4	4.0	0.2
6 to 5:	0.7	0.3	0.3	2.9	0.1
7 to 6:	0.3	1.3	0.2	3.0	0.4
8 to 7:	0.4	0.1	0.6	1.1	0.4
9 to 8;	0.7	0.4	0.1	1.9	0.1
>9:	4.8	4.3	3.7	17.5	1.7
mean:	3.2353	3.2011	2.6917	3.4518	2.2646
sorting:	0.6167	0.6421	0.4944	1.1727	0.5438
skewness:	-0.2337	-0.2117	0.2430	0.2311	-0.2641
kurtosis:	0.9152	0.8418	1.1587	1.5842	1.0801

sample:	134	135	136	137	138
phi					
0 to -1:	0.8	1.2	0.3	0.4	1.6
1 to 0:	0.9	2.5	1.0	3.3	1.4
2 to 1:	2.4	4.5	3.5	12.8	1.5
3 to 2:	3.1	3.4	18.1	15.4	1.9
4 to 3:	5.8	5.4	37.9	9.2	4.8
5 to 4:	12.2	6.9	12.5	11.4	14.1
6 to 5:	13.2	8.4	5.9	8.3	14.6
7 to 6:	6.6	9.9	4.7	5.0	9.1
8 to 7:	3.4	7.8	3.7	1.9	5.2
9 to 8;	3.5	5.5	1.9	3.6	5.7
>9:	48.1	44.5	10.5	28.7	40.1
mean:	4.9663	4.9822	3.8959	3.7479	5.2467
sorting:	1.9072	2.4464	1.4946	2.1382	2.0092
skewness:	-0.0166	-0.2232	0.3160	0.2321	-0.0395
kurtosis:	1.3530	0.9162	1.4366	0.9531	1.3407

sample:	140	141	142	143	144
phi					
0 to -1:	10.4	10.4	4.9	27.6	1.6
1 to 0:	22.2	34.2	22.8	24.1	4.0
2 to 1:	25.4	34.0	31.1	34.2	13.2
3 to 2:	15.8	12.4	9.0	2.4	27.1
4 to 3:	3.5	3.2	8.2	0.7	11.5
5 to 4:	1.0	0.5	5.0	0.7	12.3
6 to 5:	1.1	0.0	3.1	0.6	8.2
7 to 6:	1.0	0.3	1.9	0.7	5.5
8 to 7:	0.0	0.1	0.5	0.7	3.4
9 to 8;	1.3	0.4	1.2	0.9	2.3
>9:	18.3	4.5	12.3	7.4	10.9
mean:	1.4981	1.1861	1.9590	0.9242	3.4861
sorting:	1.3568	0.9774	1.6564	1.1317	1.9978
skewness:	0.2165	0.1550	0.3987	0.2944	0.3377
kurtosis:	0.9954	0.8708	1.1610	0.7872	1.0336

sample:	145	146	147	148
phi				
0 to -1:	0.2	0.0	2.7	0.1
1 to 0:	0.9	0.4	5.5	1.1
2 to 1:	3.5	15.8	9.2	1.9
3 to 2:	9.4	68.2	18.2	14.2
4 to 3:	25.2	13.4	28.4	57.1
5 to 4:	17.1	0.6	7.3	5.1
6 to 5:	12.1	0.2	3.9	1.2
7 to 6:	4.3	0.1	2.1	1.0
8 to 7:	1.3	0.3	1.7	0.8
9 to 8;	2.2	0.1	1.4	0.8
>9:	23.8	0.9	19.6	16.7
mean:	4.1444	2.4865	3.1317	
sorting:	1.5543	0.6499	1.6722	
skewness:	0.1692	0.0003	-0.0210	
kurtosis:	1.1327	1.3761	1.5022	

APPENDIX C

Method of Mineral Analysis

a) Fine Sand (4-20) Mineralogy

The 4-20 fractions of samples were collected from sieves after making particle size analyses at 10 intervals, and light fractions were separated from heavy fractions by flotation in bromoform (specific gravity = 2.90) in separating funnels. The separated fractions were collected in filter papers and washed thoroughly in acetone to remove the bromoform, before drying.

Temporary mounts were made of sub-samples from each fraction by immersion in a clove oil mixture (refractive index = 1.538) on glass slides. The minerals were identified by examination of their optical and crystallographic properties with a Zeiss polarising microscope.

b) Coarse Silt (6-40) Mineralogy .

The silt and clay (> 40) fractions of 20-40g samples were dispersed and placed in suspension in a 1000ml measuring cylinder by the method used for particle size analysis (Appendix A). The 6-40 fraction was separated from the rest by repeated stirring and settling under gravity, the finer particles being siphoned off at 20cm depth after the > 60 (16µm) had settled beyond 20cm.

After drying, samples were shaken in Bromoform in pointed glass tubes and light and heavy fractions were then separated by centrifugation. The bromoform containing the heavy minerals at the base of the tubes was frozen by placing the tubes in an ice/salt mixture so that the light minerals floating on top could be decanted. The samples were washed, mounted and identified as for the 4-20 fraction.

APPENDIX D

SAMPLE LOCATIONS AND SEDIMENT TYPES

Data for the location and sediment type of every sample discussed in the text are presented below. The abbreviations 'ub' and 'lb' under sediment type refer to upper brickearth and lower brickearth respectively.

sample no.: 1
locality : Stony Cross
grid ref. : SU248123
sediment : ub

sample no.: 2
locality : Longcross Plain
grid ref. : SU243153
sediment : ub+lb mixed

sample no.: 3
locality : Fritham Plain
grid ref. : SU224136
sediment : ub

sample no.: 4
locality : Bratley Plain
grid ref. : SU219087
sediment : ub

sample no.: 5
locality : Handy Cross
grid ref. : SU210076
sediment : ub

sample no.: 6a and b
locality : Ocknell Plain
grid ref. : SU223099
sediment : a=ub, b=lb

sample no.: 7
locality : Whitefield Moor
grid ref. : SU278026
sediment : ub

sample no.: 8
locality : Longslade View
grid ref. : SU/SZ278000
sediment : ub

sample no.: 9
locality : Horseshoe Earth
grid ref. : SU264013
sediment : ub

sample no.: 10
locality : Goatspen Plain
grid ref. : SU224019
sediment : ub

sample no.: 11
locality : Pigsty Hill
grid ref. : SU218026
sediment : ub

sample no.: 12
locality : Burley
grid ref. : SU219033
sediment : lb

sample no.: 13
locality : Spy Holms
grid ref. : SU237026
sediment : ub

sample no.: 14
locality : Wootton
grid ref. : SZ231987
sediment : lb

sample no.: 15
locality : Wootton
grid ref. : SZ236993
sediment : ub

sample no.: 16
locality : Fernhill Gate
grid ref. : SZ243964
sediment : ub

sample no.: 17
locality : Bashley Manor Fm.
grid ref. : SZ233962
sediment : ub

sample no.: 18
locality : Walkford Farm
grid ref. : SZ231948
sediment : ub

sample no.: 19
locality : Barton Common
grid ref. : SZ249933
sediment : ub

sample no.: 20
locality : Chewton Glen Fm.
grid ref. : SZ224945
sediment : ub

sample no.: 21
locality : Chewton Common
grid ref. : SZ214944
sediment : ub

sample no.: 22
locality : Hinton
grid ref. : SZ206947
sediment : ub

sample no.: 23
locality : Hinton House
grid ref. : SZ215953
sediment : ub

sample no.: 24
locality : Ashley Manor Fm.
grid ref. : SZ256940
sediment : ub

sample no.: 25
locality : Beckton Farm
grid ref. : SZ255933
sediment : ub

sample no.: 26
locality : Hordle Cliff
grid ref. : SZ274919
sediment : ub

sample no.: 27
locality : Yeatton Farm
grid ref. : SZ273945
sediment : ub

sample no.: 28
locality : Barnes Farm
grid ref. : SZ287925
sediment : ub

sample no.: 29
locality : Hollybush Farm
grid ref. : SZ275955
sediment : ub

sample no.: 30
locality : Plain Heath
grid ref. : SZ216984
sediment : ub

sample no.: 31
locality : Sturt Pond
grid ref. : SZ298911
sediment : ub

sample no.: 32
locality : Norley Inclosure
grid ref. : SZ353984
sediment : ub

sample no.: 33
locality : Bagshot Moor
grid ref. : SU365006
sediment : ub

sample no.: 34
locality : Hatchett Gate
grid ref. : SU367021
sediment : ub

sample no.: 35
locality : Beaulieu Heath
grid ref. : SU353015
sediment : ub

sample no.: 36
locality : Stockley Incl.
grid ref. : SU355023
sediment : ub

sample no.: 37
locality : Crabbswood Farm
grid ref. : SZ266975
sediment : ub

sample no.: 38
locality : Downlands Farm
grid ref. : SZ276972
sediment : ub

sample no.: 39
locality : Tiptoe Farm
grid ref. : SZ246965
sediment : ub

sample no.: 40
locality : Vidle Van Farm
grid ref. : SZ302924
sediment : ub

sample no.: 41
locality : Pennington Common
grid ref. : SZ305953
sediment : ub

sample no.: 42
locality : Little Gordleton
grid ref. : SZ296965
sediment : ub

sample no.: 43
locality : Holbury Farm
grid ref. : SZ292975
sediment : ub

sample no.: 44
locality : Sadlers Farm
grid ref. : SZ314937
sediment : ub

sample no.: 45
locality : Normandy Farm
grid ref. : SZ332944
sediment : ub

sample no.: 46
locality : Battramsley Farm
grid ref. : SZ308982
sediment : ub

sample no.: 47
locality : Dilton Farm
grid ref. : SU328004
sediment : ub

sample no.: 48
locality : Whitemoor Rough
grid ref. : SZ333993
sediment : ub

sample no.: 49
locality : Slade Farm
grid ref. : SZ326985
sediment : ub

sample no.: 50
locality : Warborne Farm
grid ref. : SZ333974
sediment : ub

sample no.: 51
locality : Snooks Farm
grid ref. : SZ342963
sediment : ub

sample no.: 52
locality : Lisle Court Farm
grid ref. : SZ346955
sediment : ub

sample no.: 53
locality : Newtown Park Fm.
grid ref. : SZ352968
sediment : ub

sample no.: 54
locality : Wormstall Hill
grid ref. : SZ364994
sediment : ub

sample no.: 55
locality : Beaulieu Heath
grid ref. : SU347003
sediment : ub

sample no.: 57
locality : Tanners Lane
grid ref. : SZ365953
sediment : ub

sample no.: 58
locality : Bridge Farm
grid ref. : SZ362972
sediment : ub

sample no.: 59
locality : Broomhill Farm
grid ref. : SZ371985
sediment : ub

sample no.: 60
locality : Newhouse Farm
grid ref. : SU376004
sediment : ub

sample no.: 61
locality : Swinesleys Farm
grid ref. : SU379015
sediment : ub

sample no.: 62
locality : Beufre Farm
grid ref. : Su395007
sediment : ub

sample no.: 63
locality : Lodge Farm
grid ref. : SZ387993
sediment : ub

sample no.: 64
locality : Thorns Farm
grid ref. : SZ389964
sediment : ub

sample no.: 65
locality : Park Farm
grid ref. : SZ400969
sediment : ub

sample no.: 66
locality : St. Leonards Fm.
grid ref. : SZ407981
sediment : ub

sample no.: 67
locality : Sowley Farm
grid ref. : SZ375963
sediment : ub

sample no.: 68 a and b
locality : Lepe Cliff
grid ref. : SZ457984
sediment : ub (a) lb (b)

sample no.: 69
locality : Fields Farm
grid ref. : SU464027
sediment : ub

sample no.: 70
locality : Fawley Inclosure
grid ref. : SU407055
sediment : ub

sample no.: 71
locality : Setley Plain
grid ref. : SU301002
sediment : ub

sample no.: 72, 73
locality : Barton-on-Sea
grid ref. : SZ236929
sediment : ub

sample no.: 74
locality : Efford Exp. Stn.
grid ref. : SZ303937
sediment : ub

sample no.: 75
locality : Durns Town
grid ref. : SZ290990
sediment : ub

sample no.: 76
locality : Buckland Manor Fm.
grid ref. : SZ312964
sediment : ub

sample no.: 77
locality : Duckhole Bog
grid ref. : SU253017
sediment : ub colluvium

sample no.: 78a to d
locality : Chilling Copse
grid ref. : SU515042
sediment : ub

sample no.: 79a to g
locality : Beaulieu Heath
grid ref. : SU339015
sediment : ub and lb

sample no.: 80a to c
locality : Wootton
grid ref. : SZ241986
sediment : lb

sample no.: 81a to d
locality : Longslade Bottom
grid ref. : SU262008
sediment : ub colluvium

sample no.: 82a to c
locality : Wilverly Plain
grid ref. : SU253012
sediment : ub

sample no.: 83a to c
locality : Hook Gravel Pit
grid ref. : SU513053
sediment : ub

sample no.: 85 to 92
locality : Wilverly Plain
grid ref. : SU253012
sediment : ub

sample no.: 93 to 97
locality : Scrape Bottom
grid ref. : SU253018
sediment : ub colluvium

sample no.: 102 to 104
locality : Longslade Bottom
grid ref. : SU263006
sediment : ub colluvium

sample no.: 105 to 107
locality : Sturt Pond
grid ref. : SZ298810
sediment : ub

sample no.: 108 to 112
locality : Thorns Farm
grid ref. : SZ389964
sediment : ub and lb

sample no.: 113 and 114
locality : Beaulieu Heath
grid ref. : SU339015
sediment : lb(113) ub(114)

sample no.: 115 and 116
locality : Black Knowl
grid ref. : SU294034
sediment : lb

sample no.: 117 and 118
locality : Holbury Pit
grid ref. : SU426049
sediment : lb

sample no.: 119 to 121
locality : Rockford Common
grid ref. : SU173084
sediment : ub,lb and gravel

sample no.: 122
locality : Barton on Sea
grid ref. : SZ236929
sediment : gravel

sample no.: 123
locality : Holbury Pit
grid ref. : SU426049
sediment : gravel

sample no.: 124
locality : Passford House
grid ref. : SZ297975
sediment : gravel

sample no.: 125
locality : Little Gordleton
grid ref. : SZ296965
sediment : gravel

sample no.: 126 and 127
locality : Calveslease Copse
grid ref. : SU323002
sediment : undif brickearth

sample no.: 128
locality : Wilverly Plain
grid ref. : SU253012
sediment : ub

sample no.: 129
locality : Longslade Bottom
grid ref. : SU263006
sediment : Barton Sand

sample no.: 130
locality : Barton on Sea
grid ref. : SZ238929
sediment : Barton Sand

sample no.: 131
locality : Lyndhurst
grid ref. : SU308080
sediment : Barton Sand

sample no.: 132
locality : Hordle Cliff
grid ref. : SZ269921
sediment : Headon Beds Sand

sample no.: 133
locality : Rockford Common
grid ref. : SU164083
sediment : Bracklesham Sand

sample no.: 134
locality : Ocknell Plain
grid ref. : SU223099
sediment : lb

sample no.: 135
locality : Tanners Lane
grid ref. : SZ365953
sediment : lb

sample no.: 136
locality : Burley Moor
grid ref. : SU214043
sediment : ub

sample no.: 137
locality : Hordle Cliff
grid ref. : SZ269921
sediment : lb

sample no.: 138
locality : Fritham Plain
grid ref. : SU224136
sediment : lb

sample no.: 140
locality : Rockford Common
grid ref. : SU173084
sediment : gravel

sample no.: 141 and 142
locality : Calveslease Copse
grid ref. : SU323002
sediment : gravel

sample no.: 143
locality : Lepe Cliff
grid ref. : SZ457984
sediment : gravel

sample no.: 144
locality : Rockford Common
grid ref. : SU173084
sediment : ub

sample no.: 145
locality : Lepe Cliff
grid ref. : SZ457984
sediment : ub

sample no.: 146
locality : Mudeford
grid ref. : SZ190924
sediment : Bracklesham Sand

sample no.: 147
locality : Tanners Lane
grid ref. : SZ365953
sediment : lb

sample no.: 148
locality : Calveslease Copse
grid ref. : SU323002
sediment : undif. brickearth

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Fig. 4.2 Distribution of brickearth in south west Hampshire