Quaternary of the Thames

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Chapter 3

The Middle Thames

INTRODUCTION

The term 'Middle Thames' refers to that part of the river's course between the Goring Gap and London. The most complete record of fluvial deposition to be found in the Thames catchment is preserved on the dip slope of the Chilterns escarpment, making the Middle Thames basin a classic area for Thames research. Indeed, on the northern side of the valley between Maidenhead and Staines, an impressive sequence from the pre-Anglian Beaconsfield Gravel to the post-Hoxnian Taplow Gravel is present (see Figs 3.1 and 3.2). In this same area, the Devensian Kempton Park Gravel (Upper Floodplain Terrace) is preserved on the south side of the valley. The stratigraphical sequence can be extended upwards, in the areas both upstream and downstream, by way of undissected remnants of older gravels preserved on the Chilterns dip slope (Figs 3.1, 3.2 and 3.3).

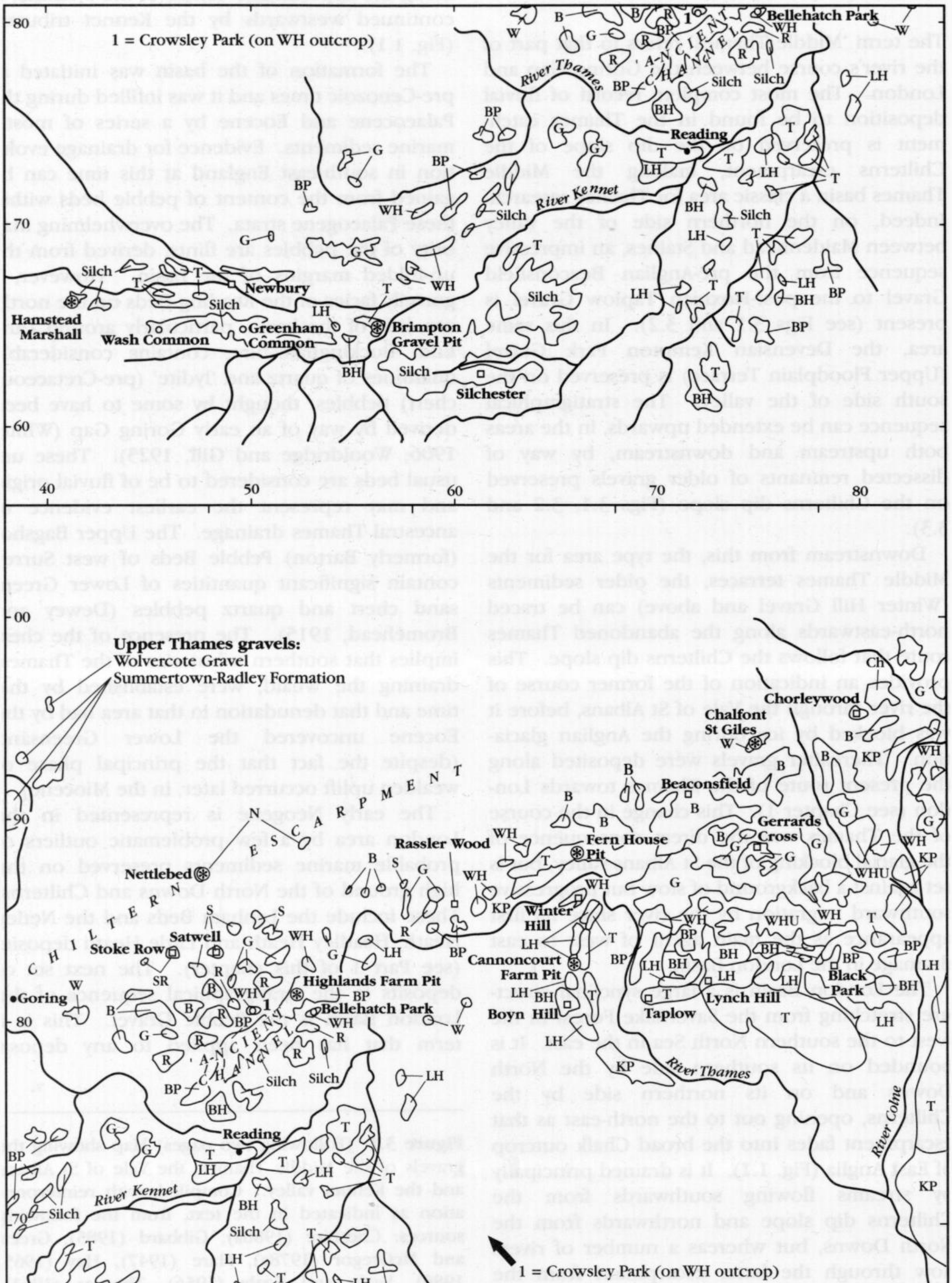
Downstream from this, the type area for the Middle Thames terraces, the older sediments (Winter Hill Gravel and above) can be traced north-eastwards along the abandoned Thames route that follows the Chilterns dip slope. This provides an indication of the former course of the river through the Vale of St Albans, before it was blocked by ice during the Anglian glaciation. Thereafter gravels were deposited along the present route of the Thames towards London (see Chapter 1). This change in the course of the Thames was the direct consequence of the glacial blocking of the St Albans valley, but is set against a background of slow but progressive southward migration by the river since its first appearance as the main agent of west to east drainage in the London Basin.

The London Basin is a large synclinal structure stretching from the Savernake Forest in the west to the southern North Sea in the east. It is bounded on its southern side by the North Downs and on its northern side by the Chilterns, opening out to the north-east as that escarpment fades into the broad Chalk outcrop of East Anglia (Fig. 1.1). It is drained principally by streams flowing southwards from the Chilterns dip slope and northwards from the North Downs, but whereas a number of rivers flow through the latter escarpment from the Weald, only the Thames has a substantial catchment to the north of the Chilterns. The role of the Thames as a 'strike' river, flowing along the approximate centre of the syncline, is continued westwards by the Kennet tributary (Fig. 1.1).

The formation of the basin was initiated in pre-Cenozoic times and it was infilled during the Palaeocene and Eocene by a series of mostly marine sediments. Evidence for drainage evolution in south-east England at this time can be gained from the content of pebble beds within these Palaeogene strata. The overwhelming majority of the pebbles are flints, derived from the up-folded margins of the basin. However, a gravelly facies of the Reading Beds on the northern side of the basin, particularly around Lane End, Buckinghamshire, contains considerable quantities of quartz and 'lydite' (pre-Cretaceous chert) pebbles, thought by some to have been derived by way of an early Goring Gap (White, 1906; Wooldridge and Gill, 1925). These unusual beds are considered to be of fluvial origin and may represent the earliest evidence of ancestral Thames drainage. The Upper Bagshot (formerly Barton) Pebble Beds of west Surrey contain significant quantities of Lower Greensand chert and quartz pebbles (Dewey and Bromehead, 1915). The presence of the chert implies that southern tributaries of the Thames, draining the Weald, were established by this time and that denudation in that area had by the Eocene uncovered the Lower Greensand (despite the fact that the principal phase of wealden uplift occurred later, in the Miocene).

The early Neogene is represented in the London area by a few problematic outliers of probable marine sediments preserved on the high ground of the North Downs and Chilterns. These include the Lenham Beds and the Netley Heath, Headley Heath and Little Heath deposits (see Part 1 of this chapter). The next set of deposits in the stratigraphical sequence of the London Basin is the Pebble Gravel. This is a term that has been applied to any deposit

Figure 3.1 (Following two pages) Map showing the gravels of the Middle Thames, the Vale of St Albans and the Kennet valley. Compiled, with reinterpretation as indicated in the text, from the following sources: Cheshire (1986a), Gibbard (1985), Green and McGregor (1978a), Hare (1947), Hey (1965, 1980), Sealy and Sealy (1956), Thomas (1961), Wooldridge (1927a) and the Geological Survey's New Series 1:50,000 and 1:63,360 maps. GCR sites and type localities are shown.


1 = Crowsley Park (on WH outcrop)
Bellehatch Park
River Thames
Reading
River Kennet
Newbury
Hamstead Marshall
Wash Common
Greenham Common
Brimpton Gravel Pit
Silchester
Upper Thames gravels:
Wolvercote Gravel
Summertown-Radley Formation
CHILTERN ESCARPMENT
Rassler Wood
Nettlebed
Satwell
Stoke Row
Highlands Farm Pit
Goring
ANCIENT CHANNEL
Chorleywood
Chalfont St Giles
Beaconsfield
Gerrards Cross
Fern House Pit
Winter Hill
Cannoncourt Farm Pit
Boyn Hill
Taplow
Lynch Hill
Black Park
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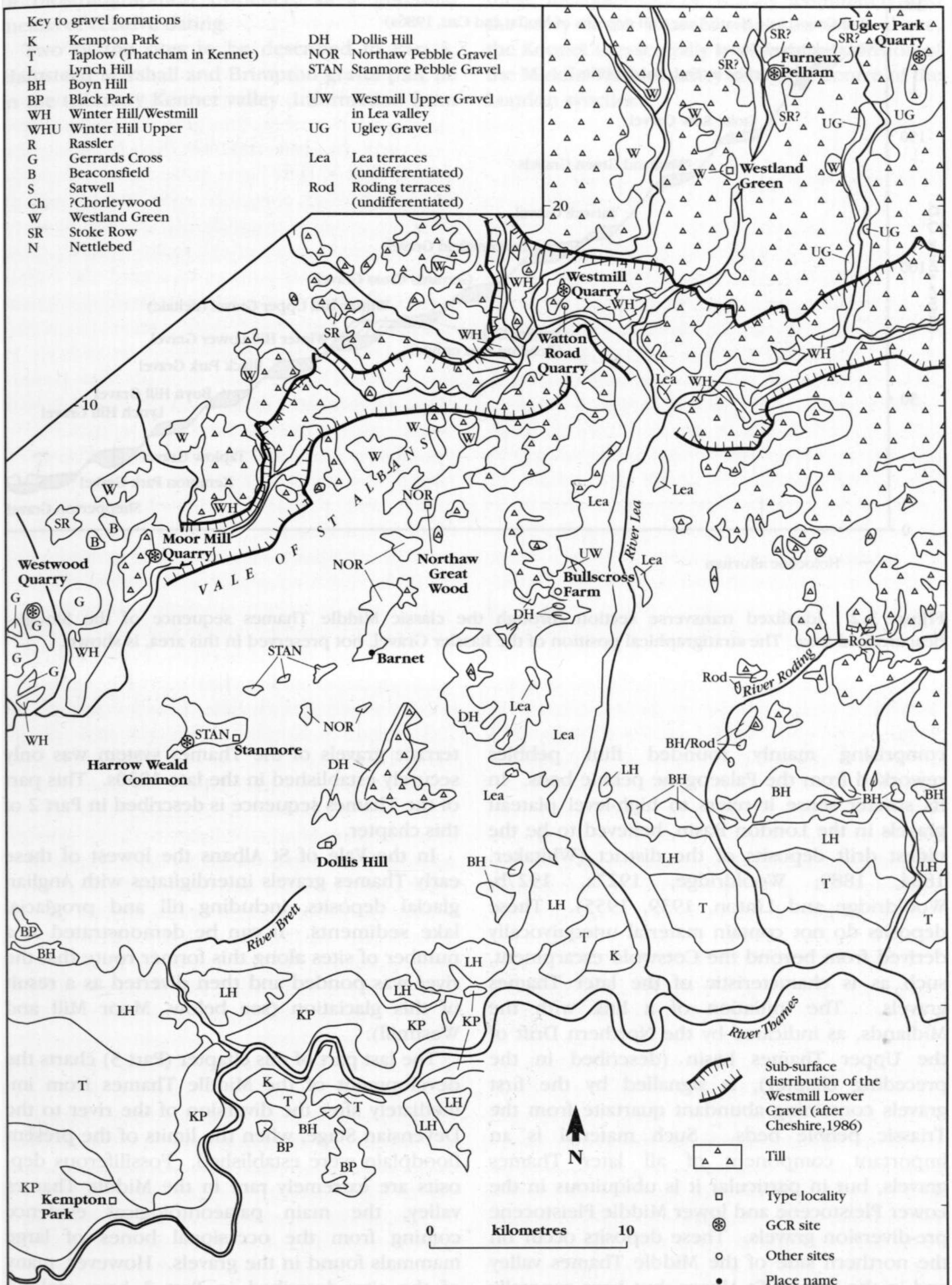

Key to gravel formations
K Kempton Park
T Taplow (Thatcham in Kennet)
L Lynch Hill
BH Boyn Hill
BP Black Park
WH Winter Hill/Westmill
WHU Winter Hill Upper
R Rassler
G Gerrards Cross
B Beaconsfield
S Satwell
Ch ?Chorleywood
W Westland Green
SR Stoke Row
N Nettlebed
DH Dollis Hill
NOR Northaw Pebble Gravel
STAN Stanmore Pebble Gravel
UW Westmill Upper Gravel in Lea valley
UG Ugley Gravel
Lea Lea terraces (undifferentiated)
Rod Roding terraces (undifferentiated)
Ugley Park Quarry
Furneux Pelham
Westland Green
Westmill Quarry
Watton Road Quarry
Moor Mill Quarry
Westwood Quarry
VALE OF ST ALBANS
Northaw Great Wood
Bullscross Farm
Barnet
Stanmore
Harrow Weald Common
Dollis Hill
Kempton Park
River Lea
River Roding
River Brent
River Thames
Sub-surface distribution of the Westmill Lower Gravel (after Cheshire, 1986)
Till
Type locality
GCR site
Other sites
Place name
N
0 kilometres 10
10
20
30
40
50

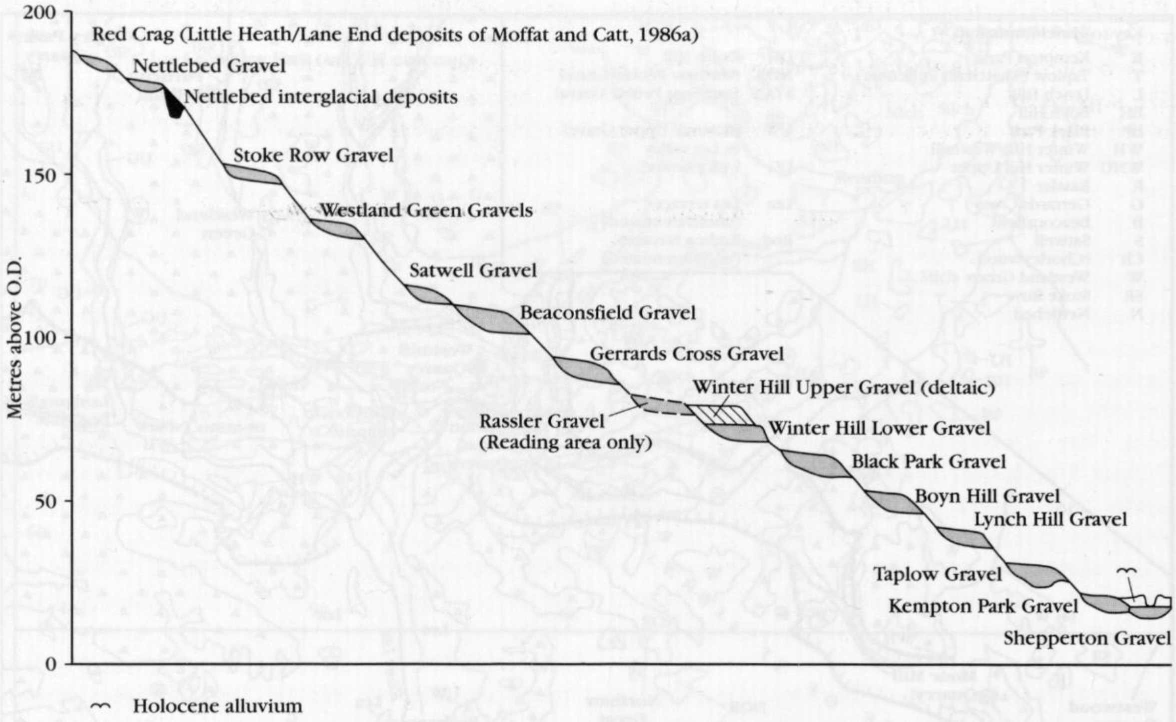


Figure 3.2 Idealized transverse section through the classic Middle Thames sequence of the Slough–Beaconsfield area. The stratigraphical position of the Rassler Gravel, not preserved in this area, is shown.

comprising mainly rounded flint pebbles reworked from the Palaeogene pebble beds. In its stricter sense it refers to high-level plateau gravels in the London Basin, believed to be the oldest drift deposits of the district (Whitaker, 1864, 1889; Wooldridge, 1927a, 1927b; Wooldridge and Linton, 1939, 1955). These deposits do not contain material unequivocally derived from beyond the Cotswold escarpment, such as is characteristic of the later Thames gravels. The initiation of a link with the Midlands, as indicated by the Northern Drift of the Upper Thames basin (described in the preceding chapter), is signalled by the first gravels containing abundant quartzite from the Triassic pebble beds. Such material is an important component of all later Thames gravels, but in particular it is ubiquitous in the Lower Pleistocene and lower Middle Pleistocene pre-diversion gravels. These deposits occur on the northern side of the Middle Thames valley and in the Vale of St Albans, but have generally been classified on Geological Survey maps as 'Glacial Gravels'. Their interpretation as early terrace gravels of the Thames system was only securely established in the late 1930s. This part of the Thames sequence is described in Part 2 of this chapter.

In the Vale of St Albans the lowest of these early Thames gravels interdigitates with Anglian glacial deposits, including till and proglacial lake sediments. It can be demonstrated at a number of sites along this former route that the river was ponded and then diverted as a result of this glaciation (see below, Moor Mill and Westmill).

The last part of this chapter (Part 3) charts the development of the Middle Thames from immediately after the diversion of the river to the Devensian Stage, when the limits of the present floodplain were established. Fossiliferous deposits are extremely rare in the Middle Thames valley, the main palaeontological evidence coming from the occasional bones of large mammals found in the gravels. However, many of the sites described in Part 3 have yielded important assemblages of Palaeolithic artefacts; these take on extra significance, in the absence of biostratigraphical evidence, as a potential means of relative dating.

Two of the sites to be described in Part 3, Hamstead Marshall and Brimpton gravel pits, lie in the tributary Kennet valley. Information from these localities can be readily assimilated into the story of the Thames since, as noted above, the Kennet is essentially a westward extension of the Middle Thames valley along the centre of the London syncline.

Part 1

PLIOCENE/LOWER PLEISTOCENE DEPOSITS IN THE LONDON BASIN

D.R. Bridgland

Introduction

High-level deposits, often capping Palaeogene outliers, are sporadically preserved on the Chilterns and North Downs, the Chalk escarpments bordering the London Basin to the north and south. The highest of these deposits have usually been attributed to Late Pliocene/Early Pleistocene marine episodes, although the incidence of corroborative palaeontological evidence is very rare. In addition, many of the hills north of London, both to the north and south of the Vale of St Albans (Fig. 3.1), are covered by gravelly deposits composed predominantly of rounded flint pebbles of the type that make up the various Palaeogene pebble beds. This type of deposit is commonly known as Pebble Gravel.

Early studies of Pliocene/Lower Pleistocene deposits were concentrated on the North Downs. Most early descriptions of the fossiliferous Lenham Beds on these hills in Kent attributed them to the Pliocene (Prestwich, 1858a; Lyell, 1865; Geikie and Reid, 1866; Reid, 1890; Newton, 1916; Wooldridge, 1927a; see Little Heath), although they are now considered to be Miocene (Curry *et al.*, 1978). Similar deposits were recognized on the North Downs of Surrey at Netley Heath and Headley Heath (Whitaker, 1862; French, 1888) containing, at the former site, fossil molluscs (Stebbing, 1900; Davies, 1917; Chatwin, 1927; Dines and Edmunds, 1929; John and Fisher, 1984). These are poorly preserved moulds in ferruginously indurated horizons and/or clasts that provide evidence of correlation, not with the Lenham Beds, but with the Red Crag of East Anglia. Although formerly regarded as Pliocene (Reid, 1890; Harmer, 1902), the Red Crag has for much of this century been considered to be basal Pleistocene (Baden-Powell, 1950; Boswell, 1952). Later appraisal suggested that at least part of the Red Crag belongs to the Upper Pliocene Series (Cambridge, 1977; West, 1977). Recent estimates of the age of this formation and its suggested correlation with the Praetiglian and Upper Reuverian Stages of The Netherlands imply that the Red Crag is wholly pre-Pleistocene, dating from between 3.5 and 2 million years BP (Zalasiewicz and Gibbard, 1988).

There are very few deposits south of the main Red Crag outcrop and north of the Thames that contain biostratigraphical evidence for a Pliocene age. However, the various high-level outliers rich in well-rounded flint pebbles, the Pebble Gravel, have been recognized as deposits of considerable antiquity, possibly as old as Pliocene, since the middle of the last century. The rounded nature of the majority of its clasts has led numerous authors to regard the Pebble Gravel as a series of marine or littoral deposits (Hughes, 1868; Wood, 1868; Prestwich, 1881, 1890a, 1890b; Whitaker, 1889). In addition to the rounded flints, these deposits also contain small amounts of subangular flint, together with quartz, quartzites and sarsens. The term Pebble Gravel was first used by Whitaker (1864, 1875, 1889), who regarded this type of material as the oldest 'drift' deposit, distinguishing it from the fossiliferous Pliocene beds that occur in comparable situations capping high ground, but which he regarded as part of the 'solid' geology. There has, however, been considerable confusion as to whether certain high-level deposits lacking fauna are unfossiliferous Pliocene marine beds or part of the Pebble Gravel.

In one of the earliest descriptions of the Pebble Gravel, Hughes (1868) referred to it as 'Gravel of the Upper (or Higher) Plain', forming the higher of two dissected gravel-covered plateaux recognized by him in Hertfordshire. According to Hughes: 'there are just enough subangular flints and large partly worn pieces of quartz etc. to show that this gravel derives its pebbly character from the waste of older pebble beds, with which the unworn fragments got mixed, and not that they were all worn together into pebbles along the shingly shore of the Higher-Plain Gravel-sea' (Hughes, 1868, p. 285). Like Hughes, Whitaker (1889) also realized that the rounded nature of the flints in the Pebble Gravel was a feature inherited from the Palaeogene, although both he and Hughes nevertheless favoured a marine origin. Prestwich (1881, 1890b) correlated the Pebble Gravel of the area north of London with his 'Mundesley and Westleton Beds' (later simply 'Westleton Beds'), which he sought to trace southwards and westwards, at increasing altitudes, from East Anglia. Prestwich interpreted the deposits as evidence for a Late Pliocene/Early Pleistocene marine incursion into the London Basin. He realized that these beds dated from near the Pliocene/Lower Pleistocene boundary and considered them to be 'the base of the Quaternary Series' (Prestwich, 1890a, p. 85).

Salter (1896) attempted to subdivide the Pebble Gravel on the basis of composition, recognizing four types. These were:

a. Barnet Gate type – strongly dominated by flint and occurring widely on the highest land in Hertfordshire.

b. Hampstead type – of more restricted occurrence, characterized by smaller pebbles than (a) and by the presence of Greensand chert.

c. High Barnet type – distinguished from (a) and (b) by a sandier matrix, a considerably greater complexity of pebble composition and with a more widespread distribution.

d. Bell Bar type – differing from the others in that it occupies lower levels and has an even greater complexity of composition than (c), including plentiful quartzites.

Within all these compositional divisions, the elevations of the various outliers generally decline from west to east, a factor that led Salter to reject the marine hypothesis in favour of an interpretation of the deposits as reflecting the onset of 'Glacial' conditions. He believed that the various types of Pebble Gravel were the 'first deposits of the Glacial Series' (Salter, 1896, p. 404), but he later emphasized the role played by rivers in their deposition (Salter, 1898, 1901, 1905). In many ways Salter's work, combining altitude and clast-lithological composition as criteria for classification, was far ahead of its time; in the first half of the twentieth century theoretical geomorphology and denudation-chronology prevailed and there was little progress in the interpretation of the Pliocene/Lower Pleistocene deposits in the London Basin.

White (1906) proposed a possible solution to one of the major puzzles presented by the Pebble Gravel, that of the relatively large proportion of quartz it contains, especially in the finer gravel fractions. This material is foreign to the London Basin, and is generally absent in the Palaeocene and Eocene pebble beds. However, White reported the discovery of a markedly different facies of the Palaeocene Reading Beds, at Lane End in Buckinghamshire. Reading Beds gravel at this locality contains abundant quartz as well as subangular flint and 'lydite'. White suggested that this facies was once widespread to the north-west of the present Chiltern escarpment, prior to the erosional recession of the latter during the Pleistocene. This quartzose facies of the Reading Beds was seen by White as a potential source for the non-flint component of the Pebble Gravel.

There followed several years of controversy over the precise age of these deposits at Lane End. Barrow (1919a) questioned White's assertion that they belonged to the Reading Beds. A major factor in favour of White's interpretation was that the quartzose gravel is overlain by what appears to be basal London Clay. Barrow suggested that this clay could have been redeposited and that the quartzose gravel belonged itself to the Pliocene Pebble Gravel. He cited the deposit at Little Heath (see below, Little Heath) as a typical example of Pebble Gravel with a comparable composition. Barrow suggested a mechanism of 'static washing', whereby the mixture of flint and quartz pebbles surrounded by a clayey matrix was left as a residue capping some of the hills in the area north of London. He regarded this type of residual material as the normal Pebble Gravel, quite distinct from a series of deposits occurring at around 400 ft (120 m) O.D. on the Chilterns dip slope, which he believed to be true marine Pebble Gravel. He interpreted the slightly higher Pebble Gravel of the Stanmore area (Stanmore Pebble Gravel – see below, Harrow Weald Common), at up to 500 ft (155 m) O.D., as a beach deposit of equivalent age to the 120 m deposits, regarding the latter as sea-floor sediments, formed near the margins of a Pliocene sea that covered all but the highest parts of the Chalk escarpment.

Some discussion of the age and origin of the Pebble Gravel was undertaken in the various local Geological Survey memoirs published during the following few years (Sherlock, 1922; Sherlock and Noble, 1922; Sherlock and Pocock, 1924; Bromehead, 1925). Sherlock (1924) produced a more detailed argument, in which he proposed that the deposits should be assigned to the Pleistocene rather than the Pliocene and that they were formed by locally nourished glaciers which merely rearranged the local Tertiary materials.

Discussion of the Pliocene/Lower Pleistocene deposits of the London Basin was dominated for the next thirty years by S.W. Wooldridge and his

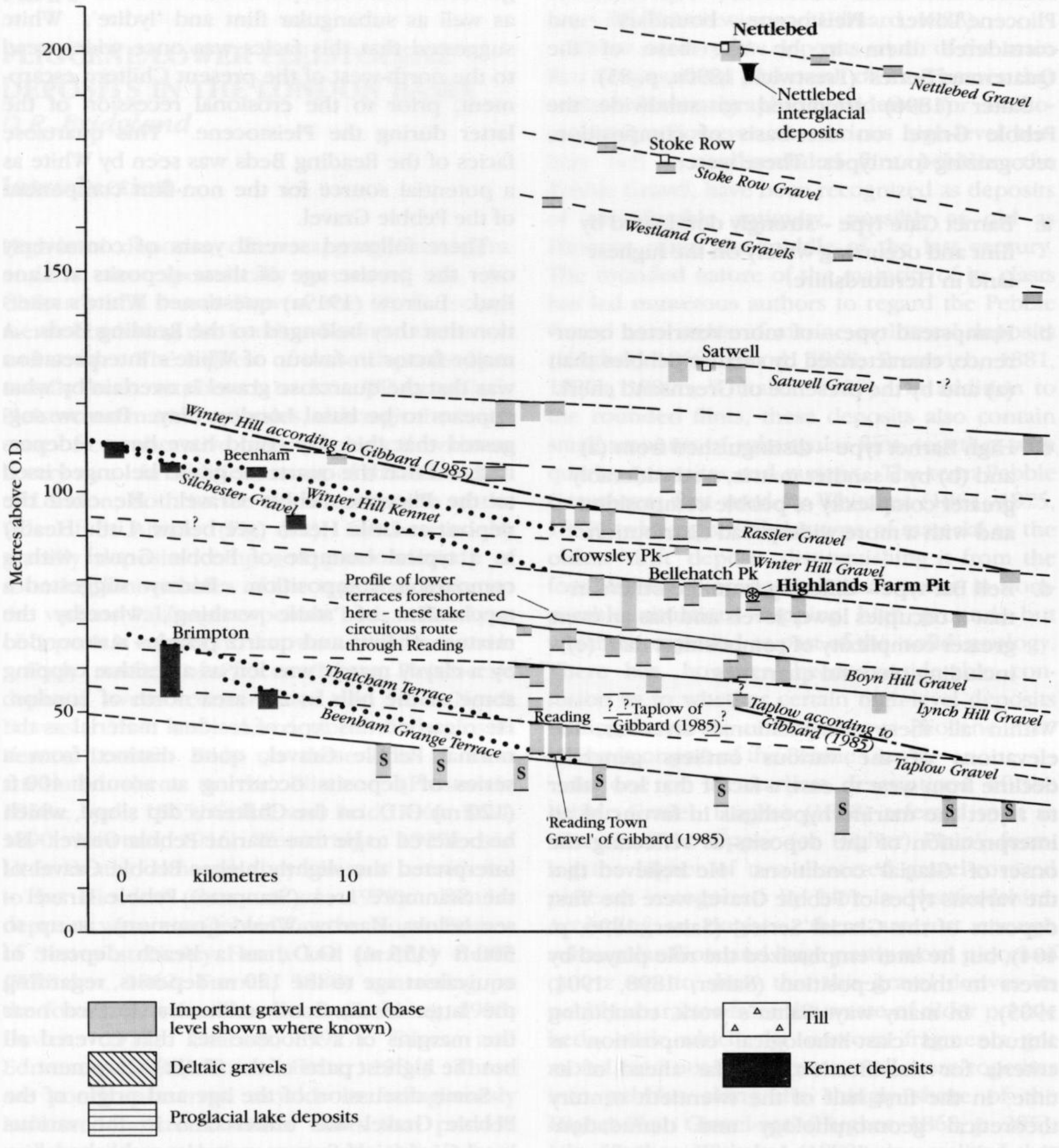
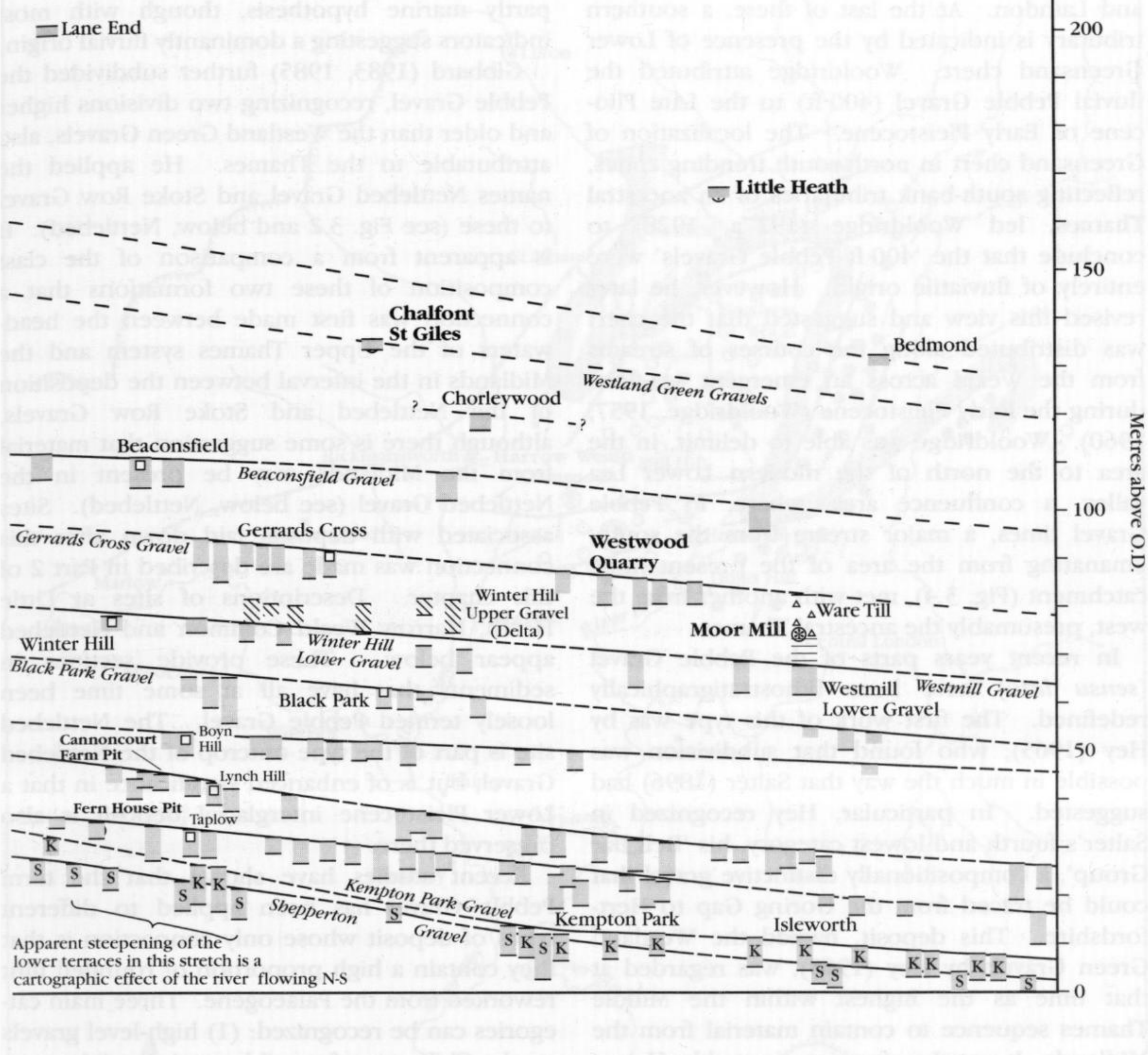


Figure 3.3 Long-profiles of terrace formations in the Middle Thames. Compiled predominantly from data provided by Gibbard (1985), with subordinate information from Sealy and Sealy (1956) and Thomas (1961). Modifications to the source information are described in the text.

co-workers. Wooldridge and Gill (1925) re-investigated the quartzose gravels at Lane End and confirmed their Reading Beds age. They noted that a later Pebble Gravel also occurred at the locality, capping the Palaeogene outlier. They suggested that this younger deposit was of Late Pliocene to Early Pleistocene age and reaffirmed White's view that the quartzose component of the Pebble Gravel might, in the main, have been secondarily derived from the quartzose facies of the Reading Beds. Indeed, they went further and suggested that the Greensand chert that occurs locally in the Pebble Gravel might also have been reworked from the Palaeogene.

In a much-quoted sequence of publications,



Wooldridge (1927a, 1957, 1960; Wooldridge and Linton, 1939, 1955) redefined the term Pebble Gravel to apply only to the deposits concentrated at around 122 m (400 ft) O.D., Barrow's sea-floor sediments. These deposits, which occupy an area known as the 'South Hertfordshire Plateau' (more or less coincident with Hughes (1868) 'Upper Plain'), have become known as the 'Hertfordshire', 'Lower' or '400 ft Pebble Gravels'. Wooldridge recognized that the higher-level deposits of the Stanmore area contain less non-flint material than the '400 ft' gravels (he regarded the latter as Pebble Gravel *sensu stricto*), thus confirming Salter's observations. Wooldridge ascribed these higher-level gravels to the Late Pliocene marine incursion recognized on the North Downs (at Netley Heath), considering the deposits at Little Heath and Stanmore to be lateral equivalents (see below, Little Heath and Harrow Weald Common). He recognized that chert from the Lower Greensand is locally abundant in the '400 ft Pebble Gravels', reflecting input from Wealden rivers.

Wooldridge (1928) described regional variants of his Pebble Gravel *sensu stricto* in south-west Essex, around Brentwood, Billericay and Laindon. At the last of these, a southern tributary is indicated by the presence of Lower Greensand chert. Wooldridge attributed the fluvial Pebble Gravel (400 ft) to the Late Pliocene or Early Pleistocene. The localization of Greensand chert in north-south trending zones, reflecting south-bank tributaries of an ancestral Thames, led Wooldridge (1927a, 1928) to conclude that the '400 ft Pebble Gravels' were entirely of fluviatile origin. However, he later revised this view and suggested that the chert was distributed along the courses of streams from the Weald across an emergent sea-floor during the Early Pleistocene (Wooldridge, 1957, 1960). Wooldridge was able to delimit, in the area to the north of the modern Lower Lea valley, a confluence area, where, in Pebble Gravel times, a major stream from the south, emanating from the area of the present Mole catchment (Fig. 3.4), met with another from the west, presumably the ancestral Thames.

In recent years parts of the Pebble Gravel (*sensu lato*) have been lithostratigraphically redefined. The first work of this type was by Hey (1965), who found that subdivision was possible in much the way that Salter (1896) had suggested. In particular, Hey recognized in Salter's fourth and lowest category, his 'Bell Bar Group', a compositionally distinctive gravel that could be traced from the Goring Gap to Hertfordshire. This deposit, named the Westland Green Gravels by Hey (1965), was regarded at that time as the highest within the Middle Thames sequence to contain material from the Midlands. It was therefore interpreted by Hey as the first true Thames gravel (see Part 2 of this Chapter). Hey *et al.* (1971) conducted a study of the surface textures of sand grains from all the various types of Pebble Gravel, using scanning electron microscopy. They found a progressive decrease in grain-surface features indicative of a marine or beach environment between the higher-level Pebble Gravel (the Stanmore type – see below, Harrow Weald Common) and the Westland Green Gravels. They concluded from this evidence that the high-level deposits were true littoral gravels, deposited following the maximum Early Pleistocene transgression as 'a single series of regressional marine beaches' (Hey *et al.*, 1971, p. 381). These results confirmed the Westland Green Gravels as fluvial deposits, but the '400 ft Pebble Gravels' appeared to yield conflicting grain-surface evidence, with some support for a partly marine hypothesis, though with most indicators suggesting a dominantly fluvial origin.

Gibbard (1983, 1985) further subdivided the Pebble Gravel, recognizing two divisions higher and older than the Westland Green Gravels, also attributable to the Thames. He applied the names Nettlebed Gravel and Stoke Row Gravel to these (see Fig. 3.2 and below, Nettlebed). It is apparent from a comparison of the clast composition of these two formations that a connection was first made between the headwaters of the Upper Thames system and the Midlands in the interval between the deposition of the Nettlebed and Stoke Row Gravels, although there is some suggestion that material from the Midlands may be present in the Nettlebed Gravel (see below, Nettlebed). Sites associated with deposits laid down after this connection was made are described in Part 2 of this chapter. Descriptions of sites at Little Heath, Harrow Weald Common and Nettlebed appear below. These provide sections in sediments that have all at some time been loosely termed Pebble Gravel. The Nettlebed site is part of the type outcrop of the Nettlebed Gravel, but is of enhanced significance in that a Lower Pleistocene interglacial deposit is also preserved there.

Recent studies have shown that the term Pebble Gravel has been applied to different types of deposit whose only connection is that they contain a high proportion of rounded flint reworked from the Palaeogene. Three main categories can be recognized: (1) high-level gravels on the Chilterns, of possible marine origin, as at Little Heath; (2) high-level remnants north of the Vale of St Albans, of early Thames origin, such as at Nettlebed (these form the highest elements of the terrace 'staircase' that is preserved on the dip slope of the Chilterns) and (3) hill-capping gravels in North London and south Hertfordshire, of fluvial origin, but laid down by south-bank tributaries of the Thames. Only deposits of the third category occur in the type area of the Pebble Gravel, where they were described and classified by Barrow (1919a) and Wooldridge (1927a), although both of these authors suggested correlations with remnants on the Chilterns. The marine gravels, if correctly interpreted, are essentially unrelated to the evolution of the fluvial system, so they should be distinguished from the Pebble Gravel and the latter term restricted to the early fluvial

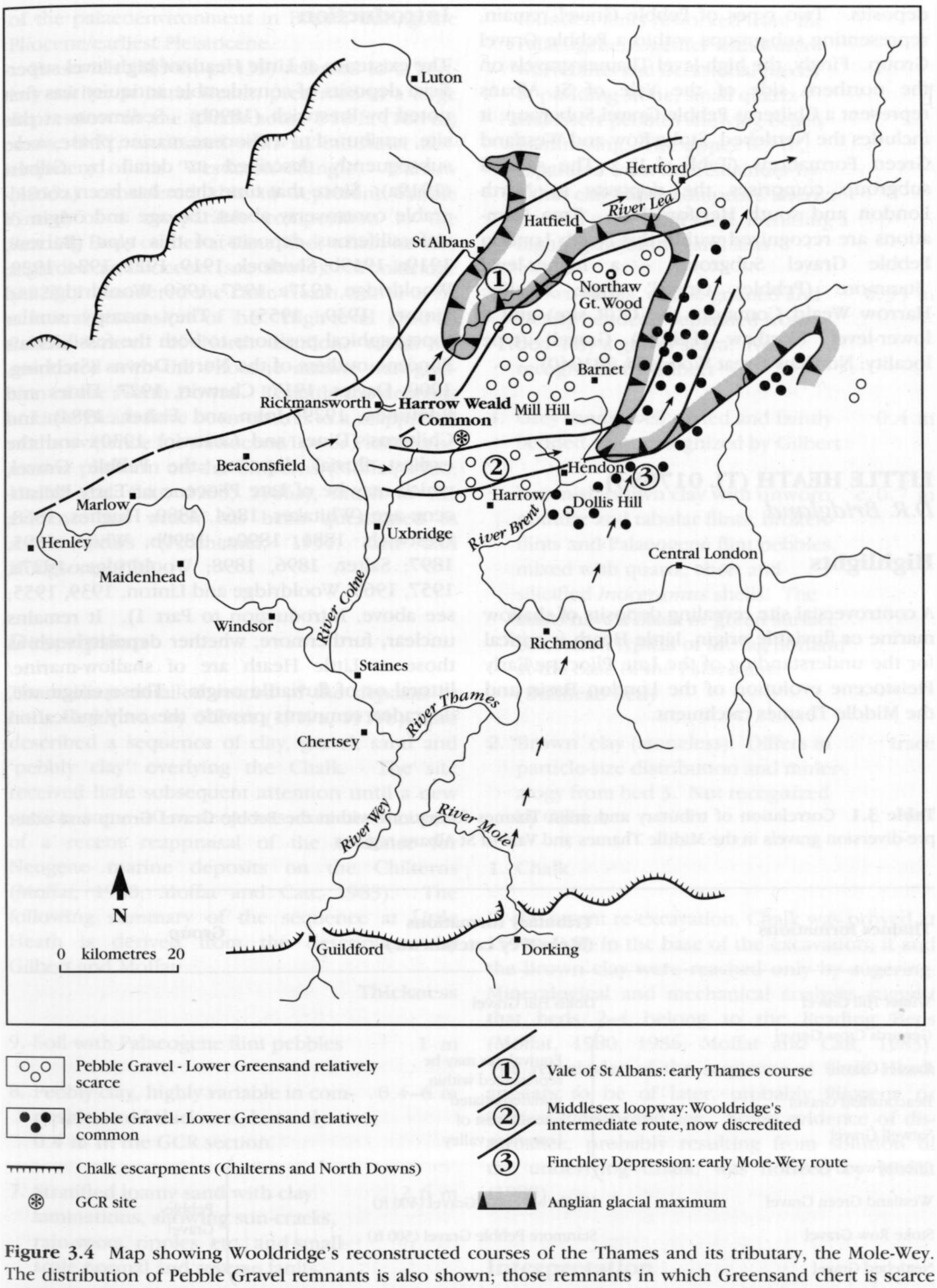


Figure 3.4 Map showing Wooldridge's reconstructed courses of the Thames and its tributary, the Mole-Wey. The distribution of Pebble Gravel remnants is also shown; those remnants in which Greensand chert is scarce are distinguished from those in which it is relatively common.

deposits. Two types of Pebble Gravel remain, representing sub-groups within a Pebble Gravel Group. Firstly, the high-level Thames gravels on the northern side of the Vale of St Albans represent a Chilterns Pebble Gravel Subgroup; it includes the Nettlebed, Stoke Row and Westland Green Formations (Table 3.1). The second subgroup comprises the deposits in North London and south Hertfordshire. Two formations are recognized within this North London Pebble Gravel Subgroup – a higher-level 'Stanmore (Pebble) Gravel' (type locality: Harrow Weald Common, the GCR site) and a lower-level 'Northaw (Pebble) Gravel' (type locality: Northaw Great Wood, TL 281040).

LITTLE HEATH (TL 017083)

D.R. Bridgland

Highlights

A controversial site revealing deposits of shallow marine or fluviatile origin, Little Heath is critical for the understanding of the Late Pliocene/Early Pleistocene evolution of the London Basin and the Middle Thames catchment.

Introduction

The existence at Little Heath of high-level superficial deposits of considerable antiquity was first noted by Prestwich (1890b). Sediments at this site, attributed to a Pliocene marine phase, were subsequently described in detail by Gilbert (1919a). Since that time there has been considerable controversy about the age and origin of unfossiliferous deposits of this type (Barrow, 1919a, 1919b; Sherlock, 1919, 1922, 1924, 1929; Wooldridge, 1927a, 1957, 1960; Wooldridge and Linton, 1939, 1955). They occupy similar topographical positions to both the fossiliferous Pliocene outliers of the North Downs (Stebbing, 1900; Davies, 1917; Chatwin, 1927; Dines and Edmunds, 1929; John and Fisher, 1984) and Chilterns (Dines and Chatwin, 1930) and the earliest fluvial deposits, the Pebble Gravel, which may be of Late Pliocene or Early Pleistocene age (Whitaker, 1864, 1889; Hughes, 1868; Prestwich, 1881, 1890a, 1890b; White, 1895, 1897; Salter, 1896, 1898; Wooldridge, 1927a, 1957, 1960; Wooldridge and Linton, 1939, 1955; see above, Introduction to Part 1). It remains unclear, furthermore, whether deposits such as those at Little Heath are of shallow-marine/littoral or of fluviatile origin. These enigmatic, degraded remnants provide the only indication

Table 3.1 Correlation of tributary and main Thames formations within the Pebble Gravel Group and other pre-diversion gravels in the Middle Thames and Vale of St Albans regions.

Thames formations	Tributary formations (Mole-Wey catchment?)	Group
Winter Hill Gravel	Dollis Hill Gravel	
Gerrards Cross Gravel	Equivalents may be represented within undifferentiated gravels west of Lower Lea valley	
Rassler Gravel		
Beaconsfield Gravel		
Satwell Gravel		
Chorleywood Gravel		
Westland Green Gravel	Northaw Pebble Gravel (400 ft)	Pebble Gravel
Stoke Row Gravel	Stanmore Pebble Gravel (500 ft)	
Nettlebed Gravel		

of the palaeoenvironment in Britain during the Pliocene/earliest Pleistocene.

Prestwich (1890b, p. 139) referred to a Tertiary outlier at Little Heath, preserved in a large depression in the Chalk some 550 ft (168 m) above O.D., associated with an indistinct development of his 'Westleton Shingle'. Barrow (1919a) considered this to represent Pebble Gravel of a comparable composition to the Reading Beds outlier at Lane End, which he also regarded as Pliocene (see above). Wooldridge (1927a) considered the Little Heath Gravel to be a lateral extension of his 'High-level (500 ft) Pebble Gravel' of North London, which he correlated with the Pliocene marine transgression of the North Downs. Recently the deposits at Little Heath have been central to a reappraisal of the evidence for a Pliocene/Lower Pleistocene marine platform on the Chilterns (Moffat, 1980; Moffat and Catt, 1983, 1986a), much of the evidence for which has been questioned in recent years (Pinchemel, 1954; Catt and Hodgson, 1976).

Description

The earliest detailed record of the deposits at Little Heath was by Gilbert (1919a, 1919b), who described a sequence of clay, gravel, sand and 'pebbly clay' overlying the Chalk. The site received little subsequent attention until a new section some 10 m deep was excavated as part of a recent reappraisal of the evidence for Neogene marine deposits on the Chilterns (Moffat, 1980; Moffat and Catt, 1983). The following summary of the sequence at Little Heath is derived from the descriptions by Gilbert and Moffat:

	Thickness
9. Soil with Palaeogene flint pebbles	1 m
8. Pebbly clay, highly variable in composition and thickness, but only 0.4 m in the GCR section	0.4–6 m
7. Stratified loamy sand with clay laminations, showing sun-cracks, rain-spots, ripples, etc., and small-scale normal and reverse faults	2.6 m
6. Stratified coarse gravel, with an undulating surface. This comprises rounded flints reworked from the Palaeogene, together with water-worn flints and occasional pieces of pudding-stone, small quartz and chert pebbles showing beach hammering. The upper 0.3 m, separated from the remainder by a thin clay band, comprises alternations of gravel and sand, including a highly glauconitic sand lens	5.6 m
5. Brown sands, coarse-grained and clearly bedded. Separated from bed 4 by a gravel seam. Not recognized by Gilbert	0.35 m
4. Grey sands, well sorted and faintly bedded. Not recognized by Gilbert	0.4 m
3. Greenish-brown clay with unworn nodular and tabular flints, broken flints and Palaeogene flint pebbles, mixed with quartz, chert and silicified *Inoceramus* shells. The clasts have a black or green surface coloration typical of the lag horizon at the base of the Palaeogene (Bullhead Bed)	*c.* 0.7 m
2. Brown clay (stoneless). Differs in particle-size distribution and mineralogy from bed 3. Not recognized by Gilbert	trace
1. Chalk	

In the recent re-excavation, Chalk was proved at 159 m O.D. in the base of the excavation; it and the brown clay were reached only by augering. Mineralogical and mechanical analyses suggest that beds 2–4 belong to the Reading Beds (Moffat, 1980, 1986; Moffat and Catt, 1983). The remainder of the sequence at Little Heath appears to be of later, probably Pliocene or earliest Pleistocene age. Some evidence of disturbance, probably resulting from solution of the underlying Chalk, was noticed by Moffat (1980).

Interpretation

Gilbert (1919a) based his interpretation of the gravel and loamy sand (beds 6 and 7) at Little

Heath as marine deposits on a number of observations. Firstly, these deposits fine upwards, a feature that he likened to Cambrian marine conglomerates, but which would now be regarded as equally typical of fluvial sedimentation. They possess a grain-supported structure, which Gilbert interpreted as a feature of marine, rather than fluviatile or glacial gravels. There is a gradation between unworn and well-rounded pebbles, which he considered similar to that found on modern beaches in which the materials are 'immediately derived'. Gilbert noted that large clasts showed evidence of beach hammering and that the surface morphology of the gravel body was suggestive of a beach. Finally, laminations and evidence for periodic exposure (sun-cracks, rain-spots, etc.) in the sand (bed 7) were interpreted by Gilbert as evidence of an intertidal environment.

According to Gilbert, the Little Heath gravels were not confined to a depression in the Chalk, as Prestwich (1890b) had claimed, but also capped the Chalk plateau as a horizontal undisturbed sheet. Gilbert compared them to the high-level deposits capping the North Downs in Surrey, attributing both to a Pliocene marine episode. Barrow (1919a) agreed with this assessment, likening the Little Heath gravel to the Pebble Gravel of the area north of London, which contains only local materials plus quartz and 'lydite' pebbles from the Lower Greensand.

Barrow (1919b) divided the Pebble Gravel into two types: one composed of smaller pebbles and occupying a platform at 400 ft, the 'Upper Plain' of Hughes (1868), and the other, a higher, coarser type, typically occupying land at *c.* 500 ft (152 m) O.D. in the Stanmore area. It was with the latter type that Barrow (1919a) classified the Little Heath gravel, noting that it lay even higher, 50 ft (15 m) above the Stanmore deposit, an increase in elevation that was accompanied by a further increase in pebble size. Barrow believed that the coarser, higher (500 ft) Stanmore Pebble Gravel was a beach deposit associated with the same marine episode as the 400 ft (Northaw) Pebble Gravel.

Sherlock (1919) was not convinced of the Pliocene age of the Little Heath deposits. He pointed to the occurrence of gravel in the Reading Beds at Lane End, Buckinghamshire (White, 1906), of similar composition to that at Little Heath, containing quartz, 'lydite' and subangular flints. Sherlock suggested that the various high-level gravels of the Chilterns might also be *in situ* Reading Beds; indeed, in the Aylesbury Geological Survey memoir (Sherlock, 1922), he included all the stratified deposits at Little Heath in the Reading Beds. In an extensive review he argued strongly against the existence of Barrow's '400 ft Platform' and against there having been a submergence in Pliocene times (Sherlock, 1924). He interpreted the Pebble Gravel (*sensu lato*) as 'a Glacial Drift derived from local materials' (Sherlock, 1924, p. 9).

Of considerable significance to this dispute was the allied controversy over White's (1906, 1908a) interpretation of the quartzose gravel at Lane End, Buckinghamshire, as *in situ* Reading Beds (see above, Introduction to Part 1). Although White had interpreted a deposit overlying these gravels as basal London Clay, Barrow (1919a) did not accept that they were Palaeogene. The similarity of the gravels at Lane End and Little Heath, cited by Barrow as evidence that the former was of Pliocene age, was equally indicative to Sherlock (1919, 1922, 1924) that the Little Heath deposits were part of the Reading Beds. However, the Lane End deposits were reinvestigated by Wooldridge and Gill (1925), who fully confirmed White's findings.

Wooldridge (1927a) recognized numerous outliers at high levels on the North Downs and South Downs, all of which he regarded as Diestian (Pliocene) in age, on the basis of their heavy-mineral content. A characteristic heavy-mineral suite, with an abundance of garnet and a relative abundance of monazite and coarse andalusite, had been recognized in the Lenham, Netley Heath and Headley Heath Beds of the North Downs by Davies (1915, 1917). Wooldridge attributed these deposits, together with a number of isolated outliers of high-level gravel on the North Downs and a few in the Chilterns, to a Diestian marine transgression, proposing that they be collectively referred to as Lenham Beds. According to Wooldridge (1927a, p. 80) 'the only locality at which the Lenham Beds are well-developed on the Chiltern plateau is at Littleheath near Berkhampstead'. He claimed that the heavy-mineral assemblage from Little Heath was of Diestian character and quite different from Reading Beds mineral suites (Wooldridge, 1927a, 1927b, in Sherlock, 1929). He also pointed out that the Little Heath sands, being marine, are finer grained and better sorted than the typical (fluviatile) Reading Beds sands of the district. Wooldridge distinguished the various Diestian outliers from the true

Pebble Gravel, although he regarded the latter as little if any younger than the Lenham Beds, and interpreted the highest Pebble Gravel of the Stanmore area as a 'true Diestian shingle'.

The correlation, based on heavy minerals, between the Netley Heath Beds and the Lenham Beds was disproved by the discovery of Late Pliocene (Red Crag) fossils in the former (Chatwin, 1927), indicating that they post-date the Lenham Beds. As a result, Sherlock (1929) argued strongly against the stratigraphical usefulness of heavy-mineral analysis and remained unconvinced that the Little Heath Gravel was of Pliocene age. Red Crag fossils were later discovered in sandstone blocks within high-level drift at Rothamsted, apparently confirming the existence of a Pliocene marine episode in Hertfordshire (Dines and Chatwin, 1930).

Wooldridge and Ewing (1935) carried out a reappraisal of the Palaeocene and alleged Pliocene deposits of the Chilterns, including a detailed petrographical examination. As a result, they concluded that the Little Heath gravel, together with many other patches of high-level deposits in the area, were of Pliocene age. Wooldridge and Linton (1939, p. 55) emphasized the relation of the Little Heath outlier to 'sharply rising ground behind the escarpment edge at Ivinghoe Beacon'. They claimed this to be a fossil shoreline, more conspicuous in the Chiltern area than on the North Downs, being traceable from near the Goring Gap to beyond Luton.

Doubts about this type of geomorphological evidence have been expressed in more recent accounts, however, both in the Chilterns (Pinchemel, 1954; Jones, 1974; Catt and Hodgson, 1976; Moffat, 1980; Moffat and Catt, 1986a, 1986b; Moffat *et al.*, 1986) and south of the Thames (Docherty, 1967; John, 1980; Fisher, 1982). In particular, Moffat (1980; Moffat *et al.*, 1986) noted that the alleged marine 'bench' on the Chiltern dip slope corresponds closely with monoclinal folding of the Chalk and suggested that the feature results from this geological structure rather than from marine erosion. Similar explanations of alleged Pliocene/Early Pleistocene 'benches' in north-west Kent (Docherty, 1967, 1971) and Surrey (John, 1980) have been put forward in recent years.

Moffat (1980; Moffat and Catt, 1983) concluded, on mineralogical grounds, that the lowest three units (beds 2–4) at Little Heath were *in situ* Reading Beds, differentiating them from the overlying gravel and sands on the same basis. He interpreted the upper gravel at Little Heath (bed 6) as a beach deposit, principally on sedimentary grounds, although the presence of *c.* 25% glauconite in the lens of sand within this unit (see above) provides strong evidence for a marine influence, as this mineral is formed only in marine conditions (Porrenga, 1967) and there is no obvious source from which it could be derived secondarily in such quantities. Moffat also considered the overlying sand to be of marine origin, the main evidence being the presence in it of *c.* 5% glauconite. He found no evidence of a glacial origin for the uppermost unbedded gravel (bed 8); the matrix of this unit was found to closely resemble the Reading Beds and to differ from the underlying sand and gravel (beds 5–7). Moffat therefore concluded that the deposit was a colluvial accumulation of bedrock and drift material, presumably derived from upslope areas now removed or modified by erosion.

Although concluding that the geomorphological case for a Pliocene shoreline on the Chilterns was unfounded, Moffat (1980; Moffat and Catt, 1983) supported Wooldridge's (1927a) interpretation of the Little Heath deposits as being of marine origin. He cited the similarity between the particle-size properties of this deposit and the Headley Formation of Surrey as supporting evidence, in addition to similarities in fine-sand mineralogy between both of the above and the Rothamsted Red Crag (Moffat, 1980; Moffat and Catt, 1983, 1986a).

Only one other high-level outlier was accepted by Moffat and Catt (1986a) as an *in situ* Pliocene or Early Pleistocene marine deposit. This is a remnant of Pebble Gravel (*sensu lato*) at Lane End (SU 817917), *c.* 203 m O.D., above the quartzose Reading Beds and basal London Clay (White, 1906; Wooldridge and Gill, 1925; see above, Introduction to Part 1). This remnant was found to be similar to the Little Heath gravel in both its clast and heavy-mineral composition. It lies 28 km to the south-west of the Little Heath outlier and over 30 m higher. Moffat and Catt considered this difference in altitude to be the result of differential tectonic movement in south-eastern Britain since the Pliocene (see below). Moffat (1986) demonstrated that the clast-size distribution of quartz pebbles in the two widely separated outliers was distinct from those in other high-level gravels, but similar to that from quartzose Reading Beds, suggesting derivation solely from that source (see Harrow Weald Common). Other gravel remnants at Gustardwood (TL 175160) and Cowcroft (SP 983017) were interpreted as possibly derived, at least in part, from earlier gravels of the Little Heath type (Moffat, 1980). Moffat considered the matrix of the gravel at Gustardwood to include Late Pleistocene loessic material, implying that the deposit in its present form originated comparatively recently, although *in situ* pedogenic mixing may have caused the introduction of much later (Upper Pleistocene) loess into a Pliocene or Lower Pleistocene gravel.

Moffat and Catt (1986a) demonstrated the degree of post-Pliocene tectonic activity using a projection of the basal surface of the Red Crag from ordnance datum in north-east Essex to almost 200 m O.D. in Surrey and south Buckinghamshire (Fig. 3.5). They attributed the inclination of this surface to subsidence of the north-eastern part of the London Basin during the Pleistocene. It seems likely, however, that uplift of the western area may also have occurred, perhaps as an isostatic response to erosion (Chapter 1), as well as subsidence of the North Sea Basin. The outliers on the North Downs at Netley Heath and Headley Heath have been used to reconstruct this surface, as well as the residual blocks of fossiliferous Red Crag sand at Rothamsted (Fig. 3.5). The Little Heath and Lane End deposits are at suitable elevations to suggest a correlation on this basis with the Red Crag, despite their lack of fossils (Moffat and Catt, 1986a).

However, as Fig. 3.6 shows, the relations

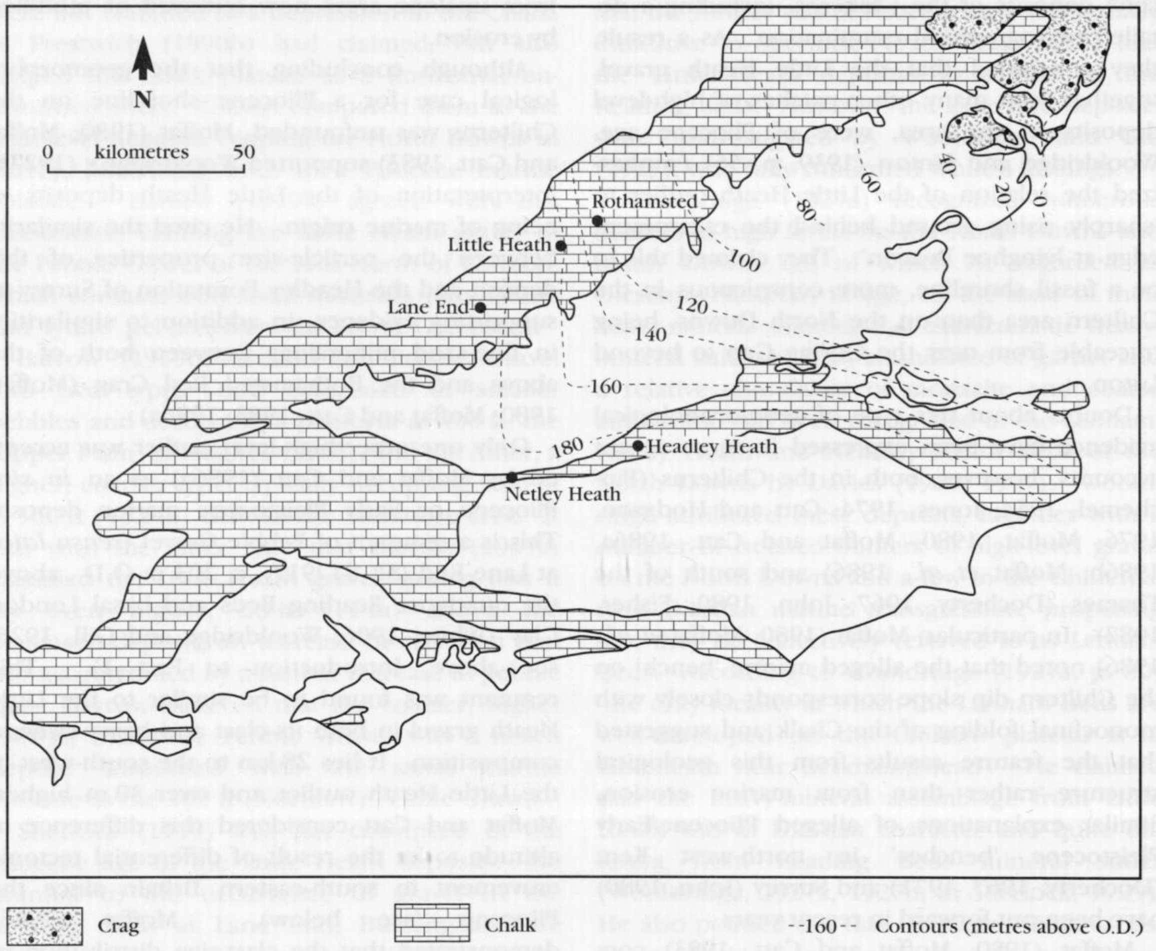


Figure 3.5 Contours on the base of the Red Crag. The positions of sites on the Chilterns and North Downs that may correlate with the Red Crag are shown (after Moffat and Catt, 1986b).

between these two outliers, if they are contemporaneous, imply a north-eastward gradient comparable to that observed in the highest Thames terrace deposits. In the case of the latter, the gradient at least partly reflects an original downstream slope. A fluvial interpretation of the Lane End and Little Heath deposits, which would make them the earliest Neogene river deposits to have been preserved, must therefore be considered. As in the various types of Pebble Gravel, sublittoral/littoral characteristics such as clast shape may reflect derivation from older Palaeogene or Neogene strata. The clast-lithological composition of the gravel at Little Heath (above and Table 3.2) is very much what might be expected for the earliest fluviatile gravels of the Thames system. Thus interpretation as a fluvial aggradation would satisfy the limited evidence that exists for the origin of these deposits, with the possible exception of their high glauconite content at Little Heath. This suggests that it might be premature to consider the littoral origin of the gravel at Little Heath to be settled. The question of whether such remnants truly result from a marine episode is likely to remain controversial for the foreseeable future.

The Little Heath outlier thus represents one of only two gravel remnants that can be interpreted as littoral deposits of Late Pliocene or Early Pleistocene age, out of many such outliers once recognized. It is possible that this deposit broadly correlates with the Red Crag of East Anglia. The evolution of the London Basin at the time of the Pliocene/Lower Pleistocene transition is poorly understood, there being little remaining evidence from which to reconstruct the contemporary coastal or drainage lines. The very existence of high-level littoral deposits *in situ* is a subject of controversy. The GCR site at Little Heath provides an important facility for the study of this enigmatic phase in the early development of the Thames catchment.

Conclusions

The sequence of clay, gravel, sand and pebbly clay deposits overlying the Chalk at Little Heath has long been controversial; even today there is much uncertainty over the age and origin of these sediments. An early interpretation, formerly widely accepted and still with some advocates, held that the Little Heath deposits

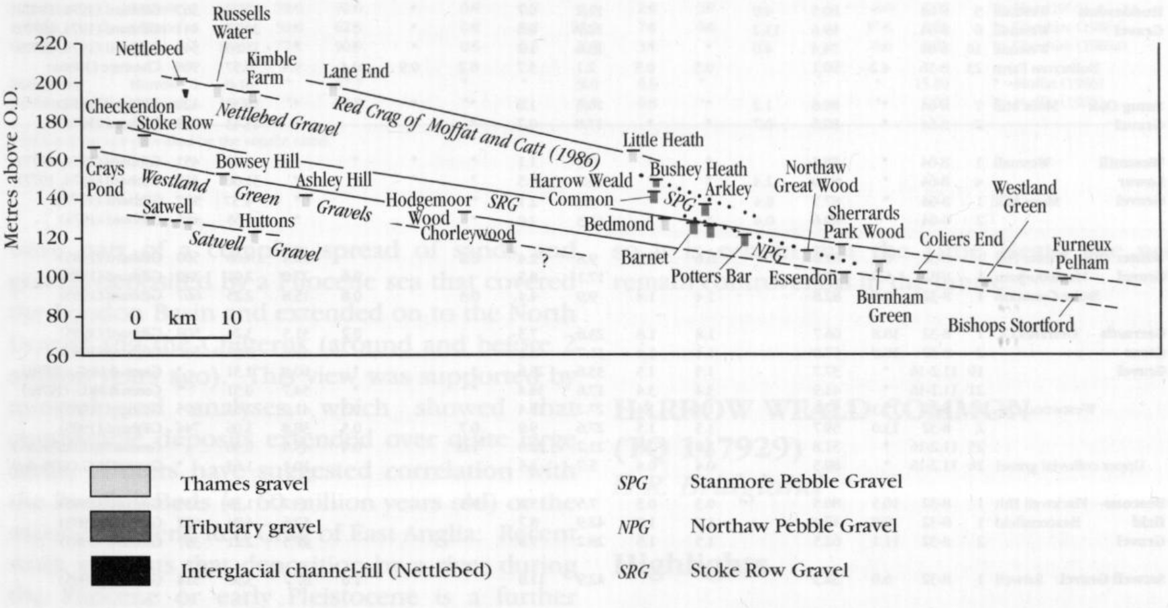


Figure 3.6 Long-profile diagram of higher deposits in the Middle Thames and the Vale of St Albans, showing the North London Pebble Gravels, attributed in this volume to deposition by a south-bank tributary of the early Thames.

Table 3.2 Clast-lithological data (in percentage of total count) from the Middle Thames and Vale of St Albans (compiled from various sources). The data concentrates on key sites, GCR sites and localities mentioned in the text. Note that many different size ranges are included and that these yield strikingly different data (this can be observed where results from different fractions from the same deposits have been analysed). As in Tables 4.2, 5.1 and 5.3, the igneous category includes metamorphic rocks (very rarely encountered) and the quartzite category includes durable sandstones. The Tertiary flint category comprises rounded pebbles (sometimes subsequently broken) reworked from the Palaeogene (see glossary with Table 4.2).

				Flint		Chalk	Southern		Exotics								
Gravel	**Site**	**Sample**	**Size range**	**Tertiary**	**Total**	**Chalk**	**Gnsd chert**	**Total**	**Quartz**	**Quartzite**	**Carb chert**	**Rhax chert**	**Igneous**	**Total**	**Ratio (qtz:qtzt)**	**Total count**	**Source**
Shepperton	Shepperton	1	8-32	4.2	95.4		1.1	1.1	2.3	1.2				3.5	1.85	569	Gibbard (1985)
Gravel	Bray		8-32	3.4	95.5		0.6	0.8	2.7	1.1				3.7	2.43	642	Gibbard (1985)
Kempton	Kempton	1	8-32	11.1	62.5		1.5	1.5	28.2	7.8				37.5	2.21	397	Gibbard (1985)
Park Gravel	Park																
Taplow	Taplow	1	8-32	2.5	91.4		2.1	2.1	5.0	1.5				6.5	3.26	525	Gibbard (1985)
Gravel	Fern House Pit	1	8-32	5.3	93.4		1.5	1.5	1.8	3.2				5.0	0.57	778	Gibbard (1985)
Lynch Hill	Lynch Hill	1	8-32	8.3	91.3		1.9	1.9	4.1	2.7				6.8	0.57	635	Gibbard (1985)
Gravel	Cannoncourt	12	11.2-16	12.7	86.1		4.8	5.1	4.2	2.9	0.9	0.2	0.4	8.8	1.46	454	Harding *et al.* (1991)
	Farm Pit	13	11.2-16	9.7	90.5		4.6	4.6	1.8	1.8	1.0	0.2		4.8	1.00	611	Harding *et al.* (1991)
	Switchback Pit	14	11.2-16	12.6	87.6		4.0	4.4	3.8	3.3	0.2	0.2	0.2	8.0	1.13	452	Harding *et al.* (1991)
Cannoncourt (tributary) **gravel**	Cct Fm Pit	15	11.2-16	1.9	96.1		2.8	3.1	0.2		0.7			0.9		459	Harding *et al.* (1991)
Boyn Hill Gravel	Boyn Hill	1	8-32	6.6	88.9		2.5	2.5	6.6	2.1				8.7	3.21	401	Gibbard (1985)
Black Park	Black Park	1	8-32	9.1	84.6		3.0	3.0	8.5	3.7				12.4	2.27	507	Gibbard (1985)
Gravel	Highlands Fm	1	8-32	5.1	86.4		0.8	0.8	6.3	5.9	0.5		0.2	12.9	1.08	662	Gibbard (1985)
Ugley	Ugley Park	1	16-32	32.5	68.1	13.3			2.7	0.6	1.8	0.2	1.5	20.3	4.50	671	Bridgland (1983a)
Gravel	Quarry	2	16-32	2.2	53.6	26.4			1.6	1.0	1.9	1	1.2	19.9	1.57	683	Bridgland (1983a)
		3	8-16	1.6	50.8	28.0			1.6	3.4	0.5	1	0.8	21.2	1.63	1139	Cheshire (1986a)
		5	8-16	0.6	44.7	38.1	0.1	0.1	0.5	1.6	0.2	0.9	0.9	17.1	0.33	1261	Cheshire (1986a)
	Westmill	11	8-64	•	61.8	21.0	•	•	4.5	8.5	•	•	•	•	0.53	440	Gibbard (1974, 1977)
	Westmill	14	8-64	•	63.2	19.8	•	•	11.6	3.8	•	•	•	•	3.02	444	Gibbard (1974, 1977)
Hoddesdon	Westmill	5	8-64	•	80.5	4.0	•	•	11.2	0.7	•	•	•	•	15.72	367	Gibbard (1974, 1977)
Gravel	Westmill	6	8-64	•	69.6	13.2	•	•	12.9	0.5	•	•	•	•	28.73	441	Gibbard (1974, 1977)
	Westmill	10	8-64	•	74.4	4.0	•	•	13.6	1.2	•	•	•	•	11.83	349	Gibbard (1974, 1977)
	Bullscross Farm	23	8-16	4.2	90.1		0.5	0.5	2.1	3.7	0.2	0.9	0.4	9.4	0.57	968	Cheshire (1986a)
Smug Oak	Moor Mill	1	8-64	•	80.6	1.2	•	•	16.5	1.6	•	•		•	10.31	428	Gibbard (1974)
Gravel		2	8-64	•	80.6	0.7	•	•	17.8	0.7	•	•		•	25.43	738	Gibbard (1974)
Westmill	Westmill	1	8-64	•	88.3		•	•	9.3	1.1	•	•	•	•	8.45	451	Gibbard (1974, 1977)
Lower		4	8-64	•	82.0	1.4	•	•	15.8	0.5	•	•	•	•	31.60	315	Gibbard (1974, 1977)
Gravel	Moor Mill	1	8-64	•	87.7	0.4	•	•	9.6	2.1	•	•		•	4.57	507	Gibbard (1974)
		2	8-64	•	89.6	0.4	•	•	11.3	2.0	•	•		•	5.65	455	Gibbard (1974)
Winter Hill	Winter Hill	1	8-32	6.4	81.0		6.6	6.6	9.8	2.4	0.2			12.4	4.08	500	Gibbard (1985)
Gravel	Mapledurham	1	8-32	5.9	72.8				17.1	8.5			0.6	27.2	2.01	340	Gibbard (1985)
	Stoke Common	1	8-32	8.0	82.8		1.4	1.4	9.9	4.4	0.3		0.8	15.8	2.25	667	Gibbard (1985)
Gerrards	Gerrards Cr.	1	8-32	18.8	66.7		1.8	1.8	23.6	7.3			0.2	31.5	3.24	508	Gibbard (1985)
Cross		2	8-32	18.9	57.0		1.4	1.4	31.7	8.1				41.6	3.92	507	Gibbard (1985)
Gravel		19	11.2-16	•	37.7		1.5	1.5	33.6	25.6	•		•	60.8	1.31	•	Green & McG. (1978a)
		21	11.2-16	•	41.9		3.4	3.4	17.6	34.4	•		•	54.7	0.51	•	Green & McG. (1978a)
	Westwood Qu.	1	8-32	15.3	57.6		1.4	1.4	27.2	10.4			0.3	41.0	2.61	595	Gibbard (1985)
		2	8-32	13.0	59.7		1.5	1.5	27.6	9.0	0.7		0.5	38.8	3.06	744	Gibbard (1985)
		25	11.2-16	•	51.8		2.8	2.8	21.2	22.0	1.0?		0.4	45.4	0.96	•	Green & McG. (1978a & c)
	Upper colluvial gravel	26	11.2-16	•	89.5		0.4	0.4	5.7	3.5				10.1	1.63	•	Green & McG. (1978a & c)
Beacons-	Flackwell Hth	1	8-32	10.5	86.5		0.3	0.3	7.5	5.4	0.3			13.2	1.39	334	Gibbard (1985)
field	Beaconsfield	1	8-32	9.8	47.4		1.0	1.0	42.9	8.7				52.6	4.94	622	Gibbard (1985)
Gravel		2	8-32	11.1	62.5		1.5	1.5	28.2	7.8				37.5	2.21	397	Gibbard (1985)
Satwell Gravel	Satwell	1	8-32	6.0	32.3				42.9	11.0			1.0	67.7	3.90	514	Gibbard (1985)
Additional	Chorleywood	1	8-16	•	35.2		•	•	44.2	18.0	•		•	•	2.46	•	Moffat (1986)
formation?		1	16-32	•	44.8		•	•	27.9	22.3	•		•	•	1.25	•	Moffat (1986)
		10	11.2-16	•	52.1		2.1	2.1	28.5	15.4	•		•	45.8	1.85	•	Green & McG. (1978a)

				Flint		Chalk	Southern				Exotics						
Gravel	**Site**	**Sample**	**Size range**	**Tertiary**	**Total**	**Chalk**	**Gnsd chert**	**Total**	**Quartz**	**Quartzite**	**Carb chert**	**Rhax chert**	**Igneous**	**Total**	**Ratio (qtz:qtzt)**	**Total count**	**Source**
Westland Green Gravels	Cray's Pond	1	8-32	13.2	88.2				7.0	4.6			0.2	11.8	1.50	517	Gibbard (1985)
	Chalfont	1	8-16	•	37.6		•	•	46.1	14.6	•		•	•	3.15	•	Moffat (1986)
	St Giles	1	16-32	•	56.5		•	•	22.1	15.9	•		•	•	1.33	•	Moffat (1986)
		2	8-16	•	33.7		•	•	42.6	19.3	•		•	•	2.21	•	Moffat (1986)
		2	16-32	•	51.1		•	•	20.1	16.9	•		•	•	1.19	•	Moffat (1986)
	Hodgemoor Wood	1	16-32	42.0	66.0		0.5	0.5	22.0	10.0	1.5		•	33.5	2.20	•	Hey (1965)
		86	11.2-16	•	52.2		0.7	0.7	26.4	18.8	•		•	47.0	1.40	•	Green & McG. (1978a)
	Westland Green	1	16-32	53.0	75.0		0.8	0.8	16.0	6.5	1.3		•	24.2	2.46	•	Hey (1965)
Stoke Row Gravel	Stoke Row	1	16-32	29.0	66.0				21.0	6.7	4.7		•	34.0	3.13	•	Hey (1965)
		2	8-32	15.4	46.1				49.9	3.8	0.3			53.9	3.16	369	Gibbard (1985)
	Bedmond	1	8-16	•	41.6		•	•	42.1	10.3	•		•	•	4.09	•	Moffat (1986)
		1	16-32	•	72.3		•	•	14.3	8.9	•		•	•	1.61	•	Moffat (1986)
	Sherrardspark Wood	1	8-16	•	36.4		•	•	42.8	10.1	•		•	•	4.24	•	Moffat (1986)
		1	16-32	•	74.8		•	•	14.2	6.7	•		•	•	2.12	•	Moffat (1986)
		2	8-16	29.8	40.7		0.1	0.1	42.0	12.9	2.9			59.2	3.26	•	Cheshire (1986a)
	Furneux Pelham	1	16-32	52.9	74.6		0.2?	0.2?	18.7	6.0	0.5			25.1	3.12	418	Hey (pers. comm.)
		7	8-16	23.1	45.9		0.3	0.3	37.5	10.3	2.8		•	53.8	3.64	•	Cheshire (1986a)
		7	16-32	56.6	69.0		0.9	0.9	16.8	10.6	1.8		•	30.1	1.58	•	Cheshire (1986a)
Nettlebed Gravel	Nettlebed	1	8-16	•	83.9				11.9	0.6	1.8			16.1	19.83	•	Moffat (1986)
		1	16-32	•	96.2				1.4	0.3	1.7			3.8	4.67	•	Moffat (1986)
	Windmill Hill	C	8-32	32.0	85.0				10.6	4.2	0.2			15.0	2.55	719	Gibbard (1985)
		B	8-32	37.5	81.3				15.1	3.4	0.3			18.7	4.49	416	Gibbard (1985)
	GCR site, above organics	D	8-32	39.5	81.7				14.0	4.1	0.1			18.2	3.41	729	Gibbard (1985)
	Kimble Farm	1	8-32	32.8	92.7				3.9	3.0	0.5			7.3	1.30	281	Gibbard (1985)
Little Heath Deposit	Little Heath	1	8-16	•	99.5				0.2		0.3			0.5		•	Moffat (1986)
		1	16-32	•	95.0				3.1	0.2	1.7			5.0	15.50	•	Moffat (1986)
		2	8-16	•	99.8				0.1	0.1	0.1			0.2	1.00	•	Moffat (1986)
		2	16-32	•	95.6				3.2	0.1	1.1			4.4	32.00	•	Moffat (1986)
Tributary gravels (Mole-Wey system)																	
Dollis Hill Gravel and similar	Dollis Hill	1	8-64	44.3	91.3		7.0	7.0	•	•	•			1.7		368	Gibbard (1979)
	Cockfosters	1	8-64	22.0	90.6		6.3	6.3	•	•	•			3.2		464	Gibbard (1979)
	Nursery Grove	1	8-16	45.6	74.8		11.3	11.3	7.4	2.4	•			13.9	3.08	1509	Cheshire (1986a)
	Bullscross Fm	11	8-16	56.0	86.1		9.1	9.3	1.8	0.4	1.1			4.6	4.50	1072	Cheshire (1986a)
Northaw Pebble Gravel	Northaw	1	16-32	78.0	92.0		0.7	0.7	4.4	2.2	0.7			8.0	2.00	•	Hey (1965)
	Great Wood	5	8-16	50.0	62.3		0.2	0.2	24.9	7.1	0.6			37.5	3.51	•	Cheshire (1986a)
		5	16-32	77.1	90.9		0.5	0.5	2.5	3.1				8.6	0.81	•	Cheshire (1986a)
Stanmore Pebble Gr.	Harrow	1	8-16	•	87.7		•	•	9.0	0.6	•			•	15.00	•	Moffat (1986)
	Weald Com.	1	16-32	•	98.9		•	•	0.3	0.3	•			•	1.00	•	Moffat (1986)

* Information not provided by the source cited.

were part of a complex spread of sands and gravels deposited by a Pliocene sea that covered the London Basin and extended on to the North Downs and the Chilterns (around and before 2 million years ago). This view was supported by mineralogical analyses, which showed that comparable deposits extended over quite large areas. Others have suggested correlation with the Reading Beds (*c.* 60 million years old) or the marine Pliocene Red Crag of East Anglia. Recent work suggests that deposition by a river during the Pliocene or early Pleistocene is a further possibility, which would make the sediments at Little Heath the earliest known Neogene deposits of this type. The marine origin so widely suggested, however, cannot yet be discounted, so it is certain that the Little Heath site will remain controversial in the future.

HARROW WEALD COMMON (TQ 147929)

D.R. Bridgland

Highlights

One of the earliest 'drift' deposits preserved in the Thames catchment, the High-level or Stanmore Pebble Gravel, is exposed at Harrow Weald Common. Although a shallow-marine or beach origin has long been favoured, it is suggested here that this gravel was deposited by a south-bank tributary of the early Thames, probably in Pliocene or Early Pleistocene times.

Introduction

Old gravel workings on Harrow Weald Common provide a rare opportunity to study the Stanmore Pebble Gravel of North London. This deposit aroused interest around the turn of the century (Prestwich, 1890c; Monckton and Herries, 1891; Salter, 1896, 1901; Barrow, 1919a, 1919c). Terms such as '500 ft', 'High-level' or 'Higher Pebble Gravel' have been widely used (Wooldridge, 1927a, 1957, 1960; Wooldridge and Linton, 1939, 1955; Hey *et al.*, 1971) to distinguish the gravels of the Stanmore–Bushey plateau from the lower deposits, now termed Northaw Pebble Gravel (see above). Confusingly, the term 'Higher Pebble Gravels' has been used by Green and McGregor (1978a; McGregor and Green, 1978; Green *et al.*, 1982) in references to Pebble Gravel generally, to distinguish it from lower-level Thames formations.

Most early workers interpreted the Stanmore Gravel as marine, but a recent reinvestigation (Moffat, 1980; Moffat and Catt, 1986a) has suggested that it represents one of the oldest fluvial deposits to be preserved within the Thames Basin.

Description

Shallow pits covering the area of Harrow Weald Common mark the sites where gravelly material has been removed from beneath the plateau surface, which reaches *c.* 145 m O.D. Very little undug ground remains, but faces in the GCR site, at the edge of a residual causeway, reveal *c.* 2 m of gravel, composed predominantly of rounded flint pebbles set in a sandy and loamy matrix.

Whitaker (1864, p. 69) first reported that Pebble Gravel was spread 'over the whole of the hill-top' at Stanmore, in a quotation from the notebook of R. Trench. Prestwich (1890c) provided one of the earliest descriptions of the Stanmore Pebble Gravel at a brick pit that, according to Bromehead (1925), lay to the south of the present GCR site. Prestwich illustrated a section in which *c.* 2 m of unstratified gravel overlay what is now classified as Claygate Beds (then included in the London Clay), the contact being deformed by the loading or involution of the gravel into the underlying silty clay. Salter (1896) recorded the occurrence of 2 m of gravel, composed predominantly of rounded flint pebbles, at 'Harrow Weald', some 146 m (480 ft) above sea level. Unfortunately he did not provide details of its precise location and, in a later paper, listed the same locality, but at 122 m (400 ft) O.D., one mile to the south of Stanmore. The last-mentioned outlier is not identified on the New Series Geological Survey map (Sheet 256), which does, however, show a large spread of Pebble Gravel covering Bushey Heath, Stanmore Common and Harrow Weald Common. Barrow (1919c) described in some detail a section on Harrow Weald Common seen by a Geologists' Association excursion (in May, 1919) close to the Kilns, where he noted that a rare undug remnant of gravel survived. From the description given, the locality visited in 1919 seems likely to have been the GCR site. Barrow observed *c.* 2 m of unbedded gravel composed of large rounded flints with smaller clasts and sand filling the interstices. In the most recent investigation of the site, Moffat (1980) considered the gravel to be vaguely horizontally stratified. He carried out clast-lithological analysis of the material, confirming the preponderance of flint, particularly in the coarser gravel fractions (Moffat, 1980, 1986; Moffat and Catt, 1986a). Moffat's grid reference (TQ 147932) and elevation (133 m) place his section on the slope of the hill 200 m to the north of the GCR site, where *in situ* material would not be expected, although his description appears appropriate for the exposure under consideration here.

Interpretation

The Harrow Weald Common GCR site provides the best available section in the Stanmore Pebble Gravel (= 500 ft or High-level Pebble Gravel of earlier workers). The history of research on these high-level deposits is complex. Prestwich (1890c) regarded the Stanmore deposits as the residue of the Eocene Bagshot Beds, although he noted that materials foreign to the Palaeogene had been introduced into them. He assigned them to his 'Brentwood Group', associating them with similarly flint-dominated gravels in southern Essex. Prestwich

(1881, 1890b) correlated the more widespread lower-level Pebble Gravel (Northaw Pebble Gravel) with his 'Westleton Beds', so he clearly differentiated the Stanmore deposits from the latter. This differentiation was questioned by Monckton and Herries (1891, p. 112), who were inclined to regard the Stanmore deposit as 'a variety of the Westleton Group'. Reid (1900), like Prestwich, also considered the Stanmore gravels to be disturbed Bagshot Beds. This view received further support from Bromehead (in Woodward *et al.*, 1922) and Sherlock (1929), although Bromehead (1925) later adopted the views of A.E. Salter (see below). Conversely, other early workers made no distinction between the Stanmore deposits and the more widespread, lower (400 ft) Northaw Pebble Gravel of south Hertfordshire (Hughes, 1868; Wood, 1868; Whitaker, 1889).

Salter (1896) cited the locality at 'Harrow Weald' as an example of his 'Barnet Gate Type' of 'pebbly gravel', thus associating it with deposits capping high ground at Shooters Hill (south-east London) and the Brentwood area. Salter (1896, 1901) showed that material foreign to the London Basin was a small but important constituent of these deposits and attributed them to the activities of post-Miocene consequent streams, regarding them as 'the first deposits of the Glacial Series' (Salter, 1896, p. 404). In this statement, Salter intended to convey the meaning that the deposits were Early Pleistocene fluvial or glaciofluvial accumulations, rather than remnants of a Pliocene beach, as was the popular view.

Despite Salter's interpretation, most workers continued to favour a marine origin for the Stanmore deposits. Barrow (1919c) considered that the gravel at Harrow Weald Common resembled a beach deposit. He thought it similar to that at Little Heath (see above) and suggested that the two were contemporaneous. Barrow (1919a) interpreted the higher (Stanmore) Pebble Gravel as a beach deposit of equivalent age to the similar, more widespread deposits at the lower level of *c.* 400 ft (122 m) in south Hertfordshire (Northaw Pebble Gravel), regarding the latter as sea-floor sediments (see above, Introduction to Part 1).

Wooldridge (1927a, 1957, 1960; Wooldridge and Linton, 1939, 1955) considered the '400 ft' (Northaw Gravel) deposits to be the true Pebble Gravel, recognizing that they contain more non-flint material than the higher-level outliers of the Stanmore area; in particular, he noted that Greensand chert is locally abundant in the former type. This led Wooldridge (1927a) to conclude that the '400 ft' (Northaw) Pebble Gravel was of fluviatile origin, although he later changed his view, subsequently favouring deposition on 'the emergent (?Sicilian) sea-floor' (Wooldridge, 1957, 1960, p. 119). However, Wooldridge consistently regarded the higher-level gravels of the Stanmore/Bushey area as marine, agreeing with Barrow that they were the same age as the Little Heath deposits.

The first attempt to test the various hypotheses for the origin of the high-level gravel of the type exposed at Harrow Weald Common was by Hey *et al.* (1971), whose studies of the surface textures of sand grains from various types of Pebble Gravel (*sensu lato*) included samples from the Stanmore Formation at Bushey Heath and Arkley. These showed evidence (v-shaped breakage patterns and straight, or nearly straight, grooves or fractures) of having formed in a fairly low-energy beach environment. Samples from the Northaw Pebble Gravel, on the other hand, contained sand grains showing additional evidence of modification in a fluvial environment, as well as the aforementioned marine features. These results were cited by Hey *et al.* as evidence of a marine origin for the Stanmore Pebble Gravel. However, the possibility exists that sand grain surface textures indicative of beach conditions have been inherited from the Palaeogene deposits that presumably supplied most of the sand in these gravels.

Moffat (1980, 1986) divided the various high-level Neogene gravels of North London and the Chilterns, on the basis of petrology, into four groups, two of which were subdivided (with a further group for Palaeogene gravels). His work provided some support for Wooldridge's correlation of the Stanmore and Little Heath gravels: by comparison of the characteristics of their quartz components, both were classified in a group intermediate between the highly quartzose Westland Green-type Thames gravels and deposits containing little else but flint (the last are gravels of restricted local origins). However, the Stanmore Pebble Gravel, which he sampled at Harrow Weald Common, and the much higher gravel at Nettlebed, were separated by Moffat from other comparable deposits on the basis of particle size and mineralogy. Whereas other members of the group were interpreted as Pliocene/Early Pleistocene marine gravels, more or less *in situ* (see above, Little Heath), the Stanmore and Nettlebed deposits were attributed to Early Pleistocene fluvial activity (Moffat and Catt, 1986b).

Moffat (1986) cited variations in the distribution of different-sized quartz material ('quartz signatures') between types of high-level gravel as an indication that the quartz has come from three distinct sources. He found that the 'quartz signatures' from the supposed Pliocene/Early Pleistocene marine gravels at Little Heath and Lane End were similar to those from quartzose Reading Beds gravels and suggested that the latter had provided the quartz component of the former. Other quartzose gravels, including that at Harrow Weald Common, contain more quartz than could have been supplied by the Reading Beds, with a 'signature' suggesting a source rich in smaller clasts of quartz (4–8 mm), such as the Lower Greensand (see below). Gravels on the Chilterns dip slope, interpreted as remnants of the Stoke Row and Westland Green Formations of the Thames (Moffat, 1986; Moffat and Catt, 1986a), contain yet more quartz, with a third variety of 'quartz signature', indicating a supply of larger sized material. The association of this change with the appearance of 'Bunter quartzites' suggests that additional quartz in these gravels has come from sources outside the Thames catchment, adding support to the view that they were deposited by an early Thames flowing from the Midlands (see Part 2 of this chapter) and are clearly separable from the Pebble Gravel of North London (Stanmore and Northaw Gravels), which contains no material from the Midlands.

The plotting of the elevations of the high-level gravels discussed here against the projected downstream gradients of early Thames formations (see below) supports the interpretation of the Stanmore Gravel as fluviatile (Fig. 3.6). In particular, the distinct west to east gradient, recognized but dismissed as unimportant by Wooldridge (1927a), is readily apparent. A similar gradient is observed between outcrops of the lower Northaw Pebble Gravel between Barnet and Northaw Great Wood. In both cases the gradient is higher than projections of the early Thames gravels on the Chilterns dip slope (Fig. 3.6). Furthermore, gravels with larger quartz components and containing 'Bunter quartzites' have been recognized (Moffat, 1980; Moffat and Catt, 1986a) on the northern flanks of the Vale of St Albans at elevations well above the Westland Green Gravels of Hey (1965), which suggests an antiquity comparable to the North London Pebble Gravel. Moffat and Catt (1986a) suggested that gravels of this type at Bedmond (TL 104037) and Sherrards Park Wood (TL 225138) might be outliers of the Stoke Row Gravel of Gibbard (1983, 1985), a suggestion that is supported by their altitude (Fig. 3.6). These gravels must be at least as old as the Northaw Pebble Gravel, since they are at a comparable altitude.

The composition and steeper gradients of the two North London Pebble Gravel formations, the Stanmore and Northaw Gravels (Fig. 3.6), imply that they are the deposits of tributaries of the early Thames, not the Thames itself. This is supported by their location, well to the south of the earliest Thames route along the Chiltern dip slope. The distribution of these formations suggests north-eastward trending sediment bodies, now highly dissected, converging with the Thames route through the Vale of St Albans. Their composition is also consistent with deposition by a south-bank tributary of the Thames, a river draining the northern Weald and tapping sources of Greensand chert. The quartz component of these gravels, which is predominantly confined to the smaller size ranges, was probably secondarily derived from the Reading Beds and the Lower Greensand. Indeed, the 'quartz signature' determined by Moffat (1986) from the Harrow Weald Common gravel is suggestive of a Lower Greensand provenance. A similar quartz component has been encountered in (pre-Thames diversion) Mole-Wey deposits in the Finchley area, the Dollis Hill Gravel of Gibbard (1979) (see Fig. 3.1 and Tables 3.1 and 3.2). It seems likely, in fact, that several (as yet undifferentiated) left-bank terrace gravels of the erstwhile Mole-Wey river are represented in the area between the Lower Lea valley and the main Pebble Gravel outcrops of North London. The Northaw Pebble Gravel can be interpreted as a high-level element within this same terrace system; the term should be restricted to those outliers on the crest or the eastern side of the ridge, in which Greensand chert occurs (Fig. 3.1 and Table 3.2). Deposits at similar elevations further west, such as at Shenley, are unlikely to be *in situ* Mole-Wey deposits and may well be of colluvial origin, derived from the gravels capping the ridge. In a stone count of the Shenley gravel, Hey (1965) found no Greensand chert.

Small amounts of such chert are, however, recorded from the Stanmore Pebble Gravel (Wooldridge, 1927a; Moffat, 1980; Moffat and Catt, 1986a), suggesting that this deposit might represent the earliest evidence of the Mole-Wey drainage system. The altitudinal distribution and gradient of this deposit suggest correlation with the Stoke Row Gravel of the Thames, whereas the Northaw Gravel can probably be correlated with the Westland Green Gravels (see Fig. 3.6 and Table 3.1). Correlation of the deposit at Nettlebed with the Northaw Pebble Gravel, as suggested by Gibbard (1985) and Moffat and Catt (1986a), is not supported by this interpretation; the Nettlebed Gravel appears to be an older deposit than any part of the North London Pebble Gravel Subgroup (Table 3.1).

The exposure of the Stanmore Pebble Gravel at Harrow Weald Common is one of very few, in the Thames basin, in which Pliocene/Early Pleistocene deposits can be examined. The origin of this type of material has been a subject of considerable controversy but, until recently, most authors have favoured a shallow-marine origin. Recent reappraisal has considerably undermined the case for a Pliocene or Early Pleistocene marine episode in the London Basin, such that the Pebble Gravel Group is now generally thought to comprise fluviatile deposits, their marine characteristics having been inherited from earlier Cenozoic gravels. The suggestion, in this report, that the Stanmore Pebble Gravel represents a south-bank tributary of the early Thames is based on re-evaluation of published evidence. Further research on the deposit at Harrow Weald Common and other sites in the Stanmore and Northaw Gravels is required to test this theory and provide more information about the palaeogeography of the London Basin during the poorly understood Late Pliocene–Early Pleistocene period. The goal of such work would be a more complete understanding of the early history of the River Thames, prior to its acme, in the Early Pleistocene, as a huge river draining the West Midlands as well as the present catchment.

Conclusions

The gravel at Harrow Weald Common was once widely believed to have been deposited in a Pliocene sea, two million or more years ago. However, a reconsideration of the evidence from here and other sites suggests that these sediments are river deposits; their altitude and sedimentary characteristics are consistent with deposition by a south-bank tributary of the early Thames. This view stems from the application of more modern analytical methods, such as detailed studies of the constituent rock types and sand grains present in the gravels. The characteristic markings found on quartz grains when viewed under high magnification with a scanning electron microscope (SEM) provide a means of distinguishing between marine and fluviatile deposits. Such analyses suggest that the marine characteristics of the deposits were inherited from older sediments that have been incorporated in the fluviatile Stanmore Pebble Gravel. As a rare exposure of these early tributary deposits, the Harrow Weald Common site will be essential to any reinterpretation of the early history of the Thames catchment.

PRIEST'S HILL, NETTLEBED (SU 700872)

D.R. Bridgland

Highlights

A site high on the Chiltern escarpment, Priest's Hill is the location of what may be the oldest interglacial deposits to be preserved in the Thames catchment. Critical to the interpretation of the interglacial sediments and their implications for the evolution of the River Thames is the relation between the Priest's Hill deposits and the Nettlebed Gravel, which covers higher ground in the vicinity. The Nettlebed Gravel is widely believed to be the earliest true Thames gravel, derived through an early Goring Gap.

Introduction

This site lies on the western side of Windmill Hill, Nettlebed, which at 211 m O.D. is one of the highest points on the Chiltern escarpment in the area of the Goring Gap. The modern river passes through the gap in the escarpment *c.* 10 km to the south-west and 150 m below the level of the deposits at Nettlebed. These unbedded, clayey, sandy gravels, containing a high proportion of rounded flint pebbles, were classified as 'Westleton Beds' by Prestwich (1890b), a term also used by Monckton and Herries (1891) and White (1892, 1895). The deposits were subgrouped with the Pebble Gravel (Blake, 1891; Salter, 1896; Shrubsole, 1898; White, 1908b) and appear as such on the Geological Survey map (New Series, Sheet 254). On the basis of its elevation, Wooldridge (1927a) grouped this outlier with his high-level Pliocene (Diestian) marine deposits, which he later (Wooldridge, 1957, 1960) redefined as Early Pleistocene. The gravel remnants at Nettlebed have recently been reinterpreted as fluvial deposits (Horton, 1977, 1983; Gibbard, in Turner, 1983; Gibbard, 1985). Gibbard regarded them as early Thames deposits, classifying them as Nettlebed Gravel, the highest lithostratigraphical division within his system of Middle Thames terrace gravels and, therefore, probably the earliest Thames formation to have been preserved (if the interpretation of the Little Heath and Lane End gravels as marine is correct – see Little Heath).

Priest's Hill is of exceptional significance, since an Early Pleistocene interglacial organic deposit has been discovered there, in association with the Nettlebed Gravel (Horton, 1977, 1983; Turner, 1983; Gibbard, 1985). Although the precise relation between the organic sediments and the gravel is unclear at present, the former offers a potential means of determining the age of the earliest elements of the Middle Thames sequence.

Description

Several gravel remnants are preserved at Nettlebed, occurring slightly below the summit of Windmill Hill and on the subsidiary summit of Priest's Hill (203 m O.D.), in both cases overlying thin basal London Clay above Reading Beds. The summit of Windmill Hill, 211 m above O.D., is gravel-free (Blake, 1891; White, 1892; Horton 1977). White (1892) regarded the surviving drift remnants on Windmill Hill as the infills of 'pipes' and hollows in the Reading Beds and considered it likely that the hill-top was once covered with a similar deposit, since removed by denudation. The gravel consists primarily of flint (both reworked from Palaeogene beds and derived directly from the Chalk) and quartz, with subordinate Palaeozoic chert and quartzite (Table 3.2). The size and origin of the quartzite component is a subject of some doubt (see below).

Prestwich (1854), in the earliest record of the site, illustrated a section showing 1.5 m of crudely stratified gravel above *c.* 4 m of bedded white and yellow sand with flint and quartz pebbles, the latter having an erosive base cutting into Reading Beds sands and clays. The base of the gravel was also irregular and it is not clear whether Prestwich regarded the sand as part of the drift or of the solid geology. Monckton and Herries (1891), who described a comparable section at Priest's Hill, considered the sand to be associated with the gravel. It is possible that this sand is equivalent to that seen underlying the organic sediments in recent temporary sections (Horton, 1977, 1983; below).

The Nettlebed interglacial site has only been investigated from boreholes and temporary exposures. In July 1975 the following sequence was revealed, apparently filling a depression in the Reading Beds (Horton, 1977, 1983; Fig. 3.7):

		Thickness
6.	Soil	0.2 m
5.	Grey, poorly sorted clayey gravel (= Nettlebed Gravel?)	1.35 m
4.	Grey-white sand	0.04 m
3.	Humic, pebble-free clay	0.025 m
2.	Dark brown humic silt with scattered pebbles and plant remains	0.66 m
1.	White silty, pebbly sand	0.93 m

Turner (1983) published a preliminary pollen diagram from the Nettlebed organic deposits (beds 2 and 3), showing rather more than the first half of a typical Pleistocene interglacial cycle (see Fig. 3.8).

Interpretation

Prestwich (1890b) and White (1892, 1895) regarded the 'Westleton Beds' at Nettlebed as marine deposits of Pliocene or Early Pleistocene age. Salter (1896), who classified the deposits with his 'High Barnet Type' of pebbly gravel, was unusual amongst early workers in dissenting from this view, regarding all the high-level gravels as fluviatile. Wooldridge (1927a) closely associated the gravel at Nettlebed with that capping the Palaeocene outlier at Lane End (see above, Little Heath), *c.* 12 km to the north-east and 10 m lower in altitude. He correlated these and other high-level deposits on the Chilterns with the Lenham Beds of Kent, on the basis both of altitude and heavy-mineral content, attributing them to a Late Pliocene/Early Pleistocene marine incursion into the London Basin (Wooldridge, 1927a, 1957, 1960; Wooldridge and Linton, 1939, 1955). Recent work by Moffat (1980; Moffat and Catt, 1986a) has confirmed the possibility that the Lane End gravel is a Pliocene/Early Pleistocene marine deposit, but they and most other recent workers have favoured Salter's fluviatile interpretation of the Nettlebed sediments.

Horton (1977) recorded channelling within the sequence at Nettlebed, including the channel filled with humic silts and clays (beds 2 and 3) containing terrestrial pollen. He therefore thought the deposits to be of fluvial origin. Further support for this interpretation came from a resistivity survey, which revealed a channel trending NNW–SSE, approximately parallel with the orientation of the Goring Gap (Turner, 1983). Turner (1983) and Gibbard (1985) also cited evidence from a study by scanning electron microscopy (SEM) of sand grains from the Nettlebed Gravel, the surfaces of which showed various stages in the eradication (presumably during fluvial transport) of characteristic features formed by attrition in a marine environment, presumed to have been inherited from Palaeogene deposits (see above, Harrow Weald Common). Both Turner (1983) and Gibbard (1985) attributed the Nettlebed Gravel to the Thames, but were uncertain of its relation to the organic channel deposits.

The palynological sequence from the Nettlebed interglacial sediments (beds 2 and 3) (Turner, 1983; Fig. 3.8) begins with a pre-temperate phase (biozone I), passes through an early temperate phase (biozone II) and includes the early part of a late-temperate phase (biozone III). Birch (dominant), pine and subordinate spruce pollen characterize biozone I. Oak (abundant) and elm appear in biozone II, whereas biozone III is heralded by the appearance in the pollen record of hornbeam and the marked expansion

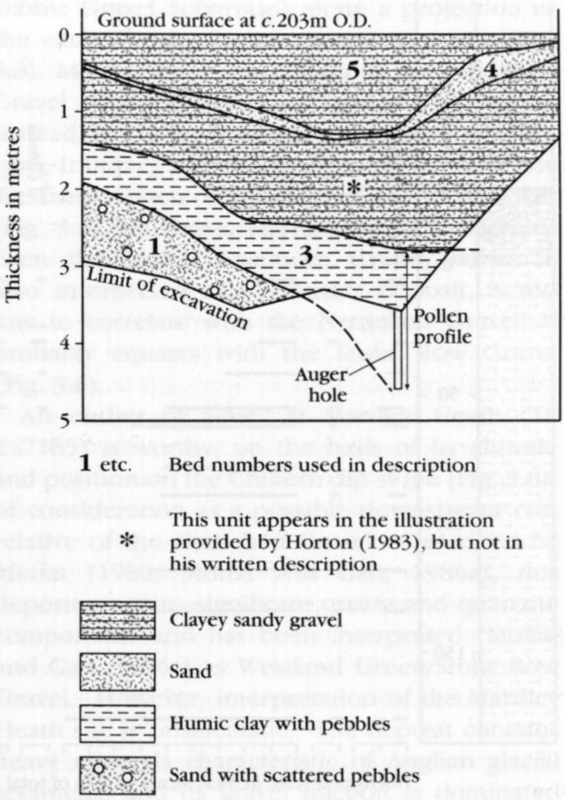


Figure 3.7 The stratigraphy of the deposits at Priest's Hill, Nettlebed, as recorded from a temporary section. The position of the pollen profile is shown (after Horton, 1983).

of hazel. Despite the absence of exotic taxa from this record, spruce being the only non-native tree represented, Turner considered it quite different from interglacial pollen diagrams from the Middle and Upper Pleistocene. He pointed to the absence of temperate indicators such as ivy, holly and lime, to the late rise of hazel and to the early appearance of spruce as significant features, concluding that the deposit represents an interglacial episode prior to the Cromerian Stage, probably one hitherto unrecognized in Britain. Gibbard (1985) was in broad agreement with Turner's conclusions and proposed the provisional term 'Nettlebedian' for the stage represented. He suggested that the non-polleniferous sands (bed 1) underlying the organic sediments might have formed during a previous cold episode. Gibbard assessed the palaeobotanical evidence for correlation of the Nettlebed interglacial with the more complete continental Pleistocene

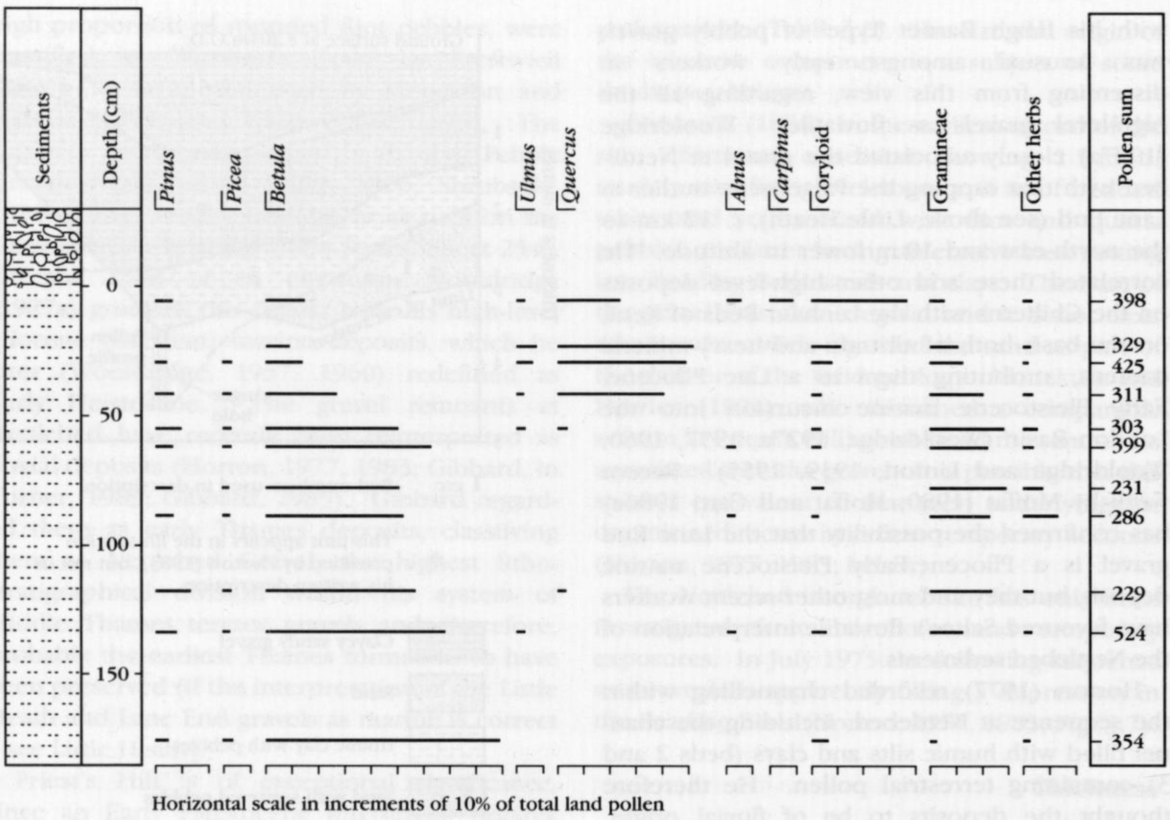


Figure 3.8 Pollen from the organic silts at Nettlebed (after Turner, 1983).

record and concluded that it probably belonged somewhere within the late Early Pleistocene/ early Middle Pleistocene 'Cromerian Complex' of The Netherlands. The stratigraphical position of the deposit, at a very high level within the Thames terrace system, implies a considerable age (Turner, 1983). Its relation to the Thames terrace system, as described in Chapter 1 (Figs 1.3 and 3.3), suggests that the Nettlebed deposit is very much older than that at Sugworth or any of the temperate-climate sediments in Essex that are ascribed to the 'Cromerian Complex' (see Chapter 5). It is considerably higher within the terrace sequence than the Gerrards Cross Gravel, for which an Early Pleistocene age now appears likely (see Chapter 1; below, Westwood Quarry). Further investigation of the Priest's Hill sediments is urgently required in order to address this question. In particular, evidence from palaeomagnetism, to establish whether the site pre-dates the Matuyama– Brunhes reversal (see Chapter 1), would be of considerable value.

The Nettlebed interglacial sediments have great potential as a means of dating the earliest Pleistocene deposits of the Thames system. Unfortunately, there is some doubt as to their precise relation to the Nettlebed Gravel. Gibbard (1985) observed that the clayey gravel (bed 5) overlying the organic channel-sediments closely resembles the Nettlebed Gravel of the Windmill Hill outlier in its clast-composition (Table 3.2), suggesting a direct correlation. However, the former has a very clayey matrix, in places reminiscent of the local Reading Beds, raising the possibility that the pollen-bearing sediments are capped by a solifluced mixture of Nettlebed Gravel and Palaeogene clay and, therefore, that the channel deposits may post-date the deposition of the early Thames gravel at this altitude. The fact that Priest's Hill lies a few metres lower than the Windmill Hill outlier increases the feasibility of the latter interpretation.

It is therefore uncertain whether the Nettlebed Gravel was deposited before or after the interglacial sediments. However, the fact that both appear to be fluvial deposits belonging to the Thames terrace system suggests, given the small amount of vertical separation between them, that they are closely related in time. Even if the channel deposits are the product of a tributary, their position near the crest of the escarpment implies considerable antiquity. In terms of terrace stratigraphy, both the Nettlebed Gravel and the Priest's Hill channel deposits appear to pre-date the Stoke Row and Westland Green Gravels (Fig. 3.2), the earliest formations to provide unequivocal evidence for a Thames catchment that extended beyond the Cotswolds.

Further possible outliers of Nettlebed Gravel have been recognized at Russell's Water (SU 714889) and Kimble Farm (SU 749888), both downstream from the type locality (Turner, 1983; Gibbard, 1985; Fig. 3.6). This suggests a downstream gradient of *c.* 0.9 m per kilometre for this formation. Although it falls directly in line between Nettlebed and Kimble Farm, analysis of the Russell's Water deposit by Moffat (1980; Moffat and Catt, 1986a) shows it to be composed dominantly of angular flint, which suggests that it is not part of the Nettlebed Gravel.

Gibbard (1985) suggested a correlation of the Nettlebed Gravel with the 400 ft (Northaw) Pebble Gravel, but the Nettlebed deposit contains fewer rounded flints, reworked from Palaeogene deposits, than the latter (Table 3.2; see above, Harrow Weald Common). However, Nettlebed lies near the edge of the Tertiary sedimentary basin, beyond which Chalk would presumably have outcropped when the Nettlebed Gravel was deposited, as it does now, providing a supply of fresh flint. Rounded flint would have been progressively picked up from Palaeogene sources between Nettlebed and Hertfordshire. The compositional differences between the Nettlebed Gravel and the Northaw Pebble Gravel do not, therefore, preclude their correlation. However, Moffat and Catt (1986a) have identified gravels equivalent to Gibbard's Stoke Row Gravel, which post-dates the Nettlebed Gravel (see Fig. 3.2 and Table 1.1), on the Chiltern dip slope in Hertfordshire, at altitudes comparable to the Northaw Gravel (Fig. 3.6). Plotting of the altitudinal distribution of the Pebble Gravel remnants on the dip slope (Chiltern Pebble Gravel Subgroup) and in North London and south Hertfordshire (North London Pebble Gravel Subgroup) along a projection of the early Thames course across the area (Fig. 3.6), indicates that correlation of the Nettlebed Gravel with the Northaw Gravel is untenable. Instead, the latter is likely to represent a south-bank tributary stream and to correlate with the Westland Green Formation of the main river (Fig. 3.6; see above, Harrow Weald Common). Even the higher Stanmore Gravel, which is also interpreted as a tributary deposit, is too low to correlate with the Nettlebed Gravel; it probably equates with the Stoke Row Gravel (Fig. 3.6).

An outlier of gravel at Mardley Heath (TL 247185) is worthy, on the basis of its altitude and position on the Chiltern dip slope (Fig. 3.6), of consideration as a possible downstream correlative of the Nettlebed Gravel. Described by Moffat (1980; Moffat and Catt, 1986a), this deposit contains significant quartz and quartzite components and has been interpreted (Moffat and Catt, 1986a) as Westland Green/Stoke Row Gravel. However, interpretation of the Mardley Heath site is problematic. The deposit contains heavy minerals characteristic of Anglian glacial sediments and its gravel fraction is dominated by non-rounded flint (Moffat, 1980), both of which suggest that it is Anglian outwash and, therefore, of no relevance to the early evolution of the Thames.

Turner (1983) cited the presence of quartz and quartzites in the Nettlebed Gravel as an indication that a link between the Kennet-Thames and the Midlands already existed at the time of its deposition, rejecting White's (1906) theory that such material was reworked from the quartz-rich facies of the Reading Beds. However, the increased amounts of Midlands material that are present in later Thames formations indicate that the main input of 'exotic' material through the Goring Gap occurred after the deposition of the Nettlebed Gravel. Different estimates of the composition of the Nettlebed Gravel have been given by Moffat (1980, 1986; Moffat and Catt, 1986a) and Gibbard (in Turner, 1983, 1985). The most important discrepancy is that Moffat found less than 1% quartzite above the 8 mm sieve size, whereas Gibbard recorded *c.* 4% and concluded that the quartzose component of the gravel indicated a Midlands provenance (Table 3.2). Moffat (1986) interpreted the 'quartz signature' (see above, Harrow Weald Common) from the Nettlebed deposit as evidence for derivation from the Reading Beds and the Lower Greensand, but not from Triassic deposits. This would seem to imply that the Oxfordshire extension of the Thames was already in operation, but that no Triassic material had, up to that time, entered the catchment. Horton (1977) listed 18.5% quartzite from Nettlebed, but this figure clearly includes vein quartz and so must be disregarded. However, he did state that 'Northern Drift' pebbles were absent, suggesting support for Moffat's findings. Amongst the early workers, the views of Prestwich (1890b) are of some relevance to this problem, as he gave clear details of the composition of the gravel at Nettlebed. Prestwich (1890b, p. 140) considered that 'Pebbles of hornstone (?), veinstone, and Sarsen stone' accounted for 8% of the deposit. The record of sarsen suggests that he regarded the quartzitic material present as being of Palaeogene derivation. Hornstone (= schorl-rock?) is a highly durable lithology that is usually attributed to a Midlands Triassic source, but such material is also present in Mesozoic pebble beds within the present Thames catchment (Bridgland, 1986b). Thus it remains uncertain, at present, whether the Nettlebed deposits contain material from outside the present Thames basin. This question is of considerable importance, since it has major implications for Pleistocene palaeogeography and the evolution of Thames drainage.

The high-level gravel at Nettlebed is of major importance, therefore, as it probably represents the earliest evidence for Thames drainage that has survived. The GCR site at Priest's Hill is of even greater importance, however, on account of the very early interglacial sediments that have been preserved there in association with the Nettlebed Gravel. These are thought to represent an Early Pleistocene temperate episode hitherto unrecognized in Britain. The occurrence of fluvial sediments at this considerable altitude indicates that the present crest of the Chilterns was at valley-floor level at that time. This last fact demonstrates the enormous amount of erosion that has occurred during the Pleistocene.

Conclusions

At Priest's Hill, underlying a clayey gravel, are beds of silt and clay, containing pollen, that seem to fill an old river channel. Analysis of the pollen reveals a dominance of temperate-climate plant species and indicates that the silt and clay accumulated during a warm ('interglacial') phase of the Quaternary Ice Age. The high altitude of this site (around 200 m above sea level) suggests a very early age. It is similar to the level of the Nettlebed Gravel, the highest and oldest Thames gravel to be recognized. The Nettlebed Gravel is preserved in the vicinity of the Priest's Hill site and may be represented by the clayey gravel overlying the pollen-bearing sediments. This would suggest that the interglacial deposits were part of the Nettlebed Gravel Formation and would indicate that they are of very great antiquity. An alternative interpretation is possible, however. The clayey gravel may be a later mixture of material, largely derived from the Nettlebed Gravel, that has accumulated above the channel-fill sediments. In this case the interglacial beds could be considerably younger than the Nettlebed Gravel. However, their high altitude inevitably indicates that they are very early and of great significance; no major river can have flowed at this level for a very long time. The evidence from Nettlebed provides a clear indication of the vast amount of erosion that has taken place during the Pleistocene.

Part 2

PRE-DIVERSION DEPOSITS IN THE MIDDLE THAMES BASIN AND THE VALE OF ST ALBANS

D.R. Bridgland

Introduction

In this part of Chapter 3 the most extensive gravel formations to have been produced by the Thames are described. These were laid down after the river gained headwaters that drained a large part of the West Midlands, probably also extending into Wales (the 'Severn-Thames' of early writers), and before the diversion of the river by the Anglian Stage glaciation of the Vale of St Albans. Evidence for this diversion, which took the river into its modern valley through London, is derived from sites in the Vale of St Albans (see below, Moor Mill). The 'Severn-Thames', as envisaged by many Victorian authors and recently promoted by Hey (1986; see Chapter 2), was a huge river, probably the largest to have existed in Britain during the Quaternary. It appears to have come into existence in the Early Pleistocene, although its initiation probably post-dated the interglacial represented at Nettlebed (see above). The decline of the Thames appears to have begun before its diversion into the modern valley, in the Anglian. According to Whiteman (1990), the river had already lost its headwaters beyond the Cotswolds by the Anglian Stage, by which time it was more or less confined to the present catchment (see Chapter 1). Evidence from Essex suggests that the river's size was much diminished by 'Cromerian Complex' times, during which it formed a series of terrace deposits in the north-east of that county for which few equivalents have thus far been recognized upstream in the Middle Thames (see Chapters 1 and 5).

The deposits of the pre-diversion Thames are so extensive, and their far-travelled component so dominant, that they have often been interpreted as glacial outwash material and were mapped by the Geological Survey largely as 'Glacial Gravel'. The earliest 'Severn-Thames' gravels are, however, found within the high-level deposits of the Pebble Gravel Group, already described in Part 1 of this chapter. The oldest major fluvial formation to be recognized in the London Basin is the Nettlebed Gravel (Gibbard, 1985; see above), but the first appearance of a significant component of material from beyond the present Thames catchment is in lower-level formations within the Pebble Gravel, the Stoke Row and Westland Green Gravels (Table 3.1).

Salter (1896) had recognized that the lowest deposits of Pebble Gravel type could be separately defined on the basis of their distinctive clast composition, which included abundant quartz and quartzites. He classified such gravels as his 'Bell Bar type'. Hey's (1965) reinvestigation of these gravels confirmed that they represent a compositionally distinctive gravel type that can be traced across the London Basin from the Goring Gap to eastern Hertfordshire. He demonstrated that the quartz and quartzite content of these deposits, which he named the 'Westland Green Gravels', was consistently at least twice that of other deposits that had been classified as Pebble Gravel. He also noted that pebbles of orthoquartzite from the Triassic ('Bunter') pebble beds of the Midlands were present in the Westland Green Gravels, but not in other varieties of Pebble Gravel. He noticed that remnants of Westland Green Gravels occurred at progressively lower altitudes eastwards from the Goring Gap, falling from 174 m O.D. to 107 m O.D. near Bishops Stortford. He concluded that these deposits, which he later traced into Essex, Suffolk and Norfolk (Hey, 1980; Chapter 5) were of Thames origin and that they represented the first influx of material from the Midlands through the Goring Gap.

A large proportion of the high-level gravels in the Thames valley has been classified at various times as 'Glacial Gravel'. This terminology dates back to Wood (1867, 1870; Wood and Harmer, 1868, 1872), who assigned the till and associated gravel of East Anglia to his 'Glacial Series'. Wood's classification was adopted by the Geological Survey throughout the London Basin (for example, Whitaker, 1875, 1889; Sherlock and Noble, 1922; Bristow, 1985). Generally the gravels were classified as 'Middle Glacial' and the overlying till (later the Lowestoft Till) as 'Upper Glacial' (Wood and Harmer, 1868, 1872). The lowest tier of Wood's tripartite classification, the 'Lower Glacial', referred to a till of more localized distribution, later identified as part of the Scandinavian-derived North Sea Drift. Although Wood's original classification seems to have had predominantly stratigraphical (rather than genetic) implications, the term led inevitably to the misinterpretation of the gravel deposits as glaciofluvial outwash.

White (1895) was the first to advocate the idea that such gravels were the remains of early terrace deposits of the Thames, but this view did not gain widespread acceptance until Sherlock and Noble (1912) traced gravels rich in Midlands lithologies from the Goring Gap towards Watford and suggested that the Thames formerly flowed along this more northerly route. Shrubsole (1898) subdivided the various high-level gravels of Berkshire and Oxfordshire according to their clast content, which he listed in percentages. He defined four categories (in addition to 'local gravel'), as follows: 'Pebble Gravel', 'Goring Gap Gravel', 'Quartzose Gravel' and 'Quartzite Gravel'. The last two incorporated the lower pre-diversion Thames formations, classified as 'Glacial' by most of Shrubsole's contemporaries. The change from 'Quartzose' to 'Quartzite' type is reflected in the progressive decline in the quartz : quartzite + sandstone ratios subsequently recognized within the pre-diversion Thames sequence (Hey, 1980, 1986; Green and McGregor, 1986; Table 3.2). Shrubsole's work was therefore much ahead of its time, but he did not positively associate these gravels with the Thames.

The first attempt to define early terraces of the Thames within the so-called 'Glacial Gravels' of the lower Chiltern dip slope was by Saner and Wooldridge (1929). They recognized a 'Winter Hill Terrace' in addition to, and higher than, the previously identified terrace gravels. This and two older, much-dissected Thames aggradations, the 'Higher' and 'Lower Gravel Trains', were fully described by Wooldridge (1938). Hare (1947), on the basis of detailed geomorphological mapping of the area between Slough and Beaconsfield, redefined the Lower Gravel Train as the 'Harefield Terrace'. Later studies by Sealy and Sealy (1956), Thomas (1961) and Allen (1978) extended Hare's terrace mapping both westwards and eastwards. These workers added a number of new terraces to the Thames sequence, in some cases upgrading minor features that Hare had previously recognized. The separate existence of most of these has not been upheld in recent work by Gibbard (1985), although the Rassler Terrace of Sealy and Sealy (1956) has been interpreted in Chapter 1 as the product of a genuine and additional Thames aggradation, between the Harefield and Winter Hill Terraces as defined by Hare (1947).

Hey's (1965) work on the Westland Green Gravels pioneered an approach based on clast-lithological analysis (see Chapter 1). Using this technique, he distinguished the Westland Green Formation from the rest of the Pebble Gravel and recognized it as an early aggradation of the Thames, despite the fact that erosion has reduced this deposit to small patches of gravel capping hills. The Westland Green Gravels were the oldest Thames deposits to be recognized until Gibbard (1983, 1985) identified the earlier Nettlebed and Stoke Row Gravels (above, and Tables 3.1 and 3.2). Gibbard recognized another additional Thames formation, his Satwell Gravel, which is intermediate, within the terrace sequence, between the Higher Gravel Train and the Westland Green Gravels (Table 3.1). Gibbard (1977, 1978a, 1983, 1985) redefined the Thames terrace deposits on a lithostratigraphical basis, generally using the geographical names that had previously been applied to the terrace surfaces. He replaced the terms 'Higher Gravel Train' and 'Lower Gravel Train' (Harefield Terrace) with Beaconsfield Gravel and Gerrards Cross Gravel respectively, thus establishing the system of nomenclature presently in use.

It is interesting to note that the elevation of the deposit at Chorleywood (TQ 023953), claimed by Moffat and Catt (1986a) as a further representative of the Westland Green Gravels, appears from its altitudinal position (Fig. 3.6) more likely to result from a separate aggradation, hitherto unrecognized, between that formation and the later Satwell Gravel. According to analyses by Moffat (1986; Moffat and Catt, 1986a), this deposit, which is situated approximately 10 m below the expected level of the Westland Green Formation, contains higher levels of quartz and quartzites and less flint than other outliers of the Westland Green Gravels (Table 3.2). A further low-level Westland Green Gravels outlier with a high quartz and quartzite content appears to have been recorded by Green and McGregor (1978a), on the opposite side of the River Chess from Chorleywood, to the north-west of Croxley Green. Caution must be exercised in the interpretation of altitudinal evidence on the Chilterns dip slope, given the prevalence of Chalk solution phenomena. However, the apparent clast-lithological distinction is potentially significant, particularly as it is in keeping with the progressive trend, in successively lower pre-Gerrards Cross Gravel formations, of increasing quartzose rocks at the expense of flint (see Table 3.2). Further investigation of this area is called for, to assess whether an additional terrace formation is preserved there.

THE VALE OF ST ALBANS THAMES AND ITS DEMISE

D.R. Bridgland

Salter (1905) was apparently the first to recognize that fluvial drainage through the Goring Gap formerly continued north-eastwards into Hertfordshire by way of the Vale of St Albans. He observed that varieties of rock introduced into the area in glacial deposits are absent in the gravels associated with this former drainage route, but that they occur in all the gravels associated with the modern drainage system. He thus concluded that the initiation of this system must have coincided with the glaciation. Perhaps because these far-reaching conclusions were lost in a weighty description of deposits over the whole of south-eastern England, they received no immediate support. Thus Sherlock and Noble (1912), who claimed that the Thames formerly flowed from the Beaconsfield area towards Watford, through the Vale of St Albans, and that the glaciation of this district brought Thames drainage by this route to an end, are often given credit for the initiation of the theory. Later, Sherlock (1924), Sherlock and Pocock (1924) and Clayton and Brown (1958) described lacustrine deposits in the Vale of St Albans that, they suggested, were related to the ponding of the Thames by ice. Overspill from the proglacial lake so formed was considered to have effected the diversion of the river into its modern valley.

Wooldridge (1938, 1960) believed that the Thames had formerly occupied two different northerly courses, one running through the Vale of St Albans and a later route through Finchley (Fig. 3.4). He suggested that both of these routes were abandoned as a result of ice advances, the Vale of St Albans route because of an early 'Chiltern Drift' advance (Barrow, 1919a) and the Finchley route as a result of the main 'Chalky Boulder Clay' advance (now attributed to the Anglian Stage). Wooldridge considered that the Higher and Lower Gravel Trains and the Winter Hill Terrace all continued eastwards via the intermediate Finchley route.

Hey (1965) traced his Westland Green Gravels from the Goring Gap along the Chiltern dip slope to Hertfordshire, thus confirming that the river at this time flowed through the Vale of St Albans. Later work showed that the Beaconsfield, Gerrards Cross and Winter Hill Gravels also extended along this route (Gibbard, 1974, 1977, 1983, 1985; Green and McGregor, 1978a, 1978b; McGregor and Green, 1978), rather than through Finchley, as suggested by Wooldridge. Hare (1947) had recognized that the Winter Hill Terrace, in the area immediately west of the Colne confluence, flattens downstream until it has a very small eastward gradient. He attributed this marked decrease in downstream gradient to the ponding of the Thames at this time by ice. Gibbard (1977, 1985) confirmed this interpretation, although he attributed the flattened terrace surface in this area to an upper, deltaic division of the Winter Hill Formation (Chapter 1), his 'Winter Hill Upper Gravel'.

Gibbard traced the fluviatile Winter Hill Gravel downstream beneath the glacial deposits of the Vale of St Albans, where it is synonymous with the Westmill Lower Gravel (*sensu* Cheshire, 1986a; see below, Westmill). He showed that this gravel is overlain in the Watford area by proglacial lake deposits, which are themselves overlain by till. Gibbard concluded that this lake arose from the same glacial ponding event that produced the Winter Hill Upper Gravel, and that the overspill from the lake eventually brought about the diversion of the Thames from its early course into its modern valley, without there having been an intermediate route as envisaged by Wooldridge. The evidence for a 'Chiltern Drift' glaciation, which Wooldridge believed to have diverted the Thames from the Vale of St Albans into his intermediate route, has been challenged by recent workers (Avery and Catt, 1983; Green and McGregor, 1983; McGregor and Green, 1983a). Cheshire (1981, 1983a, 1983b, 1986a; in Allen *et al.*, 1991) has further refined the stratigraphical succession in the Vale of St Albans and has recognized greater complexity in the sequence of Anglian glacial events in the area (this chapter, Moor Mill, Westmill and Ugley). Cheshire's work was based on a detailed examination of particle size, carbonate content and small-clast lithology of till samples from sites throughout eastern

Hertfordshire and western Essex. Cheshire has recognized four separate ice advances within the Anglian glaciation of the Vale of St Albans, the first of which diverted the Thames into its modern valley.

CHALFONT ST GILES BRICK PIT (SU 977942) and FURNEUX PELHAM GRAVEL PIT (TL 442267)

D.R. Bridgland

Highlights

The Chalfont St Giles and Furneux Pelham pits are important sites that provide evidence for the early history of the River Thames. Such evidence has been used to reconstruct the river's former course across Hertfordshire and into East Anglia, prior to its southward deflection by Anglian Stage ice.

Introduction

Sites at Chalfont St Giles and Furneux Pelham are important in establishing the route taken by the Thames during the formation of the Early Pleistocene Westland Green Gravels, as defined by Hey (1965). These gravels have been traced from the Middle Thames through the Vale of St Albans towards East Anglia (Hey, 1965, 1980). The Chalfont St Giles pit lies within the Middle Thames region, at the northernmost and highest edge of the classic 'staircase' of terrace deposits preserved between the Thames and Colne valleys (Fig. 3.1). The pit at Furneux Pelham, on the other hand, lies at the eastern end of the Vale of St Albans, only 6 km from the type locality of the Westland Green Gravels (Hey, 1983). The deposits contain rocks derived from the West Midlands and, it is believed, North Wales, the latter suggesting that glaciation of upland areas may have occurred at this early stage of Thames evolution (Green *et al.*, 1980; Hey, 1980; Bowen *et al.*, 1986a).

The Westland Green Gravels were the first Thames deposits to be traced across the London Basin from the Reading area to East Anglia (Hey, 1980, 1982; Bowen *et al.*, 1986a). Allen (1983, 1984) and Gibbard (1983, 1985) later proposed subdivisions of this unit in Suffolk (Chapter 5, Part 1) and the Middle Thames respectively. Gibbard (1983, 1985) concluded that the westernmost outlier recognized by Hey (1965), at Stoke Row (SU 686834), represents a higher and even earlier Thames aggradation, which he termed the Stoke Row Gravel. Re-evaluation of the various outliers in Hertfordshire identified by Hey (1965, 1980) as Westland Green Gravels suggests that some, including that at Furneux Pelham, may represent the earlier Stoke Row Gravel (Fig. 3.6).

Recent work by Whiteman (1990) indicates that the deposits classified as Westland Green Gravels in the Middle Thames and East Anglia do not belong to the same formation, although the basic conclusion that the Thames followed the route envisaged by Hey is upheld (see Chapter 5).

Description

Chalfont St Giles Brick Pit, Buckinghamshire

This site is an intermittently worked brick pit exploiting the silty clays of the Reading Beds. Up to 2 m of poorly stratified Westland Green Gravels occur as overburden above the Reading Beds. The site lies near the north-eastern edge of a small plateau, occupied by Hodgemoor Wood, at about 140 m O.D. The Geological Survey showed 'Glacial Gravel' overlying Reading Beds in the area of the brick pit (Old Series, Sheet 7, 1871; New Series, Sheet 255, 1922). An early description of the site was provided by Barrow (1919a). According to Barrow (1919a, p. 38), the Chalfont St Giles pit showed 'quartz pebble gravel ... somewhat churned up by the passage of ice over it, and in consequence mixed with a considerable number of far-travelled stones'. Despite this supposed glacial contamination, Barrow included the Hodgemoor Wood outlier in the Pebble Gravel. Hey (1965) recognized that the Hodgemoor Wood plateau represents one of the largest remnants of the Westland Green Gravels. He pointed to the occurrence in these deposits of quartzites and Carboniferous chert from the Midlands as evidence of a Thames origin; such materials are common constituents of the Northern Drift of the Upper Thames catchment (see Chapter 2), leading Hey to conclude that they were introduced into the London Basin, through an early Goring Gap, by the ancestral Thames. Green and McGregor (1978a) published the results of a stone count of a sample that appears, from their map and profile diagram, to be from this site or nearby, their sample 86 (see Table 3.2). The Chalfont St Giles pit was reinvestigated by Moffat (1980, 1986; Moffat and Catt, 1986a), who confirmed that Westland Green Gravels occur there.

Furneux Pelham Gravel Pit (Hillcollins Pit), Hertfordshire

This site lies in the present catchment of the River Lea, 10 km north of Ware, where that river turns south from the Vale of St Albans into the lower part of its valley, towards its confluence with the Thames in east London (see Fig. 3.1). The pit is 6 km north of the Westland Green type locality, which is now overgrown. As at Chalfont St Giles, Geological Survey maps (Old Series, Sheet 18) indicate 'Glacial Gravel' at Furneux Pelham (showing that the early mappers separated these deposits from the Pebble Gravel). The pit exposes 3–4 m of well-bedded sandy gravel, aggraded to *c.* 107 m O.D. and showing the abundance of quartzites and flint pebbles reworked from the Palaeogene that characterizes the Westland Green Gravels. Matrix-supported gravel is interbedded with cross-stratified sand lenses. Over much of the pit, the deposits appear to dip sharply to the north-west, perhaps towards a solution hollow in the underlying Chalk. Hey (1983) described the following section:

		Thickness
4.	Wind-blown sand	up to 1 m
3.	Coarse, poorly sorted gravel, the uppermost beds clay-enriched and reddened	6 m
2.	Yellow sand, with one band of flint pebbles	2 m
1.	Dark purplish-brown clayey sand	1 m
	Base not seen	

A hitherto unpublished stone count of the gravel at this site (bed 3) shows *c.* 77% flint, over two-thirds of which consists of reworked Palaeogene pebbles, with 19% quartz and 6% quartzite and sandstone (R.W. Hey, pers. comm.; Table 3.2). This analysis falls within the range of counts from the Westland Green Gravels previously published by Hey (1965). Table 3.2 also includes clast-lithological data from this site supplied by Cheshire (1986a).

Interpretation

The recognition by Hey (1965) of an Early Pleistocene 'Westland Green Gravels' aggradation, extending across an area from the Goring Gap to Hertfordshire, was a landmark in Thames research. Salter (1896, 1905), who had attempted to trace various types of gravel from the Chiltern dip slope to East Anglia, had previously included many of the Westland Green Gravels outcrops in his 'Bell Bar type', although he was apparently not aware of the outlier at Hodgemoor Wood. Hey traced the Westland Green Gravels from Stoke Row, on the Chilterns, via Ashley and Bowsey Hills and across Hertfordshire, where it occurs at Hodgemoor Wood, Hatfield Park, Essendon, Little Berkhamsted, and several sites between the Mimram and Stort valleys. The last included the best exposure available at the time of his survey, at Westland Green (TL 422215), near Little Hadham. He renamed the deposits after this locality, since he had observed that the sediments at Bell Bar, taken as the type section for this gravel by Salter (1896), were not *in situ*. Warren (1945, 1957) had previously attributed the gravel at Westland Green to the early Thames.

Support for the fluvial origin of the Westland Green Gravels was derived from their regional and altitudinal distribution, shown by Hey (1965) to closely resemble the long-profile of a river. The steep upstream part of Hey's reconstructed long-profile was, however, removed when Gibbard (1983, 1985) redefined the highest outlier, at Stoke Row, as part of an earlier formation (see below). A study of sand grain surfaces, using scanning electron microscopy, provided confirmatory evidence that the Westland Green Gravels are of fluviatile origin (Hey *et al.*, 1971). The distribution and composition of the gravels, which contain a similar suite of pebbles to later Thames terrace deposits, led

Hey (1965) to claim that the Westland Green Gravels were the earliest product of the River Thames. The further suggestion that deposition of the Westland Green Gravels corresponded with glaciation in areas to the north-west of the Thames catchment (Hey, 1965) found favour with later authors, notably Bowen *et al.* (1986a). This was based on the occurrence in these deposits of volcanic rocks thought to be derived from Wales, although these appear to be more common in the lower pre-Anglian gravels (Green *et al.*, 1980).

Evans (1971, fig. 50), in his early attempt to relate the various Thames terrace aggradations to the cold and warm cycles of the deep-sea oxygen isotope record, allocated the Westland Green Gravels to his cycle 16W and suggested an age of about 620,000 years for this formation. Evans's cycle 16W would appear to equate with Stage 31 of the current oxygen isotope chronological nomenclature (see Chapter 1). According to the latest estimates (Ruddiman *et al.*, 1989), a correlation with Stage 31 would imply an age of just less than one million years. Evans, however, based his correlations on extrapolated interglacial sea levels, which he took to have fallen progressively during the Pleistocene. He considered the major terrace formations to have aggraded during interglacials, an idea largely superseded by the modern view that they were predominantly deposited during cold episodes. His model implied a sea level of 103 m above present ordnance datum during Westland Green times. This would require that the type area in Hertfordshire, where the gravels fall below 110 m O.D., lay close to the contemporary coastline. The modern association of gravel aggradation with cold episodes renders Evans's sea-level prediction obsolete (Chapter 1), but the broad correlation between climatic cycles and terrace sequences that he envisaged, essentially one of counting backwards, compares quite closely with more recent interpretations based on the oxygen isotope chronology (see Chapter 1). Only a very crude approximation of the age of the Westland Green Gravels would be claimed from this type of correlation today, however.

Hey (1976b, 1980) went on to address the problem of correlating the Westland Green Gravels of the Middle Thames with the Pleistocene sequence in East Anglia, attempting to trace the unit to north Norfolk. He recognized (1980) that deposits of Westland Green type occur within the higher levels of the Kesgrave Group (Rose *et al.*, 1976). He noted that a marine gravel on the foreshore at Beeston Regis, Norfolk (TG 260402), ascribed to the 'Pre-Pastonian a' Stage, contains a similar range of clast types to the Westland Green Gravels. Hey (1980) suggested that the Westland Green Gravels were the terrestrial equivalent of this marine gravel. Subsequent work has shown that the Kesgrave Group deposits in Norfolk that were correlated by Hey with the pre-Pastonian marine gravel at Beeston belong to a later Thames formation than the Westland Green Gravels, implying that the latter may be even older than the 'Pre-Pastonian a' Stage (Whiteman, 1990; Chapter 1).

Gibbard (1983, 1985) concluded that the deposit at Stoke Row on the Chilterns dip slope, the furthest upstream of Hey's Westland Green outliers, probably represents an earlier aggradational phase. He assigned this outlier to the newly defined Stoke Row Gravel. Hey (1965) had noticed that this remnant was, at 174 m O.D., some 6 m above the projected long-profile (thalweg) reconstructed from the other occurrences of Westland Green Gravels. He suggested an increased gradient in the upstream part of the river system as a possible explanation. Gibbard, however, found gravel at the expected elevation of the Westland Green Formation, lower down the dip slope in this area, around Crays Pond (SU 637805). Remnants of gravel, generally similar in composition to the Westland Green Formation but at a higher level, have subsequently been identified at Bedmond (TL 104037) and Sherrards Park Wood (TL 225138). These have been assigned to the Stoke Row Formation (Moffat, 1980; Cheshire, 1986a; Moffat and Catt, 1986a). Moffat and Catt (1986a) suggested that these outliers have larger quartz : quartzite + sandstone ratios than samples of the Westland Green Gravels; their clast-lithological data supports this view, but it is difficult to determine whether the same is true of the data published by Hey (1965) and Gibbard (1985), largely because of differences between the categories and size fractions used by these various workers (Table 3.2).

Plotting the remnants of Westland Green Gravels and Stoke Row Gravel along the generalized early-Thames route from the Goring Gap to eastern Hertfordshire (Fig. 3.6) suggests that a vertical separation of 12–15 m, as demonstrated by Gibbard in the Goring Gap area, is maintained as far downstream as Essendon. However, the various outliers in the Westland Green type area fall somewhat randomly between the projected Westland Green and Stoke Row levels, so that all are higher than would be expected for the former and lower than for the latter. In particular, the gravel at Furneux Pelham, with a surface height of 107 m O.D., plots significantly higher than the other remnants, given its position at the downstream end of Fig. 3.6; it is only a few metres below the projected Stoke Row level (based on the two sites at Bedmond and Sherrards Park Wood). It therefore seems likely that the fluvial deposit at the Furneux Pelham GCR site does not represent the Westland Green Gravels, as was asserted by Hey (1983), but is instead a degraded remnant of the Stoke Row Formation.

There is some support for this interpretation from clast-lithological data from the Furneux Pelham site. The ratios of quartz to quartzite + sandstone at Furneux Pelham, indicated by the available stone-count data, are amongst the highest recorded from gravels of Westland Green type in Hertfordshire (Table 3.2). Although the suggestion that higher ratios of this type might characterize the Stoke Row Gravel (Moffat and Catt, 1986a) has yet to be confirmed, the figures from Furneux Pelham appear to support the altitudinal evidence for correlation with that formation.

Further work is required to clarify the distribution of the earliest Thames gravels in and downstream from eastern Hertfordshire, in order to determine whether the division into Stoke Row and Westland Green Formations can be continued north-eastwards. There is some indication that the long-profiles of these formations converge downstream, as a result of a shallowing of the Westland Green gradient, a steepening of the Stoke Row gradient, or perhaps both (Fig. 3.6). Moffat and Catt's (1986a) observation that the Stoke Row Gravel may have larger quartz : quartzite + sandstone ratios than are typical of the Westland Green Gravels hints at a possible method, independent of altitude, for distinguishing the two aggradations.

The GCR sites at Chalfont St Giles and Furneux Pelham thus represent an extremely important period in the history of the River Thames, close to the time when the river was first initiated as a drainage route from the Midlands into the London Basin. Although both were originally ascribed to the Westland Green Gravels, reappraisal of the deposits in eastern Hertfordshire suggests that the Furneux Pelham site exposes the earlier Stoke Row Gravel. The latter appears at present to be the earliest Thames deposit containing abundant material from the Midlands, indicating that a link with the present Severn catchment may have existed across the Cotswolds (see above; Chapters 1 and 2). The two GCR sites provide rare opportunities for studying exposures in these formations and as such are of significant value to British Pleistocene stratigraphy.

Conclusions

The gravels exposed at these sites provide evidence for the early history of the River Thames. Their height, distribution and gravel content have all been used as evidence in tracing the river's early course. These sites show that the Thames once flowed along a more northerly course across Hertfordshire and eventually into East Anglia. Although both sites were thought to show gravels of the same type and age, differences in their topographical position and stone content suggest that deposits of somewhat different ages may be present at each site. The oldest of these (the Stoke Row Gravel), at Furneux Pelham, is possibly the earliest gravel to contain material carried by the early Thames from beyond the Cotswolds escarpment. Both gravels were deposited at a time when the river had a much larger catchment than at present, probably extending into the West Midlands and possibly as far as Wales.

WESTWOOD QUARRY (TQ 071993)

D.R. Bridgland

Highlights

This is an important locality for the study of terrace stratigraphy in the Middle Thames basin. The gravels at Westwood Quarry yield possible evidence, in the form of volcanic rocks transported from North Wales, for glaciation in the Early Pleistocene.

Introduction

Westwood Quarry exposes sand and gravel deposited by the Thames when it flowed north of London, through the Vale of St Albans and central Essex, towards East Anglia. These deposits belong to the Gerrards Cross Gravel (Gibbard, 1983, 1985), formerly known as the Lower Gravel Train (Wooldridge, 1938). The upper surface of this formation, where present, forms the Harefield Terrace of Hare (1947). The sections at Westwood Quarry reveal bedded gravel and sand overlain by probable solifluction gravel (Green and McGregor, 1978c; McGregor and Green, 1983a, 1983b; Gibbard, 1985). The site is notable for the occurrence, in the upper levels of the bedded gravel, of a clay-enriched and iron-stained horizon of possible pedogenic origin.

Description

The sequence at Westwood Quarry can be summarized as follows (based on published reports and on the re-excavated GCR section):

		Thickness
3.	Coarse, very clayey gravel, heavily iron-stained	up to 4 m
2a.	Sandy gravel, clay-enriched and mottled (soil developed in top of bed 2)	
2.	Sandy, clayey, bedded gravel (Gerrards Cross Gravel)	up to 5 m
1.	Chalk, forming pinnacles	

The first description of sections at Westwood Quarry was by Green and McGregor (1978c), who recorded well-bedded sands and gravels (bed 2) overlying 'pinnacled Chalk' and in turn overlain by compact clayey gravel (bed 3). The clayey gravel, which contains a higher proportion of local material than the well-bedded gravel (Table 3.2), was interpreted by Green and McGregor (1978c; McGregor and Green, 1983a, 1983b) as a colluvial deposit. McGregor and Green (1983a) recorded a clast-fabric orientation from the upper gravel suggesting derivation by solifluction from the east, although no high ground now exists in that direction. They also presented palaeocurrent evidence (clast fabrics and foreset orientations) from the fluvial gravel (bed 2) compatible with emplacement by an eastward-flowing river. Surface elevations of 84 m and 88 m were recorded by Green and McGregor (1978a) and Gibbard (1985) respectively.

Similar deposits at Westwood Quarry were recorded by Gibbard (1985), who additionally referred to lenses of brown pebbly clay interbedded with the gravels. He attributed these poorly sorted lenses to mass-movement of material from the valley side. In all these descriptions the effects of solution of the underlying Chalk were noticed; this process has given rise to a pinnacled bedrock surface, to faulting in the overlying gravel and to the formation of pipes and associated collapse structures filled with later, usually fine-grained, sediments. The reddening, mottling and clay enrichment of the upper levels of the lower fluvial gravels (bed 2a) is interpreted as evidence for pedogenesis prior to the accumulation of the upper solifluction gravel (P.L. Gibbard and J.A. Catt, pers. comms).

Interpretation

A principal part of the geological interest at Westwood Quarry arises from the interpretation of the gravels there as early Thames deposits, laid down at a time when the river flowed through the Vale of St Albans. The history of research leading to this interpretation is long and complex. It was formerly thought that high-level sand and gravel of this type was of glacial origin; early Geological Survey maps show the deposits of this area as 'Glacial Gravel' (Old Series, Sheet 7, 1871; New Series, Sheet 225, 1922; see above, Introduction to Part 2). However, some of the early authors recognized that these high-level deposits are disposed in terrace-like remnants similar to the well-established terraces of the valley gravels (White, 1895, 1897, 1907; Shrubsole, 1898).

It was also observed at an early stage (although not widely accepted until much later) that the far-travelled element of these gravels, mainly quartz, quartzite and chert pebbles from the West Midlands and the Welsh borderlands, are types that have been transported into the London Basin not by ice, but by an ancestral Thames flowing through the Goring Gap (White, 1895). The extension of these ancient gravel deposits from the Middle Thames valley into the Vale of St Albans, rather than along the modern valley through London, was recognized by Salter (1905).

Wooldridge (1938) provided the first systematic subdivision of the belt of old Thames drifts that extends from the Goring Gap to Ware, where it passes beneath true glacial deposits. He recognized three new terrace aggradations at higher levels than those mapped by the Geological Survey, although the two highest are so dissected that he declined to refer to them as terraces. Instead he called them the 'Higher Gravel Train' and the 'Lower Gravel Train'; these occur at 122 m and 113 m O.D., respectively, in the classic Middle Thames area north of Slough. Hare (1947) showed that the Lower Gravel Train is sufficiently well-preserved in the Beaconsfield district to be recognized as a terrace, which he called the 'Harefield Terrace'.

Wooldridge (1938, 1957, 1960; Wooldridge and Linton, 1939, 1955) did not believe that the Thames flowed through the Vale of St Albans after Pebble Gravel times. He suggested that the Lower Gravel Train river flowed in a course via the 'Middlesex Loopway' and 'Finchley Depression' (Fig. 3.4), rejoining the earlier northern route near Hertford. Hare (1947) traced this formation (in the form of his Harefield Terrace) to the Harefield area, where he supposed that it entered the 'Middlesex Loopway'. Wooldridge (1957, 1960) perpetuated this view, but no description of Thames gravels in either the 'Middlesex Loopway' or the 'Finchley Depression' was ever provided. Wooldridge (1938) applied the term 'Leavesden Gravel Train' to the deposits now exposed in Westwood Quarry, attributing them to a westward-flowing tributary of the Higher Gravel Train Thames, which he also believed to have flowed through the 'Middlesex Loopway' and the 'Finchley Depression'.

It was later demonstrated, from analyses of the distribution and composition of gravel deposits, that Thames drainage through the Vale of St Albans persisted until the river was diverted by ice during the Anglian Stage (Gibbard, 1974, 1977, 1978a, 1983; Green and McGregor, 1978a, 1978b; McGregor and Green, 1978). Gibbard (1979) also concluded that the 'Finchley Depression' was continuously occupied by the Mole-Wey tributary prior to the diversion of the Thames and that the latter river shifted directly from the Vale of St Albans route into its modern course. Gibbard (1974, 1977, 1978a) recognized that the maximum elevation of the fluvial part of the gravel at Westwood Quarry, and its clast composition, indicate that it is part of the Lower Gravel Train, a view supported by Green and McGregor (1978a, 1978b, 1978c; McGregor and Green, 1978). Gibbard proposed the name 'Leavesden Green Gravel' for this aggradation in the Vale of St Albans, but later (1983, 1985) dropped the term in favour of the name 'Gerrards Cross Gravel', which he applied to all the deposits formerly assigned to the Lower Gravel Train.

According to Gibbard, the Gerrards Cross Gravel represents the penultimate phase of terrace aggradation by the Thames in its Vale of St Albans route, the last being the Winter Hill/Westmill Gravel (Gibbard, 1977, 1978a, 1983, 1985). The deposition of the latter immediately preceded the glaciation of the Vale of St Albans and the resultant diversion of the Thames (see below, Moor Mill and Westmill). Remnants in the Reading–Henley area of an intermediate Rassler Gravel Formation, previously recognized by Sealy and Sealy (1956), are here attributed to aggradation by the Thames in the interval between the deposition of the Gerrards Cross and Winter Hill Formations (see Chapter 1; Fig. 3.2).

The clast composition of the Gerrards Cross Gravel shows it to be the richest of all the Thames terrace formations in exotic material from beyond the present catchment (McGregor and Green, 1978, 1983b, 1983c, 1986; Green *et al.*, 1980; Gibbard, 1985; Table 3.2), particularly the familiar volcanic (including pyroclastic) pebbles that are believed to come from North Wales (Hey and Brenchley, 1977; Green *et al.*, 1980; Whiteman, 1983). McGregor and Green (1983b) noted that these igneous clasts are concentrated in certain areas, perhaps suggesting the localized fragmentation of larger ice-rafted blocks, and that the proportions of the various types differ from those in the Kesgrave Sands and Gravels of Essex and Suffolk, where they have also attracted attention. Despite his agreement that these exotic lithologies 'reach their acme' in the Gerrards Cross Gravel, Gibbard (1985, p. 16) presented data that shows twice as much igneous material (8–32 mm size range) in the Beaconsfield Gravel (average 0.46%) as in the Gerrards Cross Gravel (average 0.23%). Gibbard did, however, record high levels of igneous rocks at Westwood Quarry (average 0.44%). Data from 11.2–16 mm clast counts published by Green and McGregor (1978a, 1983), Green *et al.* (1980) and McGregor and Green (1986) clearly indicate that the highest frequencies of volcanic clasts occur in the Gerrards Cross Gravel; the record of 3.16% volcanics in a sample from the M1 motorway (McGregor and Green, 1986) appears to be the highest value from any of the various Thames formations.

The occurrence, in the Gerrards Cross Gravel, of the highest frequencies of igneous material within the Thames terrace succession has led to the suggestion that deposition of this formation coincided with a glacial advance from Wales and the north-west into the upper reaches of the catchment (Green and McGregor, 1978a). Since the Gerrards Cross Gravel is older than the Winter Hill Gravel, which immediately pre-dates the Lowestoft Till, this Welsh glaciation must have been earlier than any that occurred during the Anglian Stage. After comparison with the influx of far-travelled material into East Anglia in the Early Pleistocene (Hey, 1976b), Green and McGregor (1978a) suggested that a glaciation of Baventian age, or of post-Baventian/pre-Anglian age, had introduced exotic material into the Thames catchment during the deposition of the Gerrards Cross Gravel and, probably, on earlier occasions. Bowen *et al.* (1986a) interpreted the occurrence of such materials in the various early Thames formations as evidence for repeated glaciation in upland Britain. However, Gibbard (1983, 1985) favoured an early Anglian age for the Gerrards Cross Gravel and any corresponding glaciation of the upper reaches of the catchment. He reported that the study of sand-grain surfaces by scanning electron microscope had revealed little evidence for a proximal glacial source of the Gerrards Cross Gravel.

The recognition in this volume of an additional terrace formation in the Middle Thames between the Gerrards Cross and Winter Hill Gravels (above; see Chapter 1) makes an early Anglian age for the Gerrards Cross Formation unlikely. The conclusions of Whiteman (1990), and their implications for correlation between the Thames sequence and that in East Anglia (see Chapter 1), indicate that the Gerrards Cross Gravel is very much older than the Winter Hill/Westmill Formation. Early attempts to correlate the Gerrards Cross Gravel with parts of the Kesgrave Sands and Gravels (Green *et al.*, 1982; Green and McGregor, 1983; McGregor and Green, 1986; Bowen *et al.*, 1986a) were based largely on Hey's (1980) projection of the Westland Green Gravels into East Anglia, although Bridgland (1988a) also used deposits related to the Anglian glaciation and its diversion of the Thames within Essex as a stratigraphical marker. Whiteman's work suggests that the Gerrards Cross Gravel is the direct correlative of the deposits in Suffolk and Norfolk identified by Hey (1980) and Allen (1983, 1984) as Westland Green Gravels. The implication of this is that the sequence of lower pre-diversion gravels (Low-level Kesgrave Subgroup – see Chapter 5) recognized in southern East Anglia is poorly represented in the Middle Thames valley, there being a major gap in the terrace succession in the latter area between the Gerrards Cross and Winter Hill Formations. The suggested correlation of the early Thames gravels in Suffolk and Norfolk with the East Anglian sequence (Hey, 1980; see above and Chapter 1) points to an Early Pleistocene age for the Gerrards Cross Gravel, implying that deposition of the Westland Green and Winter Hill Gravels was separated by a considerable period of time, including the entire early Middle Pleistocene. The poorly preserved Rassler Formation, recognized in the Reading area (Chapter 1), appears to be the only deposit in the Middle Thames that represents part of this interval.

Whiteman's views represent a considerable challenge to workers in the Middle Thames valley, which has long been held to be the classic area for studies of the river's development. If his correlation scheme is correct, the pre-Anglian sequence in East Anglia is considerably more complete than that in the Middle Thames. Whiteman has interpreted the Gerrards Cross Gravel as the last aggradation by the 'Severn-Thames', subsequent formations reflecting a river, much reduced in size, that had lost its headwaters beyond the Cotswolds escarpment. The coincidence of this formation with the peak in exotic gravel lithologies suggests that a fairly major Early Pleistocene glaciation may have occurred at this time. This raises the possibility that this glaciation may have influenced fluvial evolution in the area beyond the Cotswolds and may have been responsible for diverting the drainage of this area away from the Thames, probably into the Trent system (which was represented at that time by a river flowing from southern Lincolnshire into northern East Anglia, the 'Ingham River' (Rose, 1987, 1989; Bridgland and Lewis, 1991)).

Little is known about the palaeosol that occurs in the upper levels of the Gerrards Cross Gravel at Westwood Quarry. This may be of similar origin and age to the Valley Farm Soil, which is developed on the Kesgrave Sands and Gravels in East Anglia (Rose *et al.*, 1976; Rose and Allen, 1977; Kemp, 1985a; see Chapter 5, Newney Green), and may therefore provide further evidence for correlating the Gerrards Cross Formation with divisions of the Kesgrave Group. Apart from the widely recognized Valley Farm Soil, the occurrence of a buried palaeosol is an extreme rarity within the Thames terrace sequence. Study of the soil horizon at Westwood Quarry may produce corroborative evidence for the great age of the Gerrards Cross Gravel implied by Whiteman's interpretation of Lower/lower Middle Pleistocene Thames stratigraphy.

Conclusion

The Gerrards Cross Gravel, exposed at Westwood Quarry, charts the course of the early River Thames, which once flowed through the Vale of St Albans towards eastern Hertfordshire and East Anglia. This river brought with it exotic rocks from as far afield as the West Midlands and North Wales. Such evidence has been used to suggest that, at this time (probably over three-quarters of a million years ago), the Thames drained a much larger area than at present. Some workers believe that glaciation in the upland area of North Wales brought some of the more exotic rock-types into the Thames catchment. If so, this is a rare indication of glaciation prior to the growth of the well-known Anglian ice sheets, about 450,000 years ago.

WESTMILL QUARRY (TL 344158)

D.R. Bridgland and D.A. Cheshire

Highlights

Exposures at this site have provided evidence for determining the Anglian history of the River Thames and its tributaries. They reveal a complex sequence of gravels and tills that records the replacement of the Thames in this area by a newly formed River Lea. This was a direct response to glacial inundation of the former Thames valley, which eventually deflected that river into its modern course through London.

Introduction

One of the thickest Pleistocene sequences in the Thames basin can be seen at Westmill Quarry, Hertfordshire, where over 20 m of sediments, all attributed to the Anglian Stage, are exposed. These deposits represent the drift sequence, made up of fluvial, glacial, glaciofluvial and glaciolacustrine sediments, that plugs the old valley of the Thames. This old valley separates the Chilterns and the hills of North London, occupying an area known as the Vale of St Albans. The fact that the Vale of St Albans was once glaciated was recognized by Walker (1871) and Whitaker (1889). Salter (1905) and Sherlock and Noble (1912) suggested that this glaciation brought about the cessation of north-eastward drainage, a view that was subsequently confirmed by the recognition of proglacial lake deposits in various parts of the Vale of St Albans (Sherlock, 1924; Sherlock and Pocock, 1924; Clayton and Brown, 1958; Gibbard, 1974, 1977; see below, Moor Mill).

The sequence of events during the Anglian glaciation of the Vale of St Albans was reconstructed by Gibbard (1974, 1977, 1978a), the Westmill Quarry section providing critical evidence for his interpretation. Gibbard recognized two glacial advances into the Vale of St Albans during the Anglian. He considered the Thames drainage to have survived the first of these advances, despite local ponding in the Ware area, but that the river was blocked and diverted by the second. Subsequently Cheshire (1981, 1983a, 1983b, 1986a), in a detailed study of till lithologies and stratigraphy, found evidence for four separate Anglian ice advances into the area. According to Cheshire, it was the first of these that effected the diversion of the Thames.

Description

Westmill Quarry is a modern excavation, first described by Gibbard (1974, 1977, 1978a, 1978b), who recorded a sequence of two gravels and two tills. A further till was subsequently recognized by Cheshire (1983a, 1983b, 1986a), who also suggested that the upper till at Westmill, the Eastend Green Till of Gibbard, should be renamed the 'Westmill Till', on the grounds that it is not stratigraphically equivalent to the tills exposed at Gibbard's type site at Eastend Green (see below). The sequence currently recognized at Westmill is therefore as follows (see Fig. 3.9):

			Thickness
5.	Chalky till, blue-grey to brown	(Westmill Till)	up to 4 m
3b.	Chalk-rich gravel	(Ugley Gravel)	0–3.5 m
4.	Very chalky till, pale brown (N.B. occurs as lenses within or below 3a)	(Stortford Till)	
3a.	Chalk-poor gravel	(Hoddesdon Gravel)	
3.	Sand and gravel, cross-bedded	(Westmill Upper Gravel)	7–11 m
2.	Chalky till, dark grey	(Ware Till)	0–3 m
1.	Sand and gravel, cross-bedded	(Westmill Lower Gravel)	up to 9 m

Chalk surface, 48–54 m O.D., rising towards the north-west.

Two separate fluviatile formations are represented in this sequence, which also includes glacigenic members. Gibbard (1974, 1977) regarded the fluvial deposits here as equivalent to the Winter Hill Formation of the Middle Thames, of which they appear to be a downstream continuation. However, further stratigraphical studies have shown that only the Westmill Lower Gravel is actually a continuation of the Winter Hill Formation; the Westmill Upper Gravel can be mapped in parts of the Lea catchment not formerly occupied by the Thames as a distinct body of sediment, probably equivalent to the Black Park Formation of the main river (Cheshire, 1986a; see below).

The Westmill Lower Gravel (unit 1) is generally more massive in its lower part, usually with a very coarse flinty 'lag' at the base, resting on an irregular Chalk surface that has suffered scouring and/or solution. Towards the top of the unit the proportion of cross-bedded sand and calcareous silt (the latter interpreted as channel-fill material) increases. Both tabular and trough cross-bedding occur and fining-upwards sequences are common. Imbrication in the gravel and foreset orientation in the sand reveal that palaeocurrent flow was towards the north-east. The gravel contains a mixture of flint (over 80%) and quartz and quartzite (accounting for most of the remainder), plus subordinate southern and far-travelled (exotic) material. This is a composition suggestive of a Thames origin (Table 3.2), an interpretation that is supported by the palaeocurrent evidence (Gibbard, 1974, 1977; Cheshire, 1983b, 1986a).

The Ware Till (unit 2) rests upon the eroded surface of the Westmill Lower Gravel, which varies from 55 m to 60.2 m above O.D. Occasionally present at the base of the till is a yellowish-brown laminated silty clay about 0.15 m thick, the laminations suggesting deposition in water; elsewhere the same till overlies the deposits of a local proglacial lake (Gibbard, 1974, 1977). The upper surface of the till is erosional, the deposit having been cut out completely by later channelling in some areas. Because its matrix consists largely of unoxidized clays (with occasional pyrite) derived from the Jurassic, the Ware Till is dark greyish-brown in colour and has a lower calcareous content than the other two tills in the Westmill area. Its particle-size distribution is remarkably uniform throughout, possessing a large and characteristic peak in the fine-sand fraction and a low proportion of pebble clasts in comparison with the later tills. Although the small-clast composition is more variable than the particle-size distribution, the till is characteristically richer in quartz and poorer in flint and *Rhaxella* chert than later tills in the Vale of St Albans sequence. The Ware Till in this area is brecciated; fabric studies show no preferred clast-orientation, indicating emplacement under low-stress glacial conditions or subsequent multi- or non-directional disturbance. *Rhaxella* chert is a rock made up largely of sponge spicules of very characteristic shape and size, occurring only in the Oxfordian and Portlandian (Middle Jurassic).

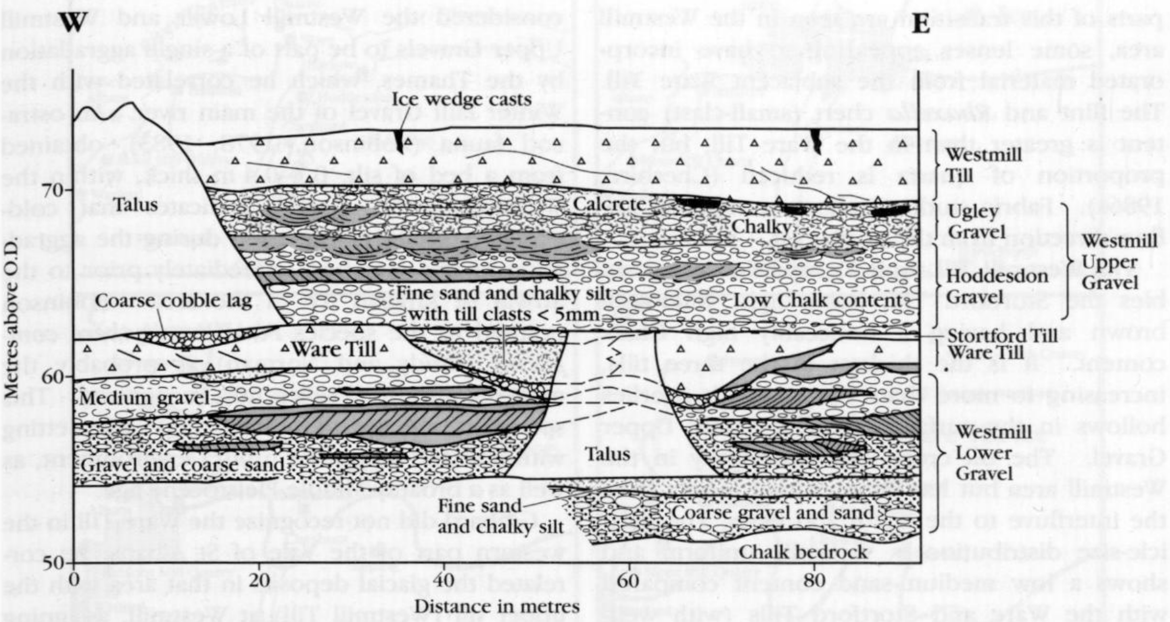


Figure 3.9 Section in the north face of Westmill Quarry, recorded in June 1981 (after Cheshire, 1983b).

It is believed to have been carried in quantity into the London Basin by Anglian ice, from sources in north Yorkshire (Bridgland, 1986a).

The Westmill Upper Gravel (unit 3) is variable in lithology and lateral extent. It contains lenses and larger bodies of cross-stratified sand and finer gravel, but is predominantly massive. The upper part of the deposit is also sandy and shows trough cross-stratification. There is a change in composition within these gravels that coincides with a major change in palaeocurrent direction. Immediately above the Ware Till the gravel contains relatively abundant Chalk (13%) and soft 'erratics'. Higher in the sequence these become less frequent, the Chalk component falling to 2–4%. Palaeocurrent measurements from these levels indicate flow towards the north-east. In the upper 3–4 m of the gravel, the Chalk content dramatically increases to 22%, again associated with an increase in soft far-travelled material, particularly from the Mesozoic of central and eastern England. Palaeocurrent measurements from this horizon show local flow to the south-west. Gibbard attributed this change in composition and palaeocurrent directions, which occurs at around 68 m O.D. in the Westmill sequence, to the initiation of a new stream flowing from the north-east. He considered this stream to represent outwash from an approaching ice sheet, that which deposited the overlying (Westmill) Till. Cheshire (1986a) has correlated this higher division of the Westmill Upper Gravel with his Ugley Gravel, as defined at Ugley Park Quarry (see below). The lower division of the Westmill Upper Gravel has been referred by Cheshire to his Hoddesdon Gravel, which contains less Chalk than the Ugley Gravel (Table 3.2); it contains no Chalk at all in the Lower Lea valley south of the Hoddesdon type locality (TL 354077).

The Stortford Till (unit 4) occurs as detached lenses or channel-fills above, within or cutting through the Ware Till (Fig. 3.9). In places a coarse gravel up to 0.8 m thick intervenes between the two tills (basal Hoddesdon Gravel). Although the occurrence of the Stortford Till is localized, at its maximum thickness of 3.5 m this deposit exceeds the laterally more persistent Ware Till. It may be easily distinguished from the latter in the field by its very much greater Chalk content and lighter colour. Unlike the Ware Till, the Stortford Till does not have a vertically uniform particle-size distribution. At its type locality (Stortford Green borehole, TL 479195; Cheshire, 1986a), the Stortford Till shows a progressive decline in the frequency of medium-fine sand from its base to its top. Only parts of this transition are seen in the Westmill area, some lenses appearing to have incorporated material from the subjacent Ware Till. The flint and *Rhaxella* chert (small-clast) content is greater than in the Ware Till, but the proportion of quartz is reduced (Cheshire, 1986a). Fabric studies indicate a regional ice-flow direction from the north-east.

The Westmill Till (unit 5) superficially resembles the Stortford Till, being light yellowish-brown and having a noticeably high Chalk content. It is the thickest of the three tills, increasing to more than 4 m where it overlies hollows in the surface of the Westmill Upper Gravel. The till crops out extensively in the Westmill area but has been eroded locally from the interfluve to the north and east. The particle-size distribution is vertically uniform and shows a low medium-sand content compared with the Ware and Stortford Tills (with well-defined modes in the 125 and 63 micron fractions). The proportion in the pebble fraction is also greater. The small-clast composition is remarkably uniform, being characterized by relatively high proportions of flint and *Rhaxella* chert, whereas there is less quartz than in other tills. Shear planes are present, generally dipping towards the north-east, indicating ice movement from that direction. Fabric studies show a very strong NE–SW preferred orientation (Gibbard, 1974; Cheshire, 1986a), confirming ice movement from the north-east.

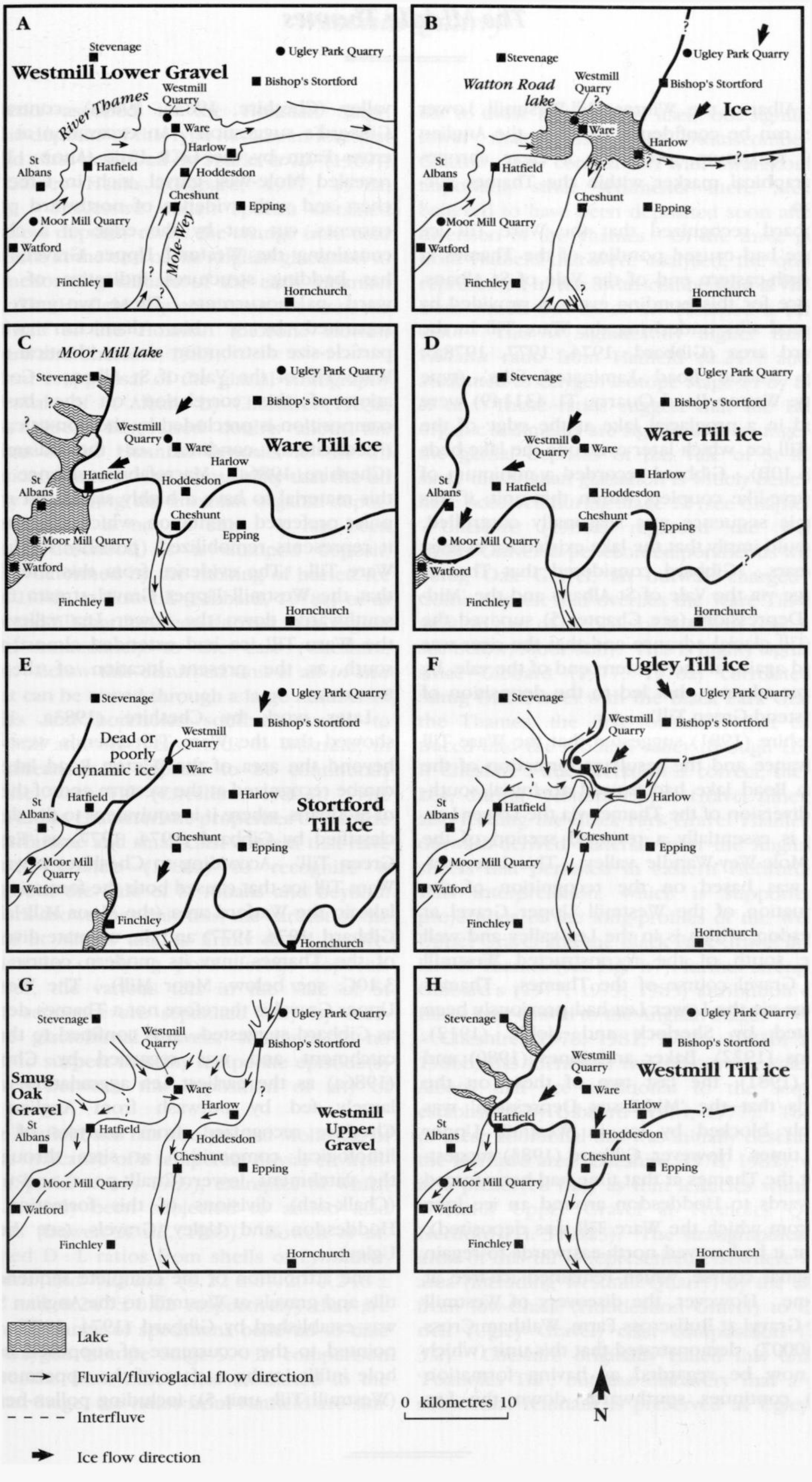
Interpretation

Westmill Quarry, perhaps because of its considerable size and depth, has proved to be a most valuable site for examining the thick sequence of Anglian Stage deposits that fills the old Thames valley through the Vale of St Albans. Although this sequence has been dissected in post-Anglian times by streams of the Colne and Lea systems, a large proportion of the Anglian sediments remains intact. Detailed studies of the area in recent years (Gibbard, 1974, 1977, 1978a; Cheshire, 1981, 1983a, 1983b, 1986a) have increased knowledge of the characteristics and three-dimensional form of these deposits. The importance of the Westmill site in such studies is underlined by the fact that it is the type locality of the Westmill Lower and Upper Gravels, the Ware Till and the Westmill Till.

Gibbard (1974, 1977, 1978a, 1983, 1985) considered the Westmill Lower and Westmill Upper Gravels to be part of a single aggradation by the Thames, which he correlated with the Winter Hill Gravel of the main river. An ostracod fauna (Robinson, 1978, 1983), obtained from a bed of silt, 0.3–0.4 m thick, within the Westmill Lower Gravel, indicates that cold-climate conditions prevailed during the aggradation of this member, immediately prior to the arrival of Anglian ice in the area. Robinson pointed to the species *Paralimnocythere compressa* (Brady and Norman) as probably the most significant of seven taxa recognized. This species is believed to indicate a fluviatile setting within a cold steppe or tundra environment, as well as a broadly Middle Pleistocene age.

Gibbard did not recognize the Ware Till in the western part of the Vale of St Albans; he correlated the glacial deposits in that area with the upper till (Westmill Till) at Westmill, assigning both to his 'Eastend Green Till' (see below, Moor Mill). Gravel underlying the Ware Till in the latter area was termed Westmill Gravel by Gibbard, who considered it to be the lateral equivalent of both gravel members at Westmill Quarry. Gibbard's correlation of the Westmill Gravel with the Winter Hill Gravel of the Middle Thames, on the basis of elevation and composition, provided an important link between the Thames terrace sequence and the glacial stratigraphy of eastern England. Cheshire's (1981, 1983a, 1983b, 1986a) subsequent revision of this stratigraphical scheme, in which the Westmill Upper Gravel was recognized as a post-diversion River Lea deposit, demonstrated that only the Westmill Lower Gravel (Fig. 3.10A) is a correlative of the Winter Hill Gravel. The stratigraphical link established by Gibbard was upheld by Cheshire, however; on account of its close association with the glaciation of the Vale

Figure 3.10 Palaeodrainage during key phases of the Anglian evolution of the Vale of St Albans (from Cheshire, 1986a):
(A) During deposition of the Westmill Lower Gravel;
(B) During the existence of the Watton Road lake;
(C) During the existence of the Moor Mill lake;
(D) At the maximum extent of the Ware Till ice;
(E) At the maximum extent of the Stortford Till ice;
(F) At the maximum extent of the Ugley Till ice;
(G) During the deposition of the Westmill Upper Gravel and the Smug Oak Gravel;
(H) During the Westmill Till ice advance.



A
Westmill Lower Gravel
River Thames
Mole-Wey
B
Watton Road lake
Ice
C
Moor Mill lake
Ware Till ice
D
Ware Till ice
E
Dead or poorly dynamic ice
Stortford Till ice
F
Ugley Till ice
G
Smug Oak Gravel
Westmill Upper Gravel
H
Westmill Till ice
Stevenage
Ugley Park Quarry
Bishop's Stortford
Westmill Quarry
Ware
Harlow
St Albans
Hatfield
Hoddesdon
Cheshunt
Epping
Moor Mill Quarry
Watford
Finchley
Hornchurch
Lake
Fluvial/fluvioglacial flow direction
Interfluve
Ice flow direction
0 kilometres 10
N

of St Albans, the Winter Hill/Westmill Lower Gravel can be confidently dated to the Anglian glacial maximum, providing a clear chronostratigraphical marker within the Thames succession.

Gibbard recognized that the Ware Till ice advance had caused ponding of the Thames at the north-eastern end of the Vale of St Albans. Evidence for this ponding event is provided by laminated silts underlying the Ware Till in the Hertford area (Gibbard, 1974, 1977, 1978a). These 'Watton Road Laminated Silts' (type locality: Watton Road Quarry, TL 431149) were formed in a proglacial lake at the edge of the Ware Till ice, which later overrode the lake beds (Fig. 3.10B). Gibbard recorded a minimum of 485 varve-like couplets within this unit; if this rhythmic sequence was seasonally controlled, this would imply that the lake existed for at least 485 years. Gibbard considered that Thames drainage via the Vale of St Albans and the 'Mid-Essex Depression' (see Chapter 5) survived the Ware Till glacial advance and that the river was ponded again, at the western end of the vale, by the later advance that led to the deposition of his 'Eastend Green Till'.

Cheshire (1981) suggested that the Ware Till ice advance and the resultant formation of the Watton Road lake had caused an initial southward diversion of the Thames via the Lower Lea, which is essentially a reversed section of the early Mole-Wey-Wandle valley. This interpretation was based on the recognition of the continuation of the Westmill Upper Gravel at Hoddesdon, which is in the Lea valley and well to the south of the reconstructed Westmill Lower Gravel course of the Thames. Thames drainage via the Lower Lea had previously been suggested by Sherlock and Noble (1912), Hawkins (1922), Baker and Jones (1980) and Jones (1981), the last two of these on the grounds that the 'Mid-Essex Depression' was probably blocked by ice in Westmill Upper Gravel times. However, Gibbard (1983) suggested that the Thames at that time had been forced southwards to Hoddesdon around an ice lobe (that from which the Ware Till was deposited), but that it had curved north-eastwards to regain its original course, which remained ice-free at this time. However, the discovery of Westmill Upper Gravel at Bullscross Farm, Waltham Cross (TL 340007), demonstrated that this unit (which must now be regarded as having formation status) continues southwards down the Lea valley (Cheshire, 1983c, 1986a), contrary to Gibbard's suggestion. An excavation at Bullscross Farm by the GCR Unit (Anon., 1982a) revealed Mole-Wey gravel, rich in Greensand chert and with evidence of northward palaeocurrents, cut out by the edge of a channel containing the Westmill Upper Gravel, which has bedding structures indicative of southward palaeocurrents. These two gravels are separated by a thin 'diamicton' with a particle-size distribution almost identical to the Ware Till of the Vale of St Albans. Confirmation of this correlation on the basis of composition is precluded by the non-calcareous (?decalcified) condition of the 'diamicton' (Cheshire, 1986a). Macrofabric evidence shows this material to have a highly significant monopolar preferred orientation, which suggests that it represents remobilized (possibly soliflucted) Ware Till. The evidence from this site shows that the Westmill Upper Gravel stream flowed southwards down the Lower Lea valley after the Ware Till ice had extended almost as far south as the present location of the M25 motorway.

Later work by Cheshire (1983a, 1986a) showed that the Ware Till extends westwards beyond the area of the Watton Road lake and can be recognized at the western end of the Vale of St Albans, where it is equivalent to the deposit classified by Gibbard (1974, 1977) as 'Eastend Green Till'. According to Cheshire, it was the Ware Till ice that caused both the formation of a lake in the Watford area (the Moor Mill lake of Gibbard, 1974, 1977) and the ultimate diversion of the Thames into its modern course (Fig. 3.10C; see below, Moor Mill). The Westmill Upper Gravel is therefore not a Thames deposit, as Gibbard suggested. It is confined to the Lea catchment and was regarded by Cheshire (1986a) as the earliest Lea aggradation, albeit largely fed by outwash from Anglian ice. Cheshire recognized, from analyses of clast-lithological composition at sites throughout the catchment, lower (Chalk-poor) and upper (Chalk-rich) divisions of this formation, his Hoddesdon and Ugley Gravels (see below, Ugley).

The attribution of the complete sequence of tills and gravels at Westmill to the Anglian Stage was established by Gibbard (1974, 1977), who pointed to the occurrence of supposed kettle-hole infills in the surface of the uppermost till (Westmill Till; unit 5), including pollen-bearing sediments ascribed to the Hoxnian Stage. Organic deposits of this type have been found at Hatfield (first described by Sparks *et al.* (1969)) and Colney Heath (Gibbard, 1977, 1978a, 1978c). Successive pollen spectra obtained from these deposits reveal the change from cold conditions at the end of the Anglian glaciation to the ameliorating climate of the early Hoxnian Stage. The Hatfield sequence continues into the latter half of the Hoxnian (biozone HoIIIb) (Gibbard and Cheshire, 1983).

Recent reappraisal of the glacial stratigraphy in the Vale of St Albans by Cheshire (1983a, 1983b, 1986a) has raised doubts about the relations of the Hoxnian deposits to the till sequence. There is also a possibility that the till directly underlying the Hoxnian organic deposits at Hatfield is not *in situ*. It has been variously described as a slumped deposit, possibly deformed by the melting of buried ice (Rose, 1974), as flow till (Gibbard, 1978c) or as soliflucted till that has been derived from higher ground immediately to the east (Cheshire, 1986a). Below this disturbed unit is an *in situ* till that can be traced through a large number of quarries and boreholes south-westwards to Moor Mill and north-eastwards to Westmill; in both directions it appears to be continuous with the Ware Till (Cheshire, 1986a). The Ware Till has characteristic properties of particle size, carbonate and small-clast content that have allowed Cheshire (1986a) to recognize it throughout the Vale of St Albans and beyond. His work shows that only this, the earliest of the Vale of St Albans tills, is firmly dated as pre-Hoxnian by overlying polleniferous deposits. However, the various tills in the Vale of St Albans sequence are separated only by cold-climate glaciofluvial gravels, so there is no reason to suspect that any temperate episode(s) occurred between the deposition of any of them.

The Hatfield site has also yielded Mollusca, of species indicative of a temperate fluvial environment (Sparks *et al.*, 1969), examples of which have recently been subjected to amino acid analyses (Bowen *et al.*, 1989). Bowen *et al.* obtained D : L ratios from shells of *Lymnaea*, *Gyraulus* and *Valvata* (0.22 ± 0.02, 0.246 ± 0.002 and 0.247 ± 0.02 respectively) that are within the range of specimens believed to date from Oxygen Isotope Stage 9. In comparison with results from other sites attributed to the Hoxnian Stage, the ratios from Hatfield are similar to those from Hoxne itself, but significantly lower than those from Swanscombe and Clacton. The comparison with Swanscombe is important, since sediments there are also believed to have been deposited soon after the diversion of the Thames. Of the three genera from Hatfield that were analysed, the only one represented in the Swanscombe data is *Valvata*, from which Bowen *et al.* obtained a ratio of 0.30. This is significantly higher than the *Valvata* ratio from Hatfield (0.247) and was attributed to Oxygen Isotope Stage 11 by Bowen *et al.* These ratios suggest that the Hatfield organic sediments are significantly younger than the glacial deposits of the Vale of St Albans, since the Anglian glaciation is widely believed to have occurred during Stage 12 (see Chapter 1).

Cheshire (1986a) regarded the Westmill Upper Gravel as penecontemporaneous with the Smug Oak Gravel, an outwash-charged early Colne deposit that overlies the Ware Till in the western part of the Vale of St Albans (Fig. 3.10G; see below, Moor Mill). This is highly significant, since Gibbard (1977, 1978a) correlated the Smug Oak Gravel with the Black Park Gravel of the Thames, the first formation that can be traced into the modern valley through London. If Cheshire's interpretation is correct, the River Lea, during Westmill Upper Gravel times, was also feeding the Black Park Gravel Thames with outwash-derived material from the Anglian ice sheets that persisted in eastern Hertfordshire. This interpretation, which is supported by projections of the long-profiles of the Westmill Upper Gravel and the Black Park Gravel into the Lower Thames (see Fig. 4.7), further strengthens Gibbard's (1977, 1979, 1985) attribution of the Black Park Gravel to the Anglian Stage.

Cheshire (1978, 1981, 1983a, 1983b, 1986a, 1986b) has identified two tills in the Vale of St Albans that are additional to the sequence established by Gibbard (1974, 1977). The first of these additional tills was initially described in the Hertford area (Cheshire, 1978, 1981), where it is preserved only as thin lenticles within the Westmill Upper Gravel at Foxholes Quarry, Hertford (TL 340123). The stratigraphical position of this till is represented elsewhere in the area (including Westmill Quarry) by the change from low-Chalk (Hoddesdon Gravel) to Chalk-rich (Ugley Gravel) clast composition (Table 3.2). Cheshire originally called this unit the 'Foxholes Till', but the discovery that a more substantial remnant is preserved at Ugley (see below, Ugley Park Quarry) led him to adopt the name Ugley Till. The other additional till, the Stortford Till, is the middle of the three tills recognized at Westmill (unit 4). It represents a glacial advance into the Vale of St Albans intermediate between deposition of the Ware Till and the Ugley Till (Fig. 3.10E). The Stortford Till is therefore stratigraphically the second till in the regional sequence.

According to the revised stratigraphy established by Cheshire (1986a; in Allen *et al.*, 1991), the Ware Till, deposited by the earliest of the four ice advances, can be traced throughout the Vale of St Albans. It rests upon proglacial lake deposits in the Watford area (Gibbard, 1977; see Fig. 3.10C and D), indicating its importance in effecting the diversion of the Thames. In the area south-west of the northern suburbs of Hatfield, the Ware Till is not overlain, directly or indirectly, by any subsequent glacial deposit. Decay of the Ware Till ice initiated independent drainage in the Lea and Colne basins. The Stortford Till advance possibly occurred before the wasting of the Ware Till ice was complete. Dead ice from the Ware Till ice lobe would have formed a barrier to this second advance, which may explain why the Stortford Till does not extend across the low ground to the south-west of the Hertford area (Cheshire, 1986a). The main thrust of the Stortford Till advance reached further south than that of the Ware Till, with lobes extending to Finchley, in the former Mole-Wey valley (Fig. 3.10E) and Hornchurch (see Chapter 4). The Stortford Till ice then retreated to a position north of Bishop's Stortford before a third advance of ice, extending as far as Hertford, led to the deposition of the Ugley Till (Fig. 3.10F). The ice once more retreated to the north of Bishop's Stortford and the carbonate-rich Ugley Gravel, the upper division of the Westmill Upper Gravel, was added to the sequence (the drainage pattern before and after the Ugley Till advance was probably similar – see Fig. 3.10G). The final ice advance, leading to the deposition of the Westmill Till, extended further than the Ugley Till, sending lobes into the Vale of St Albans and the Lower Lea valley that reached terminal positions in north Hatfield and near Waltham Cross respectively (Cheshire, 1986a). All four tills record the advance of ice into the region from the north and/or north-east.

From the foregoing account it would seem that the southward-draining River Lea arose as a reversal of part of the pre-Anglian Mole-Wey-Wandle course, as a result of the advance of Ware Till ice into the Hertford area. Cheshire (1983c, 1986a) in fact suggested that the Mole-Wey may have already been captured by a tributary of the Darent-Medway prior to the glaciation, with a southward-flowing river occupying the Lower Lea valley by this time. He considered that southward through-drainage via the Lower Lea was initiated by overflow from the Watton Road lake, which was dammed by Ware Till ice during the early part of its advance into the Vale of St Albans (Fig. 3.10B). This event preceded the formation of the Moor Mill lake, which did not occur until the Ware Till ice had advanced beyond the Hertford area, blocking the Vale of St Albans drainage entirely and diverting the Thames southwards to the Windsor area (Fig. 3.10C and D). Thus for a brief interval, during the existence of the Watton Road lake and during the latter part of the interval represented by the Winter Hill/Westmill Lower Gravel, Thames waters presumably found their way from the Vale of St Albans into the Medway system via the Lower Lea valley, perhaps initiating deposition of the gravel identified in the Lea valley as Westmill Upper Gravel. The initial diversion of the Thames therefore seems to have resulted from the overflow of the Watton Road lake, not that at Moor Mill. This earlier lake-overflow produced a very short-lived Thames route via the Vale of St Albans and the Lower Lea, similar to that envisaged by earlier authors (Sherlock and Noble, 1912; Hawkins, 1922; Baker and Jones, 1980; Cheshire, 1981; Jones, 1981). If this earliest diverted route is represented at all within the sedimentary record of the Thames downstream from London, it would be expected to have contributed to the earliest post-diversion deposits within the channel-system recognized in eastern Essex, which are correlated with the Black Park Formation of the Middle Thames (Bridgland, 1988a; Chapter 5). Thus the latest parts of the Winter Hill/Westmill Lower Gravel aggradation would be contemporaneous with deposits at the Black Park level, east of London, although the latter have been buried by the subsequent (early Saalian) deposition of the Boyn Hill/Orsett Heath Gravel and have yet to be separately identified (see Chapter 4, Hornchurch and Wansunt Pit). The close association of the Winter Hill and Black Park Gravels is well-established; it has been suggested above that the downcutting from the Winter Hill to the Black Park level was simply a response to the diversion of the Thames (see above, Chapter 1).

The Westmill succession therefore represents a remarkably complete record of Anglian Stage deposition in the Vale of St Albans, including both fluvial and glacial deposits. The sequence in this district, established over several years from exposures in Westmill Quarry, is unique in the Vale of St Albans, in that tills related to three of the four Anglian glacial advances now recognized in Hertfordshire and western Essex are represented. The fluvial sediments in this sequence represent the last phase of pre-diversion Thames aggradation and the newly formed (post-Thames diversion) River Lea.

Conclusions

Westmill Quarry provides exposures through a complex series of gravels and tills (boulder clays), laid down during probably the most significant cold phase of the Quaternary ice age, around 450,000 years ago (the Anglian Stage). The lowest gravel (the Westmill Lower Gravel) was laid down by the Thames when it flowed through the Vale of St Albans and into Essex, along a more northerly route than the present river. This gravel was the last to be deposited by the Thames in this old northern course. The overlying deposits at Westmill consist of a complex series of tills (deposits laid down directly by ice sheets) and fluvial gravels deposited by the newly formed River Lea, the latter fed by meltwater streams flowing from ice sheets as they advanced and retreated across the area. It was these Anglian ice sheets that were responsible for the blocking and diversion of the Thames, eventually leading to the formation of the modern Thames valley through London.

In all, four separate advances of ice into this part of Hertfordshire have been recognized, three of which have left a direct record, in the form of till, at Westmill. Thus, collectively, the deposits exposed here are important for charting the course of the Thames before it was diverted southwards by the ice, as well as for establishing the number, extent and direction of movement of the various Anglian ice advances that are known to have affected this region.

MOOR MILL QUARRY (TL 145027)

D.R. Bridgland

Highlights

This is a classic locality that shows pre-diversion Thames deposits overlain by laminated, pro-glacial lake clays, Anglian till and a later suite of gravels deposited by the early River Colne, the sequence as a whole illustrating the glacial diversion of the Thames from this area.

Introduction

The sequence at Moor Mill Quarry, which is situated in the western part of the Vale of St Albans, is of major importance for demonstrating the glacial diversion of the Thames. The sequence includes glaciolacustrine sediments that are believed to have been deposited in a lake formed by the ponding of the Thames by Anglian Stage ice. Till overlies the lacustrine beds, indicating that the ice subsequently over-rode the lake. Gravels below the lake beds are attributed to the Thames, whereas those above the till were deposited by the newly formed River Colne. The replacement of the Thames by the Colne in the western part of the Vale of St Albans can thus be shown to have occurred in the interval represented at Moor Mill by glacial deposits.

The overflow from the Moor Mill lake is considered to have brought about the diversion of the Thames into its modern valley through London (Gibbard, 1977, 1979), although overflow from an earlier lake in the Hertford area may have resulted in the diversion of the river into southern Essex via the Lower Lea (Cheshire, 1981, 1986a; see above, Westmill).

Description

The first description of exposures at Moor Mill was by Evans (1954), although Prestwich (1858b) had described a similar sequence (excluding the lacustrine sediments) at Bricket Wood, about 2 km to the south-west. The Moor Mill site was described in detail by Gibbard (1974, 1977, 1978d). The nomenclature applied to some elements of the sequence has been modified as a result of later work in the Vale of St Albans by Cheshire (1986a). The sediments exposed at Moor Mill are as follows:

		Thickness
4. Sand and gravel, cross-bedded	(Smug Oak Gravel)	5 m
3. Chalky till, blue-grey	(Ware Till)	6 m
2. Laminated clay	(Moor Mill Laminated Clay)	2.6 m
1. Sand and gravel, cross-bedded	(Westmill Lower Gravel)	6.5 m
Chalk		

Evans's (1954) sections, to the north and west of the present GCR site, differed from the above only in that he recorded slightly decreased thicknesses for all the units. He suggested that the laminated sediments were of glaciolacustrine origin, the banding being of seasonal origin and comparable to Swedish varves. Gibbard's (1974, 1977) descriptions, which are the basis of the sequence reproduced above, fully confirmed the stratigraphy reported by Evans.

The Westmill Lower Gravel (unit 1) rests on an uneven surface of brecciated Chalk. It comprises laterally persistent, massive, coarse gravels and current-bedded coarse sands and fine gravels, as well as localized silt. Gibbard (1974) reported an ice-wedge cast from the lower part of these deposits, indicating periglacial conditions during deposition (see Fig. 3.11). According to Gibbard, imbrication of the lowermost, coarsest gravel and cross-stratification in the sands both indicate a north-eastward palaeocurrent direction. Clast-lithological analysis revealed a flint-dominated composition (85–90%) with quartz and quartzite (9–12%), small amounts of Lower Greensand chert and various far-travelled minor components (Gibbard, 1974, 1977; Table 3.2). This is similar to the composition that characterizes the various terrace gravels of the Middle Thames, particularly those originally mapped as 'Glacial' (see above, Introduction to Part 2).

Moor Mill Quarry is the type locality for the Moor Mill Laminated Clay (unit 2). Evans (1954) noted that, in the sections he studied, the lower part of this deposit was of a brownish hue and that it resembled Reading Beds material, whereas the upper part comprised alternations of pale silt and dark grey clay, similar to the matrix of the local till. Only the upper part of the member appears to have been recorded in more recent exposures, which show laminated deposits directly overlying the Westmill Lower Gravel (Gibbard, 1974, 1978d; Cheshire and Gibbard, 1983). The upper part of the unit has been somewhat deformed, presumably when overriden by the ice that deposited the overlying till (Gibbard, 1974, 1978d). Trace fossils have been recognized on bedding planes within the laminated sediments (Gibbard and Stuart, 1974).

The Moor Mill Laminated Clay resembles a classic glacial lake deposit (Fig. 3.12). A minimum total of 342 laminar pairs was counted from a vertical section through this deposit at the nearby Harper Lane Quarry (TL 164019). If these laminar pairs can be interpreted as annual varves, their number points to the existence of a lake in the area for a period of at least that many years (Cheshire and Gibbard, 1983). Only 246 laminar couplets have been recorded at Moor Mill (Gibbard, 1974, 1978d).

The overlying Ware Till (unit 3) consists of a grey silty clay, passing upwards into a massive chalky till. Gibbard suggested that the lower part of the till was deposited from floating ice, this giving rise to its partial stratification. The superposition of this till over the lacustrine laminated clays indicates that the ice sheet finally advanced and overrode the proglacial lake. Fabric analysis of the till suggests that ice movement was from the north-east (Gibbard, 1974, 1977, 1978d).

The Smug Oak Gravel (unit 4), which also has its type site at Moor Mill, has an irregular base, filling channels in the upper surface of the underlying till. The gravel is weakly cross-bedded and somewhat disturbed. Palaeocurrent measurements, from imbrication and foreset orientation, indicate flow to the south-west (Gibbard, 1974, 1978d). Stone counts show, in comparison with the Westmill Lower Gravel, a larger proportion of quartz and quartzite, a higher chalk content and the disappearance of Greensand chert, confirming a significant change in provenance (Gibbard, 1974, 1978d; Table 3.2).

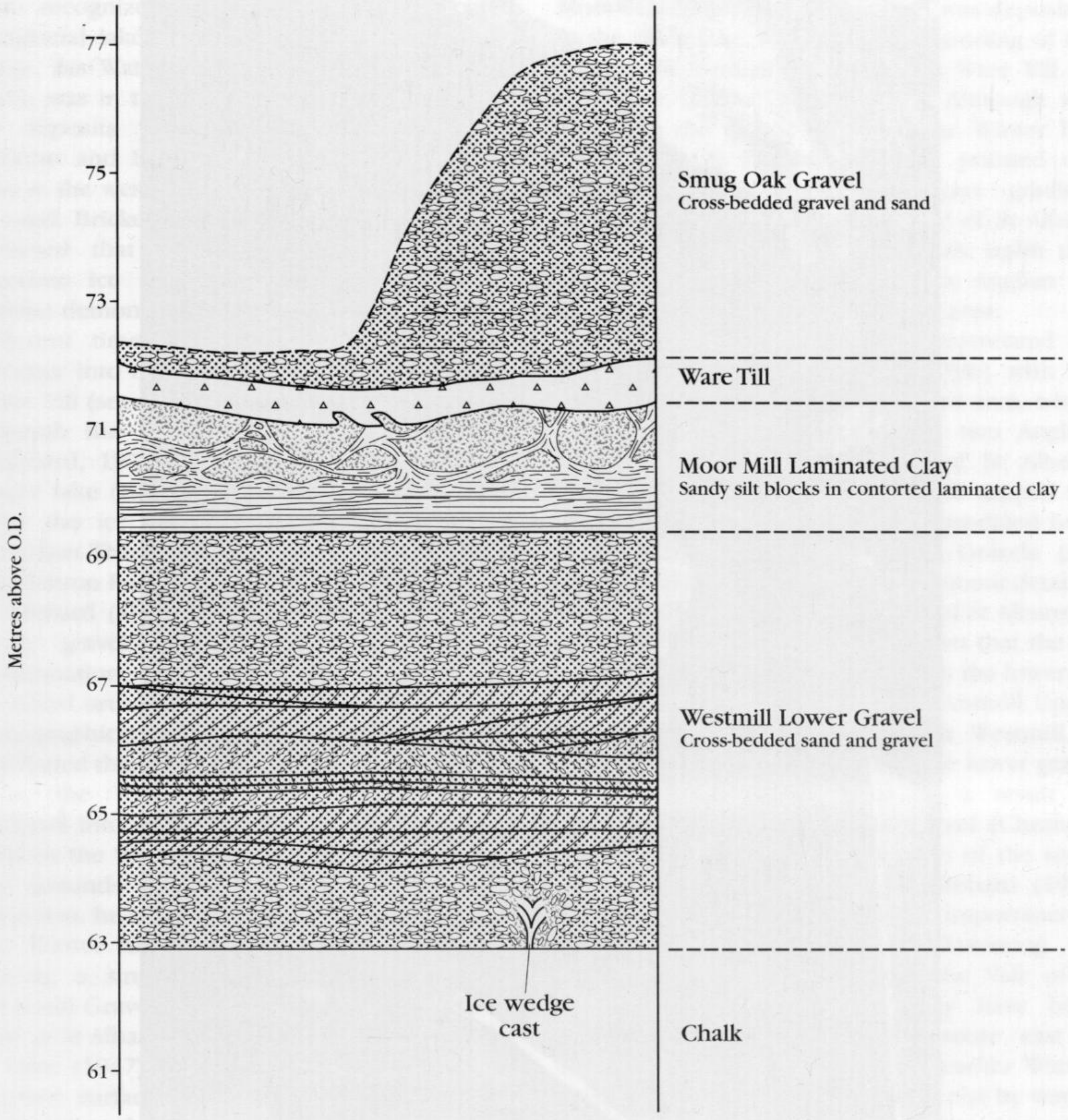


Figure 3.11 Section in the south face of Moor Mill Quarry, recorded in July 1972 (after Gibbard, 1978d).

Interpretation

The occurrence of glaciolacustrine deposits in the Vale of St Albans has been known since the 1920s. Sherlock (1924; Sherlock and Pocock, 1924) described possible lacustrine beds in the Watford area and suggested that these were related to the glacial ponding of the early Thames. Evans (1954) and Clayton and Brown (1958) provided further records of such lacustrine beds. Clayton and Brown described deposits of this type over a wider area, including the eastern Vale of St Albans and the 'Finchley Depression'. They postulated that an ice advance from the north-east had formed a large ice-dammed lake (Lake Hertford) in this area.

The involvement of the 'Chalky Boulder Clay' (Anglian) glaciation in the diversion of the Thames from the Vale of St Albans was not universally accepted, however. Wooldridge (1938, 1957, 1960) and Wooldridge and Linton (1939, 1955) believed that the river had abandoned the Vale of St Albans for an intermediate route through Finchley long before this

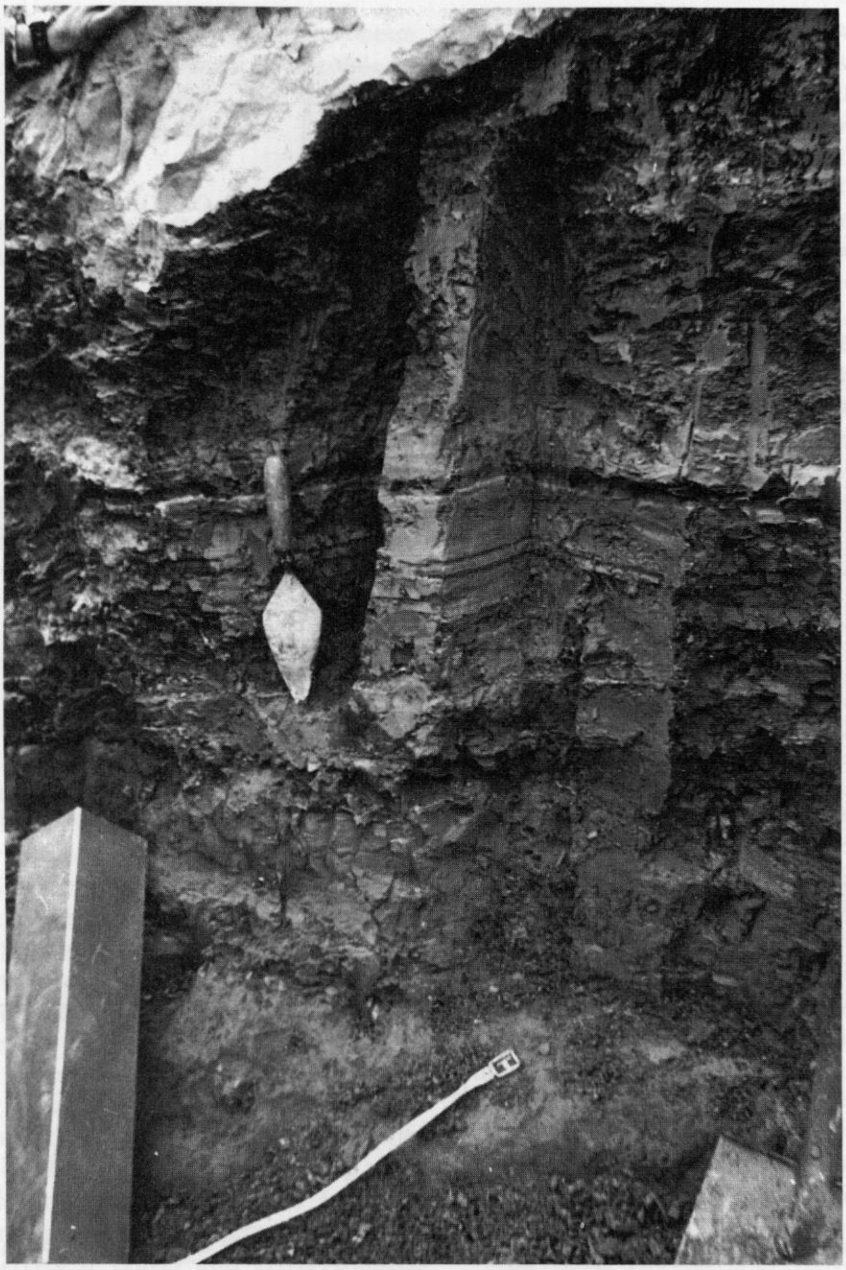


Figure 3.12 Detail of laminated lake beds at Moor Mill Quarry. (Photo: P.L. Gibbard.)

glaciation, perhaps in response to an earlier invasion by ice (Fig. 3.4; see above, Introduction). Zeuner (1945, 1959) preferred to attribute the diversion of the Thames to river capture. Rose *et al.* (1976) considered that the Thames had ceased to flow northwards to East Anglia by Cromerian times, since they recognized a Cromerian palaeosol developed in the upper surface of early Thames (Kesgrave Group) gravels in Suffolk (see Chapter 5, Part 1). Later work has, however, identified lower-level pre-diversion Thames gravels in north-east Essex that lack this fossil soil and are attributed to the Anglian Stage (Bridgland, 1988a), thus reconciling the disappearance of the Thames in Suffolk prior to the Anglian with the theory of Anglian glacial diversion from the Vale of St Albans.

The first systematic work in the Vale of St Albans was by Gibbard (1974, 1977, 1978a), who recognized the deposits of two separate proglacial lakes, both of Anglian age. One of these, his Watton Road lake (see above, Westmill), was in the Ware area (Fig. 3.10B), where its deposits were previously recognized by Clayton and Brown (1958). The second lake was at the western end of the Vale of St Albans, around Bricket Wood (Fig. 3.10C). Gibbard believed that these lakes were ponded by separate ice advances, but Cheshire (1983a, 1986a) demonstrated that both formed (albeit at different times) as a result of the first ice advance into the area, that which deposited the Ware Till (see above, Westmill). Lacustrine beds beneath the Ware Till at Moor Mill Quarry (Gibbard, 1974, 1978d) represent the second, larger lake (Fig. 3.10C). This lake was formed after the ice advanced upstream in the pre-diversion Thames valley, beyond the position of the Watton Road lake.

Gibbard (1974, 1977, 1978a) interpreted the lower gravel at Moor Mill as an upstream continuation of the Westmill Gravel of the Hertford area, on the basis of its composition, stratigraphical position and palaeocurrents. He attributed this deposit to the Thames. In its type area, the Westmill Gravel was divided by Gibbard into upper and lower members, separated by the Ware Till (see above, Westmill). On the grounds of distribution, composition and elevation, he correlated the Westmill Gravel with the Winter Hill Gravel of the Middle Thames, tracing a single formation, the Winter Hill/Westmill Gravel, from the Reading area into the Vale of St Albans.

Hare (1947) had shown that the Winter Hill Terrace surface has a very low gradient as it approaches the Thames-Colne confluence. He attributed this to the effects of the aggradation of outwash from the 'Great Eastern Glaciation' (now assigned to the Anglian Stage) in this area, recognizing (following Wooldridge (1938)) that the Winter Hill Thames and the Vale of St Albans glaciation were broadly coeval. Gibbard found that the low-gradient part of the Winter Hill Terrace profile, around Stoke Common, Buckinghamshire (SU 983852), is underlain by gravel and sand with very large-scale cross-stratification, suggestive of a deltaic origin. He interpreted these deposits as a localized Winter Hill Upper Gravel Member, formed as a delta built out into the proglacial (Moor Mill) lake at the western end of the Vale of St Albans. This member is therefore of equivalent age to the Moor Mill Laminated Clay, which was deposited in the same lake, formed by the ponding of the Thames in front of the advancing Ware Till ice (Cheshire, 1986a; Fig. 3.10C). Although not disputing the deltaic origin of the Winter Hill Upper Gravel, Cheshire (1986a) pointed out that the flattening of the terrace gradient immediately upstream of the Vale of St Albans may be partly the result of isostatic uplift that followed the disappearance of the Anglian ice sheets from the eastern part of the area.

The till at Moor Mill was correlated by Gibbard (1974, 1977, 1978a, 1978b) with his 'Eastend Green Till' of the Hertford area, which he attributed to the second of two Anglian glacial advances into the Vale of St Albans. According to Gibbard, this same till capped the sequence at Westmill and thus post-dated both the Westmill Upper and Lower Gravels (see above, Westmill). However, subsequent detailed reappraisal of the tills of the Vale of St Albans by Cheshire (1983a, 1986a) has shown that the till at Moor Mill can be correlated with the lower till at Westmill, the Ware Till. The Westmill Upper Gravel, which overlies this till at Westmill, is therefore later than any part of the lower gravel at Moor Mill, which must as a result be redefined as Westmill Lower Gravel (Cheshire, 1983a, 1986a). This modification of the sequence of events established by Gibbard (1974, 1977) in no way undermines the importance of the Moor Mill sequence in illustrating the diversion of the Thames from the Vale of St Albans, although the river may have been initially diverted from its old route east of Hertford by the overflow of the earlier Watton Road lake, flowing for a brief interval by way of the Vale of St Albans and the Lower Lea valley (Cheshire, 1983c, 1986a; see above, Westmill).

The palaeocurrent data from the Smug Oak Gravel, which caps the Moor Mill sequence, contrasts with that from the Westmill Lower Gravel and indicates that the river responsible for its deposition drained in the opposite direction to the Thames. Gibbard (1977) traced this gravel to Uxbridge, where it forms the Black Park Terrace of the Colne (Hare, 1947). He therefore interpreted the Smug Oak Gravel as an early Colne deposit, equivalent in age to the Black Park Gravel, which has been shown to be the earliest terrace formation represented in the modern Thames valley through London (Wooldridge and Linton, 1955; Gibbard, 1979; Chapter 1). Gibbard (1977) considered the Smug Oak

Gravel to be of late Anglian age, deposited by meltwater from his 'Eastend Green Till' ice sheet. Cheshire (1986a) correlated the Smug Oak Gravel with the Westmill Upper Gravel of the Lea basin, which, he believed, was also fed by outwash from Anglian ice sheets as they fluctuated around the eastern end of the Vale of St Albans (see above, Westmill).

The change, in the western part of the Vale of St Albans, from a north-eastward to a south-westward flowing river is clearly seen from the sequence at Moor Mill Quarry to be associated with the advance of the Ware Till ice into the area. Since it could not have coexisted in the vale with the south-westward draining Colne, as represented by the Smug Oak Gravel, the diversion of the Thames must have taken place prior to the deposition of this gravel, during the interval represented at Moor Mill by the laminated clay and till. This strongly supports the hypothesis that the Thames was glacially diverted from the Vale of St Albans, presumably as a result of the blocking of its valley by the Ware Till ice sheet. This initially caused the ponding of a proglacial lake in the Moor Mill area, which was eventually overriden by a further advance of the ice, its waters escaping southwards through the Chertsey area into the modern valley (Gibbard, 1977). The valley through London is considered to have already been established, in pre-Anglian times, as a tributary of the River Medway, which flowed northwards across eastern Essex (Bridgland, 1980, 1988a).

The diversion of the Thames, as demonstrated by the sequence at Moor Mill, provides an important stratigraphical marker that can be used for correlation between parts of the Thames basin and particularly with the sequence downstream in Essex, where the diversion resulted in the Thames adopting the pre-existing valley of the Medway (Bridgland, 1980, 1983a, 1983b, 1988a; see Chapter 5, Part 2; St Osyth and Holland-on-Sea). This correlation provides a basis for wider comparison of the sequences in the Middle Thames/Vale of St Albans and East Anglia.

Conclusions

The sequence at Moor Mill Quarry is important for reconstructing Quaternary Ice Age events, at around 450,000 years ago, that had a major influence on the evolution of the Thames drainage system. It illustrates that the Thames formerly flowed through this area, that it was ponded by an ice sheet and that this resulted in a reversal of the local drainage, with the replacement of the Thames by the south-westward-flowing River Colne. The sequence begins with a Thames gravel, with evidence from bedding structures confirming deposition by this north-eastward-flowing river. This gravel is overlain by a distinctive laminated clay deposit, typical of sedimentation in a glacial lake. This lake is believed to have formed when the Thames was blocked by an ice sheet advancing south-westwards up its valley, during the Anglian glaciation. Direct evidence for the presence of this ice sheet is provided by the next element of the Moor Mill sequence, the Ware Till. This is a typical 'boulder clay' deposit laid down beneath the advancing ice sheet as it finally extended across the area of the lake. The final deposit in the Moor Mill sequence is a further gravel, this time deposited by the Colne, flowing towards the south-west. The change from a north-eastward-flowing river in the lower gravel to a south-westward-flowing river in the upper gravel thus records the diversion of the Thames from its old route through the Vale of St Albans. The newly formed River Colne, as represented by the upper gravel at Moor Mill, flowed into the diverted Thames at the western end of the vale.

UGLEY PARK QUARRY (TL 519280)

D.A. Cheshire and D.R. Bridgland

Highlights

Ugley Park Quarry is important for demonstrating the stratigraphical relations of the glacial and glaciofluvial deposits formed during the later part of the glaciation of the Vale of St Albans, and for correlating these with the fluvial sequences in the Thames catchment. It offers a rare opportunity for the study of ice-proximal glaciofluvial deposits.

Introduction

Ugley Park Quarry is the most north-easterly of the sites described in this chapter, being situated virtually on the interfluve between the catchments of the River Stort (a tributary of the Lea) and of the Cam or Granta (part of the Great Ouse system, draining to the Wash). The quarry is excavated in Pleistocene sediments that fill a valley cut through Reading and Thanet Beds (Palaeogene) into Chalk. This particular valley-fill lies to the west of the subglacially formed Stort-Cam tunnel valley (Woodland, 1970), which traverses the East Anglian chalklands from north to south. The valley at Ugley has been interpreted as a glaciofluvial spillway (Hopson, 1981). The fluvial sediments that now fill this valley, at elevations of 80–100 m O.D., were deposited by north-bank tributaries of the Thames shortly after its diversion from the Vale of St Albans, at a time when the ice sheets of the Anglian glaciation persisted in the vicinity. These ice sheets supplied outwash to the river system and, intermittently, advanced across the gravel floodplains, depositing the tills that are interbedded with the fluviatile sequence.

The significance of the site accrues partly from its geographical position on the modern watershed between the Thames system and the drainage of the Wash basin; it thus provides a link between the fluvial and glaciofluvial sediments of the Middle Thames/Vale of St Albans and the equivalent glacial deposits of central-southern East Anglia. The main value of the site is that it demonstrates more clearly than elsewhere the stratigraphical relations between the late Anglian sediments of both these areas.

Description

Ugley Park Quarry consists of separate east and west pits, of which the latter has been partly infilled. The floor of the west pit formerly exposed the junction between the Upper Chalk and the overlying Palaeogene, here represented by the Thanet Beds (with the characteristic Bullhead Bed at the base, at 80.5 m O.D.). The Thanet Beds and the succeeding Reading Beds formed the floor of the eastern part of the west pit, but have not been seen in the east pit, as the full Pleistocene sequence there has not been worked. London Clay is not seen, but occurs 300 m east of the east pit, below till. Silty sand and clay that have been interpreted as Palaeogene in age appear in the eastern face of the east pit but, as discussed later, are probably not *in situ*.

Attention was drawn to the deposits at Ugley Park Quarry by Hopson (1981) and they were discussed briefly by Wilson and Lake (1983). The latter authors recognized two Pleistocene sedimentary beds: up to 10 m of poorly sorted chalky flint-gravels succeeded by up to 6 m of chalky till. The chalky gravel has been attributed to a proximal glacial origin and is thought to be the infilling of a north-south aligned channel parallel to, but 1.5 km to the west of, the Stort-Cam tunnel valley (Hopson, 1981). Wilson and Lake (1983, p. 78) noted that, in the north-east part of the east pit, the chalky till contained 'intercalations of silts with laminated beds, and irregular silty sands with complex convoluted structures and lenticles of firm olive grey clay'. They asserted that the lenticles of clay were derived from soft Palaeogene bedrock.

Cheshire (1986a) recognized a further lithostratigraphical unit in the east pit. This unit, a stiff, dark grey chalky till, does not outcrop in the eastern face, the face that has received the most attention, and appears not to have been recognized earlier. Boreholes in the quarry floor have revealed that an additional gravel unit occurs beneath the till, although in places the latter rests directly upon Reading Beds. This basal gravel is poorly sorted and contains cobbles of flint and Chalk.

The full sequence is therefore as follows:

		Maximum thickness west pit/east pit
4. Chalky till, brown/yellow-brown	(Westmill Till)	2.0 m/3.0 m
3. Chalky gravel and sand, cross-bedded	(Ugley Gravel)	9.5 m/4.6 m
2. Chalky till, dark grey	(Ugley Till)	—/6.9 m
1. Clayey, silty sandy gravel		—/>3.7 m

The Ugley Till occurs only in the east pit, where the top 2 m has been exposed. It is stiff, massive, compact and apparently structureless. The particle size, acid solubility, and small-clast composition are similar to those of the Westmill Till, both at this site and at Westmill Quarry.

Fabric data from the Ugley Till reveals statistically significant preferred orientations suggestive of lodgement by ice moving from the north-west or north-north-west.

The Ugley Gravel lies in a channel with its base at about 85 m O.D. It overlaps the Ugley Till at elevations of between 88 m and 94 m O.D. in the east pit. The maximum thickness is seen in the west pit, where the gravel reaches 9.5 m; it thickens as the top of the Ugley Till descends eastwards across the east pit. The orientations of large-scale trough and tabular cross-bedding in the chalky gravel and sand in the west pit suggest southward palaeocurrents. These structures also suggest deposition in a braided river with fluctuating energy conditions. Similarly, southward palaeocurrents are indicated by structures in chalky sand in the east pit. The gravel in the east face of the east pit incorporates a till-derived debris flow and massive matrix-supported gravel in its lowest three metres. This is succeeded by a thin buff silty clay and up to 1.4 m of cross-bedded coarse chalky sand.

The Ugley Gravel has a clast composition that differs markedly from other gravels in the Thames system (Bridgland, 1980, 1983a, 1986b; Cheshire, 1986a; Bridgland *et al.*, 1990; Table 3.2). In particular, it has a very low proportion of rounded flint pebbles reworked from the Palaeogene; this can be as low as 1–2%, but is highly variable. The gravel also contains abundant Chalk and exotic limestones (mainly Jurassic), the calcareous fraction sometimes approaching half the total count. Another significant constituent of the gravel is *Rhaxella* chert, at up to 1.5% (including calcareous *Rhaxella*-bearing rocks). Clasts of this rock are believed to have been introduced in quantity into the London Basin for the first time by Anglian ice. Exotic rocks that are characteristic components of Thames deposits are relatively scarce in the Ugley Gravel, particularly in comparison with the pre-diversion Thames formations. The extremely calcareous Ugley Gravel contains the highest proportion of Chalk recorded in any fluvial deposit yet studied in Hertfordshire and Essex and has been taken as a standard for Anglian Stage ice-proximal outwash (Bridgland, 1980, 1986b; Bridgland *et al.*, 1990; Table 5.1).

Resting upon the eroded but generally even surface of the Ugley Gravel in both pits is the Westmill Till. This brown to yellowish-brown, very chalky till increases in thickness north-eastward, reaching 8.6 m at The Hall, Ugley (TL 521285). Its particle-size distribution is remarkably uniform both vertically and laterally and, in common with the same till at Westmill Quarry, it contains little medium-grade sand in comparison with the Ware and Stortford Tills. The small-clast composition includes relatively high proportions of flint and *Rhaxella* chert; quartz is less abundant and the acid-soluble content higher than in the Ware and Stortford Tills. Fabric analysis indicates ice-movement from due north.

The thickness of chalky Westmill Till is reduced to about 1 m in the north-eastern part of the east pit, where the lower part of this member contains a large body of silty medium-fine sand. This sand, which contains faint cross-bedding, appears similar to Palaeogene bedrock sediment, but lies 12 m above the maximum height at which Palaeogene strata are known to occur in this part of the quarry. However, in small pits at the base of the face, the silty sand was seen to overlie coarse chalky sand of the Ugley Gravel. This silty sand is probably the same material observed by Wilson and Lake (1983) in the north-eastern part of the site. Streaks and small lenses of chalky till occur in the upper 0.5 m of this sand body, which is thought to represent a large raft (at least 15 m across) of Palaeogene sediment transported, possibly as a frozen block, by the Westmill Till ice.

Interpretation

The sections at Ugley Park Quarry record the only known sequence that demonstrates conclusively the stratigraphical relations of the Ugley Gravel and the Ugley Till. The Chalk-rich Ugley Gravel can be traced, mainly through borehole records, down the Stort valley to the modern Lea valley, where it can be correlated with that part of the Westmill Upper Gravel occurring above 68 m O.D. at Westmill Quarry. Gibbard (1974, 1977) showed that the carbonate content of the Westmill Upper Gravel increases significantly at that elevation within the Westmill sequence, in conjunction with a change in palaeocurrent direction (see above, Westmill). This higher carbonate content (principally Chalk) has been recorded by Cheshire (1981, 1986a) in the upper part of the Westmill

Upper Gravel at other sites in eastern Hertfordshire and western Essex, the largest calcareous component occurring at Ugley Park Quarry. The latter site was therefore selected as the type locality for the upper division of the Westmill Upper Gravel, the Ugley Gravel. The thickness and Chalk-content of the Ugley Gravel is considerably reduced in the area between the type site and Westmill. The lower part of the Westmill Upper Gravel was redefined by Cheshire (1986a) as the Hoddesdon Gravel (type locality: Cock Lane Quarry, Hoddesdon, TL 354077).

The Ugley Till, unit 2 at Ugley Park Quarry, is absent at Westmill. However, at the former Foxholes Quarry (TL 340123 and TL 342125), south of Hertford, a till with particle-size, small-clast lithology and carbonate properties identical to the lower till at Ugley occurs below a Chalk-rich gravel that is correlated with the Ugley Gravel (see above, Westmill). At this site, the Ugley Till had a highly significant fabric orientation, suggesting lodgement from the north-east. Cheshire (1986a) considered that the Ugley Till at Foxholes Quarry was deposited near the ice margin, implying that it represents the least extensive of the four glacial advances that affected the Hertfordshire/western Essex region.

In previous schemes for Anglian glacial stratigraphy in this area, only two glacial advances were recognized. West and Donner (1956) and Clayton and Brown (1958) advocated the separation of upper and lower tills over a wide area of southern East Anglia on the basis of distinctive fabric orientations. According to these authors, fabrics from lower tills were indicative of ice-movement from the north-west and those from upper tills from the north. Gibbard (1977) agreed that tills in the wider region can be separated by their fabric properties and also recognized two advances in Hertfordshire, those associated with his Ware and Eastend Green Tills. At Quendon, 3 km north of Ugley Park Quarry, Baker (1977) identified a lower till, which he named the Quendon Till, in a similar sequence to that found at Ugley. The Quendon Till is 1.8–7.6 m thick, dark grey and has a preferred fabric orientation indicating ice-movement from the north-west, similar to the Ugley Till, to which it is quite possibly equivalent. However, Baker and Jones (1980) equated the Quendon Till with the Ware Till of Gibbard (1977) and the Maldon Till of Clayton (1957), on the basis that it is the lower of the two tills that were recognized over a wide area at that time. Baker and Jones cited evidence (after Baker, 1977), from proglacial varves in lacustrine sediments, implying that, between the deposition of their lower and upper tills, the ice front retreated to the Newport area in northern Essex and stabilized there for a minimum period of 5400 years.

Cheshire (1986a) has shown that tills in the south Hertfordshire/western Essex area possess distinctive petrographical properties, which, with the use of similarity indices, enable correlation from site to site. These methods show that the distinctive Ware Till signature may be traced from site to site towards Ugley, but cannot be recognized in the Ugley Till. Thus the Ugley Till cannot be equated with the Ware Till, despite having a fabric orientation that indicates ice advance from the north-west or north-north-west. Although the Ware Till, Stortford Till and Westmill Till may be differentiated from each other by their petrographical properties, the Westmill Till and Ugley Till are petrographically similar. They may, however, be differentiated by their stratigraphical positions respectively above or below the Ugley Gravel.

At Westmill Quarry, the Westmill Till shows a preferred fabric orientation that, coupled with structural discontinuities related to ice-movement, indicates lodgement from the north-east; this contrasts with the northerly origin of the same till at Ugley. This general pattern, which is reproduced to a greater or lesser extent in sediments deposited by each of the four ice advances into the Vale of St Albans, may be interpreted as the result of ice repeatedly approaching the Thames Basin from the north or the north-north-west, as proposed by Perrin *et al.* (1979). As the ice crossed the Chalk escarpment and entered the former valley of the Thames, it spread out to the south-west in Hertfordshire, to the south-east in Essex and Suffolk (Allen, 1983), and southwards in central Essex (Allen *et al.*, 1991).

Samples of the gravel detected in boreholes below the Ugley Till were not available for analysis of petrographical properties, but the material is probably equivalent to the Hoddesdon Gravel, the lower, less calcareous division of the Westmill Upper Gravel. This unit, like the Ugley Gravel, can be traced down the Lower Lea valley as far as Bullscross Farm (Cheshire, 1983c, 1986a; see above, Westmill). Thus all the sediments at Ugley Park Quarry were deposited after the Thames had been diverted from its Vale of St Albans course, in what had already become the catchment of the River Lea.

The sequence at Ugley Park Quarry shows the stratigraphical relations of the later Anglian glacial and glaciofluvial deposits in the northern part of the Thames Basin. It complements the site at Westmill, in which the Ugley Till is missing from the sequence. The Ugley Park Quarry site also provides the best exposure of the chalky Ugley Gravel outwash. Thus both Westmill and Ugley can be regarded as key Anglian sites, each exhibiting part of a complex sequence.

Conclusions

The complex sequence of sands, gravels and till (boulder clay) at Ugley Park Quarry is important for showing that, during the cold Anglian Stage of the Quaternary Ice Age (about 450,000 years ago), the Thames catchment was repeatedly invaded by ice moving from the north or north-north-west. The evidence from Ugley is critical, in conjunction with that from Westmill, in demonstrating that there were at least four of these Anglian glacial advances, each of which deposited characteristic tills. Gravels and sands, found between and underneath the tills at Ugley, were deposited by meltwater streams flowing from the ice sheets and feeding the newly formed River Lea system.

Part 3

THE SEQUENCE POST-DATING THE DIVERSION OF THE THAMES (SITES IN THE MIDDLE THAMES AND ITS TRIBUTARY, THE KENNET)

D.R. Bridgland

Introduction

This part of Chapter 3 is concerned with the terrace deposits laid down by the Thames since its diversion into its modern course. The Black Park Gravel Formation, aggradation of which occurred while Anglian ice persisted in the Vale of St Albans, post-dates the diversion and so is included at the beginning of this section, represented at Highlands Farm Pit and Hamstead Marshall Gravel Pit (the latter in the tributary Kennet valley). Subsequent to its diversion, the history of the river is recorded in the Middle Thames basin by an extensive sequence of terrace gravels, in marked contrast to the paucity of depositional evidence from the immediate pre-Anglian period (see Part 2 of this chapter).

The history and extent of research on this sequence is considerable. Prestwich (1855) divided the valley gravels into high-level and low-level terrace deposits, but the first systematic account of the drift geology of the Thames valley in which the importance of depositional river terraces was recognized was by Whitaker (1864, 1889). He identified three distinct terraces, which he illustrated in a map of the Maidenhead district (Whitaker, 1889, p. 391). This work, extended by Pocock (1903), formed the basis for the tripartite terrace system – Boyn Hill Terrace, Taplow Terrace and Floodplain Terrace – recognized by the Geological Survey from 1911 (Bromehead, 1912), the type localities for which occur in the Beaconsfield district (Sherlock and Noble, 1922). Upper and lower divisions of the Floodplain Terrace were recognized by Dewey and Bromehead (1921).

When the (higher) Winter Hill Terrace was added to the Middle Thames sequence (Saner and Wooldridge, 1929; Wooldridge, 1938; Wooldridge and Linton, 1939), it was thought to follow the modern valley through London. It was later discovered that the Winter Hill Terrace, as originally defined, was multiple. The lowest division of this multiple terrace, the Black Park Terrace of Hare (1947), was later recognized to be the first gravel formation in the modern Thames valley (Wooldridge and Linton, 1955; Gibbard, 1979). Hare (1947), who carried out detailed geomorphological mapping around Slough and Beaconsfield, recognized that there was a further important aggradation between the Boyn Hill and Taplow Terraces, forming his

Table 3.3 Post-Winter Hill terraces and gravel formations in the Middle Thames and Kennet valleys.

Thames		Kennet	
Terrace	**Gravel formation**	**Terrace**	**Gravel formation**
Lower Floodplain	Shepperton	Beenham Grange	•
Upper Floodplain	Kempton Park	within Thatcham?	
Taplow⁺	Taplow⁺	Thatcham⁺	
Lynch Hill	Lynch Hill	•	
Boyn Hill	Boyn Hill	•	•
Black Park	Black Park	Hamstead Marshall	Silchester
Winter Hill	Winter Hill	Upper Winter Hill of Thomas (1961)	

• not separately named.
⁺ lower and upper (geomorphological) divisions of the Taplow and Thatcham Terraces were recognized by Sealy and Sealy (1956) and Cheetham (1980) respectively. The validity of these is doubtful (see Fern House Pit).

Lynch Hill Terrace (Table 3.3). Both of these newly defined terraces had previously been subsumed within rather broader definitions of those already established. Hare's work was extended upstream by Sealy and Sealy (1956) and Thomas (1961), the latter taking the new scheme into the tributary Kennet and Blackwater-Loddon valleys, and downstream by Allen (1978).

Hare had recorded a minor, lower facet of the Taplow Terrace, which Sealy and Sealy (1956) subsequently redefined as a separate 'Lower Taplow Terrace', Hare's Taplow Terrace becoming their 'Upper Taplow Terrace'. Gibbard (1985) found the Upper Taplow Terrace to be formed by the fluviatile Taplow Gravel plus an overlying loessic silt (brickearth), whereas the Lower Taplow Terrace is formed by the same gravel, but with no overburden. Thus the lower of the two terraces recognized by the Sealys is the true fluviatile Taplow Terrace (see below, Fern House Pit).

Allen (1978) recognized an additional 'Stoke Park Terrace' in the Yiewsley area, between the Boyn Hill and Lynch Hill Terraces. He regarded this as a downstream extension of the minor erosional facet identified by Hare (1947) as the 'Stoke Park Cut'. Gibbard (1985) again rejected this as an additional aggradational terrace, pointing out that the gravel assigned by Allen to the Stoke Park Terrace probably represents the northern feather-edge of the Lynch Hill Formation, separated from the thicker part of the Lynch Hill sequence immediately to the south by diapirically uplifted London Clay.

Gibbard (1985) has provided a recent reappraisal of the Middle Thames terrace sequence, basing his work on studies of the deposits rather than surface morphology. He combined the reconstruction of the sediment bodies that form the various terraces with clast-lithological analysis of the gravels to establish a lithostratigraphical scheme. As Table 3.2 illustrates, there is a progressive decline in the exotic (far-travelled) component of the post-diversion Thames gravels, a trend that began following the deposition of the Gerrards Cross Gravel. Gibbard considered individual terrace aggradations to be of member status, emphasizing the role of clast composition in their differentiation. Bridgland (1988b, 1990a) argued instead that the principal basis for recognizing individual terrace aggradations is mapping; therefore each forms a mutually exclusive primary lithostratigraphical unit and should be regarded as a separate formation (see Chapter 1). Comparable lithostratigraphical schemes have been used to classify fluvial sequences in adjacent areas, providing a reliable mechanism for the description and correlation of terrace formations (Gibbard, 1977, 1978a, 1982, 1989; Allen, 1983, 1984; Bridgland, 1983a, 1983b, 1988a; Bridgland and Harding, 1985; Cheshire, 1986a; Gibbard *et al.*, 1988). The terms Boyn Hill Gravel and Taplow Gravel (Bromehead, 1912), already used on most New Series Geological Survey maps of the area, have been retained for the Middle Thames. Gibbard (1985) extended this nomenclature to include the additional terraces recognized by Hare (1947), establishing a parallel stratigraphical scheme but retaining Hare's place-name nomenclature (Table 3.3 and Fig. 3.1). He also provided names for the deposits underlying the Upper and Lower Floodplain Terraces, respectively his Kempton Park and Shepperton Gravels (Gibbard *et al.*, 1982; Gibbard, 1985; Table 3.3).

The stratigraphical scheme developed for the Middle Thames terraces has frequently been used to classify the gravel spreads of the Kennet valley, particularly since Thomas (1961) traced the terraces defined by Hare (1947) and Sealy and Sealy (1956) upstream to the Newbury area. White (1907) had previously provided local names for the higher gravels of the Kennet, equivalents of the Winter Hill, Gerrards Cross and older gravels of the Thames. Chartres *et al.* (1976), Cheetham (1980) and Chartres (1981) subsequently proposed a separate nomenclature for terraces in the Kennet valley. Gibbard (1982) used a modified version of White's term – 'Silchester Gravel' – to describe the terrace sediments in the Kennet valley that equate with the Black Park Gravel of the Middle Thames. Correlation with Middle Thames formations is not problematic, because the gravel-bodies can be traced and/or projected between the two valleys and the Thames sequence is well-preserved in the confluence area. The use of Thames nomenclature, except where correlation is problematic, would seem perfectly feasible therefore.

The Kennet sequence falls into two clear groupings. Firstly, the older gravels recognized by White (1907) are preserved as wide spreads that form a southward-declining sequence. This sequence culminates in the Silchester/Black Park Gravel, which caps extensive plateaux to the south of the modern river. Later deposits are much less extensive, perhaps because the Kennet became entrenched along the line of its present valley. Equivalents of the Boyn Hill and Lynch Hill Formations are poorly represented in the Kennet, being restricted to a few degraded patches of gravel either side of the valley near Brimpton (Fig. 3.1). Later formations are better preserved, remnants of Thatcham Terrace deposits (= Taplow Formation) occurring at Thatcham and Brimpton (see below, Brimpton), while Beenham Grange (Floodplain) Terrace (= Shepperton Gravel) deposits are well preserved at and downstream of Thatcham.

HIGHLANDS FARM PIT (SU 744813)

D.R. Bridgland

Highlights

This is the best-known site in the deposits forming the floor of the 'Ancient Channel' of the Thames (now correlated with the Black Park Gravel) in the Caversham–Henley area. Highlands Farm Pit provides important evidence for the Palaeolithic occupation of Britain prior to the Hoxnian Stage.

Introduction

Highlands Farm Pit, Oxfordshire, exposes gravel that is assigned to the Black Park Gravel Formation of the River Thames. In this district the Black Park Gravel forms the floor of an abandoned section of an early valley of the Thames, generally known as the 'Ancient Channel' (Treacher *et al.,* 1948; Wymer, 1956, 1961, 1968). This old valley, now much dissected by later erosion, runs from Caversham (Mapledurham) to Henley (Fig. 3.1). It lies to the north of the modern valley, which takes a more circuitous route between those towns (via Sonning). As the Black Park Gravel was the last formation to be deposited before the Thames abandoned the 'Ancient Channel', this gravel is preserved in this area as a dissected valley-floor rather than the more usual north-bank terrace. The particular importance of Highlands Farm Pit lies in the occurrence in the gravel there of abundant Palaeolithic artefacts, as first reported by White (1895). Since it is derived from the Anglian Stage Black Park Formation, this assemblage is one of the oldest from the Thames system. Extensive collections of Palaeolithic material from Highlands Farm have been described (Smith, 1917; Treacher *et al.*, 1948; Wymer, 1956, 1961, 1968). They have been central to the continuing controversy during recent decades over the timing of Palaeolithic man's earliest occupation of Britain.

The attribution of the gravel forming the floor of the 'Ancient Channel' to the Black Park Formation was established relatively recently (Clarke and Dixon, 1981; Gibbard, 1983, 1985). It had previously been included in the Winter Hill Terrace (Wooldridge, 1938; Treacher *et al.*, 1948; Wymer, 1961, 1968) or in the Lower Winter Hill terrace (Sealy and Sealy, 1956). The occurrence of well-made Palaeolithic artefacts in so high a terrace within the Thames sequence (Arkell and Oakley, 1948), with the implication of an Anglian age (Table 1.1), was until recently considered problematic, since many authorities believed that only crude implements, if any, were made in Britain prior to the Hoxnian Stage. This problem has been resolved following recent discoveries at Boxgrove, West Sussex (Roberts, 1986), which have demonstrated that flint tools of high quality were made in pre-Hoxnian times (see Chapter 1).

Description

All the published descriptions of exposures at Highlands Farm Pit post-date the reopening of the workings in the 1950s. This extension of the pit enabled a rich assemblage of palaeoliths to be obtained from sections specially cleared for the purpose (Wymer, 1956, 1961, 1968; Gibbard and Wymer, 1983; Gibbard, 1985). Wymer recorded *c.* 4 m of gravel at the site, aggraded to 76 m O.D. The gravel is much disturbed by solution of the underlying Chalk, which has caused the overlying deposits to collapse into pipes of varying size. The lowest 3 m comprise coarser gravel, but throughout the sequence lenses of current-bedded sand occur (Gibbard and Wymer, 1983). The upper levels are disturbed by cryoturbation and are overlain by 0.3 m of silt (brickearth). The gravel is dominated by flint, quartz and quartzites, with subordinate crystalline rocks, cherts and sandstones (Walder, 1967; Gibbard and Wymer, 1983; Table 3.2), a composition confirming deposition by the Thames.

Wymer's work at Highlands Farm Pit led to the discovery that Clactonian flakes and cores accompanied the (Acheulian) hand-axes that had already been found there in great numbers. The absence of Clactonian artefacts in the earlier collections from the site probably reflects both the inability of the gravel diggers to recognize the cores and flakes of this industry and the preference of the collectors for hand-axes. There are other reports of artefacts collected from Highlands Farm, by Case and Kirk (1952, 1955) and Wymer (1958, 1959, 1960, 1962, 1964a); detailed summaries of the material have been provided by Roe (1968a, 1981) and Wymer (1968). The only faunal remains to come from the pit, or from any site in the Black Park Gravel of the 'Ancient Channel', are a horse tooth from a few centimetres above the Chalk and a piece of elephant tooth from an unspecified location (Wymer, 1964a).

Interpretation

In order to demonstrate the significance of Highlands Farm Pit, it is necessary to outline the research history both of the site and of the 'Ancient Channel' in some detail. The various gravel deposits to the west of Henley, including that at Highlands Farm, appeared as 'Glacial Gravel' on the Old Series geological map of the area (Sheet 13, 1860: Hull and Whitaker, 1861), but were later designated 'Plateau Gravel' (New Series, Sheet 254, 1905: White, 1908b). Following their reinterpretation by Wooldridge (1938), however, the gravels of this district have been recognized as early Thames terrace deposits and have recently been shown as such on new Geological Survey maps (Squirrell, 1978; New Series, Sheet 254, 1980 revision).

The earliest reference to the GCR site was by White (1895, p. 20), who noted that no distinction could be made between the 'glacial' and river gravels of the district and that Palaeolithic artefacts had been found there by L. Treacher and G.W. Smith 'so far distant from the river as Highlands Farm' (outside the area mapped as river gravels). At that time the site consisted merely of one or more shallow pits, presumably for farm use, and the gravel had not been commercially exploited. The Treacher collection contains specimens from this site (then called Helen's Farm) labelled 1889 and 1892 (Arkell and Oakley, 1948). Highlands Farm was also noted by Smith (1917) as a locality where implements could be obtained from high-level deposits. Thus the site was established as unusual, in that it appeared to lie above the general level of the terrace gravels, yet it yielded palaeoliths, which are usually confined to the latter deposits.

White again referred to Highlands Farm in the Henley memoir (Jukes-Browne and White, 1908, p. 88), in which he described terraces within the plateau gravel of the area, including: 'south-west of Henley, a clearly defined terrace between 255 and 260 ft above sea level (160 ft above the Thames)'. He associated the Highlands Farm site with this feature and suggested a correlation with the 'Silchester stage' of the Kennet and Lodden (White, 1902, 1907, 1908b). However, as has already been noted, the Highlands Farm deposits are not part of a simple north-bank terrace of the Thames. They lie at the eastern end of an abandoned section of valley cut through the Chalk (Fig. 3.1). Treacher (1926) first recognized the significance of this feature, from the fact that higher-level gravel at Shiplake, on the interfluve between the 'Ancient Channel' and the present river, contains up to 60% of Lower Greensand chert, implying deposition by a south-bank Thames tributary on the north side of the present valley. The deposit at Shiplake is thought to represent the early Blackwater-Loddon River, which at that time drained a large area of Lower Greensand outcrop that now falls within the Wey catchment (Walder, 1967). Saner and Wooldridge (1929) and Ross (1932) attributed the gravels of the area south-west of Henley to a terrace that could be traced downstream to Winter Hill, Maidenhead and beyond, which they called the Winter Hill Terrace. Wooldridge (1938) ascribed the gravels of the 'Ancient Channel' (which he termed the 'Crowsley Park Trench') to this Winter Hill Terrace. He differentiated the Winter Hill Terrace deposits flooring the channel from older gravels to the north and south on the basis of composition and elevation and, from an exposure 2–3 km south-west of Highlands Farm, was able to demonstrate their fluvial origin.

The definitive description of the 'Ancient Channel', and of the Treacher collection of Palaeolithic implements, was by Treacher *et al.* (1948). Although Highlands Farm was mentioned, the main sites listed were commercial pits exploiting the 'Ancient Channel' gravel;

these provided the bulk of the palaeoliths discovered prior to the reopening of Highlands Farm Pit. Arkell and Oakley (1948) concluded that these collections represented an 'Abbevillian' or 'Early Acheulian' culture, which they regarded as typologically older than assemblages from the Boyn Hill Terrace of the Middle Thames. They suggested a correlation with similar industries from gravels at Fordwich (Kent) and Farnham (Surrey) that are thought to pre-date the Boyn Hill Formation. They noted that Hare (1947) had associated the Winter Hill Terrace with the glaciation of the London area, which suggested that the implements from the 'Ancient Channel' were made before this glaciation, thought to be of Mindel (Anglian) age.

Following the extension of Highlands Farm Pit in 1954, Wymer (1956, 1961, 1968) made the important discovery that Clactonian artefacts were also present. This material, mainly crude flakes and cores in a rolled condition, was in fact dominant in the new Highlands Farm assemblage, despite being barely represented in the Treacher collection. Wymer also found well-made hand-axes to be more common at Highlands Farm than the crude types that had been ascribed to the Early Acheulian. The archaeological record is, however, without stratification; all the artefacts are in an abraded condition, although the well-made hand-axes are generally less rolled (Wymer, 1961, 1968, 1977a). Wymer's conclusions were broadly confirmed by Roe (1964, 1968a), following statistical analyses in which he compared the Highlands Farm material with that from the Treacher collection. Roe (1968a, p. 59) concluded that the assemblage from Highlands Farm was 'heavily dominated by the only slightly disturbed output of a single nearby working site'.

The Clactonian Industry had been shown to be stratigraphically earlier than the Acheulian hand-axe industry at Swanscombe (see Chapter 4) where, as at the Clacton type site (Chapter 5), it is overlain by or incorporated in the lower part of a Hoxnian aggradation. Both the Clactonian and Acheulian industries were held to have appeared during the Hoxnian, but the Clactonian seemed, on the basis of the Swanscombe sequence, to have been present earlier and to represent the earliest Palaeolithic occupation of Britain (see Chapter 1). Thus it was thought that humans did not reach Britain until the late Anglian or early Hoxnian, certainly after the glaciation of the London district (Wymer, 1961). Because a correlation had been established between this terrace and the glaciation of the Vale of St Albans (see Part 2 of this chapter), the attribution of the 'Ancient Channel gravel' to the Winter Hill Terrace was difficult to reconcile with the occurrence, at sites such as Highlands Farm, of Palaeolithic artefacts. This was particularly the case since many of the artefacts from the 'Ancient Channel' show refined workmanship, whereas the only other assemblages from Britain that were widely believed to be pre-Hoxnian comprise crude stone-struck material (Wymer, 1961, 1977a). This conflict in views led to suggestions that the artefact-bearing gravels in the 'Ancient Channel' post-date the occupation by the Thames of this section of valley. One alternative interpretation of such deposits suggested emplacement by colluvial processes, at some time after the Anglian Stage, mixing reworked Thames gravels with later material, the latter containing the artefacts (Wymer, 1961, 1976, 1977a). A similar alternative interpretation attributed the deposits yielding palaeoliths to reworking by a later tributary stream flowing through this abandoned section of the valley formerly occupied by the main Thames (Gibbard and Wymer, 1983).

Because of the controversy that had arisen over the age and origin of the 'Ancient Channel gravel', the workers who sought to extend Hare's (1947) scheme to the Reading area and beyond (Sealy and Sealy, 1956; Thomas, 1961; Walder, 1967) paid particular attention to its correlation with the terrace sequence and to its abandonment by the Thames. White (in Arkell and Oakley (1948)) suggested that during aggradation of the '150 ft' (Winter Hill) gravel the Thames parted into two 'arms', one flowing through the 'Ancient Channel' and the other via the modern course further to the south, the latter receiving the (Greensand) chert-bearing waters of the Loddon. This view was further developed by Sealy and Sealy (1956), who considered that their 'Lower Winter Hill Terrace', to which they assigned the 'Ancient Channel gravel', converged with the (lower) Black Park Terrace in the Reading area. This resulted, according to the Sealys, from the unusually steep gradient of the Black Park Terrace and the shallow gradient of the 'Lower Winter Hill Terrace'. Sealy and Sealy postulated that in 'Lower Winter Hill' times the Thames flowed in two separate channels between Caversham and Henley (as suggested by White) and that rejuvenation prior to the formation of the Black Park Terrace incised the southern (modern) course more effectively, because of softer Tertiary bedrock in that area, causing the Thames to abandon the more northerly ('Ancient Channel') route through the Chalk. Thomas (1961) agreed with the terrace correlations proposed by the Sealys, but considered that the new route was likely to have been established before the pre-Black Park rejuvenation occurred in the Reading area, perhaps in response to the enhanced erosive capacity of the Kennet and Blackwater-Loddon tributaries in comparison with the main Thames.

Walder (1967), in a pioneering study based on the analysis of their clast-lithological content, showed that gravels forming the floor of the 'Ancient Channel' contain significantly more flint than earlier formations. She noted, however, that the 'Lower Winter Hill' and Black Park Terraces could not easily be separated in the area upstream from Henley. Clarke and Dixon (1981) went further, proposing, on the basis of altitude, that the 'Ancient Channel gravel' represents the Black Park and not the Winter Hill Terrace. This view was confirmed by Gibbard (in Gibbard and Wymer, 1983; Gibbard, 1985), who included the deposits between Caversham and Henley (previously designated as Lower Winter Hill Terrace) in his Black Park Gravel. Gibbard verified Walder's observation that this formation contains significantly more flint than the Winter Hill Gravel and other earlier Thames deposits (Table 3.2). The gravels previously ascribed to the Black Park Terrace in the modern Thames valley through Reading are attributed, according to this reinterpretation, to the tributary Kennet and Blackwater-Loddon streams, which, in Black Park times, united to join the 'Ancient Channel' Thames at Henley. Gibbard and Wymer (1983, fig. 36) reclassified these tributary deposits as Silchester Gravel (a name that implies a Kennet origin; see below, Hamstead Marshall). The above-mentioned tributaries appear to have established, in Black Park times, a substantial valley between Reading and Henley, subparallel to (and south of) that of the Thames. At some time between the aggradation of the Black Park and the later Boyn Hill gravels, the Thames itself adopted this more southerly route, possibly in response to its capture, in the Mapledurham area, by a tributary of the Kennet. The fact that the new Thames course was established in soft Palaeogene strata instead of Chalk may, as suggested by Sealy and Sealy (1956), have facilitated this minor diversion.

The correlation of the 'Ancient Channel gravel' with the Black Park Formation, instead of with the Winter Hill Formation, still implies an Anglian age, as ice sheets are believed to have continued to occupy parts of Hertfordshire and western Essex during Black Park times (see above, Westmill). Human occupation of the Middle Thames valley during or before this glaciation is therefore still indicated by the occurrence of artefacts at sites such as Highlands Farm Pit.

Reports of artefacts from the Black Park Gravel elsewhere in the Thames catchment are uncommon, but several instances are worthy of consideration. In the Thames they occur at Hillingdon (Town Pits, TQ 072824; Wymer, 1968). Palaeoliths from tributary-valley terraces thought to pre-date the Boyn Hill Gravel of the main river have been reported at Farnham in the Wey valley (Oakley, 1939; Arkell and Oakley, 1948), Fordwich in the valley of the Kentish Stour (Smith, 1933; Arkell and Oakley, 1948; Roe, 1977) and in the Silchester Gravel of the Kennet (Wymer, 1968, 1977b; see below, Hamstead Marshall). Only the last of these tributary sites has been firmly established as the equivalent of the Black Park Formation (Gibbard, 1983, 1985), but a similar age for the others seems likely. Few of these sites have produced well-made hand-axes of the type recovered by Wymer (1956, 1961) from Highlands Farm Pit. This typological evidence led Wymer (1961, p. 25) to state that: 'the final filling of the ancient channel of the Thames cannot be earlier than the Hoxnian interglacial', a view to which he still adhered over two decades later (Gibbard and Wymer, 1983).

Recently, evidence from sites such as Boxgrove (Roberts, 1986) and High Lodge has forced most workers to accept that well-made artefacts occur in pre-Hoxnian contexts, so the occurrence of such artefacts in gravels of Anglian age is no longer problematic. The Boxgrove site in particular, having yielded well-made implements in association with a 'late Cromerian' fauna, has undermined the use of hand-axe typology as a basis for the relative dating of Middle Pleistocene deposits (Chapter 1), which leaves no reason why the assemblage from Highlands Farm Pit cannot be derived from *in situ* Black Park Gravel, deposited during the Anglian Stage.

Conclusions

The gravels at Highlands Farm Pit do not lie in the main Thames valley, which lies further to the south, but in an abandoned section of an older Thames course between Caversham and Henley, which has been called the 'Ancient Channel'. This course was abandoned in favour of the modern route through Reading soon after the 'Ancient Channel' deposits were laid down. This was a minor rerouting in comparison with the earlier major diversion brought about by the Anglian ice sheets, when the Thames was deflected into its route through London.

The 'Ancient Channel' deposits (recently equated with the Black Park Gravel of the Slough area) are famous for the profusion of stone tools they have yielded. The occurrence of these man-made implements in such ancient river deposits has been important in showing that Man's earliest arrival in Britain was probably before the Anglian glaciation. The occurrence of well-made flint tools at 'early' sites such as Highlands Farm Pit has helped to dispel the belief that the quality of Palaeolithic workmanship is a reliable indication of age.

HAMSTEAD MARSHALL GRAVEL PIT (SU 414662)

D.R. Bridgland

Highlights

The Hamstead Marshall site provides a rare combination of sedimentological, archaeological and pedological evidence that can be used to interpret the Silchester Gravel of the River Kennet, one of the best-preserved terrace deposits in southern Britain.

Introduction

Hamstead Marshall Gravel Pit is of considerable importance for Pleistocene stratigraphy in the western London Basin, as it is the type locality of the Hamstead Marshall Terrace of the River Kennet (Chartres *et al.*, 1976; Chartres, 1981, 1984). This, the most extensive and best-preserved of all the Kennet terraces, was formerly referred to as the 'Silchester Stage' (White, 1907), a name revived by Gibbard (1982) for his Silchester Gravel. This aggradation was generally correlated with the Winter Hill Terrace of the main river (Ross, 1932; Wooldridge, 1938; Thomas, 1961; Wymer, 1968) until reappraisal of the terrace stratigraphy in the main Thames valley led Gibbard (1979, 1983, 1985) to equate it with the slightly later Black Park Gravel Formation. Either way, an Anglian age is implied, indicating aggradation during probably the most severe climatic interval during the Pleistocene.

The discovery of Palaeolithic artefacts in the gravel at Hamstead Marshall (Wymer, 1968; Roe, 1981) supports the view that humans occupied southern Britain before the Anglian Stage glaciation of the London Basin.

Description

Sections in the Hamstead Marshall pit reveal *c.* 3.0–3.5 m of gravels with occasional sandy and clayey lenses, overlying buff-coloured sands of the (Palaeogene) Reading Beds. The contact with the top of the latter is undulating, suggesting incision by a network of braided river channels prior to deposition of the basal gravels. The sequence can be divided as follows (Chartres *et al.*, 1976; Chartres, 1981, 1984; Fig. 3.13):

	Thickness
4. Topsoil	0.4 m
3. Silty gravel, unbedded	0.8 m
2. Clayey gravel, reddened matrix, especially in lower half; manganese stained near top; poorly bedded	1.0 m
1. Sandy gravel, well-bedded	up to 1.0 m
Reading Beds	

Chartres interpreted these divisions as of pedogenic rather than sedimentary origin. Micromorphological studies have shown that all but the basal part of the gravel has been affected by complex pedogenesis under various climatic conditions (Chartres, 1984).

The gravel, predominantly of coarse grade, is composed of flints with occasional sarsens. Few sedimentary structures are evident and clear stratification is confined to the lowest division (unit 1). The most noticeable structures result from post-depositional disturbance by periglacial processes, particularly prevalent in the uppermost metre, where involutions and vertically orientated stones are in evidence (Fig. 3.13). Chartres (1975) interpreted several scoop- or bowl-shaped hollows as ice-wedge casts, but these are not laterally extensive and seem more likely to have resulted from solution of Chalk clasts within the gravels (D.T. Holyoak, pers. comm.).

Interpretation

Hamstead Marshall Gravel Pit is important as a representative section in the deposits that form the terrace for which it is the type locality, the Hamstead Marshall Terrace of Chartres *et al.* (1976). This aggradation was previously attributed to the 'Silchester Stage', the lowest of three early Kennet gravels identified by White (1907). The sequence described by White was as follows:

1. Cold Ash Stage (80 m above the floodplain)
2. Bucklebury Stage (70 m above the floodplain)
3. Silchester Stage (47 m above the floodplain)

Gibbard (1982) used the term Silchester Gravel to classify the lowest of White's 'stages'. This is one of the best-preserved terrace aggradations in southern Britain, forming a wide and nearly continuous plateau on the southern flank of the Kennet valley from Wash Common (SU 455648), near Newbury, to Burghfield Common, near Reading (Wymer, 1977b). The surface of this gravel falls from 120 m O.D. to 95 m O.D. between these points, while the width of the gravel sheet reaches a maximum 5 km at its eastern (downstream) end. The longitudinal gradient shows a flattening downstream, from 1.9 m to 1.3 m per km. This remarkable spread of gravel attracted the attention of numerous early geologists; notably, in addition to White, Buckland (1823), Monckton (1892), Blake (1900, 1903) and Hawkins (1928).

A possible reason for the exceptional preserv-

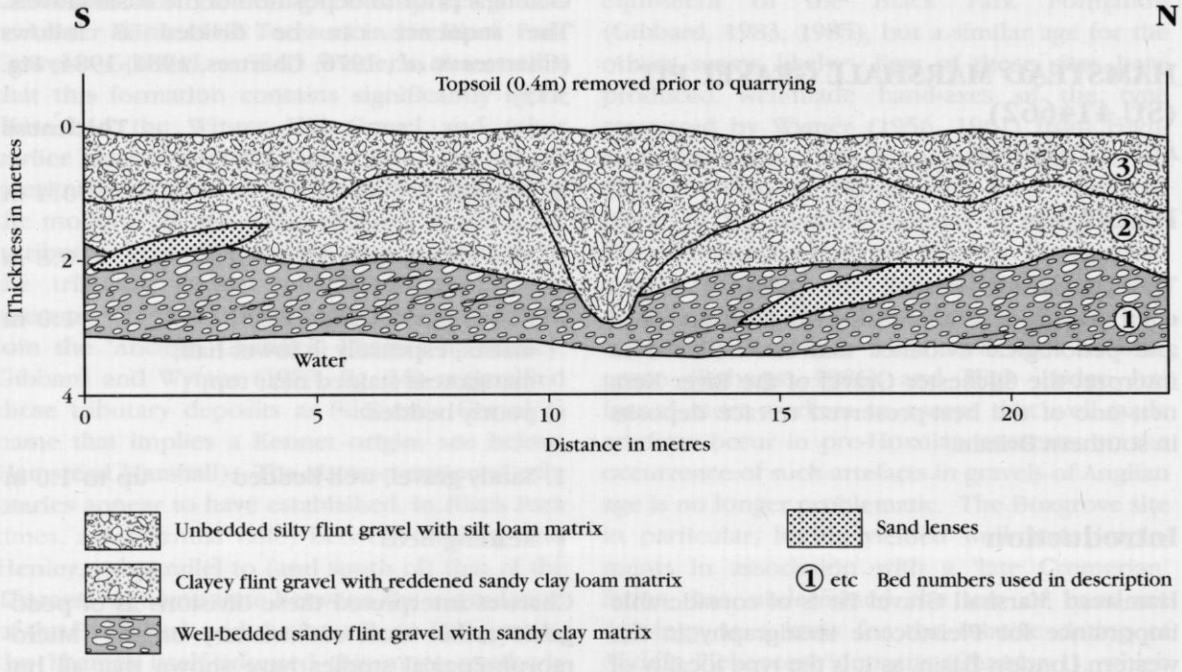


Figure 3.13 Section at Hamstead Marshall Gravel Pit, showing the three divisions of the Silchester Gravel at this site, as described in the text (numbers apply to description). Note that the boundary between divisions 1 and 2 cuts across the sedimentary bedding. Also note central ground-ice/solution structure (after Chartres *et al.*, 1976).

ation of this deposit is that subsequent phases of Kennet development were constrained by the river having cut through the Tertiary strata, which underlie the older gravels, to become entrenched in the Chalk. As noticed by Thomas (1961), the Silchester Gravel marked the end of a progressive southward migration by the Kennet, attributed by him to uniclinal shifting. Bridgland (1985b) has observed that neither migration nor the development of extensive terrace remnants are usual in valleys cut through Chalk.

Wooldridge (1938) correlated the Silchester Gravel with the then newly defined Winter Hill Terrace of the Thames (Saner and Wooldridge, 1929), an interpretation that was confirmed by Thomas (1961), who equated it with the Lower Winter Hill Terrace of Sealy and Sealy (1956). The spreads of gravel in the Thames valley with which correlations were made include the 'Ancient Channel gravel' between Mapledurham and Henley, originally included in the (Lower) Winter Hill aggradation but recently redefined by Gibbard (1983, 1985; Gibbard and Wymer, 1983) as Black Park Gravel (see above, Highlands Farm Pit). Thus the term Silchester Gravel is a synonym, applied in the Kennet valley, for the Black Park Gravel Formation.

Thomas (1961) summarized earlier observations on the gravels beneath the Hamstead Marshall (his 'Lower Winter Hill') Terrace surface, noting that their composition and appearance are remarkably consistent over a wide area. Significant variations were, however, observed in the depth of the gravels. On Wash Common, they attain a thickness of 6.1 m, but become progressively thinner downstream; they decline to 4.6 m on Greenham Common (SU 495648), 3.0 m on Brimpton Common (SU 570630) and further east to as little as 1.8–2.4 m, although they thicken towards their north-eastern margin, near Sulhamstead Abbots (SU 645677), to 3.0 m. Thicker remnants are also found on the north side of the valley, attaining a thickness of 3.7 m on May Ridge (SU 610707) and over 4.3 m at Dark Lane (SU 615745). Thomas (1961) argued that these variations, together with the character of the gravels and the great extent of the terrace, indicate a considerable period of planation followed by a short, rapid period of aggradation, during which the gravels were deposited by a fast-flowing braided river. He also suggested that the planation occurred under interglacial conditions, whereas the gravels were seen as possible products of solifluction from surrounding hillslopes under periglacial conditions.

In comparison with the deposits forming the later Thatcham and Beenham Grange Terraces of the Kennet (Chartres *et al.*, 1976), which are much less well developed, the Silchester Gravel is intensively cryoturbated and generally more weathered in appearance. It is possible that this extensive, relatively thin and uniform gravel-spread results from the frequent lateral shifting of a network of braided river channels. Alternatively, it could represent a long period of deposition in an essentially stable fluvial environment.

The occurrence of palaeoliths on and in the Silchester Gravel (Shrubsole, 1906; Smith, 1915; Wymer, 1968) has attracted considerable interest, on account of the correlation of the former with (originally) the Winter Hill Terrace and (since the early 1980s) the Black Park Gravel of the Thames. Both of these correlations imply contemporaneity with the (Anglian Stage) glaciation of the Vale of St Albans (Hare, 1947; see above, Highlands Farm Pit). There is no direct local evidence for the age of the Silchester Gravel, so correlation with the Thames sequence forms the basis for most attempts at relative dating (Thomas, 1961; Chartres *et al.*, 1976; Chartres, 1980).

The widely held view, prevalent until quite recently, that the earliest human occupation of Britain was during the Hoxnian Stage (see above, Highlands Farm Pit; Wymer, 1961), led Wymer (1968, 1977b) to suggest that most, if not all, of the finds from the Silchester Gravel were probably artefacts dropped on to the terrace surface and incorporated into the top of the deposits by cryoturbation. He noted, however, that the abraded condition of hand-axes from sites on this gravel at Sulhamstead (SU 645680) and, in particular, the pits at Hamstead Marshall indicate that they have been transported with the gravel and so are presumably contemporaneous with it or older. Palaeolithic artefacts have continued to be found in the gravel at the Hamstead Marshall GCR site by local collectors; Wymer (1968) listed five hand-axes (plus a broken fragment) but, by 1992, the number had increased to at least 23 hand-axes (J.J. Wymer, pers. comm.). The occurrence of hand-axes in the Black Park Formation is now well established (see above, Highlands Farm Pit), so the finds at this site need no longer be regarded as anomalous.

Roe (1981) suggested that the abraded hand-axes from sites on the Silchester Gravel, which can be confidently interpreted (because they are water-worn) as derived from the body of the Black Park Formation, are 'archaic-looking', thick and narrow in form. More 'advanced' ovate hand-axes from the same terrace are generally unabraded; Roe agreed with Wymer (1968) that the latter were probably surface finds or artefacts intruded into the top of the gravel by cryoturbation. Roe likened the small assemblage of 'crude' implements from the Silchester Gravel to collections of similar artefacts, from other high-level (pre-Boyn Hill) gravels, that he had previously interpreted as 'Early Acheulian' (Roe, 1964, 1968a). The view that a distinctive and stratigraphically significant 'Early Acheulian' culture existed in Britain during the Middle Pleistocene, promoted by Roe (1964, 1968a, 1981), is less convincing now that well-made hand-axes have been discovered in an apparently pre-Hoxnian context at Boxgrove (see Chapter 1).

The role of pedogenesis in the modification of the Silchester Gravel at Hamstead Marshall has been confirmed by studies of micromorphology and mineralogy (Chartres *et al.*, 1976; Chartres, 1981, 1984). Micromorphological studies showed that the clayey matrix in the middle division of the gravel sequence (unit 2) is of illuvial origin, indicating soil formation under temperate conditions. This clay is strongly orientated, but has been disrupted following illuviation, probably under permafrost conditions. Chartres considered the silt in the matrix of the upper division (unit 3) to be of aeolian (loessic) origin, an interpretation that was supported by the analysis of its mineralogy (Chartres, 1981). This revealed significant quantities of minerals such as epidote, which are rare in pre-Quaternary deposits in the Kennet valley but are common constituents of loess. Chartres concluded that a covering of loess had been deposited on the surface of the gravel and then mixed into the upper disturbed division (unit 3) by cryoturbation. He suggested that this intrusive silt had been prevented from penetrating to depths below 1.2 m from the surface by the clayey layer (unit 2), which had already been formed by pedogenesis prior to the accumulation of the loess.

Micromorphological studies have revealed significant differences, below the levels affected by recent pedogenic activity, between soils formed on the different terraces in the Kennet valley (Chartres, 1975, 1980, 1984; Chartres *et al.*, 1976). As might be expected, the older, higher-level gravels show more evidence for pre-Holocene pedogenesis than those of lower terrace levels; soils on the higher gravels also have a more complex history of modification. Chartres found that the high-level gravels, including those at Hamstead Marshall, were the only ones to contain concentrations of significantly rubified illuvial clay (ferriargillans and papules). These were considered by Chartres to be relict features, since they are generally embedded in yellow illuvial clay, thought to be the product of a later phase of illuviation. The soil has been thoroughly disturbed on at least two occasions; once between the two phases of illuviation, breaking up the reddened illuvial clay, and again after the second illuvial phase. Chartres (1980, p. 140) attributed these disturbance events to cryoturbation, considering that wetting and drying, the principal alternative mechanism, would not have been able to produce the 'general disturbed nature of the profiles'.

The pedogenic evidence from Hamstead Marshall implies that the Silchester Gravel has been subjected to soil-forming processes during at least two temperate intervals and two cold intervals. This may be taken as an indication of relative antiquity. The occurrence of reddened illuvial clay may provide further evidence for the relative antiquity of the gravel. Chartres (1980) cited work in the Paris Basin by Federoff (1971) that suggests that rubification to the degree observed in the earliest papules at Hamstead Marshall is only found there in pre-Saalian soils. The Kennet sequence, in which such reddened material is found in soils formed on the Silchester Gravel and higher formations, but not on the younger Taplow (Thatcham Terrace) Gravel, appears to follow a similar pattern, since the latter deposit is probably of Saalian or post-Saalian age (see below, Brimpton). It has been shown, however, that rubification has occurred under favourable soil conditions in Germany during the Holocene (Schwertmann *et al.*, 1982), raising doubts about the stratigraphical significance of rubified horizons in palaeosols (R.A. Kemp, pers. comm.).

Chartres's research was carried out before the greater complexity of climatic fluctuation during the Middle Pleistocene, as indicated by the oceanic oxygen isotope record (Chapter 1), was widely acknowledged in land-based studies. It is possible that detailed micromorphological analyses in the future will determine that more phases of illuviation and disruption have affected the gravel at Hamstead Marshall than were recognized by Chartres, although the resolution of complex sequences of pedogenic activity in relict soils is fraught with difficulty (Whiteman and Kemp, 1990).

Although the Silchester Gravel is now recognized as an upstream continuation of the Black Park Formation of the Middle Thames (see Fig. 3.1), it is possible that deposits equivalent to the (higher) Winter Hill Gravel, as redefined in this volume (see Chapter 1), are also represented within this aggradation in the upper reaches of the Kennet. This is because of the unique association between the Winter Hill and Black Park Gravels, both of which are at least partly coeval with the glaciation of the Vale of St Albans (see Part 2 of this chapter). The rejuvenation from the Winter Hill to the Black Park floodplain level is believed to have resulted directly from the diversion of the Thames. This rejuvenation is not thought to have extended upstream in the Upper Thames basin beyond the Abingdon area (see Chapter 2, Sugworth). The shallow and steep downstream gradients of the Winter Hill and Black Park Formations (respectively) provide important evidence in support of this interpretation (Fig. 1.3); these formations appear to converge upstream from the Goring Gap. In the Kennet valley, possible remnants of the Winter Hill Formation were recorded in the Beenham area by Thomas (1961), who classified them as Upper Winter Hill Terrace. He correlated these gravels with remnants in the Henley area that Sealy and Sealy (1956) also ascribed to the Upper Winter Hill Terrace. The Lower Winter Hill Terrace of both the Henley area and the Kennet valley is now assigned to the Black Park Formation and the remnants of Upper Winter Hill Terrace recognized by the Sealys have been reinterpreted in this volume as part of the Winter Hill Formation (Chapter 1). Thus the deposits at Beenham probably represent the continuation of the Winter Hill Formation upstream into the Kennet valley (Figs 3.1 and 3.3). As downstream gradients in the Kennet are generally steeper than in the main Thames, foreshortening the various terraces in comparison to their equivalents in the Upper Thames (Fig. 1.3), it might be expected that the convergence of the Winter Hill and Black Park terrace surfaces occurs a shorter distance upstream in the Kennet than in the Thames. This would mean that it occurs between Hamstead Marshall and the Beenham area (Fig. 1.3), so that the deposits at the Hamstead Marshall site include equivalents of both formations. This may explain why remnants of the Silchester Gravel are thicker in the higher reaches of the Kennet than those further down the valley; in the former area aggradation would have continued at the same floodplain level throughout the period of Winter Hill and Black Park Gravel deposition, whereas downstream these two formations are separately represented.

Conclusions

The Silchester Gravel at Hamstead Marshall was deposited during what was probably the most severe climatic phase of the Quaternary Ice Age – during the Anglian Stage. The Hamstead Marshall site shows deposits that form part of a huge spread, or terrace, formed by these ancient Kennet gravels. This terrace is one of the finest and most extensive examples in southern Britain, extending laterally some 5 km at its widest point. It probably accumulated at a time when the river flowed in many individual channels, separated by gravel bars, across a hostile, sparsely vegetated landscape. Detailed analyses of the gravels show that soils subsequently formed on the terrace surface on at least two separate occasions during the warmer 'interglacial' episodes of the Ice Age, with disruption of these soils by frost action during colder phases. The man-made flint implements recovered from the gravels at this site add a further controversial element to its interest, having a major bearing on the time when humans first appeared in Britain.

CANNONCOURT FARM PIT (SU 878831)

D.R. Bridgland

Highlights

A reference site for the Pleistocene Lynch Hill Gravel of the Middle Thames basin, Cannoncourt Farm Pit is also the source of one of the richest and most important assemblages of British Palaeolithic artefacts.

Introduction

Cannoncourt Farm Pit, at Furze Platt, Maidenhead, is one of the most celebrated Palaeolithic sites in Britain. It is a gravel pit, worked by hand during the early part of the century, in which large numbers of artefacts were found, many of elegant form and in excellent condition (Lacaille, 1940; Wymer, 1968). The deposits belong to the Lynch Hill Gravel of the Thames, not one of the earliest terrace formations to be recognized, but now acknowledged as one of the most important, particularly in view of its Palaeolithic content (Wymer, 1968, 1988). The Lynch Hill Terrace was originally defined by Hare (1947), although previously it had been observed locally, principally at Furze Platt, and given a number of different names, as follows: the Furze Platt Stage (Warren, 1926, 1933), based on observations by Treacher (1909); the Furze Platt Terrace (Wright, 1937); Taplow Terrace No. 1 (Burchell, 1934a), the upper of two Taplow Terraces recognized by Burchell (not to be confused with the two divisions of the Taplow Terrace recognized by Sealy and Sealy (1956); see above, Introduction to Part 3); the Iver Stage (King and Oakley, 1936) and the Lower Boyn Hill Terrace (Lacaille, 1940).

Reviews of the Furze Platt site and its Palaeolithic industry were provided by Wymer (1968, 1977c), Roe (1981) and Cranshaw (1983). A recent housing development in the area immediately to the north of the GCR site has provided new sections in the deposits underlying the Lynch Hill Terrace, prompting a reappraisal of the Pleistocene geology at Furze Platt (Harding *et al.*, 1991).

Description

Cannoncourt Farm Pit is part of a complex of old workings that once exploited the Lynch Hill Gravel. It lies in a part of the Thames valley where the river has flowed from north to south since the aggradation of the Black Park Gravel (Hare, 1947; Fig. 3.1). The earliest mention of a site at Furze Platt appears to be that by Treacher (1896), who reported that Palaeolithic implements and waste flakes were found close together at the bottom of the gravel, in a layer comprising large unrolled flints in a sandy matrix. This layer, which was overlain by 4 m of well-stratified gravel, was, according to Treacher, the nearest approximation to a Palaeolithic 'workshop' to have been seen in the area. Treacher (1904) later described only 2.5 m of gravel at the site, the lowest 0.5 m yielding artefacts, 500–600 of which (excluding waste flakes) had been found by that time. The implements described were hand-axes showing a minimum of secondary chipping, mainly of small size, although including a few large and massive specimens. In early descriptions of the Furze Platt artefacts, the economy of labour in their manufacture was noted, a minimum number of blows having been utilized to produce the finished implements (Treacher, 1896, 1904; Shrubsole, 1906). The various early records suggest that the present GCR site was not in existence before 1909 and that Treacher's earlier descriptions appertain to the former 'Cooper's Pit' immediately to the north (Fig. 3.14; Wymer, 1968; Cranshaw, 1983).

The first detailed description of the Furze Platt sections was by Lacaille (1940), who recorded *c.* 3 m of poorly stratified (but clean) sandy gravel overlying Chalk at 42 m O.D. The upper part of the gravel was channelled and overlain by solifluction deposits and sandy brickearth. In addition to palaeoliths, Lacaille found poorly preserved bone fragments at this site, amongst which only an antler of giant deer and a horse tooth were identifiable. He recorded Abbevillian (Early Acheulian), Acheulian and Clactonian artefacts from the site, illustrating many of these as well as a section through the deposits. Further examples of palaeoliths were illustrated by Lacaille (1960) and Wymer (1968). Wymer did not support Lacaille's (1940) claim that the site had also yielded artefacts made using the Levallois technique (see Chapter 1).

Wymer (1968) described the history of Cannoncourt Farm Pit in great detail and included photographs taken while the pit was operational; he had himself conducted excavations there in 1953–4, when he removed some of the last remaining patches of undisturbed gravel from the floor of the pit, finding a number of artefacts in the process. The face at this time showed 1.2 m of brickearth overlying dark-stained gravel, the lower, coarsest part of which yielded a hand-axe and a few flakes. There is a strong indication, from surviving records of the Furze

Platt workings, that implements, particularly the unabraded, well-made examples, were concentrated at the base of the gravel, in places resting directly on the Chalk (Treacher, 1896; Wymer, 1968, 1977c; Roe, 1981; Cranshaw, 1983). According to Roe (1981), the total number of artefacts from this context at the Furze Platt sites exceeds 2500.

A section re-excavated at the Cannoncourt Farm Pit GCR site in April 1987 confirmed the preservation there of nearly 4 m of bedded gravel (Fig. 3.15). This and recent investigations in the area to the north, where housing development has taken place, enabled comparison with exposures in a current working quarry at Switchback Road, less than 1 km to the north (Harding *et al.*, 1991; Fig. 3.14). These sections have allowed a more detailed analysis of the sediments than had been attempted previously. A variable thickness of sandy, silty clay, often with gravelly inclusions, was found to be prominent above the Lynch Hill Gravel throughout the area. This material is repeatedly let down through the gravel in a profusion of large pipes, resulting from solution of the Chalk bedrock. In a small area between Cannoncourt Farm Pit and Cooper's Pit, the clay is itself overlain by a later gravel containing more local material than the Lynch Hill Formation (Table 3.2). The clay beneath this upper gravel is mottled and reddened and contains evidence of a palaeosol (Harding *et al.*, 1991; see below).

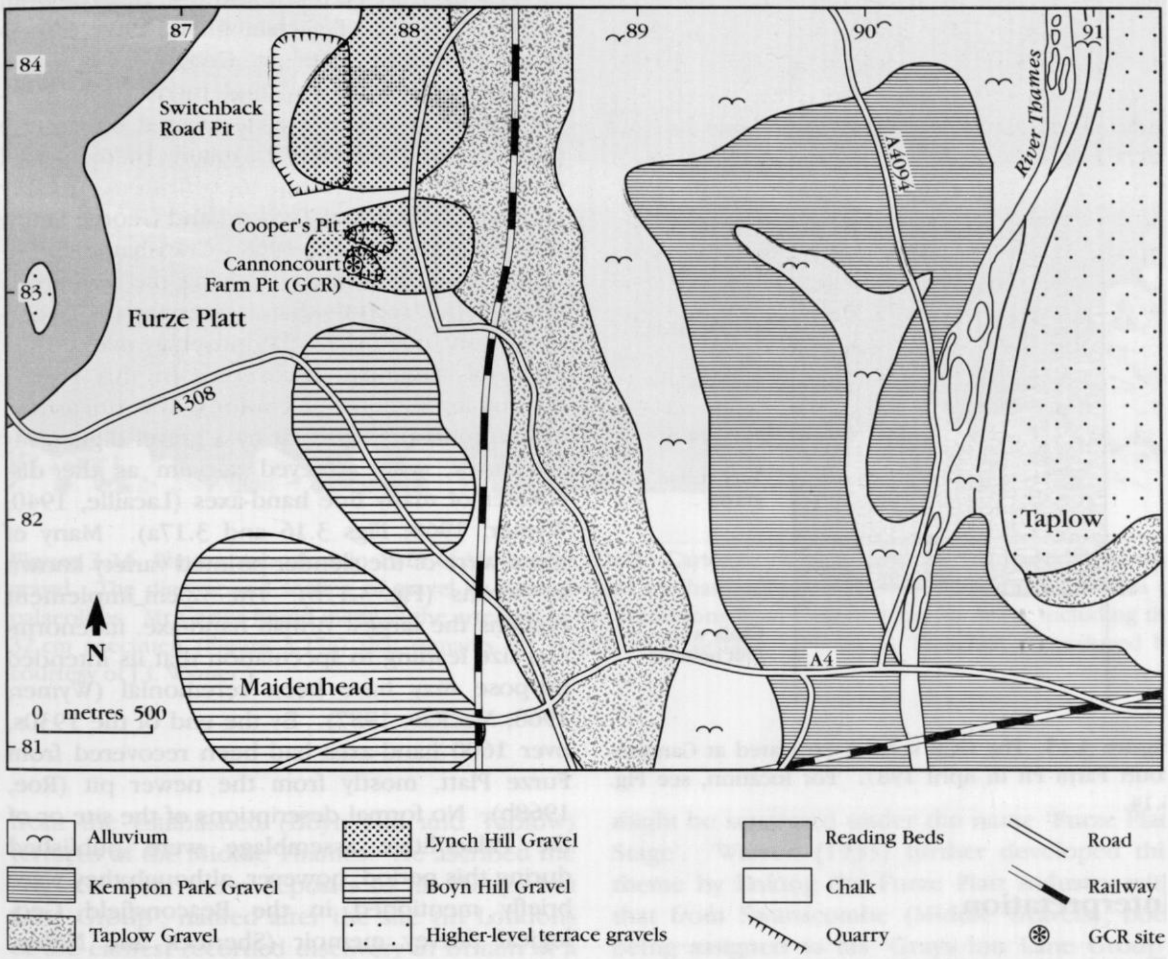


Figure 3.14 Map showing the various sites at Furze Platt and their relation to the Pleistocene geology.

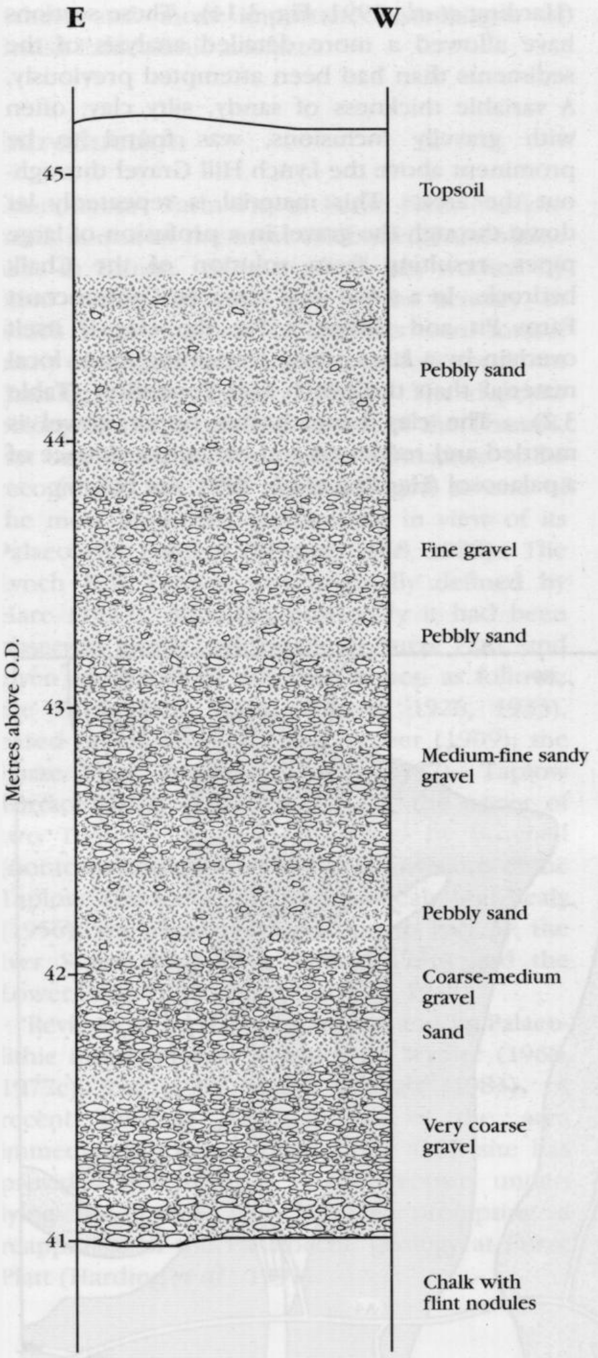


Figure 3.15 The GCR section excavated at Cannoncourt Farm Pit in April 1987. For location, see Fig. 3.14.

Interpretation

There is an extensive history of publication on the deposits at Furze Platt and their Palaeolithic content. Of particular significance was a Geologists' Association excursion visit to the locality in 1909, under the directorship of L. Treacher and H.J.O. White, who introduced on this occasion (Treacher, 1909) the idea that two distinct terraces existed in the area within the highest of the three originally recognized by Whitaker (1889). The higher of these two divisions of the 'High Terrace' (now recognized as the Boyn Hill Gravel) was exposed in a pit near Furze Platt church, in which several abraded artefacts were found, whereas the lower was represented at 'Cannoncourt (Furze Platt lower pit)', where the artefacts were more varied and less abraded (Treacher, 1909, p. 199). The latter working, almost certainly Cooper's Pit (Fig. 3.14), had at that time recently been abandoned, although a new pit opened nearby had already yielded a number of implements (Treacher, 1909). It seems likely that this newer working was the site later to be known as Cannoncourt Farm Pit and that records from before this date (Treacher, 1896, 1904; Shrubsole, 1906) all refer to Cooper's Pit.

The majority of the implements from Cannoncourt Farm Pit were discovered during the period from 1909 to 1931, mainly by the gravel diggers, who sold them to collectors, notably Llewelyn Treacher of Twyford and George Smith of Reading (Wymer, 1968; Cranshaw, 1983). Cranshaw (1983), after studying the numerous unpublished records that accompany the collections, concluded that 1919 probably marked the acme of hand-axe discovery. In this year a famous implement, 32 cm long, was unearthed in Cannoncourt Farm Pit by a gravel digger, Mr G. Carter, who achieved acclaim as the discoverer of many fine hand-axes (Lacaille, 1940; Wymer, 1968; Figs 3.16 and 3.17a). Many of these were of the slender pointed variety known as 'ficrons' (Fig. 3.17b). The 32 cm implement remains the largest British hand-axe, its enormous size leading to speculation that its intended purpose may have been ceremonial (Wymer, 1968; MacRae, 1987). By the end of the 1930s, over 1600 hand-axes had been recovered from Furze Platt, mostly from the newer pit (Roe, 1968b). No formal descriptions of the site or of the Palaeolithic assemblage were published during this period, however, although they were briefly mentioned in the Beaconsfield Geological Survey memoir (Sherlock and Noble, 1922).

Warren (1926, 1933) followed Treacher in recognizing the gravel at Furze Platt as distinct

Figure 3.16 Photograph taken in 1913 of Mr George (Deffy) Carter working at Cannoncourt Farm Pit, sieving gravel. The digging and sorting of gravel by hand, before mechanization, resulted in frequent discoveries of palaeoliths. Mr Carter found many of the artefacts in the collections from Cannoncourt Farm Pit, including the 32 cm specimen (Figure 3.17a) that remains the largest from Britain. (Photo: L. Treacher, reproduced by courtesy of J.J. Wymer.)

from the established (Boyn Hill and Taplow) terraces of the Middle Thames. He ascribed the artefacts from these deposits to his 'Grays Inn Lane Group', named after the site (in London) of the earliest recorded discovery in Britain of a Palaeolithic hand-axe, in 1690 (Evans, 1860). In a footnote, Warren (1926, p. 43) suggested that the gravels in which these artefacts occurred might be separated under the name 'Furze Platt Stage'. Warren (1933) further developed this theme by linking the Furze Platt industry with that from Swanscombe (Middle Gravels), both being assigned to his 'Grays Inn Lane Group'. Warren (1942) also correlated the Furze Platt aggradation with Palaeolithic gravels at Stoke Newington (Smith, 1894) and Leytonstone; he

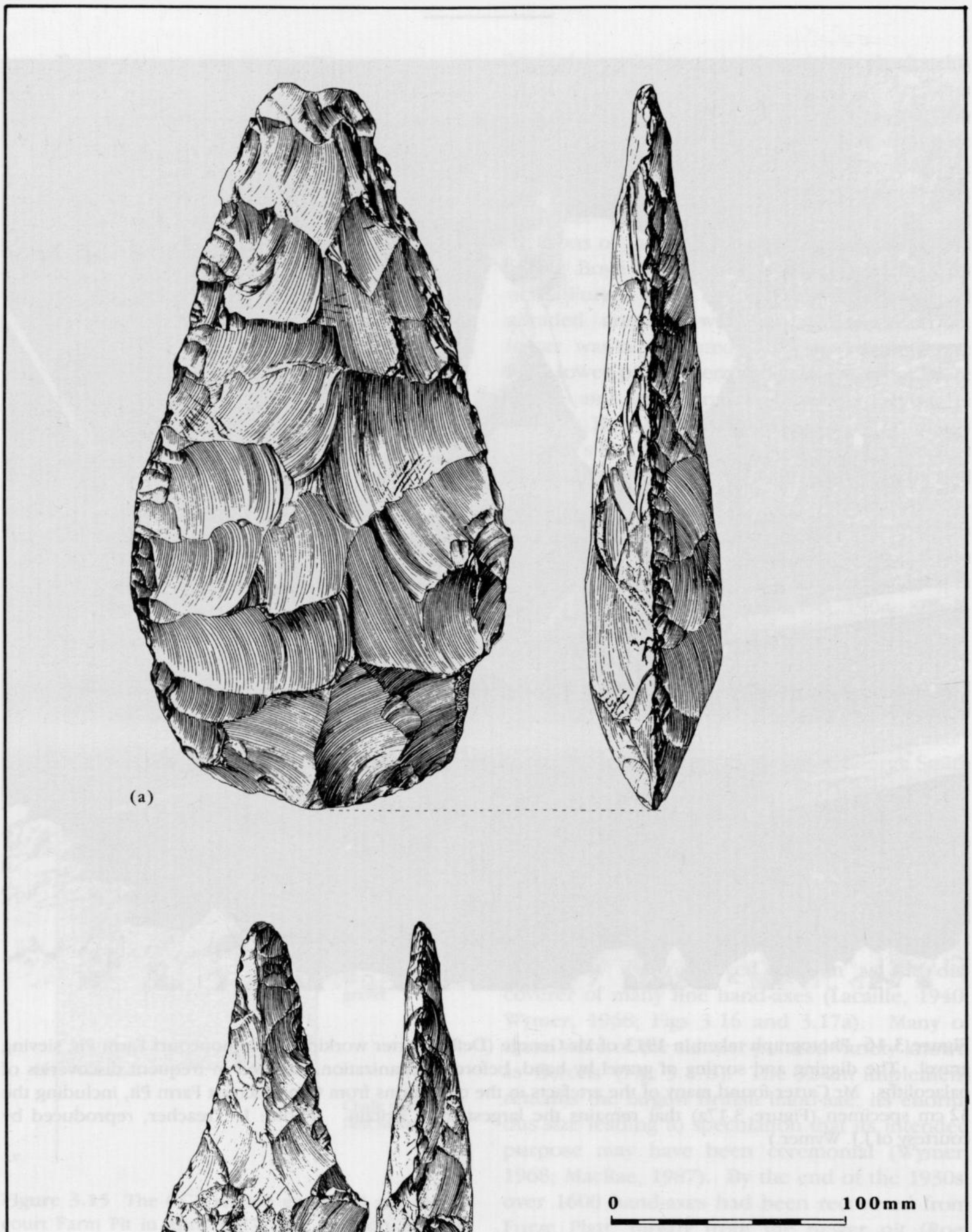


Figure 3.17 Hand-axes from Cannoncourt Farm Pit: drawings originally published by Lacaille (1940). (a) The extraordinarily large pointed hand-axe found by Mr G. Carter in March 1919. This was acquired by L. Treacher and donated by him to the Natural History Museum. (b) A fine example of a 'ficron' hand-axe.

assigned the Clactonian gravels of Swanscombe (Lower Gravel), Grays and Clacton itself to the early part of the 'Furze Platt Stage'. In a brief review of the Thames sequence, Wright (1937), alluding to the deposits at a lower level than the Boyn Hill Gravel, adopted the name 'Furze Platt Terrace'.

Lacaille (1940, p. 247) also recognized three terraces above the floodplain in the Maidenhead area; he stated that: 'The Taplow Terrace, which is the most distinct, is banked against another terrace, the ground-surface of which, east of Cannoncourt Farm, stands between 154 ft and 140 ft O.D. A shelving and undulating rise of some 20 ft marks the step to another terrace, attaining a maximum surface altitude of 171.5 ft above O.D. and 93 ft above the Thames, which rests on Chalk and extends southward. This includes the classic locality of Boyn Hill'. Lacaille recognized his 'Lower Boyn Hill Terrace' (the middle of these three, now classified as the Lynch Hill Terrace) on both sides of the river. He described exposures in the deposits of this terrace at various sites, including Cannoncourt Farm Pit.

King and Oakley (1936) believed the Furze Platt (Lynch Hill Gravel) deposits and the higher Boyn Hill Gravel to be the product of a single aggradation, built up over two separate erosional 'benches' (Fig. 3.18). They regarded the abraded artefacts from the Boyn Hill Terrace *sensu stricto* at Maidenhead as having been reworked from industries in the lower gravel (that now attributed to the Lynch Hill Formation), such as at Furze Platt. They assigned this single aggradational phase to their 'Middle Barnfield Stage', supporting Warren's (1933) correlation of the industries of Furze Platt and the Swanscombe Middle Gravel. King and Oakley also recognized another aggradational phase between the Boyn Hill and Taplow Terraces, their 'Iver Stage' (based upon observations at Iver by Lacaille). Unlike that at Furze Platt, the deposit at Iver contains Levallois flakes, together with hand-axes in abraded condition. This suggested to King and Oakley that the Iver deposits were later than those at Furze Platt. However, Gibbard (1985) followed Hare (1947) in assigning the gravels at both Furze Platt and Iver to the Lynch Hill Formation. According to Gibbard, the Levallois industry at Iver was derived from an accumulation of

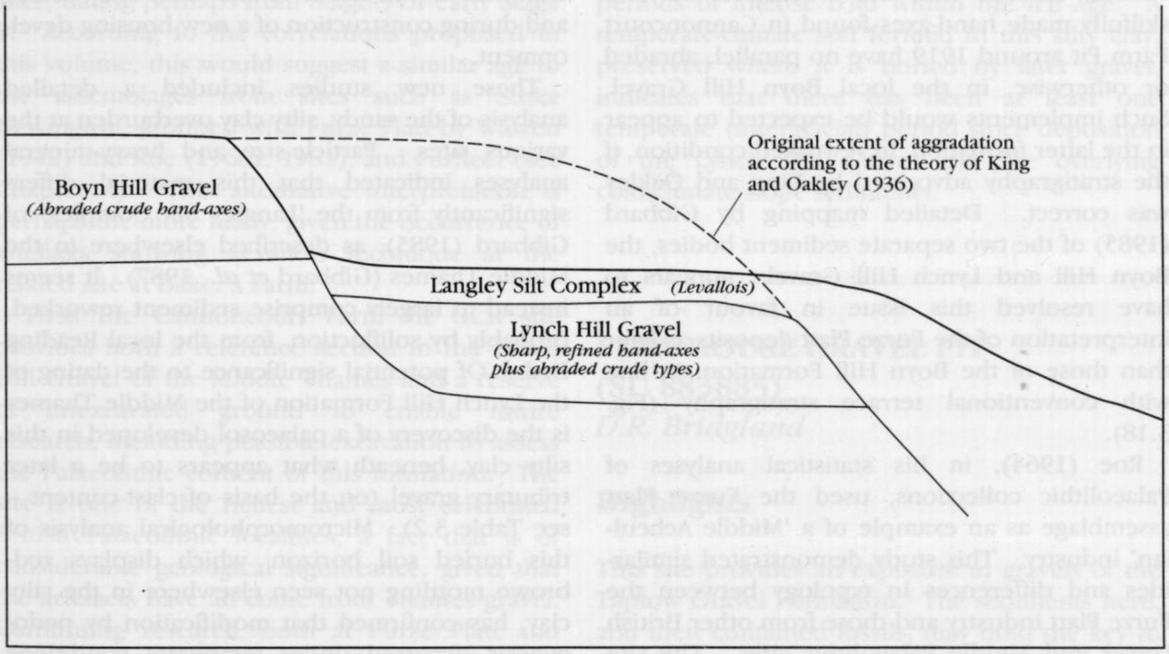


Figure 3.18 Diagrammatic representation of the relations between the Boyn Hill and Lynch Hill Gravels and the Langley Silt Complex. The types of Palaeolithic artefacts that characterize each deposit are shown. Also illustrated is the interpretation of these deposits by King and Oakley (1936).

fine-grained sediments above the Lynch Hill Gravel, dominated by wind-blown silt (loess). He assigned these fine-grained sediments to his 'Langley Silt Complex', which overlies (and therefore post-dates) the Lynch Hill Gravel, thus vindicating King and Oakley's interpretation of the archaeology.

The geomorphological and geological approaches of Hare (1947) and Gibbard (1985) produced very different interpretations of the fluvial sequence to those based on archaeology, however. Hare was unable to accept King and Oakley's single Furze Platt/Boyn Hill aggradation; he noted that the Furze Platt gravels underlie a separate terrace surface, lower than the true Boyn Hill level, which he named the Lynch Hill Terrace. Oakley (in Hare, 1947) suggested that later erosion could have produced this lower terrace feature within the single aggradation previously envisaged, a view that has continued to receive occasional support (see Wymer, 1977c; Roe, 1981). However, Cranshaw (1983) reversed King and Oakley's argument, suggesting that occasional abraded and undistinguished artefacts found at Furze Platt might have been reworked from the (older) Boyn Hill aggradation, which is characterized by similar implements. Conversely, it is clear from the various records that the well-preserved and skilfully made hand-axes found in Cannoncourt Farm Pit around 1919 have no parallel, abraded or otherwise, in the local Boyn Hill Gravel. Such implements would be expected to appear in the latter formation, in reworked condition, if the stratigraphy advocated by King and Oakley was correct. Detailed mapping by Gibbard (1985) of the two separate sediment bodies, the Boyn Hill and Lynch Hill Gravels, appears to have resolved this issue in favour of an interpretation of the Furze Platt deposits as later than those of the Boyn Hill Formation, in line with conventional terrace stratigraphy (Fig. 3.18).

Roe (1964), in his statistical analyses of Palaeolithic collections, used the Furze Platt assemblage as an example of a 'Middle Acheulian' industry. This study demonstrated similarities and differences in typology between the Furze Platt industry and those from other British Lower and Middle Palaeolithic sites. The site was also described by Roe (1968a, 1981) in his analysis of British Lower and Middle Palaeolithic hand-axe types. Roe's analyses confirmed the similarity of the Furze Platt artefacts to an assemblage from an identical stratigraphical situation, concentrated near the base of the Lynch Hill Gravel, on the opposite (eastern) side of the Thames at Baker's Farm (SU 958822). This was another pit from which collections were assembled by Treacher and Lacaille (Lacaille, 1940, 1960; Wymer, 1968). Roe (1968a, 1981) also grouped the Furze Platt industry with those from Stoke Newington and Cuxton and suggested a Mindel–Riss (Hoxnian) age for these assemblages. Wymer (1968) considered the industry from Cannoncourt Farm Pit to belong to a single phase of the Acheulian culture, with a few rolled specimens possibly derived from earlier assemblages. He denied the occurrence of Levallois flakes or cores, as had been claimed by Lacaille, although he was more convinced by Levallois material collected by Lacaille from Baker's Farm.

The past few years have seen renewed research activity at Furze Platt. The small-scale GCR excavation in Cannoncourt Farm Pit in 1987 closely followed an appraisal by the Trust for Wessex Archaeology of the nearby Switchback Road Pit (Fig. 3.14) prior to its extension (Harding *et al.*, 1991). In 1988 the same organization undertook a detailed study of those parts of the Cooper's Pit/Cannoncourt Farm Pit complex to the north of the GCR site, before and during construction of a new housing development.

These new studies included a detailed analysis of the sandy, silty clay overburden at the various sites. Particle-size and heavy-mineral analyses indicated that this material differs significantly from the 'Langley Silt Complex' of Gibbard (1985), as described elsewhere in the Middle Thames (Gibbard *et al.*, 1987). It seems instead to largely comprise sediment reworked, probably by solifluction, from the local Reading Beds. Of potential significance to the dating of the Lynch Hill Formation of the Middle Thames is the discovery of a palaeosol developed in this silty clay, beneath what appears to be a later tributary gravel (on the basis of clast-content – see Table 3.2). Micromorphological analysis of this buried soil horizon, which displays red-brown mottling not seen elsewhere in the silty clay, has confirmed that modification by pedogenesis occurred under temperate conditions prior to the deposition of the overlying gravel. If the latter deposit is attributed to a cold climatic interval, it being unlikely that a tributary stream could have carried gravel to this location during the Holocene interglacial (most such valleys in the area, being developed on Chalk, are dry at the present time), the palaeosol must date from a pre-Holocene temperate episode. This provides a minimum age for the Lynch Hill Gravel underlying the brickearth, which must pre-date the last interglacial (Harding *et al.*, 1991).

In fact, the correlation scheme for the Thames terrace sequence advocated in Chapter 1 suggests that the Lynch Hill Gravel is significantly older than this. It is ascribed, according to the climatic model for terrace formation also proposed in Chapter 1, to Oxygen Isotope Stages 10 (phase 2 gravel) and 8 (phase 4 gravel). Assuming the phase 2 part of the Lynch Hill Formation (see Chapter 1) to be present at Cannoncourt Farm Pit, this interpretation suggests manufacture of the artefacts that were found just above the Chalk surface during Stages 10 or 11. The latter age would indicate broad contemporaneity with the Swanscombe Middle Gravel industry, an interpretation that had been promoted, on typological grounds, by Warren (1933). However, it is also possible that the gravels overlying the Chalk at Furze Platt represent the phase 4 part of the Lynch Hill aggradation, in which case the artefacts could be later, dating perhaps from Stage 9 or early Stage 8. According to the correlations proposed in this volume, this would suggest a similar age to the assemblages from sites such as Stoke Newington, grouped with Furze Platt by Warren (1942) and Roe (1968a, 1981), and Purfleet (see Chapter 4). This alternative interpretation is perhaps the more likely, given the occurrence of artefacts showing Levallois technique at the related site at Baker's Farm.

Thus the Cannoncourt Farm Pit GCR site provides both a reference section in the Lynch Hill Gravel of the Middle Thames and a reserve of unexcavated ground to enable future research, including possible excavation to assess the Palaeolithic content of this formation. The site is one of the richest and most celebrated British Palaeolithic localities, a fact that is of considerable geological significance, given that the artefacts have all come from Thames gravel. Continuing research, both at Furze Platt and elsewhere, may soon provide an improved geochronological framework for this important Palaeolithic assemblage. Such studies will also provide more information about the geological history of the Lynch Hill Formation and related sediments, which form an important part of the Thames sequence.

Conclusions

The deposits at Cannoncourt Farm Pit are part of the Lynch Hill Gravel of the Thames, one of the lowest in the celebrated 'staircase' of terraces preserved in the Slough area. Here, and at adjacent sites, this gravel has long been famous for yielding a profusion of man-made flint tools and the waste-flakes from their manufacture – over 2500 such Stone-age artefacts have been found to date. Cannoncourt Farm Pit is particularly notable for the discovery there of the largest Palaeolithic hand-axe ever found in Britain.

The gravel at Cannoncourt Farm is overlain by a pebbly, silty clay deposit that, in places, has collapsed through the gravel into large solution hollows (pipes) that penetrate down into the underlying Chalk. Analysis of the silty clay shows that it is largely composed of redeposited material derived from the local Reading Beds (a much older set of sediments deposited around 60 million years ago), suggesting that it was formed not by the Thames, but through a process of slope movement, particularly during periods of intense cold within the Ice Age. A temperate-climate soil formed in this silty clay, preserved where it is buried by later gravel, indicates that there has been at least one temperate (interglacial) period since deposition of the Lynch Hill Gravel and the overlying cold-climate slope sediments.

FERN HOUSE GRAVEL PIT (SU 883885)

D.R. Bridgland

Highlights

This site provides an exposure in gravels of the Taplow Gravel Formation. The sediments here, and their contained fossils, may hold the key to elucidating a poorly understood part of the history of the Thames, that between the (glacial) Anglian Stage, when the river was diverted into its modern course, and the last (Ipswichian) interglacial.

Introduction

Fern House Gravel Pit, Buckinghamshire, also known as 'Ferns Pit' and 'Well End Pit', exposes sediments of the Taplow Gravel Formation overlain by several metres of colluvial gravels. This pit, which lies *c.* 10 km upstream from the Taplow type locality, was much visited earlier in this century, when it yielded a number of elephant remains, mostly teeth of mammoth.

The Taplow Terrace, the geomorphological feature formed by the Taplow Gravel, was one of the three Thames terraces originally defined by the Geological Survey (Bromehead, 1912). It had previously been referred to as the 'Middle' or '50 ft Terrace' (Hinton and Kennard, 1900, 1905, 1907; Pocock, 1903). The status of this formation as an important element of the Thames sequence was consolidated in later work (Dewey and Bromehead, 1915; Sherlock and Noble, 1922; King and Oakley, 1936; Oakley, 1937; Hare, 1947). Sealy and Sealy (1956) proposed a division into Upper and Lower Taplow Terraces, but these are not considered to represent separate fluvial aggradations (Gibbard, 1985).

According to Gibbard (1985), the Taplow Gravel is characterized by a mammalian fauna indicative of severe cold. However, the occurrence of occasional remains of temperate species suggests that deposition of this formation also spanned one or more temperate intervals.

Description

Fern House Pit appears first to have been operational in the early years of this century. Many years earlier, however, sections showing a 4 m thickness of (Taplow) gravel were recorded 10 km further downstream, at what was to become the type locality of both this terrace and the gravel that forms it, Taplow Station Pit (Owen, 1855; Prestwich, 1855; Sherlock and Noble, 1922; Oakley, 1937). This site yielded bones of mammoth, woolly rhinoceros and musk ox (Sherlock and Noble, 1922), the last being the first record of this species in Britain. Musk ox was later considered by Gibbard (1985) to be particularly characteristic of the Taplow Gravel.

The earliest description of Fern House Pit appears to be that by Treacher (1916) who, in a Geologists' Association excursion report, observed that two types of gravel were exposed: a lower sandy, current-bedded deposit, which he thought likely to belong to the Taplow Terrace, and an upper, less well-bedded, clayey spread, which he suggested was hillwash from Flackwell Heath to the north. During the visit, a fragment of mammoth's tooth was discovered in the lower gravel (Treacher, 1916). A pit west of Well End, probably the GCR site, was described by Sherlock and Noble (1922), who reported up to 8 m of gravel, the lower metre of chalky composition (this thickness presumably includes the upper colluvial gravel). The presence of Chalk clasts in fluvial gravels is exceptional in the Thames terrace sequence and is restricted to deposits immediately overlying the source (bedrock Chalk or coombe rock). The calcareous nature of the lower gravel may explain the preservation in it of mammalian remains in some quantity (see below).

The Geologists' Association again visited the pit in 1933 (Treacher, 1934), when the distinction between the lower fluviatile gravel and the upper 'slopewash' material was once again noted. Treacher suggested that the latter comprised material washed down from the neighbouring hills through a series of short steep valleys that converged to form a fan in the vicinity of the pit. According to Treacher, mammalian remains were commonly found in the gravel, especially molar teeth of mammoth (*Mammuthus primigenius*), although at least one tooth of straight-tusked elephant (*Palaeoloxodon antiquus*) had also been found. Treacher also noted on this occasion that the two types of gravel were separated by a band of 'loam' (silt?) averaging 1.2 m thick.

Wymer (1968) noted that the site had been overgrown since 1960, when he had observed 3 m of 'solifluction gravel' overlying sandy bedded gravel. According to Wymer, the upper gravel contains a high proportion of quartzite pebbles, indicating that it represents the redistribution of one of the early Thames drifts to the north, as suggested by Treacher. Although Treacher (1934) maintained that no artefacts had been found in the pit, Wymer believed that a very rolled primary flake in the Ashmolean Museum, found in 1941 (after Treacher's observation) and marked 'Bourne End Pit', might have originated there. Sherlock and Noble (1922) claimed the Taplow Terrace to be associated with Mousterian (Levallois) artefacts, but Gibbard (1985) considered such material to have come from wind-blown silt (loess) overlying the fluvial deposits, his 'Langley Silt Complex'. According to Gibbard, therefore, these artefacts post-date the deposition of the Taplow Formation (see, however, Chapter 4, Lion Pit and Northfleet). Gibbard provided the results of a stone count from this pit (Table 3.2), showing a typical Taplow Gravel composition, but lacking the Chalk reported by Sherlock and Noble. Gibbard's sample presumably came from the upper (Chalk-free) part of the bedded gravel at the site.

Interpretation

The Taplow Terrace and underlying Taplow Gravel have an important place in the later part of the Thames terrace succession. The middle of the three terraces originally mapped in the Maidenhead area (see above and Introduction to Part 3), this aggradation has been widely recognized throughout the Middle and Lower Thames basins (see Chapter 1). Correlation of Taplow remnants throughout this area is not without its problems, however. For example, recent work in the Lower Thames suggests that it has previously been misidentified downstream from London (see Chapters 4 and 5).

Following the introduction of the terms Taplow Terrace and Taplow Gravel by the Geological Survey (Bromehead, 1912; Dewey and Bromehead, 1915), King and Oakley (1936) proposed the name 'Taplow Stage' for the period represented by this aggradation. This was linked to the 18 m 'Main Monastirian Sea-Level' by Zeuner (1945), who believed the gradient of the terrace downstream from Ealing to be negligible (after Pocock, 1903). This now appears to be a mistaken impression that arose from miscorrelation across the London area; recent re-evaluation of the sequences in the Lower Thames and eastern Essex indicates that the Taplow Gravel declines continuously towards a low sea level (see Fig. 1.3; Chapters 4 and 5). This is consistent with aggradation of the Taplow Formation during a cold episode, as is indicated by the mammalian fauna. However, east of London the gravel is overlain by or interbedded with fine-grained sediments of probable estuarine origin that are ascribed to a high (interglacial) sea level, thought to be equivalent in age to Oxygen Isotope Stage 7 of the oceanic record (see Chapter 4).

Hare (1947), in his detailed geomorphological mapping of the Slough–Beaconsfield area, noticed a minor, lower sub-facet of the Taplow Terrace. Later authors used this as a basis for a division into Upper and Lower Taplow Terraces (Sealy and Sealy, 1956; Thomas, 1961; Evans, 1971). The importance of 'Ferns Pit', and the descriptions of it by Treacher, were acknowledged by Sealy and Sealy (1956). These authors attributed the upper gravels at this site to rapid deposition during a cold episode following the aggradation of the lower bedded gravel, which they assigned to their Upper Taplow Terrace. As this implies, they correlated the fluvial deposits at Taplow level in the Marlow district, including the lower gravel at Fern House Pit, with the Upper Taplow Terrace of the type area, around Slough, which they believed to be the major of the two divisions. Gibbard (1985), however, considered Sealy and Sealy's division of the Taplow Terrace to be of geomorphological significance only. He observed that the Upper Taplow Terrace of the type area is formed by the Taplow Gravel aggradation with an overlying layer of wind-blown silt (loess). The localized removal of this later silt has given rise to the minor, lower facet originally described by Hare. The upper surface of the Taplow Gravel, which is Sealy and Sealy's Lower Taplow Terrace, is therefore the true expression of the fluvial aggradation; the higher feature has no significance to the history of Thames drainage evolution. The layer of 'loam' at Fern House Pit, between the lower bedded gravel (presumed to represent the Taplow Formation) and the upper colluvial gravel, may well represent this wind-blown accumulation, the 'Langley Silt Complex' of Gibbard (1985).

Gibbard's reinterpretation of the Upper and Lower Taplow Terrace features applies only to the area downstream from Fern House Pit, however. The Taplow Formation has been entirely removed by erosion in the district immediately upstream from Marlow, but further west, in the Reading area, separate geomorphological terraces have again been recognized at both the Upper and Lower Taplow levels (Sealy and Sealy, 1956), despite the absence in this district of loessic overburden. Wymer (1968) recognized these as his Henley Road and Taplow Terraces, respectively. Gibbard (1985) considered the higher of these (Wymer's Henley Road

Terrace) to represent the Taplow Gravel *sensu stricto* and interpreted the lower as a unit peculiar to this area, his 'Reading Town Gravel'. He attributed this deposit to aggradation during the Early Devensian, although noting that possible temperate-climate deposits had been described from a site at this level known as Redlands Pit (SU 732727) (Poulton, 1880; Wymer, 1968). Gibbard considered that these were probably residual Ipswichian Stage deposits and that the Reading Town Gravel had been banked against them. The Redlands Pit site, some 25–30 km upstream from Fern House Pit, yielded reworked Jurassic, Cretaceous and Palaeogene Mollusca, together with (Pleistocene) bones of ox, horse, mammoth and rhinoceros (Poulton, 1880). Poulton also described tree trunks, which Wymer believed to have been reworked from the Palaeogene (leaf-beds occur in the immediate vicinity within the Reading Beds). Gibbard (1985) thought that these tree remains, tentatively identified as *Pinus* by Poulton, might equally well have been of Pleistocene age, although the original description indicates that they were partly mineralized, which would seem to support Wymer's interpretation. If they were of Palaeogene origin, the only evidence for a Pleistocene temperate episode from this pit would be the mammalian fossils, none of which can be regarded as indicating fully interglacial conditions.

Another pit in Reading on the Taplow Terrace of Wymer (1968), the 'Reading Town Gravel' of Gibbard (1985), provided stronger evidence for interglacial conditions in the form of teeth of hippopotamus (Shrubsole and Whitaker, 1902; Wymer, 1968). This site, on a separate remnant to Redlands Pit, was at Kensington Road (SU 698734). The records provide no information about the context of these remains, but there is no indication that they were associated with fine-grained or organic sediments. Gibbard (1985) cited the occurrence of these remains in his 'Reading Town Gravel' as important evidence for the Early Devensian age of the latter, since hippopotamus is believed to have been present in Britain, after the Anglian Stage, only during the last interglacial, the Ipswichian Stage (*sensu* Trafalgar Square) (see Chapter 1 and Chapter 2, Stanton Harcourt and Magdalen Grove). Attribution of the mammalian assemblage from Redlands Pit to the Ipswichian may be problematic, however, since horse is widely believed to be absent from that stage (Shotton, 1983), although Stuart (1982a) considered that it disappeared at the beginning of the Ipswichian, to reappear in pollen biozone IpIII.

Reassessment of the altitudinal distribution of gravel remnants in the Reading area attributed to the post-Lynch Hill aggradations of the Thames (Chapter 1) suggests a different interpretation to that of Gibbard (1985). If the Taplow Gravel of the type area is projected upstream, passing through the fluvial gravels at Fern House Pit (Fig. 3.3), the deposits in the Reading area that fall at the predicted elevation for this formation are those identified by Gibbard as his 'Reading Town Gravel'. It is thus concluded that this is the true upstream equivalent of the Taplow Formation at Reading (see Chapter 1), confirming the view of Wymer (1968). An alternative interpretation is therefore required for the higher gravel remnants, attributed by Gibbard to the Taplow, that lie between the true Taplow (Reading Town) Gravel and the Lynch Hill Gravel. Wymer tentatively associated these gravels, his 'Henley Road Terrace', with the deposits at Iver (see above, Cannoncourt Farm Pit), some 18 km downstream from Fern House Pit. Moreover, he regarded deposits in the Sonning area, which were also included by Gibbard in the Taplow Gravel, as part of the Lynch Hill Formation. It seems likely that all these problematic remnants represent degraded thicker parts of the Lynch Hill Gravel, separated from the downslope feather-edge of that formation by later erosion; the Henley Road Terrace may thus be an erosional terrace similar to the Stoke Park Cut, cut in Lynch Hill Gravel (see above, Introduction to Part 3 of this Chapter).

This re-evaluation of the terrace stratigraphy in the Reading area has major repercussions for correlation with deposits in the Upper Thames basin and for the relative dating of the Taplow Formation. Gibbard (1985) argued for correlation of his Reading Town Gravel with the Summertown-Radley Terrace of the Upper Thames, which he also attributed to the Early Devensian. Reappraisal of terrace correlations between the Upper and Middle Thames (see Chapter 1) supports Gibbard's view, thus implying that the downstream continuation of the Summertown-Radley Formation in the Middle Thames is the Taplow Gravel. The Summertown-Radley aggradation is seen by many workers to be a highly complex succession of both temperate- and cold-climate deposits, most if not all of which is pre-Devensian (see Chapter 2, Stanton Harcourt and Magdalen Grove). This formation is, according to the interpretation favoured in Chapter 2, dominated by cold-climate gravels that accumulated in Oxygen Isotope Stages 8 and 6, although it also incorporates interglacial sediments from Stage 7 and Substage 5e (= Ipswichian *sensu* Trafalgar Square) and may culminate in Lower Devensian gravels (Fig. 2.18).

The above correlation indicates that deposits of this wide range of ages might also be expected in the Taplow Formation downstream from the Goring Gap, certainly in the Reading area and perhaps at sites such as Fern House Pit. In the lower reaches of the river, however, the Taplow Formation is restricted in age to Oxygen Isotope Stages 8–6 (Chapters 1 and 4), incision to a new terrace level having occurred within Stage 6 (see Chapter 1). This incision (rejuvenation) was followed by the aggradation of the Kempton Park Formation, which has only been recognized in the Thames valley below Reading (see Chapters 1 and 2, Stanton Harcourt and Magdalen Grove). Within the Kempton Park Formation, each element of the aggradational sequence predicted by the climatic model for terrace formation promoted in Chapter 1 has been recognized (Fig. 2.18). After the erosional phase (phase 1), the first phase of cold-climate gravel deposition (phase 2) is represented by the Spring Gardens Gravel of Gibbard (1985), which underlies the Trafalgar Square (Ipswichian) sediments and can be attributed to Oxygen Isotope Stage 6. The sediments at Trafalgar Square (and equivalent deposits at Brentford) represent the interglacial phase of the model (phase 3), attributable in this case to the Ipswichian Stage (Oxygen Isotope Substage 5e). The major part of the Kempton Park Formation represents phase 4 of the model, the post-interglacial cold-climate aggradation, and is of well-established Devensian age (Gibbard, 1985).

The occurrence of hippopotamus in the Taplow Gravel at the Kensington Road pit suggests that Ipswichian deposits occur within that formation in the Reading area. This implies that no Stage 6 rejuvenation occurred in this area, so the terrace sequence there is equivalent to that in the Upper Thames and not to that in the London area (Fig. 2.18). It is interesting that Sandford (1932), reviewing the previously published evidence, observed that the Taplow Terrace had yielded fauna of both warm and cold affinities, pre-empting the above conclusions.

The above paragraphs provide a context for discussing the information from Fern House Pit. Evidence for the relative dating of the deposits of the Middle Thames sequence is extremely rare, there being no pre-Devensian sites within the lower terraces that have yielded molluscan remains or pollen. The only evidence to support hypotheses based on the reconstruction of terrace aggradations derives from mammals. The mammalian record from the Taplow Formation is relatively sparse and is restricted to large animals, but it appears to incorporate a cold-climate fauna, typified by musk ox (Gibbard, 1985), and temperate-climate species characteristic of both Oxygen Isotope Stage 7 and the Ipswichian Stage (*sensu* Trafalgar Square). The assemblage from the Redlands Pit at Reading includes horse and mammoth, two of the three important species of the 'Stage 7 fauna' described by Shotton (1983). The third species, straight-tusked elephant, was recorded at Fern House Pit by Treacher (1934), presumably from the main body of the Taplow Gravel. This is the most important of the three, since horse and mammoth are known from interstadial deposits and cannot alone be used as evidence for a major temperate-climatic event. Straight-tusked elephant occurs in Ipswichian deposits, however, so it could be attributed to the same origin as the hippopotamus from Kensington Road, Reading. It should be noted that most, if not all, of these large-mammal remains probably come from cold-climate gravels, into which they have been reworked; no *in situ* temperate-climate sediments have yet been recognized within the Taplow Formation in the Middle Thames area (except perhaps at Redlands Pit).

Fern House Pit is located at the extreme upstream limit of the area in which the Kempton Park Formation has been recognized. Gibbard (1985) regarded a low-level gravel at Marlow (SU 865874) as a potential outlier of the Kempton Park Gravel, the furthest upstream that he recognized. A beetle assemblage from organic sediments within this gravel is suggestive of the Upton Warren Interstadial (Coope, in Gibbard, 1985), supporting an early or mid-Devensian age. This deposit extends to *c.* 3 km upstream of Fern House Pit (Fig. 3.1). It thus seems likely that incision from the level of the Taplow Formation to that of the Kempton Park

Gravel did occur in the Marlow area during Oxygen Isotope Stage 6, following the aggradation, during the early part of this cold episode, of the main (phase 4) part of the Taplow Formation as recognized in the type area (see Fig. 2.18). This is an important concept to establish, because it implies that the straight-tusked elephant from Fern House Pit is pre-Ipswichian and that it was reworked from temperate-climate deposits laid down prior to Stage 6 (probably in Stage 7). It is possible, in the light of the recent discovery at Cannoncourt Farm Pit (see above), that the 'loam' separating the Taplow Gravel from the overlying colluvial gravel at Fern House Pit may show evidence of pedogenesis. This might provide a means for demonstrating the pre-Ipswichian age of the Taplow Formation at Little Marlow.

Fern House Pit therefore exposes an important and fossiliferous remnant of the Taplow Gravel Formation of the Middle Thames. Further work is clearly required on these sediments in order to test the revised stratigraphical interpretation of this formation outlined above. The reports of a basal chalky gravel suggest that the deposits at Little Marlow are more likely to have fossils preserved in them than the more typical non-calcareous gravel of the Middle Thames, a view supported by the early records of mammalian remains. It is hoped that re-excavation of sections in the fluviatile deposits will provide future opportunities for modern studies of the sediments and their faunal content.

Conclusions

Fern House Pit provides exposures of the Taplow Gravel, which forms the Taplow Terrace, one of the best-known and longest recognized of the Thames terraces. Well-bedded river gravel is here overlain by a thick accumulation of unbedded gravelly deposits that have moved down the valley side from the north, probably under intensely cold conditions. Teeth of woolly mammoth and the temperate-climate-dwelling straight-tusked elephant (an even larger extinct species) have been found in the bedded gravel. The dating of the deposits is controversial. It is generally agreed that they fall in an interval of geological time known as the Saalian Stage, which began around 400,000 years BP and finished 128,000 years BP. It used to be thought that this interval was a single cold (glacial) phase, intermediate between the Anglian, when the Thames was diverted by ice, and the 'last glacial', which ended only 10,000 years ago. However, it is now believed that a succession of climatic fluctuations occurred during the Saalian Stage, with three cold and two warm episodes. This view is far from being universally accepted, but the record of Thames terraces formed during the Saalian may prove critical in providing evidence for this complex series of climatic changes. To this end, the evidence from the Fern House Pit may hold the key to resolving some of the outstanding problems.

BRIMPTON GRAVEL PIT (SU 568651)

D.R. Bridgland

Highlights

Faunal and floral remains from silts and organic muds within the gravel sequence at this site provide unique but controversial evidence for reconstructing Middle and/or Late Pleistocene conditions in Britain. Although it has been argued that the biostratigraphical evidence here shows two interstadial and three stadial phases within the Devensian Stage, much of the sequence may prove to be pre-Devensian in age.

Introduction

Brimpton Gravel Pit, Berkshire, was operational during the late 1970s and early 1980s. It exploited the Thatcham Terrace deposits of the tributary Kennet valley (Chartres *et al.*, 1976). It is a site of major importance for Upper Pleistocene (possibly upper Middle Pleistocene) stratigraphy and palaeoclimatic reconstruction in Britain. Beds of silts and organic muds within a gravel sequence here provide a biostratigraphical record of two interstadial periods and at least three stadials (Bryant and Holyoak, 1980; Bryant *et al.*, 1983).

This is the type locality of the Brimpton Interstadial, as yet unknown elsewhere in Britain. Bryant *et al.* (1983) attributed the entire Brimpton sequence to the Devensian Stage, regarding the Brimpton Interstadial as a temperate interlude intermediate between the Chelford and Upton Warren interstadials within the British sequence. This view, based on biostratigraphical correlation between sediments at Brimpton and the Chelford type locality, is challenged here on the grounds that terrace correlation between the Thames and Kennet valleys implies that a pre-Devensian age for part of the Brimpton sequence is also possible.

Description

The Brimpton site is located on a low gravel-covered interfluve between the valleys of the Kennet and its tributary, the River Enborne (Fig. 3.1). The original land surface at the site was 6–7 m above the Kennet floodplain, forming part of a terrace feature that continues westwards (upstream) in the Kennet valley and southwards into the Enborne valley. This feature is the Thatcham Terrace of Chartres *et al.* (1976), which appears to be a continuation, in the Kennet valley, of the Taplow Terrace as recognized in the Reading area (see above, Fern House Pit; Fig. 3.3).

The sediments at Brimpton were progressively exposed as the working face moved westwards, between late 1979 and early 1982. At no time was the complete stratigraphical sequence visible. The deepest part of the pit coincided with a depression in the London Clay, *c.* 10 m deep and filled with bedded gravel. The available sections suggested this to be an enclosed basin, possibly representing a scour-hollow excavated at the confluence of the Kennet and Enborne rivers (Bryant *et al.*, 1983).

Lenses and more widespread bands of clay, silt and sand occur throughout the gravel sequence at Brimpton, with clasts of these lithologies occurring in the uppermost 3 m. The matrix of the upper 1–3 m of the gravels contains significant silt and clay, whereas these are generally scarcer in the matrix of the lower gravels. The division between upper (silty) gravels and lower (sandy) gravels is indistinct in some places but sharp in others, often cutting across bedding structures.

Persistent searching in the less oxidized of various clay units within the gravel sequence yielded pollen and Mollusca from numerous levels, as well as plant macrofossils and beetles from a few (Bryant *et al.*, 1983). A sequence of alternating woodland and open-country assemblages was recognized, providing the basis for a biostratigraphical subdivision of the Brimpton sediments. From the palynological succession Bryant *et al.* (1983) deduced that a complex sequence of climatic fluctuations, which they regarded as stadials and interstadials, was represented.

The sequence of fossiliferous beds or lenses, all separated one from another by gravel beds, is as shown in Table 3.4 (interpretations follow Bryant *et al.*, 1983; see also Fig. 3.19). The earliest stratigraphical level from which botanical evidence was obtained (A, Figs 3.19 and 3.20) yielded a pollen assemblage with birch

Table 3.4 Stratigraphy of the Thatcham Terrace deposits at Brimpton (after Bryant *et al.*, 1983).

Lithology	* – Local pollen zones	Interpretation/age
1. Upper silty gravels	F – Non-arboreal pollen	Cold (stadial) late mid-Devensian (^{14}C 27,400 ± 1250 BP (BM-1638))
2. Lower sandy gravels	E – Gramineae-*Betula-Pinus*	Brimpton Interstadial
	D – Cyperaceae-*Betula*	Cold (stadial)
	C – *Betula-Pinus-Picea*	Chelford Interstadial
	B – Non-arboreal pollen	Cold (stadial)
	A – Non-arboreal pollen-*Betula-Pinus*	Late Ipswichian or Wretton Interstadial

* See Fig. 3.20; A–F also coincide with labels in Fig. 3.19, which indicate sample points.

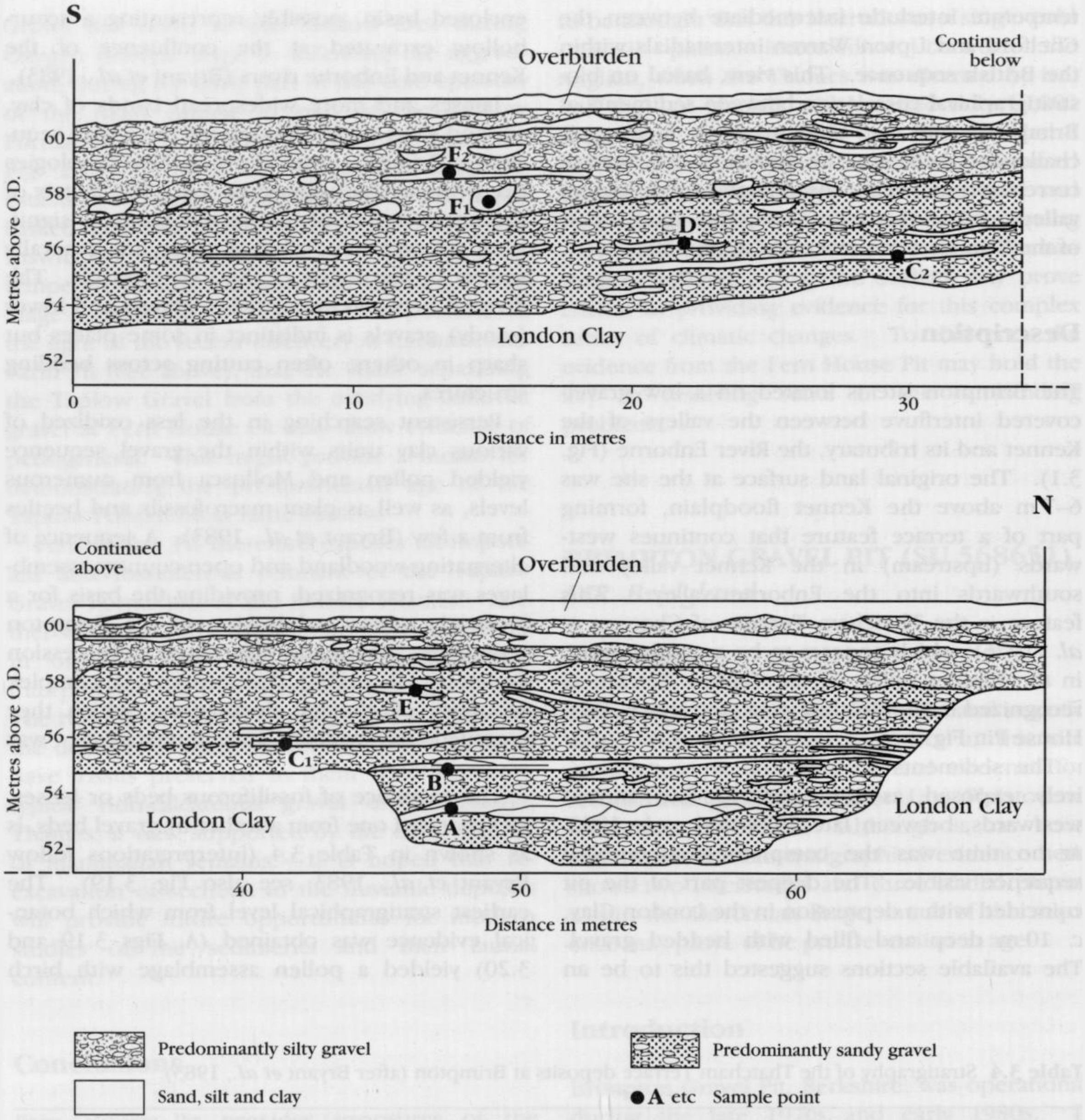


Figure 3.19 Composite section at Brimpton, showing the stratigraphical relations of the various deposits and the locations of samples of biostratigraphical significance (modified from Bryant *et al.*, 1983).

(11%), pine (16%), willow (9%) and occasional oak and spruce. Local grassland was suggested by abundant pollen of Gramineae (25%) and occasional grains from grassland herbs. Heath-land, waterside and aquatic species were also represented in an assemblage suggestive of temperate (interstadial or late interglacial) conditions. There was support for this interpretation from a plant macrofossil assemblage that included pine and various herb remains. The occurrence of a single fruit of hornbeam (*Carpinus*), an indicator of fully interglacial conditions, was attributed to reworking, as this species was not represented amongst the pollen spectra (Bryant *et al.*, 1983). This level also produced 15 aquatic and four terrestrial molluscan species, including *Vallonia pulchella* (Müller), *Trichia hispida* and *Pisidium supinum*

(Schmidt), all of which are regarded as thermophilous taxa in the British Devensian. Their presence, and the overall richness of the fauna, lend support to the interpretation, based on the palaeobotany, of this level as temperate (Bryant *et al.*, 1983).

The second level from which evidence was obtained (B, Fig. 3.19) was a silty bar-top drape. This yielded pollen, comprising 55–62% Cyperaceae, 5–10% Gramineae and less than 3% tree pollen (Fig. 3.20). Bryant *et al.* (1983) regarded this assemblage as indicative of the typical open vegetation of full stadial conditions, with trees largely absent. They claimed support for this interpretation from an impoverished molluscan fauna, also obtained from this level, comprising three freshwater species (*Anisus leucostoma* (Millet), *Lymnaea peregra* (Müller) and *Pisidium nitidum*) and three terrestrial species, all of which today tolerate arctic conditions.

At a slightly higher stratigraphical level, unoxidized clay/silt bar-top drapes and/or small channel-fills were found to contain abundant well-preserved pollen (C_1 and C_2, Figs 3.19 and 3.20). Of these, C_2 also yielded plant macrofossils and molluscs, whereas C_1 yielded nine species of Coleoptera. These levels were dominated by tree pollen (62–76%), principally birch and pine, both also represented amongst the macrofossils. Spruce formed an abundant element of the latter, but only 1–4% of the pollen. As this tree is not a high pollen producer, these facts suggest that it was an important species in local forests at the time of deposition. Occasional grains of oak and alder were also encountered. The remainder of the plant community appears to have included both shade-tolerant (forest) and open-habitat taxa, the latter possibly growing close to the river. The freshwater molluscan fauna was similar to that from the previous level (B), but the land fauna was significantly different and highly distinctive. It included the boreal forest snail *Discus ruderatus* (Férussac), only previously recorded from interglacials in Britain, and a species found only in interglacials and in the Late Devensian, *Nesovitrea hammonis* (Ströns). Although these snails extend today into the Arctic region, their presence was seen by Bryant *et al.* (1983) to provide some support for the palaeobotanical evidence for climatic amelioration at this level. Further support for this view came from the beetles, which were considered indicative of an environment similar to central and southern Fennoscandia at the present time, with much colder winters and slightly cooler summers than are currently experienced in southern Britain.

The fourth pollen-bearing level (D, Figs 3.19 and 3.20), another set of bar-top drapes, yielded sparse pollen dominated by non-arboreal types. This material actually comes from seven samples at slightly different stratigraphical levels, but their similarity suggests that they represent the same biozone, one characterized by open-vegetation species (Bryant *et al.*, 1983). This interpretation is supported by the limited molluscan fauna from the same levels, comprising taxa tolerant of arctic conditions (such as *Columella columella* and *Pupilla muscorum*), all known from Devensian stadial sediments.

The fifth fossiliferous level to be recognized was represented in silt drapes and channel-fills within the remainder of the lower sandy gravel at Brimpton (E, Fig. 3.19). Tree pollen was markedly and consistently more abundant in these silts than in level D, although the overall assemblage is suggestive of a combination of open habitats and birch-pine woodland (Fig. 3.20). This evidence for a further temperate interval is supported by a diverse molluscan assemblage that includes taxa characteristic of shallow water bodies with plentiful vegetation (*Valvata cristata* (Müller) and *Anisus leucostoma*).

Finally, pollen and plant macrofossils occur at a number of different levels within the upper silty gravel, in lenses and clasts of fine-grained sediment. Some of these are richly fossiliferous and have yielded notably varied macrofossil floras as well as pollen, mollusc and beetle remains. The pollen and plant macrofossils point to open, treeless conditions with northern and arctic-alpine species well represented. Molluscs likewise suggest stadial conditions, with a preponderance of open-habitat terrestrial species such as *P. muscorum*. With the exception of a small sample from the highest levels (see below), all the molluscs present have modern ranges extending into the Arctic and all are known from stadial deposits in Britain. Certain samples within the upper silty gravel yielded insect remains, including a wide range of beetles. Amongst these, those species that have restricted climatic ranges suggest temperatures colder than at present (*Amara quenseli* (Schoenberr), *A. torrida* (Panzer), *Otiorhynchus nodosus* (Müller), *Notaris aethiops*

Figure 3.20 Pollen from the deposits at Brimpton (after Bryant *et al.*, 1983).

and *Tachinus jacuticus* Poppius), although with little indication of the degree of severity (Bryant *et al.*, 1983).

Radiocarbon dating of willow twigs from near the base of the upper silty gravel (F_1 and F_2, Fig. 3.19) has indicated ages of 29,500 ± 460 years BP and 26,340 ± 1210 years BP, respectively (mid-Late Devensian). This is the only geochronometrical dating evidence from the site, the attribution of the lower sandy gravel to the Devensian relying on the recognition, from faunal similarities, of the Chelford Interstadial within the Brimpton sequence.

Interpretation

The significance of the Brimpton site stems from the complex biostratigraphy that has been demonstrated, largely on the basis of palynology, from the sequence there. Six pollen assemblages have been recognized at different stratigraphical levels (see above; Figs 3.19 and 3.20). Bryant *et al.* (1983) regarded the *Betula-Pinus-Picea* pollen assemblage (C, Figs 3.19 and 3.20) as equivalent to the Early Devensian Chelford Interstadial; pollen spectra from this level at Brimpton resemble those from the Chelford type locality (Simpson and West, 1958). This correlation is supported by the presence of macrofossils of Norway spruce (*Picea abies* (L.) Karsten) at both sites. If this correlation is accepted, the implication is that the lower temperate levels at Brimpton (A, Figs 3.19 and 3.20) represent either the latter part of the Ipswichian Stage or an earlier, pre-Chelford, Devensian interstadial. The higher temperate horizon (E, Figs 3.19 and 3.20) does not resemble the mid-Devensian Upton Warren Interstadial of Coope (Coope *et al.*, 1961) in its floral and faunal content, particularly since trees appear to have been present, whereas they are unknown from deposits of Upton Warren age. For this reason, level E was attributed to a hitherto unrecognized interstadial within the Devensian, named after the site at Brimpton (Bryant *et al.*, 1983). Deposits of Chelford Interstadial age have been reported from only a few sites in England (Shotton, 1977), the nearest to Brimpton being at Wretton, in Norfolk (West *et al.*, 1974). None of the sites hitherto attributed to this interstadial have yielded Mollusca, so the assemblage from Brimpton is of especial interest. It includes two snail species (*Vertigo substriata* (Jeffreys) and *Discus ruderatus*) that in Britain are otherwise known only from interglacial deposits (Bryant *et al.*, 1983).

The pollen spectra attributed to the Brimpton Interstadial (level E, Figs 3.19 and 3.20) show appreciable frequencies of *Betula* and *Pinus* (together reaching over 30% of the total pollen), leaving little doubt that these trees were growing in the region. The land-snail fauna from this level supports this evidence for a relatively temperate climate. As well as the aquatic taxa noted above (see above, Description), the occurrence of snails *Myxas glutinosa* (Müller), *Cochlicopa lubrica* (Müller), *Vallonia pulchella* and *Trichia hispida*, as well as the general diversity of the molluscan assemblage, suggests interstadial conditions (Bryant *et al.*, 1983).

The radiocarbon dates from the upper silty gravel (*c.* 27,000 years BP – see above) suggest that it was deposited late in the Devensian Stage. Sediments of similar age have been studied at Thrapston (Bell, 1969), Beckford (Briggs *et al.*, 1975a), Brandon (Shotton, 1968) and Great Billing (Morgan, 1969). Bryant *et al.* (1983) provided a full discussion of possible correlations between the Brimpton sequence and that from the post-Eemian period on the continent, where more complete sedimentary records exist. They tentatively suggested a correlation of the Brimpton Interstadial with the continental Odderade Interstadial. However, Bowen (1989; Bowen *et al.*, 1989) has recently suggested that the Upton Warren Interstadial equates with the Odderade Interstadial, attributing both to Oxygen Isotope Substage 5a. Bowen (1989, p. 44) expressed misgivings about the evidence from Brimpton; he considered that a fluvial sequence of this type, dominated by coarse-grained sediments, would inevitably be punctuated by unconformities and that 'extensive reworking and redeposition should be expected'.

Consideration of regional stratigraphical evidence in the Middle Thames and Kennet valleys suggests that the attribution of the entire Brimpton sequence to the Devensian Stage is open to question. The distribution and elevation of the deposits at Brimpton suggest that, with a surface 7–8 m above the present-day river, they form part of the Thatcham Terrace of the Kennet and/or Enborne, as defined by Chartres *et al.* (1976). Thomas (1961) included these deposits in the Lower Taplow Terrace of the Kennet, which he correlated with the terrace of the same name in the Middle Thames valley at Reading, originally described by Sealy and Sealy (1956). The Lower Taplow Terrace at Reading was redefined by Gibbard (1985) as the Reading Town Gravel. Gibbard assigned this aggradation to the Early Devensian and suggested a correlation with the Summertown-Radley Terrace of the Upper Thames, the deposits of which (Stanton Harcourt Gravel) had also been ascribed to the Devensian (Seddon and Holyoak, 1985; Chapter 2, Stanton Harcourt and Magdalen Grove). These various terrace correlations, which would appear to be in close agreement with the supposed Devensian age of the Brimpton deposits, are supported by the reappraisal of terrace correlation within the Thames catchment, outlined in Chapter 1.

However, there are strong grounds for attributing the deposits at Reading, correlated with the Thatcham Terrace, with the Taplow Formation (see Chapter 1 and Fig. 1.3; Fig. 3.3 and above, Fern House Pit). The Summertown-Radley aggradation has also been correlated in this volume with the Taplow Formation and is considered to have aggraded over a lengthy period between the mid-Saalian (Oxygen Isotope Stage 8) and the mid-Devensian, with only its uppermost levels typically dating from the latter stage (see Chapter 2, Stanton Harcourt and Magdalen Grove; Fig. 2.18). The Taplow Formation downstream from Reading has been ascribed to the Saalian Stage (Chapter 1); its aggradation is thought to have spanned the period between Oxygen Isotope Stages 8 and 6 (inclusive). A later formation, the Kempton Park Gravel, occurs downstream from Reading, representing aggradation between Stage 6 and the mid-Devensian (Gibbard, 1985; see above, Fern House Pit; Fig. 2.18). The rejuvenation during Stage 6, which separated these two formations, appears not to have occurred in the Reading area or further upstream in the Thames valley. Therefore the Taplow Formation at Reading, like the Summertown-Radley Formation of the Upper Thames, is believed to represent a considerable period of floodplain stability, from Oxygen Isotope Stage 8 to the mid-Devensian (see above, Fern House Pit).

These interpretations have important implications for the age of the deposits forming the Thatcham Terrace of the Kennet valley. The Summertown-Radley Formation provides an analogue for the Thatcham Terrace deposits; both are the upstream equivalents of the Taplow Formation of the Reading area and both lie upstream of the limit of the Stage 6 rejuvenation, when the Thames further downstream was incised to the level of the Kempton Park Gravel (see above, Fern House Pit). This comparison suggests that the Thatcham Terrace surface may overlie sediments with a considerable range of ages, from Oxygen Isotope Stage 8 to the mid-Devensian. Sediments from the earlier parts of this time interval appear to dominate the Summertown-Radley sequence, the Ipswichian Eynsham Gravel and overlying ?Devensian gravels typically being restricted to the uppermost levels of the formation (Chapter 2). The bulk of the Brimpton sequence might therefore be expected to be pre-Ipswichian, despite the similarity between faunas from some levels within it to British Devensian interstadial assemblages. It is particularly pertinent to note, at this point, that there is very little available information about faunas and floras of Saalian Stage interstadials, which are essentially unknown in Britain and are rare in Europe as a whole. Since, by definition, such periods had relatively restricted biotas, it is likely that interstadials in different 'glacial stages' within the same part of the Pleistocene appear similar in terms of their palaeontology. The basis for the correlation of level C at Brimpton with the Chelford Interstadial may therefore require re-examination.

The only part of the Brimpton sequence for which geochronometric dates indicative of the Devensian Stage have been obtained is the upper silty gravel. The radiocarbon dates from this upper division indicate that the lower sandy gravel was laid down prior to the mid-Devensian. It is possible, however, that the upper division is significantly later than the lower deposits; it may even represent the addition of a mid-Devensian Enborne gravel to a sequence of older Kennet sediments. Bryant *et al.* (1983) suggested that the change from (lower) sandy to (upper) silty gravel resulted from an increase in the deposition of fine sediment as the river aggraded to the highest levels of the floodplain. Chartres (1981), however, showed that loessic silt had been incorporated in the upper levels of the terrace gravels in the Kennet valley by pedogenic activity; the matrix of the upper gravel at Brimpton might therefore be of a similar origin, particularly since its lower limit appears to be independent of the sedimentary bedding (see above, Description). Chartres described a mechanism whereby this loessic silt was restricted to a distinct upper layer: he thought that a clayey illuvial horizon, developed by soil-forming processes prior to loess accumulation, had acted as a barrier to downward movement of silt. An upper silty layer was thus recognized by Chartres (1980, 1984) on the Thatcham Terrace at Thatcham and attributed by him to post-depositional (pedogenic) modification of the original fluvial sediments. However, although the Brimpton site is also on the Thatcham Terrace and an upper silty division has been recognized there, no illuvial clay layer has been observed at the top of the lower gravel. The question of whether the upper silty gravel at Brimpton is of sedimentary or pedogenic origin therefore remains open.

Study of soil profiles on the Kennet terrace gravels may nevertheless provide information of significance to the dating of the Brimpton sediments. Work of this type has revealed differences in levels of complexity between subsoil horizons on different terraces within the Kennet system, with the highest and oldest terraces having the most complex soils (Chartres *et al.*, 1976; Chartres, 1980, 1984; see above, Hamstead Marshall). Chartres did not work at the Brimpton site, but studied the upper levels in the same terrace formation at Thatcham, some 6 km upstream. Micromorphological analyses of samples from Thatcham revealed evidence for complex soil formation over at least one full climatic cycle (Chartres, 1980, 1984). Within the lower part of the soil profile, Chartres recognized concentrations of yellow illuvial clay (argillans), which he attributed to soil formation under temperate conditions. These clays had been disrupted and incorporated into the matrix as a result of disturbance of the soil structure by cryoturbation, under periglacial conditions (in a similar way to the disruption of presumably older red argillans in soils developed on the higher Kennet gravels, such as those at Hamstead Marshall – see above). This interpretation implies that the illuviation phase that produced the yellow argillans was followed by at least one periglacial episode and therefore must have occurred prior to the Holocene. Thus, the Thatcham Terrace surface must have been in existence during a pre-Holocene temperate episode. Chartres duly ascribed the phase of yellow-clay illuviation at Thatcham to the Ipswichian interglacial. In contrast to the evidence from the Thatcham Terrace, no disrupted argillans were observed in soils developed on the lowest terrace in the Kennet sequence, the Beenham Grange Terrace. The implication of this is that no pre-Holocene temperate-climate soil formation has affected this terrace, which fully accords with its correlation with the Late Devensian Shepperton Gravel of the Middle Thames. Chartres's observations led him to propose that pedological evidence from the various Kennet terraces provided a stratigraphical framework, with larger numbers of climatic cycles represented in the soils on higher terraces. His view that soils on the Thatcham Terrace incorporate relict Ipswichian features lends support for the proposal (above) that this aggradation is largely pre-Devensian in age.

Thus two opposing interpretations of the deposits at Brimpton have emerged. The first, that proposed in the original report on the site by Bryant *et al.* (1983), considers them to be Devensian (with possible Ipswichian remnants at the base of the sequence). The second, influenced by regional stratigraphy and by arguments for a more complex Pleistocene record, holds that the deposits may span a longer period and may be dominantly, if not wholly, of pre-Devensian age. The argument between these opposing views hinges largely on the correlation between the Chelford Interstadial and level C at Brimpton. This correlation is based on a sequence of five pollen counts from level C, which indicated a similar floral assemblage to that at Chelford. However, as has been noted above, interstadial assemblages are relatively impoverished and non-distinctive, and little is known about the characteristics of pre-Devensian interstadials. Given the contrary evidence from terrace stratigraphy, supported by pedological studies, the validity of this correlation must be questioned. The radiocarbon dates from Brimpton only indicate a Devensian age for the upper gravel; they have no bearing on the age of the largest part of the sequence. There may in any case be grounds for doubting the accuracy of these dates; the soil evidence, already described, appears to indicate a pre-Ipswichian age for the entire Thatcham Terrace sequence at Thatcham. An assessment of the soil at the top of the Brimpton sequence is clearly desirable, as are further attempts to determine the ages of the various deposits. Amino acid analyses of mollusc shells from the sequence might provide important geochronological evidence of this kind.

The Brimpton pit, with its succession of alternating cold- and temperate-climate deposits, is clearly a stratigraphical site of considerable importance. If its attribution to the Devensian Stage is correct, the site must represent one of the most complete Lower and Middle Devensian sequences in Britain. Comparable sites at Wretton (West *et al.*, 1974) and Four Ashes (Morgan, 1973; Shotton, 1977) have deposits of presumed Chelford Interstadial age, but fossil molluscan faunas are absent. The Brimpton Interstadial temperate episode has been recognized at no other site. The occurrence of molluscan and insect faunas at Brimpton, together with considerable palaeobotanical evidence, also makes this a site of considerable interest.

If the alternative interpretation of the Brimpton sequence as being largely of pre-Devensian age were to be proved correct, however, the importance of the site would not in any way be diminished; pre-Devensian interstadial sediments are extremely rare in Britain and no lengthy biostratigraphical record from any pre-Devensian glacial episode has so far been recognized at a single site.

Conclusions

Brimpton Gravel Pit reveals unique evidence for conditions in southern England during the latter part of the Quaternary Ice Age. Here, beds of gravel deposited by the River Kennet, a tributary of the Thames, alternate with silty and organic layers containing the remains of plants (including pollen) and snails. These fossil remains allow the prevailing climatic conditions at the time of deposition to be determined. Differences between the assemblages from different levels record a sequence of three warm and three cold episodes at Brimpton. It has been suggested that the sequence of deposits here was formed during the last major cold phase of the Quaternary, between about 80,000 and 10,000 years ago, when glaciers covered much of northern Britain, but failed to reach this part of southern England.

However, the Brimpton deposits form part of a terrace of the River Kennet that is correlated with the Taplow Terrace of the main Thames. This terrace, in the Thames valley, is thought to have been formed between 250,000 and 130,000 years ago. There is some reason to suspect that the Brimpton sequence may be of a comparable antiquity, for at Thatcham there is a soil developed in the same terrace that seems to indicate deposition of the gravel prior to the last interglacial (which occurred between 130,000 and 120,000 years ago). Whatever the outcome of this controversy, it is clear that the Brimpton site exposes an important sequence of sediments laid down during a period of fluctuating climate. Very few sites in Britain reveal so complex a history of climatic change, either in the last glacial or earlier; the resolution of the question of dating the Brimpton sequence is of acute urgency. Regardless of whether the Brimpton sediments are of Devensian or Saalian age (they may even include both), the site is of major significance.'