Quaternary of the Thames

D.R. Bridgland
Bridgland Earth Science Consultancy,
Darlington, UK.

Scientific Editor: D. Q. Bowen

GCR Editor: W. A. Wimbledon

JOINT NATURE CONSERVATION COMMITTEE

CHAPMAN & HALL
London · Glasgow · New York · Tokyo · Melbourne · Madras

Chapter 2

The Upper Thames basin

INTRODUCTION

This chapter is devoted to the first of three geographical divisions of the present Thames drainage system, the Upper Thames basin. This comprises the catchment areas of the various streams that combine to form the Thames upstream from the Chiltern escarpment (Fig. 2.1). In many ways the Upper Thames is most easily treated as a separate system from the valley downstream of the Goring Gap. Its Quaternary terrace record is extensive, particularly in the valley of the River Evenlode, which appears to have been the main stream until late in the Middle Pleistocene. Unfortunately, there is little preservation of terrace deposits in the area of the Goring Gap and, therefore, no continuity with the succession in the Middle Thames. This has contributed to a long-standing uncertainty over correlation between the Upper Thames terraces and those in the London Basin. The problem of correlation between the Upper and Middle Thames has been addressed in this volume using projections of sediment-body longitudinal profiles between the two areas, reinforced with biostratigraphical evidence for the age of surviving interglacial deposits (see Chapter 1 and Fig. 1.3).

THE PLEISTOCENE SEQUENCE IN THE UPPER THAMES

Classification of the Pleistocene sequence in the Upper Thames basin has been somewhat haphazard, with some deposits being named as lithological units and others named after the geomorphological terrace features to which they give rise. Following the trend towards the former method, established in other parts of the Thames catchment (Chapter 1), geological names were applied to parts of the terrace sequence by Briggs *et al.* (1985) and formal lithostratigraphy was used to classify the high-level Northern Drift deposits by Hey (1986). The nomenclature of these and earlier authors is incorporated in the lithostratigraphical scheme shown in Table 2.1, the rationale for which is discussed in Chapter 1.

The Pleistocene succession in the Upper Thames basin is readily divisible into two parts: (1) the older, high-level deposits of the Northern Drift Group (Table 2.1), which are primarily preserved parallel to the Evenlode valley and are devoid of calcareous clasts, and (2) more recent, lower-level terrace gravels composed largely of local limestones (see Figs 2.1, 2.2 and 2.3).

Table 2.1 Lithostratigraphical classification of Upper Thames deposits.

Group	Formation	Member
	Northmoor Gravel (= Floodplain Terrace)	
	Summertown-Radley	Eynsham Gravel Stanton Harcourt Gravel Stanton Harcourt Channel Deposits
	Wolvercote Gravel	Wolvercote Channel Deposits
	Hanborough Gravel	
Northern Drift	Freeland	Sugworth Channel Deposits
Northern Drift	Combe	
Northern Drift	Wilcote	
Northern Drift	Ramsden Heath	
Northern Drift	Waterman's Lodge	

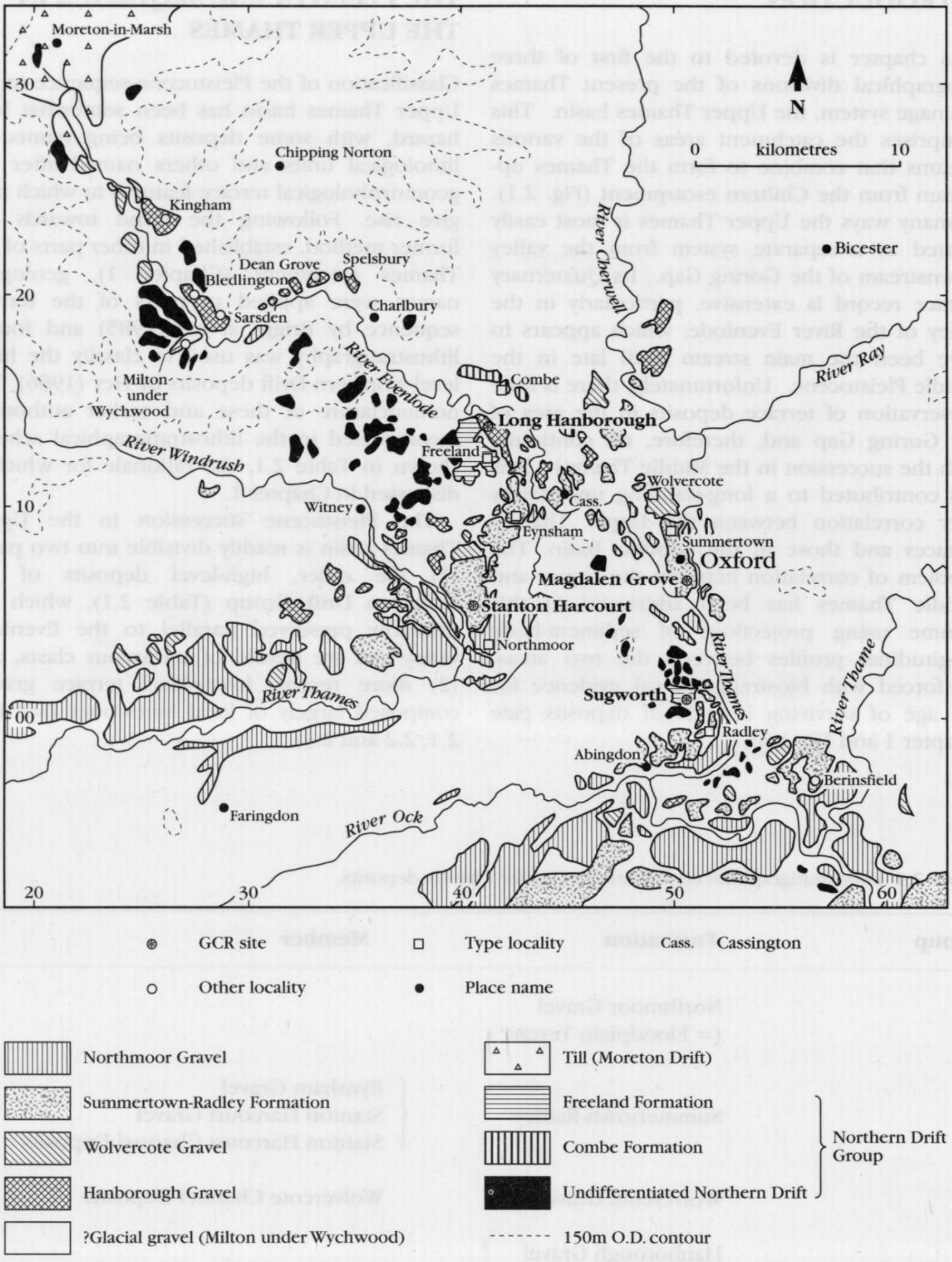


Figure 2.1 The gravels of the Upper Thames catchment.

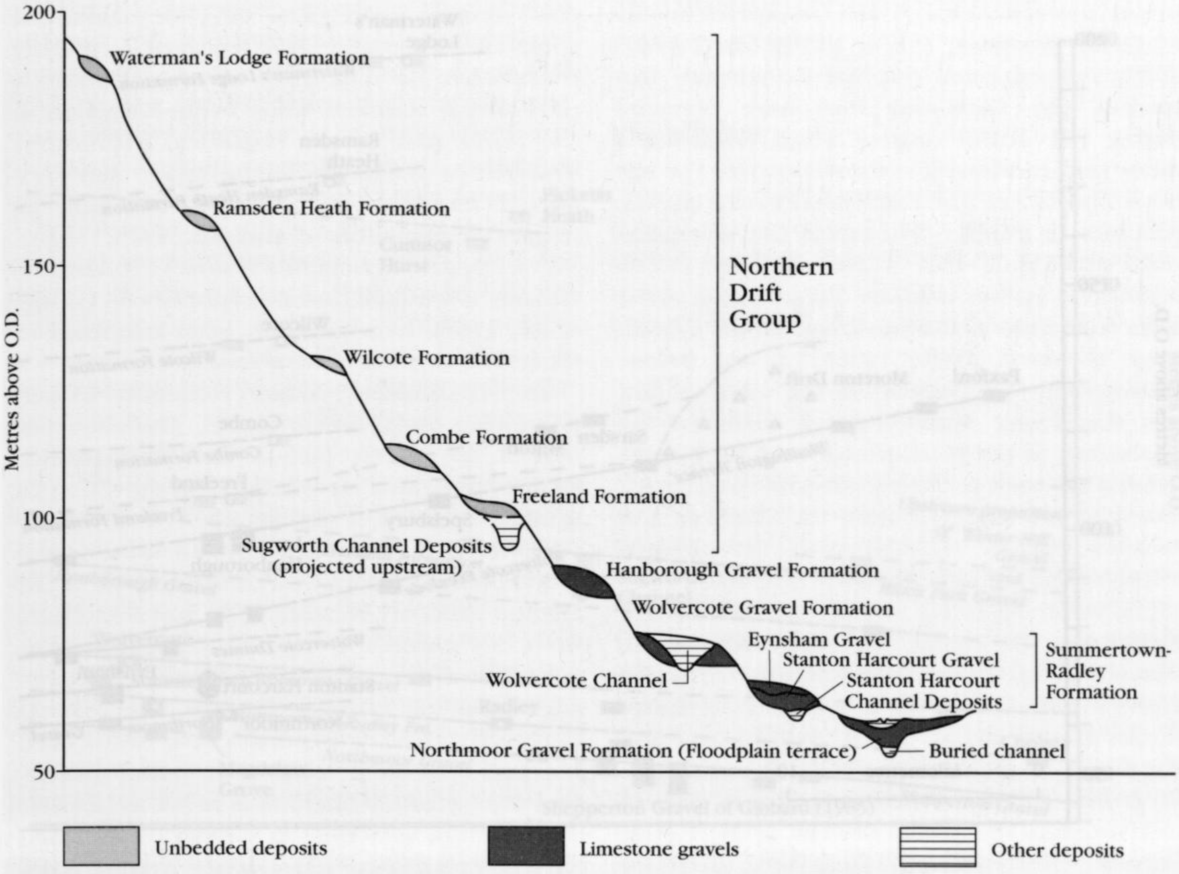


Figure 2.2 Idealized transverse section through the terrace deposits of the Upper Thames (Evenlode).

The Northern Drift remnants contain pebbles of quartz, quartzite, chert and flint derived from the area beyond and to the north of the present Thames catchment, hence the name, which was first applied to these particular deposits by Hull (1855). These high-level deposits are generally unbedded and contain large proportions of silt and clay. For this reason they have, until recently, been regarded as the decalcified remains of till, usually attributed to the Anglian glaciation (Briggs and Gilbertson, 1974). Recent discoveries at Sugworth, near Abingdon, have not only led to the rejection of this interpretation, but have somewhat undermined the distinction between the older and younger Pleistocene deposits. At Sugworth, an interglacial fluviatile channel-fill (see below) was found beneath a spread of high-level unbedded clayey gravel that has been attributed to the Freeland Formation (Hey, 1986). These interglacial sediments yielded biostratigraphical evidence for a Cromerian age and contained pebbles of limestone as well as rock-types characteristic of the Northern Drift (Shotton *et al.*, 1980). This discovery, which was the first occasion on which calcareous gravel had been observed in association with the high-level deposits, demonstrated that Northern Drift material was present in the Upper Thames basin by Cromerian times.

Since the discovery of the Sugworth site, an alternative interpretation of the Northern Drift has gradually gained credence, following the work of Hey (1986). This holds that the high-level material is the degraded and decalcified remains of old terrace gravels of the Upper Thames river system. Some workers continue to believe that glaciation was responsible for the introduction of the Northern Drift pebbles into the Upper Thames basin (Bowen *et al.*, 1986a), but others consider that the Thames catchment was once considerably more extensive,

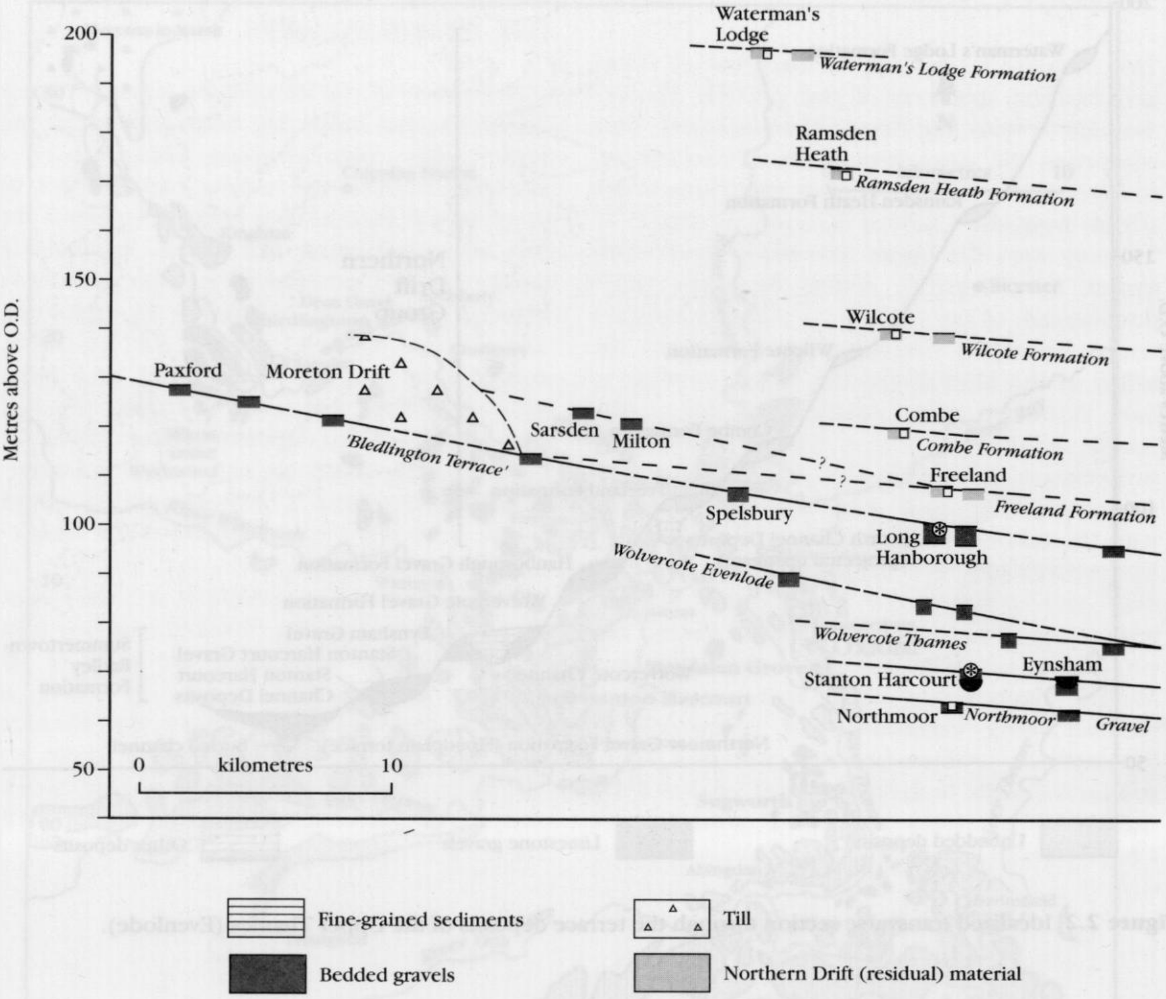
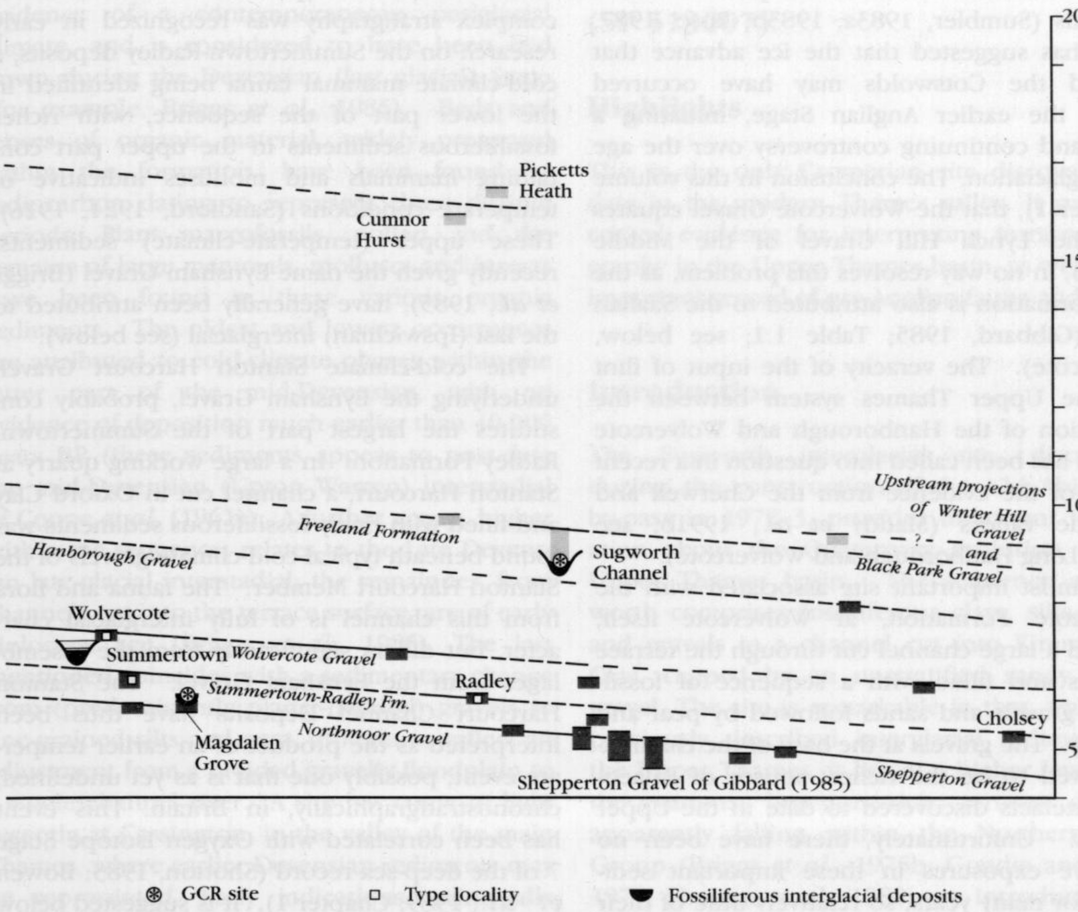


Figure 2.3 Longitudinal profiles of the Upper Thames terrace deposits. Compiled from the following sources: Arkell (1947a, 1947b); Bishop (1958); Briggs and Gilbertson (1973); Briggs *et al.* (1985); Evans (1971); Kellaway *et al.* (1971); Sandford (1924, 1926); Tomlinson (1929).

encompassing the source areas of at least some of these rock-types (Bridgland, 1988c). The distribution of the Northern Drift suggests that the Evenlode was the main drainage line at this time.

The highest and oldest of the various limestone-rich terrace gravels, the Hanborough Gravel Formation, differs from the others in that it is, like the Northern Drift, preferentially preserved in the Evenlode valley, suggesting that this river continued as the main drainage line within the Upper Thames system. This view is supported by the reconstruction of the long-profile of this formation, which extends into the present watershed area between the Evenlode and the Stour (a left-bank tributary of the Warwickshire–Worcestershire Avon) and has a gentle gradient, contrasting with those of later formations (Fig. 2.3). The Hanborough Gravel has yielded the remains of temperate-climate mammals, on the basis of which it was believed until recently to have formed during an interglacial. Most of the bones have come from the base of the deposits, however. In contrast, molluscan remains from silts interbedded with higher parts of the formation indicate cool conditions (Briggs and Gilbertson, 1973). The aggradation is therefore now attributed to a cold episode, probably within the early part of the Saalian Stage. Arkell (1947a, 1947b) considered



the Hanborough Gravel to pass upstream beneath the deposits of the Cotswolds glaciation (Moreton Drift), an interpretation of great importance in correlating the Pleistocene sequences of the Thames basin and the Midlands (see below and Chapter 1).

The next formation in the Upper Thames sequence, the Wolvercote Gravel, is of considerable stratigraphical significance, in that it has long been held to be the first to contain material introduced into the basin by the glaciation of the Cotswolds. This interpretation is generally attributed to Bishop (1958), who recognized the relatively high flint content of the terrace deposits at Wolvercote and traced the formation upstream in the Cherwell valley, linking it with the glaciation of the Fenny Compton area. However, a succession of later authors have contrasted this deposit with the (higher) Hanborough Gravel and concluded that the glaciation of the Cotswolds occurred between the aggradation of the two formations (Briggs and Gilbertson, 1973; Briggs *et al.*, 1985). Moreover, the Wolvercote Gravel has frequently been interpreted as outwash derived directly from this glaciation, an idea that originated with Tomlinson (1929), who noted the importance of the input of fresh flint many years before Bishop. The Wolvercote Formation is best developed in the Cherwell and Evenlode valleys, both of which flow from gaps in the Cotswold escarpment through which outwash is believed to have escaped from the Midlands ice sheet (Bishop, 1958; Briggs, 1973). This glaciation has generally been correlated with the Saalian Stage (Shotton, 1973a, 1973b) and the associated Wolvercote Gravel has been correlated with the Taplow Gravel of the Middle Thames (Gibbard, 1985), which has been firmly dated in the late part of that stage (see Chapter 3). However, recent re-evaluation of the sequence in the Midlands (Sumbler, 1983a, 1983b; Rose, 1987, 1989) has suggested that the ice advance that reached the Cotswolds may have occurred during the earlier Anglian Stage, initiating a major and continuing controversy over the age of this glaciation. The conclusion in this volume (Chapter 1), that the Wolvercote Gravel equates with the Lynch Hill Gravel of the Middle Thames, in no way resolves this problem, as the latter formation is also attributed to the Saalian Stage (Gibbard, 1985; Table 1.1; see below, Wolvercote). The veracity of the input of flint into the Upper Thames system between the deposition of the Hanborough and Wolvercote Gravels has been called into question in a recent review of the evidence from the Cherwell and Evenlode valleys (Maddy *et al.*, 1991b; see below, Long Hanborough and Wolvercote).

The most important site associated with the Wolvercote Formation, at Wolvercote itself, revealed a large channel cut through the terrace deposits and filled with a sequence of fossiliferous gravels and sands followed by peat and silty clay. The gravels at the base of the channel-fill proved to be the richest source of Palaeolithic artefacts discovered to date in the Upper Thames. Unfortunately, there have been no extensive exposures in these important sediments for many years, so relatively little of their palaeontological potential has been realized. It is known that they represent a cooling sequence following fully temperate conditions, possibly reflecting the end of an interglacial. There has been considerable controversy over the identity of the interglacial represented (see below, Wolvercote), but the correlation of the Thames sequence with the deep-sea record proposed in Chapter 1 suggests that the channel was infilled during Oxygen Isotope Stage 9. This revised correlation raises the possibility that neither of the traditionally recognized post-Anglian interglacials (corresponding with the Hoxnian and Ipswichian Stages) is represented at Wolvercote. Although no conservable remnant of Wolvercote Channel sediments has yet been located, it is hoped that a GCR site in these critically important deposits will be identified in due course.

The next terrace in the Upper Thames sequence, the Summertown-Radley Terrace, is the most extensively preserved. The terrace surface is underlain by a complex aggradational sequence (here classed as a formation) apparently spanning two temperate episodes and one full cold interval, with parts of two others. A complex stratigraphy was recognized in early research on the Summertown-Radley deposits, a cold-climate mammal fauna being identified in the lower part of the sequence, with richer fossiliferous sediments in the upper part containing mammals and molluscs indicative of temperate conditions (Sandford, 1924, 1926). These upper (temperate-climate) sediments, recently given the name Eynsham Gravel (Briggs *et al.*, 1985), have generally been attributed to the last (Ipswichian) interglacial (see below).

The cold-climate Stanton Harcourt Gravel, underlying the Eynsham Gravel, probably constitutes the largest part of the Summertown-Radley Formation. In a large working quarry at Stanton Harcourt, a channel cut in Oxford Clay and filled with richly fossiliferous sediments was found beneath typical cold-climate gravels of the Stanton Harcourt Member. The fauna and flora from this channel is of fully interglacial character, but differs significantly from the assemblages from the Eynsham Gravel. The Stanton Harcourt Channel Deposits have thus been interpreted as the product of an earlier temperate event, possibly one that is as yet undefined, chronostratigraphically, in Britain. This event has been correlated with Oxygen Isotope Stage 7 of the deep-sea record (Shotton, 1983; Bowen *et al.*, 1989; Chapter 1). It is suggested below that many of the historical records of interglacial sediments within the Summertown-Radley Formation that have previously been ascribed to the Eynsham Gravel (Briggs *et al.*, 1985) should be equated instead with the Stanton Harcourt Channel Deposits (see below, Stanton Harcourt and Magdalen Grove). Included amongst these reinterpreted sites is a pit in the grounds of Magdalen College, Oxford, which was re-excavated in 1984 as part of the GCR programme (Briggs *et al.*, 1985).

The Pleistocene sequence in the Upper Thames is completed by the 'Floodplain Terrace' (Sandford, 1924, 1926), otherwise known as the Northmoor Terrace (Arkell, 1947a). This aggradation, here termed the Northmoor Gravel Formation, reaches only *c.* 2–3 m above the alluvium of the modern valley floor and lies 6–10 m below the level of the Summertown-Radley Terrace (Fig. 2.2). Recent mapping has suggested that the floodplain surface is a composite morphological feature (Robson, 1976; Harries, 1977). The aggradational sequence forming the Northmoor Terrace comprises well-bedded limestone gravels, with abundant evidence of a contemporaneous periglacial climate, and is considered to have been laid down during the Devensian (last glacial) Stage (for example, Briggs *et al.*, 1985). Beds and lenses of organic material, widely preserved within the formation, have been found by radiocarbon dating to represent three distinct periods. Plant macrofossils, pollen and the remains of large mammals, molluscs and insects have been found in these various organic sediments. The oldest and lowest occurrences are attributed to cold-climate phases within the latter part of the mid-Devensian, with no evidence of deposition much earlier than 40,000 years BP (these sediments appear to post-date the mid-Devensian (Upton Warren) interstadial of Coope *et al.* (1961)). A further group, higher within the sequence, relates to the Late Devensian late-glacial interstadial; the remainder, from channels cut into the terrace surface, are of early Holocene age (Briggs *et al.*, 1985). The last mentioned coincides with a sedimentary change from (predominantly planar-bedded) gravels to fine-grained silts and peat, thought to reflect an adjustment from a braided gravelly floodplain to a single channel river. A site has come to light recently at Cassington, in the valley of the main Thames, where earlier Devensian sediments may be represented. Early indications, principally from molluscan remains, suggest that channel-fills of early or early mid-Devensian age are represented here within a sequence that is mapped as Northmoor Gravel (D. Maddy, pers. comm.; see below, Stanton Harcourt and Magdalen Grove).

Numerous commercial workings have operated in and continue to exploit the deposits of the Northmoor Formation, but the sections are consistently below the water table, so that abandoned workings rapidly become flooded. This makes the conservation of sections a difficult proposition and no sites in the Northmoor Formation have been selected in the GCR. Devensian and Holocene fluvial deposits are invariably situated at low levels in valleys, so that this problem applies quite generally. New exposures are, however, frequently opened, allowing temporary access to these widely distributed Upper Pleistocene sediments. Devensian fossiliferous deposits are represented within the GCR Pleistocene coverage of the Thames basin at Great Totham, in Essex (see Chapter 5).

SUGWORTH ROAD CUTTING (SP 513007)

Highlights

This is the only Cromerian site discovered to date in the modern Thames valley. It provides critical evidence for interpreting terrace stratigraphy in the Upper Thames basin, as well as an important record of pre-Anglian fauna and flora.

Introduction

The Sugworth interglacial site, discovered during the construction of the A34 Abingdon by-pass in 1972–3, provides important information about the Quaternary evolution of the Upper Thames basin. The sequence at Sugworth comprises fossiliferous clays, silts, sands and gravels in a channel cut into Kimmeridge Clay, capped by an unstratified sandy clayey gravel. The site is remarkable in that, unlike all previously described interglacial sediments in the Upper Thames, it lies at a higher level than the various limestone-rich terrace gravels, apparently falling within the Northern Drift Group (Briggs *et al.*, 1975b; Goudie and Hart, 1975; Shotton *et al.*, 1980; see Introduction to this Chapter).

Synonymous terms for the Northern Drift are 'Triassic Drift' (Harmer, 1907), 'Plateau Drift' (Sandford, 1924, 1926; Goudie, 1976; Briggs *et al.*, 1985) and 'Unbedded Drift', (Dines, 1928). These deposits have generally been interpreted as weathered till (Callaway, 1905; Tomlinson, 1929; Dines, 1946; Briggs and Gilbertson, 1974; Goudie, 1976), although Arkell (1947a, 1947b) considered the lower-level elements of the Northern Drift to include degraded terrace gravels (of proglacial origin). Shotton *et al.* (1980) concluded that much of the Northern Drift might be of fluvial origin, but that glacial transport must have originally carried the material into the Upper Thames basin. Hey (1986) divided the entire Northern Drift into individual fluvial aggradations on the joint bases of elevation and clast composition. He disputed the glacial origin of the material, concluding instead that the Evenlode branch of the Upper Thames once drained a considerably larger catchment, including much of the West Midlands, and that the Northern Drift was the decalcified remains of terrace gravels laid down by this river. Hey's conclusions have been supported by Bowen *et al.* (1986a), Bridgland (1988c) and Whiteman (1990).

The elevation of the Sugworth deposit in relation to the terrace sequence of both the Upper Thames and the Thames system in general, according to the correlation scheme outlined in Chapter 1 (Fig. 1.3), indicates that it is one of the earliest interglacial remnants to survive. This is confirmed by biostratigraphical evidence, particularly from molluscs (Gilbertson, 1980; Preece, 1989) and vertebrates (Stuart, 1980, 1982a), which points to a Cromerian age. Problems of terrace correlation between the Upper and Middle Thames have led to this evidence being questioned (Gibbard, 1983, 1985; Hey, 1986; Chapter 1), but the re-interpretation of the Middle Thames sequence in the Reading area proposed in this volume (Chapter 1) appears to resolve these difficulties.

Description

In 1972–3, the excavation of a cutting for the A34 Abingdon by-pass revealed a number of channels cut into the Kimmeridge Clay and infilled with Pleistocene sediments to a height of 40 m above present river level (Fig. 2.4). These sediments are predominantly medium-coarse orange sand with seams of gravel. One of the channel-fills, in a section cut during realignment of Sugworth Lane (Fig. 2.4), also includes a sequence of grey organic sands, silts and clays (Fig. 2.5). These were found to be richly fossiliferous, yielding beetles, molluscs, ostracods, vertebrates and macroscopic plant remains, as well as poorly preserved pollen (Briggs *et al.*, 1975b; Gibbard and Pettit, 1978; Shotton *et al.*, 1980; Holman, 1987). Other channel features (Fig. 2.4) to the north, at Bagley Wood, and to the south, at Lodge Hill, contain only unfossiliferous sand. Overlying these channel-fills and overlapping them onto the Kimmeridge Clay is a layer of unbedded clayey gravel, 1–2 m thick, containing a similar assemblage of pebbles to the Northern Drift of the district. This is apparently part of a large spread of such 'Plateau Drift' mapped by the Geological Survey in the area (New Series, Sheet 236). Both the fossiliferous channel sediments and the overlying unbedded clayey gravel contain the range of clast-types characteristic of the Northern Drift: predominantly quartz and quartzites, with Carboniferous chert, patinated flint and occasional igneous and metamorphic rocks.

The fossiliferous deposits were concentrated within the central section of the Sugworth Channel, the organic sediments passing laterally into unfossiliferous sands like those filling the Bagley Wood and Lodge Hill channels. Part of this central area was well-exposed in excavations for the Sugworth Lane bridge abutments (Fig. 2.5). Material was collected here from both sides of the A34 cutting, but most of the work was carried out in the excavation for the eastern bridge abutment. Unfortunately, this section is now sealed beneath the concrete bridge structure and its immediate continuation eastwards presumably lies beneath the new alignment of Sugworth Lane.

Interpretation

According to the model for terrace formation and the stratigraphical scheme for terrace correlation presented in this volume (Chapter 1), the sequence at Sugworth may be ascribed to the Freeland Formation and the Sugworth Channel Deposits regarded as a member of that formation. The latter are therefore also included within the Northern Drift Group (Fig. 2.2). They represent deposition under temperate-climate conditions (phase 3 of the terrace model – see Chapter 1), during a temperate episode within the 'Cromerian Complex' (see Chapter 1), whereas the overlying clayey gravel is regarded as the decalcified remains of the subsequent cold-climate (phase 4) aggradation, which is correlated with the Winter Hill and Black Park Gravel Formations of the Middle Thames, both attributed to the Anglian Stage.

Implications of the Sugworth deposit for terrace stratigraphy

The apparent occurrence of Northern Drift material overlying the Sugworth deposit was taken as evidence for the considerable antiquity of the latter in the preliminary reports of the site. The consensus of opinion at that time held that the Northern Drift was a glacial deposit of Anglian age (Briggs and Gilbertson, 1973, 1974; Shotton, 1973a), implying a broadly pre-Anglian age for the Sugworth Channel Deposits. Biostratigraphical evidence from

(A)

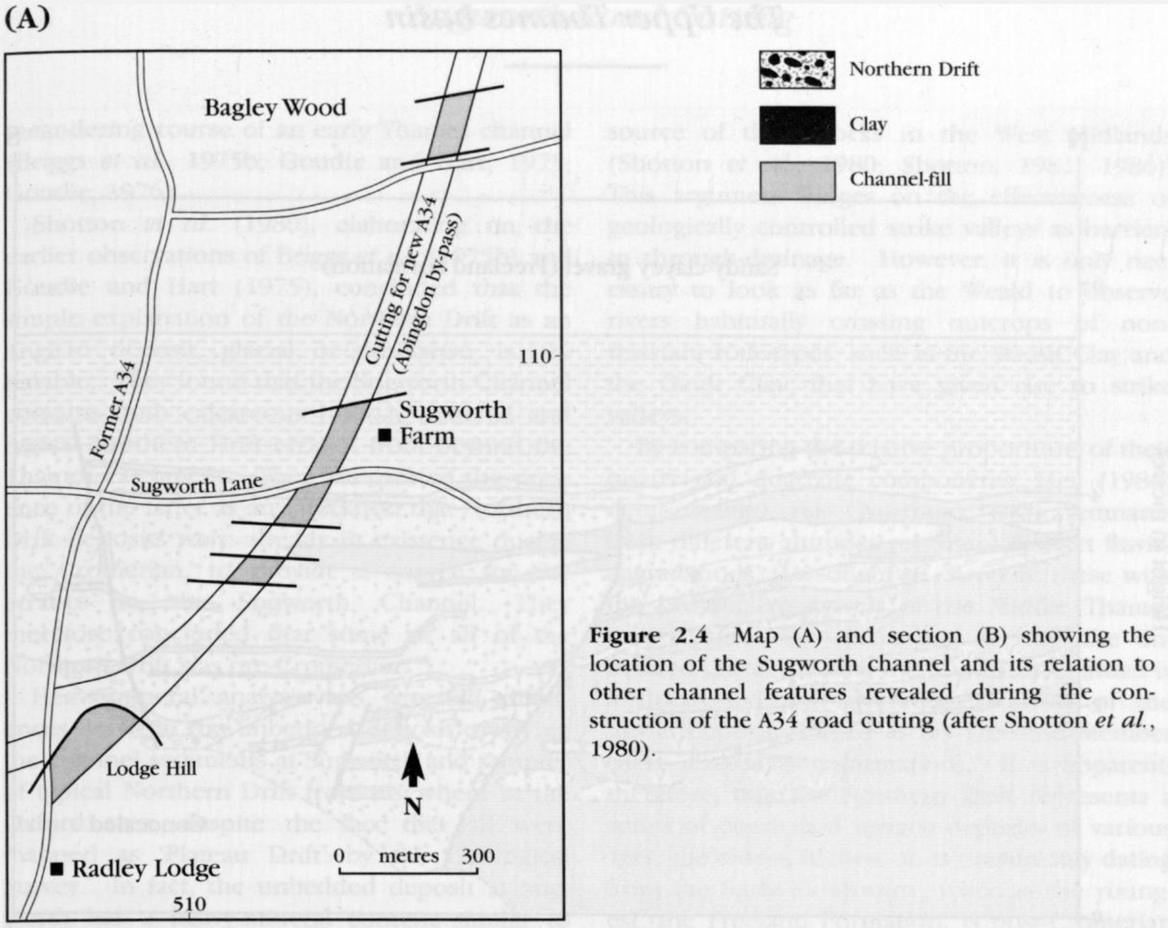
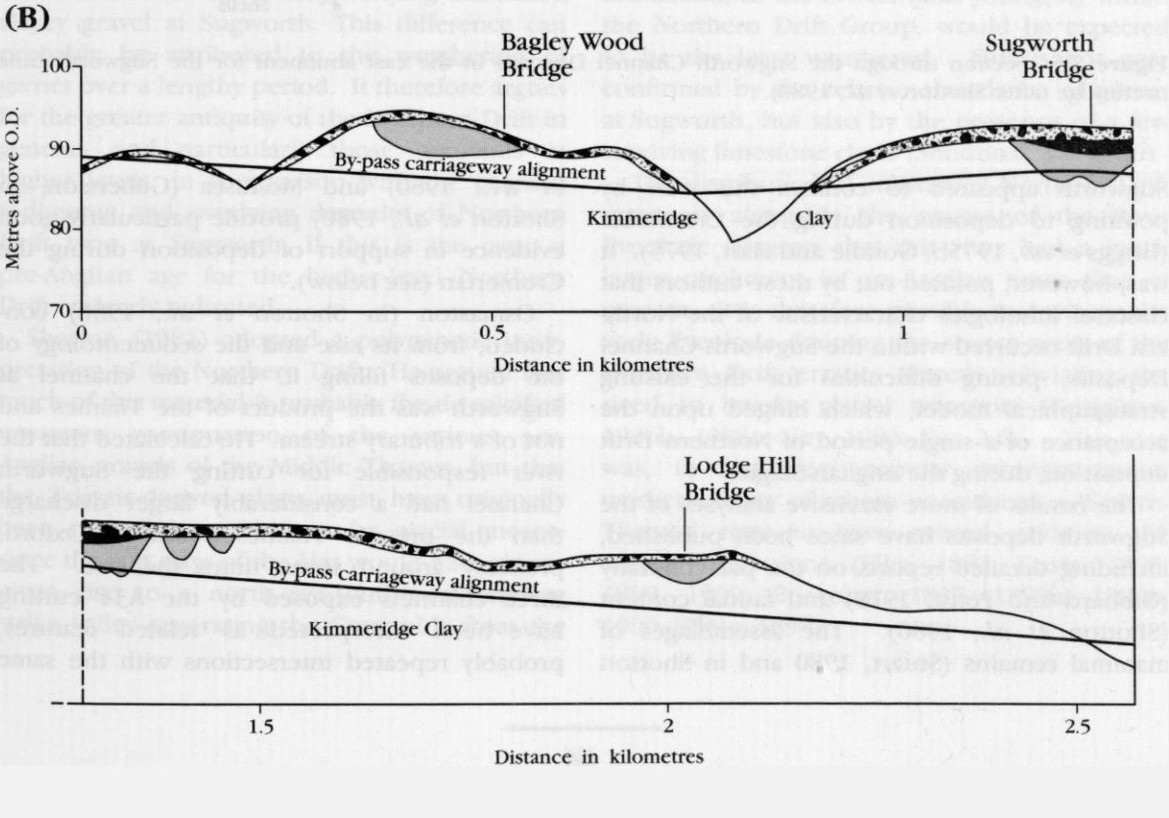


Figure 2.4 Map (A) and section (B) showing the location of the Sugworth channel and its relation to other channel features revealed during the construction of the A34 road cutting (after Shotton *et al.*, 1980).

(B)



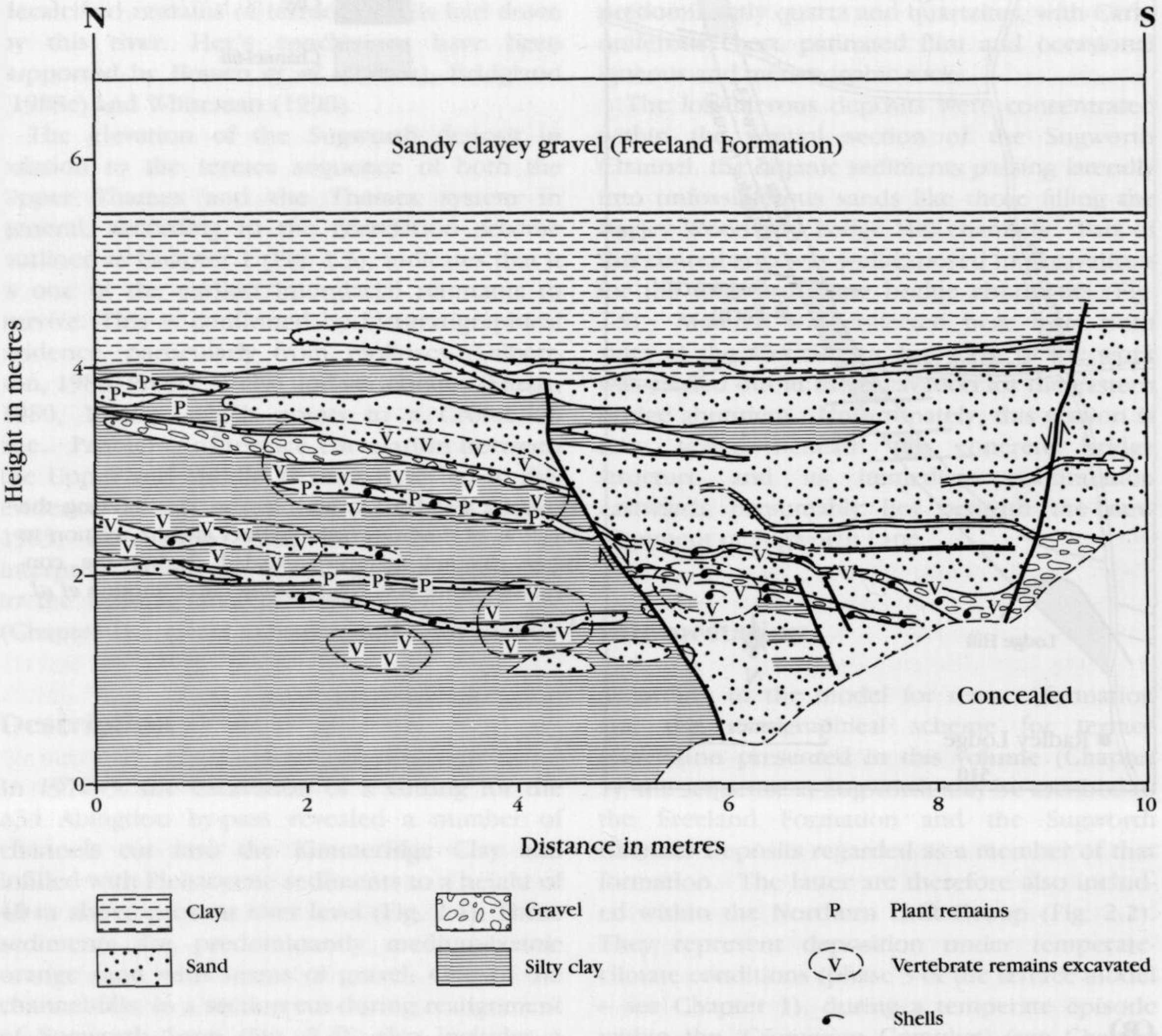


Figure 2.5 Section through the Sugworth Channel Deposits in the east abutment for the Sugworth Lane overbridge (after Shotton *et al.*, 1980).

Sugworth appeared to confirm this view by pointing to deposition during the Cromerian (Briggs *et al.*, 1975b; Goudie and Hart, 1975). It was, however, pointed out by these authors that clasts of lithologies characteristic of the Northern Drift occurred within the Sugworth Channel Deposits, posing difficulties for the existing stratigraphical model, which hinged upon the acceptance of a single period of Northern Drift deposition, during the Anglian Stage.

The results of more extensive analyses of the Sugworth deposits have since been published, including detailed reports on the palaeobotany (Gibbard and Pettit, 1978) and faunal content (Shotton *et al.*, 1980). The assemblages of mammal remains (Stuart, 1980 and in Shotton *et al.*, 1980) and Mollusca (Gilbertson, in Shotton *et al.*, 1980) provide particularly good evidence in support of deposition during the Cromerian (see below).

Osmaston (in Shotton *et al.*, 1980) concluded, from its size and the sedimentology of the deposits filling it, that the channel at Sugworth was the product of the Thames and not of a tributary stream. He calculated that the river responsible for cutting the Sugworth Channel had a considerably larger discharge than the present Thames south of Oxford, probably around seven times the size. The three channels exposed by the A34 cutting have been interpreted as related features, probably repeated intersections with the same meandering course of an early Thames channel (Briggs *et al.*, 1975b; Goudie and Hart, 1975; Goudie, 1976).

Shotton *et al.* (1980), elaborating on the earlier observations of Briggs *et al.* (1975b) and Goudie and Hart (1975), concluded that the simple explanation of the Northern Drift as an Anglian deposit, glacial or otherwise, is untenable. They found that the Sugworth Channel contains both calcareous Jurassic material and typical Northern Drift erratics from beyond the Thames catchment. They interpreted the presence of the latter as an indication that Northern Drift deposits were already in existence during the Cromerian, to provide a source for the erratics in the Sugworth Channel. They therefore concluded that some or all of the Northern Drift was pre-Cromerian.

Heavy-mineral analysis has revealed differences between the unbedded deposit overlying the channel sediments at Sugworth and samples of typical Northern Drift from elsewhere in the Oxford area, despite the fact that all were mapped as 'Plateau Drift' by the Geological Survey. In fact, the unbedded deposit at Sugworth has a heavy-mineral content similar to the underlying channel sediments (Shotton *et al.*, 1980). The main difference is the paucity of garnet in the typical Northern Drift, despite the richness of this mineral in the Triassic of the West Midlands, the main source of Northern Drift pebbles. Garnet is relatively abundant in the channel sediments and overlying unbedded clayey gravel at Sugworth. This difference can probably be attributed to the weathering of garnet over a lengthy period. It therefore argues for the greater antiquity of the Northern Drift in general, and particularly those remnants at higher levels, in comparison with the channel sediments and overlying deposits of Northern Drift type at Sugworth. If this is the case, a pre-Anglian age for the higher-level Northern Drift is clearly indicated.

Shotton (1981) adopted a polygenetic interpretation of the Northern Drift. He argued that much of this material is probably the de-calcified upstream continuation of the various pre-Anglian gravels of the Middle Thames, but that the Triassic-derived clasts must have originally been carried into the area by glacial means, since the soft clays of the Lias would have always given rise to a north-east/south-west-trending strike valley separating the Cotswolds from the source of these rocks in the West Midlands (Shotton *et al.*, 1980; Shotton, 1981, 1986). This argument hinges on the effectiveness of geologically controlled strike valleys as barriers to through-drainage. However, it is only necessary to look as far as the Weald to observe rivers habitually crossing outcrops of non-resistant rock-types, such as the Weald Clay and the Gault Clay, that have given rise to strike valleys.

By comparing the relative proportions of their quartz and quartzite components, Hey (1986) demonstrated that Northern Drift remnants from different altitudes represent distinct fluvial aggradations. He sought to correlate these with the pre-Anglian gravels of the Middle Thames (see Chapter 1). According to Hey, the unbedded gravel capping the Sugworth Channel is a decalcified and degraded remnant of the fluvial deposit defined as his Freeland Member (here classed as a formation). It is apparent, therefore, that the Northern Drift represents a series of decalcified terrace deposits of various ages, the oldest, highest units presumably dating from the Early Pleistocene, whereas the youngest, the Freeland Formation, is post-Cromerian (*sensu* Sugworth). This interpretation explains the occurrence of Northern Drift material both in and above the Sugworth Channel Deposits and also explains the preservation within the deposits at Sugworth of an unusually large amount of semi-durable garnet. The Freeland Formation, as the lowest (and youngest) within the Northern Drift Group, would be expected to be the least weathered. This is not only confirmed by the relative abundance of garnet at Sugworth, but also by the presence of a few surviving limestone clasts (Shotton *et al.*, 1980).

The distribution of substantial Northern Drift remnants alongside the course of the River Evenlode suggests that this river had a much larger catchment in pre-Anglian times than at present. It is therefore possible to envisage the early Evenlode draining the source areas of the Northern Drift erratics directly, obviating the need to invoke glacial transport (Bridgland, 1986b, 1988c; Hey, 1986; Fig. 2.6). This idea was, in fact, very popular amongst earlier workers, many of whom considered a 'Severn-Thames' river to have existed prior to the Middle Pleistocene (Ellis, 1882; Davis, 1895, 1899, 1909; Buckman, 1897, 1899a, 1899b, 1900; White, 1897).

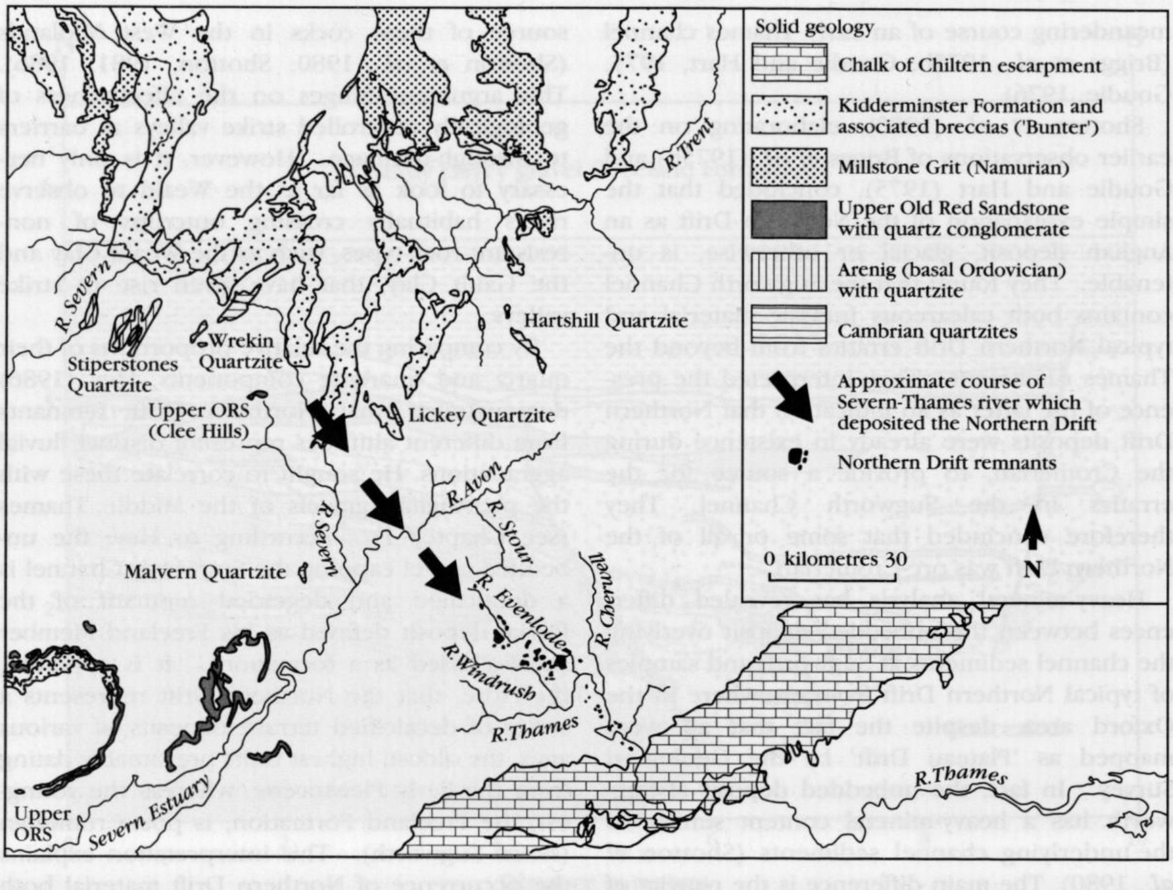


Figure 2.6 Map showing the course of the hypothetical Severn–Thames river of the Early Pleistocene.

Biostratigraphical implications of the Sugworth deposit

The most critical palaeontological evidence at Sugworth, and the strongest indication of a Cromerian age, comes from the vertebrate and molluscan remains. Large mammals from the site include *Dicerorhinus etruscus* (Falconer), restricted in Britain to the Cromerian and Pastonian Stages. Amongst the small mammals present is the water vole *Mimomys savini* (Hinton), which is unknown after the Cromerian. This species was replaced by *Arvicola cantiana* (Hinton), either during the latter part of the Cromerian Stage (*sensu* West Runton) or between it and an additional temperate episode that has been claimed, on the basis of this faunal change, to have occurred between the Cromerian and the Anglian Stage (Stuart, 1988; see Chapter 1). Teeth comparable with those of the extinct shrew *Sorex savini* (Hinton) from the type-Cromerian at West Runton were also present (Stuart, *in* Goudie and Hart, 1975; Stuart, 1980, 1982a).

The Mollusca included a number of species that first appear in the British record in the Cromerian Stage, namely *Valvata naticina* (Menke), *Bithynia inflata* (Hansén), *Marstonniopsis scholtzi* (Schmidt) and *Unio crassus* (Philipson). These occur with *Valvata goldfussiana*, which disappears from the record after the Cromerian, and *Tanousia runtoniana* (Reid) (= *Nematurella runtoniana* auctt.), which is unique to that stage. The dominance of taxa indicative of fully temperate conditions, coupled with the consistent fall in species number from the base to the top of the channel-fill (which implies climatic deterioration), suggests correlation with biozone CrIII (late temperate) of the interglacial, somewhat after the climatic optimum (Gilbertson, in Goudie and Hart, 1975; Gilbertson, 1980). Additional molluscan species have recently been recognized by Preece (1989).

Other aspects of the fauna and flora are less conclusive. The ostracods include abundant *Scottia browniana* (Jones), which limits the age to Hoxnian or earlier, together with occasional species of early Middle Pleistocene or late Early Pleistocene affinities (Robinson, 1980). The beetle fauna from Sugworth indicates a temperate climate and the presence of deciduous woodland (Osborne, in Shotton *et al.*, 1980). However, very few sites of Cromerian age in Britain have yielded insect remains, so stratigraphical comparisons cannot yet be made on this basis. The palynological evidence from Sugworth is insufficiently detailed to distinguish between the Hoxnian and Cromerian stages, although biozone III of one or the other is indicated (Gibbard and Pettit, 1978; Pettit and Gibbard, in Shotton *et al.*, 1980). The consensus view of Shotton *et al.*, based on consideration of the various biostratigraphical evidence, was that the Sugworth Channel was infilled during biozone CrIII of the Cromerian Stage.

Wider significance and correlation

Recent attempts at correlation between high-level terraces in the Middle Thames and the various decalcified aggradations of the Northern Drift Group have led to a reconsideration of the stratigraphical position and age of the Sugworth deposits. Gibbard (1985) suggested a correlation between the late Anglian Black Park Gravel of the Middle Thames and the Freeland Terrace, on the basis of elevation and projected long-profile reconstructions. The same author correlated the Winter Hill Gravel of the Middle Thames, which he held to be contemporaneous with the Anglian Stage glaciation of the Vale of St Albans, with the Combe Terrace of Arkell (1947a, 1947b), the division of the Northern Drift immediately higher in the terrace sequence than the Freeland Formation (see Fig. 2.2; Chapter 1). These correlations were supported by Hey (1986). However, as both these authors recognized, there are inherent difficulties with this interpretation. According to Hey (1986), the channel-fill at Sugworth is, on the basis of standard terrace stratigraphy, intermediate in age between the Combe and Freeland aggradations. This would appear to imply that the Sugworth Channel Deposits are themselves of Anglian age, a correlation that is clearly untenable. Gibbard's interpretation differed from that of Hey in that he did not include the upper unbedded gravel at Sugworth in the Freeland Formation. On the basis of his terrace correlations, Gibbard (1985) considered the Sugworth deposits to be too low (at 85.5–92 m O.D.) to be related to either of the Anglian aggradations, the Combe and Freeland Formations (the latter he projected to *c.* 96 m O.D. in the Sugworth area). Instead, he placed them between the late Anglian Freeland Formation and the early Saalian Hanborough Gravel. Gibbard was therefore forced into the conclusion, in spite of the biostratigraphical evidence outlined above, that the Sugworth sediments were deposited during the late Hoxnian (biozone HoIII), thus explaining his earlier inclusion (Gibbard, 1983, p. 23) of the site in the Hoxnian Stage.

This conclusion has received little support. Preece (1989) reiterated the biostratigraphical case for assigning the site to the Cromerian. He pointed out, however, that the continental record indicates considerable stratigraphical complexity for the Lower Pleistocene to lower Middle Pleistocene period. In The Netherlands, in particular, a series of glacial-interglacial cycles is known from this period, giving rise to the term 'Cromerian Complex' (Zagwijn, 1986; de Jong, 1988; see Chapter 1). Preece therefore accepted that the Sugworth sediments might represent a different temperate episode within the Middle Pleistocene to the type-Cromerian at West Runton. Despite this, he was adamant that the deposits at Sugworth could not be post-Cromerian. A similar view has been adopted by Bridgland *et al.* (1990), in a three-way biostratigraphical comparison of the sites at Sugworth, Little Oakley (Essex) and the West Runton stratotype. All three sites were interpreted as 'broadly Cromerian', although it was recognized that difficulties existed in correlation with the complex Dutch sequence. It is therefore possible that different episodes within the 'Cromerian Complex' may be represented by the three British sites (see also Chapter 5, Little Oakley).

Further support for the correlation of the Sugworth Channel Deposits with the Cromerian Stage (*sensu lato*) has recently been provided by amino acid geochronology. Preece (1989) quoted similar D-alloisoleucine : L-isoleucine ratios from *Valvata piscinalis* (Müller) shells from Sugworth (mean 0.286 ± 0.016, $n = 2$) and West Runton (mean 0.283 ± 0.037, $n = 5$). These compare with significantly lower ratios from the same species from Hoxnian sites (from Hoxne, for example, a mean of 0.243 ± 0.023, $n = 3$). These ratios were measured in the

INSTAAR laboratories of the University of Colorado. Rather different results were produced by Bowen *et al.* (1989), using the same technique. These authors obtained a comparable mean ratio from *Valvata goldfussiana* (Wüst) from Sugworth (0.296 ± 0.008, n = 4), but this is significantly lower than *V. piscinalis* ratios obtained by this laboratory from specimens from West Runton (0.348 ± 0.011, n = 5) and from Little Oakley (0.324 ± 0.004, n = 2 and 0.336 ± 0.027, n = 4) (Bridgland *et al.*, 1990; see Chapter 5, Little Oakley). The closest match for the Sugworth ratio amongst the Bowen *et al.* data for *Valvata* species is with Clacton (0.299 ± 0.002, n = 3) and Ingress Vale, Swanscombe (mean 0.297 ± 0.009, n = 5), both of which they ascribed to Oxygen Isotope Stage 11. Bowen *et al.* considered the Hoxnian (*sensu* Hoxne) to correlate with Oxygen Isotope Stage 9, so the above interpretation still holds that Sugworth is pre-Hoxnian. However, Bowen *et al.* (1986b) correlated the Anglian Stage with Oxygen Isotope Stage 12, which would therefore place Sugworth after the Anglian.

The above correlation, which implies the separation of the Anglian and Hoxnian by an extra interglacial-glacial cycle, provides some support for Gibbard's (1985) interpretation of the Sugworth Channel Deposits as Hoxnian. However, even if the Swanscombe deposits are attributed, on the basis of amino acid ratios, to a separate temperate episode, earlier than the Hoxnian (*sensu* Hoxne), the palaeontological evidence from the Swanscombe deposits strongly resembles that from other Hoxnian sites and provides little support for a correlation with Sugworth (see Chapter 4, Swanscombe). Moreover, the mammalian and molluscan assemblages from the two sites strongly indicate that Sugworth, with clear Cromerian affinities, is older than Swanscombe.

The revised scheme for terrace correlation between the Upper and Middle Thames, outlined in Chapter 1 (Fig. 1.3), allows a more satisfactory interpretation of the Sugworth Channel Deposits and their relation to British Pleistocene chronostratigraphy. This revised scheme holds that the Freeland Formation is the upstream equivalent of both the Winter Hill and the Black Park Gravels of the Middle Thames, thus indicating a much lower elevation for the Upper Thames floodplain during the earlier part of the Anglian Stage than was envisaged by Gibbard (1985). No Anglian aggradation therefore occupies a higher terrace position than the sequence at Sugworth. This interpretation allows the biostratigraphical evidence for a Cromerian age for the channel deposits to be reconciled with the relative dating of the various terrace formations, derived from their stratigraphical relation to the glaciation of the Vale of St Albans.

One of the few other Cromerian sites in Britain outside the type area (the Cromer Forest Beds of north Norfolk), that at Little Oakley (north-east Essex), also occurs within the Thames system (see Chapter 5). The deposits at Little Oakley appear to fall within the Low-level Kesgrave Group (see Chapters 1 and 5). It was suggested in Chapter 1 that during the early Middle Pleistocene, phases of downcutting (rejuvenations) by the Thames had little effect in the valley upstream from Essex. This view is supported by the Upper Thames sequence, where the Sugworth deposits, believed on palaeontological grounds to be of similar age to those at Little Oakley (Bridgland *et al.*, 1988, 1990), appear to underlie the upstream equivalent of the (Anglian) Winter Hill and Black Park aggradations, implying that no rejuvenation took place in this area between the Cromerian and the end of the Anglian.

Summary

The Sugworth GCR site is of major importance to British Pleistocene stratigraphy. The oldest interglacial remnant within the Upper Thames sequence is found at this locality. Its interpretation has been the subject of some controversy, resulting largely from difficulties in correlating terrace deposits between the areas north and south of the Chilterns. There appears, however, to be overwhelming palaeontological evidence that it is of a broadly Cromerian age. Sugworth therefore represents one of only a handful of Cromerian localities in this country. Cromerian deposits that can be related to fluvial terrace sequences are extremely rare and Sugworth is the only such site in the valley of the modern Thames. It has important implications both for Thames terrace stratigraphy and for correlation with the neighbouring Midlands region.

Satisfactory correlation of British Cromerian sites with the more complex Dutch sequence has yet to be achieved. This correlation would be an essential preliminary to matching the British terrestrial stratigraphy with the oceanic early Middle Pleistocene oxygen isotope record. Evidence from fossiliferous sites such as Sugworth will provide the basic data for such correlation. Early results from amino acid geochronology suggest that correlation with the oceanic record will be possible in the near future.

Conclusions

The richly fossiliferous channel-fill deposits at Sugworth (containing fossil molluscs, beetles, ostracods, vertebrates and plant remains, including pollen) are believed to have been deposited during an interglacial (one of the warmer, non-glacial phases of the Pleistocene 'Ice Age'), about half a million years ago.

These interglacial sediments, deposited by an ancestral Thames that was larger than the present river, are overlain by an enigmatic, clayey, gravelly deposit. This later deposit appears to form part of a river terrace that accumulated during a much colder climatic phase, about 450,000 years ago (the Anglian Stage), when ice sheets covered most of Britain. Prior to the discovery of the Sugworth interglacial channel, it was widely believed that such clayey and gravelly sediment, found covering high ground in the Upper Thames, was a true glacial till (boulder clay). This Northern Drift, as it was called (because it contains numerous pebbles of rocks derived from the area north of the Cotswolds, the present limit of the Thames catchment), is now considered to represent the remnants of a series of early river terraces, now weathered and degraded, dating from a period during the early Pleistocene when the Thames drained a far larger catchment than that of the modern river.

LONG HANBOROUGH GRAVEL PIT (SP 418136)

Highlights

This pit is the type locality for the Hanborough Gravel Formation, the oldest of the limestone terrace gravels of the Upper Thames. Sedimentary features, periglacial structures and snail faunas in the deposits at Long Hanborough have been fundamental in demonstrating that these and, by comparison, many other Thames terrace gravels are largely the products of fluvial deposition under intensely cold conditions.

Introduction

Long Hanborough Gravel Pit provides sections in the gravel that forms the Hanborough Terrace of the River Evenlode. This deposit, the Hanborough Gravel Formation, is aggraded to *c.* 100 m O.D. in its type area and is the highest of the limestone-dominated terrace gravels of the Oxford region (Sandford, 1924, 1926; Arkell, 1947a, 1947b; Briggs and Gilbertson, 1973, 1974). Higher and older formations, with the exception of the Sugworth Channel sediments, are preserved only as decalcified Northern Drift deposits, dominated by quartz and quartzites (see Introduction to this Chapter and the Sugworth report). The Hanborough Formation is also recognized in the Cherwell and Thames valleys (Fig. 2.1).

The largest remnant of Hanborough Terrace deposits is that on which the villages of Church Hanborough and Long Hanborough are built (Fig. 2.7). Since the Long Hanborough pit is situated on the 'type outcrop' of the Hanborough Gravel, it may be considered to represent the type section for this formation, there being no other exposures surviving in the area. Although earlier pits have been described (Sandford, 1924; Arkell, 1947a, 1947c), much important recent work on the Hanborough Terrace sediments has been carried out at the GCR site, notably the description of a cold-climate molluscan fauna from silty horizons within the gravel sequence (Briggs and Gilbertson, 1973, 1974). This did much to overturn old ideas that the aggradation of terrace deposits (here and elsewhere) took place during temperate periods. The Hanborough Gravel is now believed to have been laid down under cold (periglacial) conditions, but the identification of the cold episode during which this took place is the subject of controversy, particularly as a result of recent work in the Midlands (Rose, 1987, 1989), to the north-west of the Evenlode catchment (see below and Chapter 1).

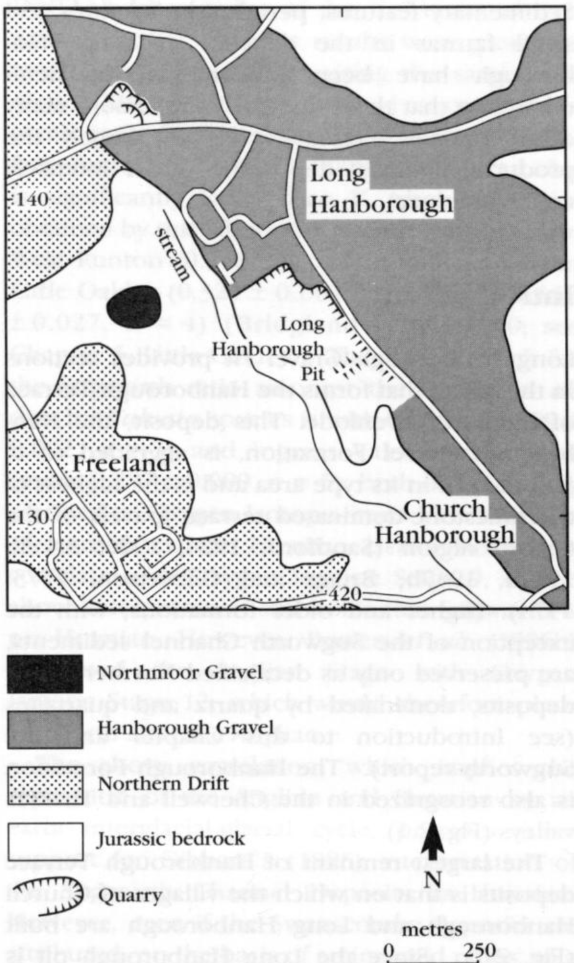


Figure 2.7 Map of the Long Hanborough area, showing the location of the GCR site. The quarry in the top left part of the diagram is Duke's Pit.

Description

Early descriptions of Hanborough Terrace deposits record a variety of different exposures. According to Arkell (1947a, p. 202), 'a dozen large pits at Long Hanborough and Church Hanborough' had existed (or did exist) by 1947. The most famous site was Duke's Pit (SP 415143), 0.5 km to the north-west of the present site, which was described by Sandford (1924), Richardson (1935) and Arkell (1947a, 1947c). Sandford (1924, 1925) also described a working known as Lay's Pit, Long Hanborough, near the northern edge of the gravel spread, and two pits in the Hanborough Terrace of the Cherwell at Kirtlington. Numerous less important exposures were described in the second Oxford memoir (Sandford, 1926), but the most extensive list of pits in the Hanborough Terrace was provided by Dines (1946) in the Witney memoir. In more recent years attention has been centred on the present site, to the south of Long Hanborough village, as well as on exposures at Dean Grove, *c.* 10 km upstream (Briggs and Gilbertson, 1973, 1974), and at Cassington (Kellaway *et al.*, 1971).

Sandford (1924) established that a number of mammalian species occurred in the gravel of the Hanborough Terrace, namely *Palaeoloxodon antiquus* (Falconer and Cantley), *Mammuthus primigenius* (Blumenbach), *Dicerorhinus* sp. (probably *D. hemitoechus* (Falconer)), *Bos primigenius* (Bojanus), *Equus ferus* (Bodaent) and *Cervus elaphus* (Falconer) (Sandford, 1924, 1925, 1926). Arkell (1947c) reported the discovery of an Acheulian hand-axe in Duke's Pit, Long Hanborough. This is the only palaeolith that can be attributed with certainty to the Hanborough Terrace gravel (Arkell, 1947c; Wymer, 1968; Roe, 1976; Briggs *et al.*, 1985), although a previous record exists of an early find that probably came from these deposits (Anon., 1908; Manning and Leeds, 1921; Wymer, 1968).

The most recent detailed description of the Long Hanborough GCR site was by Briggs and Gilbertson (1973), who recorded the following sequence at NGR SP 418138:

	Thickness
3. Loam, red-brown, unbedded. Contains scattered non-calcareous pebbles and is typically up to 1 m thick. This deposit fills pipes in the gravel down to a depth of 2.5 m from the surface	up to 1 m
2. Gravel, pale-coloured (pinkish), with cross-bedding and localized channelling; dominantly composed of limestone clasts, with quartz, quartzite and sandstone, plus rare flint and igneous or metamorphic rocks. Occasional seams and thin beds of silt occur, locally containing non-marine Mollusca (see Fig. 2.8).	1–3 m
1. Oxford Clay	

The recovery by Briggs and Gilbertson of a gastropod assemblage from silts within bed 2, comprising *Pupilla muscorum* (L.), *Oxyloma pfeifferi* (Rossmässler), *Catinella arenaria* (Bouchard-Chantereaux), *Planorbis* spp., *Columella columella* (Martens), *Agriolimax* spp., *Pisidium vencentianum* (Woodward), *P. nitidum* (Jenyns) and *Trichia hispida* (L.) provided important additional evidence for palaeo-environmental conditions during the aggradation of the Hanborough Terrace deposits. The origin of the 'pipes' filled with red brown loam (bed 3) has been the subject of considerable debate (see below).

Interpretation

The Hanborough Formation has been recognized as a separate, early division of the limestone gravels of the Upper Thames for over a century. In early Geological Survey memoirs both Hull (1859) and Green (1864) noted that the gravel at Long Hanborough and Church Hanborough lay at a greater elevation than the bulk of the terrace deposits in the area. The Hanborough Terrace, which has also been referred to as the '100 ft Terrace', the 'High Terrace' and the 'Fourth Terrace' (Pocock, 1908), is better preserved in the Evenlode valley than in the other branches of the Upper Thames system.

Sandford (1924), in the first of his major papers on the Upper Thames, introduced the term 'Handborough Terrace' (using the old spelling). He interpreted the various remnants of this formation as the product of a temperate-climate environment, on the basis of the mammalian remains found in them (see above). Arkell (1947a, 1947b) interpreted the Hanborough Terrace as an interglacial gravel 'delta', remarking on the evidence in the Upper Thames basin for a single period of major rock-disintegration and terrace formation, represented by the aggradation at Hanborough. This he correlated with the comparable 'Silchester Gravel' of the Kennet valley, assigning both to the 'First Interglacial' (this would now be equated with the Cromerian).

Arkell was the first to claim that the Hanborough Gravel has a gentler downstream gradient than later terrace deposits in the Evenlode valley, including the floodplain sediments. It therefore intersects with the projected profiles of successively more recent formations as it is traced upstream. Upstream from Kingham, where the Hanborough Gravel is only *c.* 10 m above the modern floodplain, Arkell believed it to underlie glacial deposits, the 'Moreton Drift'. These flint-rich glacial sediments are believed to result from the glaciation that deposited the 'Chalky Boulder Clay' ('Chalky Till') of the Midlands, this col in the Cotswolds escarpment representing its furthest encroachment into the modern Thames catchment (Arkell, 1947a, 1947b; Bishop, 1958; Kellaway *et al.*, 1971; Briggs, 1973). To the north, beyond the present Stour–Evenlode watershed, a limestone gravel similar to the Hanborough Formation occurs beneath the Moreton Drift in the area of Great Wolford and Stretton-on-Fosse. Arkell believed that this deposit, which he called Paxford Gravel, was an upstream continuation of the Hanborough Gravel, laid down by a formerly more extensive Evenlode.

This interpretation is of considerable importance: if the Paxford Gravel is correctly identified as an upstream equivalent of the Hanborough Formation, the latter must pre-date the 'Chalky Till' glaciation of the Cotswolds. The same conclusion has also been reached from the analysis of gravel composition. It has been widely reported that the Hanborough Gravel of the Evenlode valley does not contain the typical north-eastern erratic components, fresh flint in particular, that were introduced into the Stour–Evenlode watershed area by the 'Chalky Till' glaciation; it has been claimed instead that such material first appears in the Wolvercote Gravel (Bishop, 1958; Kellaway *et al.*, 1971; Briggs, 1988; see below, Wolvercote). This view has been challenged recently by Maddy *et al.* (1991), who have suggested that there is no significant difference between the gravel contents of these two formations in the Evenlode.

Kellaway *et al.* (1971) and Briggs and Gilbertson (1973) have supported Arkell's reconstruction of the Hanborough Terrace long-profile and its convergence upstream with the valley floor. However, Tomlinson (1929) and Kellaway *et al.* (1971) recorded gravels of Hanborough type from the Wychwood area at levels that are too high to be consistent with this interpretation. If Arkell's correlation of the Paxford and Hanborough Gravels is correct, these higher calcareous deposits may be non-decalcified remnants of the lowest Northern Drift formation(s) or they may be locally derived 'fan gravels'. However, it has been shown in

Chapter 1 that miscorrelation may have occurred between the Upper and Lower Evenlode valleys, with the implication that the gravels underlying the Moreton Drift might be older than the Hanborough Formation. Further investigation of the gravel remnants in the Evenlode valley is required in order to assess the relations of the Hanborough Formation to the glacial deposits of the Cotswolds.

More recent studies in the south Midlands have challenged Arkell's conclusion that the Hanborough Gravel dates from the Cromerian. Tomlinson (1963) placed it in the 'Great Interglacial' (Hoxnian) on the grounds of its mammalian fauna and its relation, established by Arkell, to the Cotswolds glaciation, which she attributed to the Saalian. Wymer (1968) pointed out that no elements of the fauna found at Long Hanborough are diagnostic of the Cromerian as opposed to the Hoxnian Stage and that a deposit as old as the Cromerian might be expected to be more decalcified. He also considered substantial accumulations of gravel of the type represented at Long Hanborough to be more typical of cold-climate than of interglacial conditions.

Kellaway *et al.* (1971) thought that the relative abundance of Triassic quartzites and the paucity of flint in the Hanborough Gravel implied formation during the interval between the 'Northern Drift glaciation' and the 'Chalky Till' glaciation. According to Shotton (1973a), this would place the Hanborough aggradation between the Anglian and Saalian (Wolstonian) glaciations. The rejection, in recent years, of the Northern Drift as a glacial deposit renders this view obsolete (see above, Sugworth); it is now clear that the Northern Drift is a complex group of deposits spanning the Lower and lower Middle Pleistocene (Chapter 1). Another problem in assessing the age of the Hanborough Formation is the dispute that has arisen in recent years as to which glacial episode is represented by the 'Chalky Till' of the West Midlands (see below).

An important challenge was made by Briggs and Gilbertson (1973, 1974) to the long-held belief that the Hanborough Terrace deposits were of interglacial origin. This view, based on the occurrence of occasional mammal bones in the gravels (see above), had been questioned by Wymer (1968), but reiterated by Kellaway *et al.* (1971). Briggs and Gilbertson presented new evidence from the Long Hanborough pit, from studies of sedimentology and molluscan faunas, pointing to deposition under cold-climate conditions. The sedimentological analyses, based on samples from temporary exposures at Milton-under-Wychwood and Kingham, as well as the pits at Dean Grove and Long Hanborough, revealed a considerable downstream increase in coarse-grade local material. This would have been incorporated in the gravel as the river flowed through the Evenlode Gorge, suggesting a period of highly active local erosion. In addition to this, the sediment type and the range of sedimentary structures occurring in the deposits suggest deposition by a braided river. The full picture is therefore one of a braided, gravel-bed river in an open environment with sparse vegetation.

Assemblages of non-marine Mollusca obtained by Briggs and Gilbertson (1973) from two silt/fine-sand horizons in the Long Hanborough pit (Fig. 2.8) provide further important evidence. The lower of these horizons yielded species indicative of subarctic conditions, with *Pupilla muscorum*, a xerophilous land-snail, dominating an assemblage otherwise typical of marshlands and small streams. In the higher silty horizon *P. muscorum* was replaced by *Oxyloma pfeifferi*, a snail found in marshland or damp habitats, in a general assemblage hinting at slightly milder conditions than that from the lower horizon. Briggs and Gilbertson likened the assemblages from both horizons to those from the various Devensian interstadials. They concluded that the Hanborough Gravel accumulated under cold (periglacial) conditions and that the interglacial mammalian remains previously recorded, which appear to have been concentrated near the base of the aggradation, were probably reworked from earlier deposits and/or land surfaces. They suggested an early Wolstonian (Saalian) age as the most probable, taking into account (1) the occurrence of the derived temperate-climate mammalian fauna, which they considered likely to be of Hoxnian age, and (2) the apparent link with the pre-Moreton Drift ('Chalky Till') Paxford Gravel of the Stour–Evenlode watershed area, first suggested by Arkell (1947a, 1947b). At that time the Saalian age of the Moreton Drift, now in doubt, was unchallenged. If this glaciation is of Anglian age, as suggested by more recent authors (see above), and the correlation of the Hanborough and Paxford Gravels is correct, the latest possible age for the Hanborough Gravel would be Anglian. The implication of this would be a return to the interpretation of the derived mammalian fauna as being of Cromerian age, a view that has no support from biostratigraphy and is contrary to evidence from terrace stratigraphy in the Thames basin as a whole (see below).

Biostratigraphical evidence for the age of the Hanborough Terrace is rather sparse. The Mollusca obtained by Briggs and Gilbertson (1973) are of considerable palaeoenvironmental significance, but yield no information of significance to relative dating (although amino acid ratios from these shells might prove informative at some future time). Many of the teeth of *Palaeoloxodon antiquus* from the Hanborough Terrace deposits were described as having primitive or archaic affinities (Sandford, 1925), but recent reassessment of the material has not confirmed this potential indication of antiquity (Lister, 1989). These derived mammalian remains are of potential significance, however. Both mammoth and straight-tusked elephant appear for the first time in the Pleistocene of north-west Europe in the Elsterian (Anglian) Stage and have not been recorded from pre-Elsterian interglacials (Lister, 1989). Unless this fauna represents an intra-Anglian interstadial, it would not be expected beneath Anglian glacial deposits. All the mammalian species recorded from the Hanborough Gravel have, in contrast, been recognized from deposits ascribed to the Hoxnian Stage (*sensu* Swanscombe and *sensu* Hoxne). Therefore this derived (temperate-climate) fauna provides support for the chronostratigraphical scheme for the Thames terraces

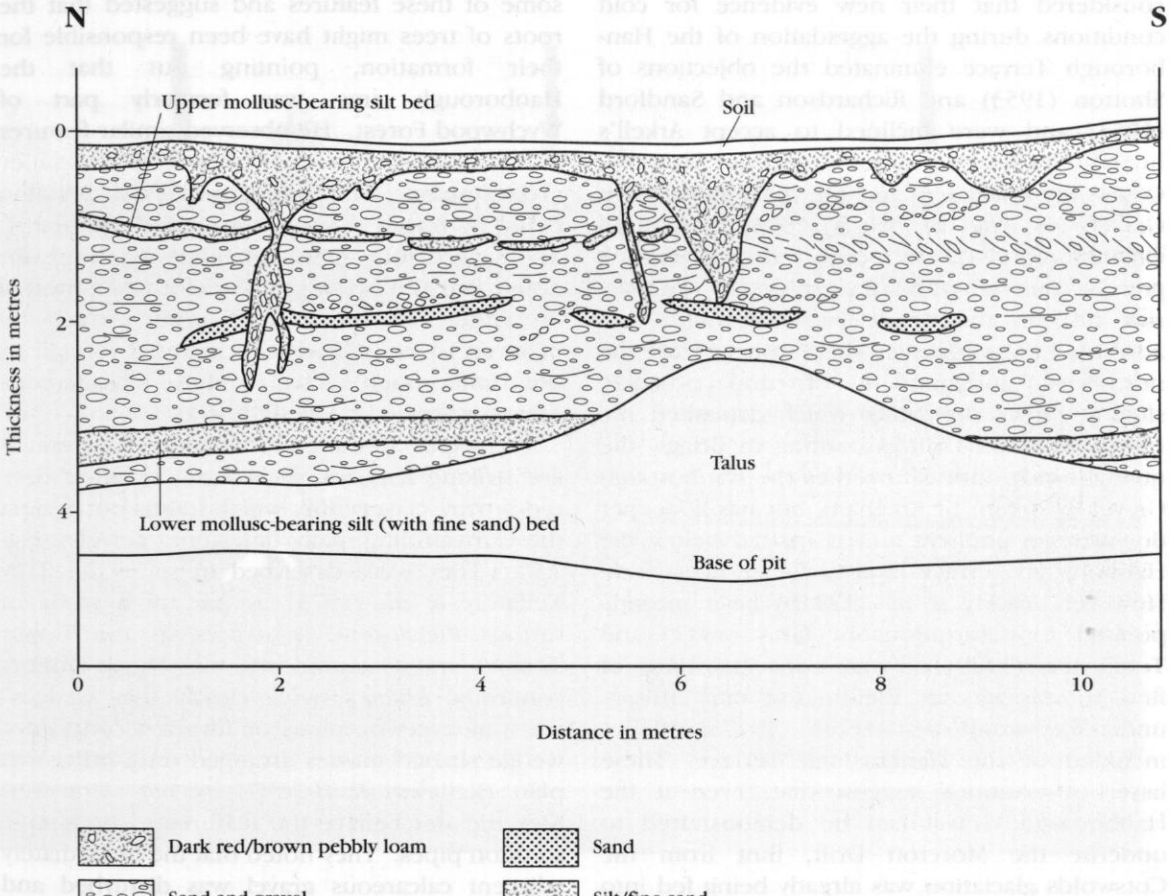


Figure 2.8 The east face at Long Hanborough Gravel Pit (after Briggs and Gilbertson, 1973). This shows 'frost boils'/decalcification pipes, filled with pebbly loam. Note the effects of frost heaving in the adjacent bedding.

proposed in Chapter 1, in which it was considered to represent Oxygen Isotope Stage 11 (Hoxnian *sensu* Swanscombe), although reworked into a Stage 10 gravel aggradation.

Arkell's correlation of the Paxford and Hanborough Gravels has been questioned by a number of authors. Shotton (1953) correlated the Paxford Gravels with the early Wolstonian (*sensu* Wolston) Baginton-Lillington Gravels of the Leamington area, whereas Richardson and Sandford (1963) described a mammalian assemblage of cold-climate affinities from the Paxford deposits. At this time the Hanborough Formation was confidently attributed to the Hoxnian, on the basis of its mammalian fauna, and regarded as interglacial in origin. Arkell's interpretation was also challenged by Kellaway *et al.* (1971), who noted compositional similarities between the Hanborough and Paxford Gravels, but regarded them as the products of separate river basins. Briggs and Gilbertson (1973, 1974) considered that their new evidence for cold conditions during the aggradation of the Hanborough Terrace eliminated the objections of Shotton (1953) and Richardson and Sandford (1963) and were inclined to accept Arkell's hypothesis. Strong additional evidence for a pre-Cotswolds glaciation age for the Hanborough Gravel was cited by Briggs (1973; Briggs and Gilbertson, 1974). He recognized quartzite-rich gravels (outwash) and a purple clay (Triassic-rich till?) in the upper Evenlode valley and attributed these to an ice sheet moving from the north-west, independent of, and probably slightly earlier than, that which deposited the (flinty) Moreton Drift. According to Briggs, the quartzite-rich outwash overlies the Hanborough Gravel upstream of Kingham, but has a steeper downstream gradient and is incised below the Hanborough Terrace level further downstream. However, Maddy *et al.* (1991b) have recently pointed to descriptions by Gray (1911) and Tomlinson (1929) of significant quantities of flint in deposits at Bledlington and Milton-under-Wychwood that Arkell (1947a, 1947b) included in the Hanborough Terrace. These latter observations suggest that, even if the Hanborough Gravel can be demonstrated to underlie the Moreton Drift, flint from the Cotswolds glaciation was already being fed into the Upper Thames by the time of Hanborough Gravel deposition. As has been discussed in Chapter 1, there is a distinct possibility that the gravels underlying the glacial deposits in the Upper Evenlode, the 'Bledlington Terrace' of Arkell (1947b), might be older than the Hanborough Gravel of the type area, perhaps the equivalent of the Freeland Formation (see Fig. 1.3).

Solution and periglacial features

The various large-scale post-depositional structures with v-shaped cross-sections that disrupt the deposits at Long Hanborough have attracted considerable interest. Periglacial and solution features have been noted in the Hanborough Terrace deposits by many workers (Sandford, 1924, 1926; Dines, 1946; Arkell, 1947a; Briggs and Gilbertson, 1973, 1974; Briggs, 1976a). According to Sandford (1924, p. 124), '... the top of the (Duke's) pit is marked by a remarkable series of so-called solution-pipes to a depth of 10 ft or more, filled with brown gravelly clay'. Sandford noted root remains in some of these features and suggested that the roots of trees might have been responsible for their formation, pointing out that the Hanborough area was formerly part of Wychwood Forest. He observed similar features in the Hanborough Gravel of the Cherwell valley at Kirtlington. Sandford reported that bedding could be traced through the 'pipes' and that it also sagged into them. Dines (1946), however, noted that the bedding was deformed upwards on either side of these features, which he believed to be infilled with material foreign to the Hanborough Gravel. These observations were confirmed by Arkell (1947a).

The 'pipes' in the gravel at Long Hanborough are striking features, picked out by their dark red-brown, clayey infill, which stands out against the surrounding pale limestone gravels (Fig. 2.9). They were described in some detail by Kellaway *et al.* (1971) as part of a study of various Pleistocene structures in the Upper Thames and Cotswold regions. These authors confirmed Arkell's view: 'clearly the "wedges" are long tapering pipes or inverted cones, not wedge shaped masses arranged on a polygonal plan' (Kellaway *et al.*, 1971, p. 12). However, they did not believe the features to be simple solution pipes. They noted that the immediately adjacent calcareous gravel was disturbed and showed no sign of decalcification. Furthermore, they suggested that the dark infill was not the residue of gravel that had been decalcified, but was derived from a formerly continuous superficial deposit that had fallen in from above. They established that the 'pipes' were widely distributed at about 3 m intervals on the flat part of the terrace remnant, but were absent from the peripheral slopes, which they believed to have been cambered. They suggested that the features were the degraded bases of 'frost boils', formed in a periglacial environment. Kellaway *et al.* also noted the occurrence of calcrete and small-scale normal faulting at Long Hanborough, as well as 'gulls' near the edge of the gravel spread at Church Hanborough, where cambering has occurred.

Briggs and Gilbertson (1973, 1974) recognized various ground-ice pseudomorphs (ice-wedge casts and frost-cracks) at several places in association with the solution pipes, as well as small-scale festooning (involutions) within the top metre of sediment. They accumulated evidence that ice-wedge formation had been contemporaneous with gravel deposition (intra-formational), claiming this as support for their conclusion that the Hanborough Terrace deposits were laid down under periglacial conditions (Briggs and Gilbertson, 1973). They later reserved judgement on the matter, considering it possible that the observed features might be 'dip and fault structures', related to cambering, rather than ice-wedge casts (Briggs and Gilbertson, 1974). Briggs (1976a, 1988) suggested that the characteristic Hanborough Terrace 'pipes' might have originated as cylindrical growths of ice within the upper part of the gravel, perhaps associated with festooning, followed, under warmer conditions, by solution at points where the gravel fabric was aligned vertically. This two-stage hypothesis of 'pipe' formation explains the fact that the upward deformation of adjacent bedding is confined to the top part of the pipes; these parts were presumably initiated by periglacial processes. The hypothesis also explains why the widest pipes show the least

Figure 2.9 Sections at Long Hanborough photographed early in this century. This view was first published in the Witney Geological Survey memoir, where it was attributed to Duke's Pit. Note the prominent 'frost boil'/pipe features, filled with darker material. Upward deformation of the gravel bedding adjacent to the left-hand pipe is clearly shown. Photograph reproduced by courtesy of the British Geological Survey (A3188).

deformation (deformed zones having been removed by solution), the opposite to what might be expected in the best-developed features if they were simple periglacial structures.

Correlation with the sequence in the London Basin

Correlation of the Hanborough Terrace with the Pleistocene sequence in the London Basin has previously proved somewhat problematic (see Chapter 1 and Fig. 1.3). Previous attempts at correlation between the Upper and Middle Thames have usually associated the Hanborough Gravel with the Boyn Hill (Sandford, 1924, 1926; King and Oakley, 1936) or the Winter Hill Formations (Sandford, 1932; Wooldridge, 1938). Arkell's (1947a) correlation of the Hanborough and Silchester Gravels (see above) would, at the time, have implied parity with the Winter Hill Terrace, but the Silchester (Hampstead Marshall Terrace) Gravel has recently been correlated with the Black Park Gravel of the Thames (Gibbard, 1985; see Chapter 3, Hamstead Marshall). Lower facets within what was recognized as the Winter Hill Terrace when Sandford and King and Oakley were active have subsequently been attributed to the Black Park Formation (see Chapters 1 and 3).

The palaeolith from Duke's Pit (see above) has also been interpreted as evidence for relative antiquity, having been regarded as 'Early Acheulian' or Abbevillian (Arkell, 1947c). This interpretation was not supported by Wymer (1968) or Roe (1976), both of whom advised against drawing conclusions from single finds. In any case, the separate existence of earlier phases of the Acheulian Industry, characterized by less skilfully made implements, is no longer widely accepted (Chapter 1).

Arkell's interpretation has remained a minority view, most authors having correlated the Hanborough and Boyn Hill Gravels, largely on the basis of the similarity of the mammalian faunas at Hanborough and Swanscombe. This view was widely accepted prior to the work of Briggs and Gilbertson (1973, 1974), both aggradations being assigned to the Hoxnian Stage (Mitchell *et al.*, 1973). Briggs and Gilbertson, in showing the Hanborough Formation to have accumulated under periglacial conditions, cast doubt on this correlation. The basis for this doubt has subsequently been negated by the work of Gibbard (1985), who has shown that the Boyn Hill Gravel of the Middle Thames is also largely the result of aggradation under periglacial conditions and that interglacial sediments such as those at Swanscombe are atypical. Gibbard placed the Boyn Hill Gravel in the early 'Wolstonian' (Saalian) Stage and considered the Hanborough Gravel to be its direct upstream equivalent. The remains of interglacial mammals found in these gravels were considered by Gibbard to have been reworked during the destruction of Hoxnian sediments similar to those preserved at Swanscombe.

Recent reappraisal of the glacial stratigraphy of the Midlands (Perrin *et al.*, 1979; Sumbler, 1983a; Rose, 1987, 1989, 1991; Chapter 1) has important implications for this correlation. In East Anglia it has been generally accepted, since the work of Bristow and Cox (1973) and Perrin *et al.* (1973), that the local 'Chalky Till' is entirely of Anglian age, but in the Midlands till of the same general type has been placed in the Saalian (Wolstonian) (Shotton, 1953, 1973a; Kelly, 1964). Recent research has challenged this last view, however, with the implication that the glaciation of the Vale of Moreton may, in fact, be of Anglian age (Sumbler, 1983a; Rose, 1987, 1989). Such an interpretation would seem to support Arkell's (1947a, 1947b) view, in which the Hanborough Terrace was regarded as earlier than the Catuvellaunian (= Anglian) glaciation. However, the scheme for terrace correlation between the Upper and Middle Thames valleys, outlined in Chapter 1 (Fig. 1.3), has an important bearing on this discussion. A pre-Anglian glaciation age for the Hanborough Gravel would rule out correlation with the Boyn Hill Gravel of the Middle Thames, which postdates the Anglian glaciation of the Vale of St Albans (Gibbard, 1979, 1985). Correlation with the Black Park Gravel would also prove difficult, since this formation is believed to have been deposited in the Middle Thames valley while Anglian ice sheets occupied parts of the Vale of St Albans (Gibbard, 1977; see Chapter 3).

The conclusion that the Hanborough Gravel may be older than the Anglian glaciation therefore poses major problems for terrace correlation between the Upper and Middle Thames. The Black Park Gravel (formerly the Lower Winter Hill Terrace – see Chapter 3, Highlands Farm Pit) is aggraded to over 90 m O.D. in the district immediately downstream from the Goring Gap (Evans, 1971, fig. 53; Gibbard, 1985, fig. 10), whereas the Hanborough Terrace has already fallen below 80 m O.D. immediately upstream of the gap (Fig. 2.3). These facts strongly indicate that the Hanborough Terrace must correlate with a formation lower, and therefore later, than the Black Park Gravel. It must also, therefore, post-date the glaciation of the Vale of St Albans. In fact, altitudinal evidence unequivocally indicates correlation between the Hanborough and Boyn Hill Gravels (Chapter 1 and Fig. 1.3), as many past authors have claimed (Sandford, 1924, 1926; King and Oakley, 1936; Gibbard, 1985).

The Arkell (1947a, 1947b) interpretation of the Hanborough Gravel underlying the glacial deposits of the Moreton-in-Marsh area is thus of considerable significance. The downstream equivalent of the Hanborough Formation, the Boyn Hill Gravel, is ascribed to the early Saalian (Gibbard, 1985), so a broadly Saalian (post-Swanscombe interglacial) age appears to be implied for the Cotswolds glaciation. It should be noted, however, that the records of flints in deposits ascribed to the Hanborough Formation (Maddy *et al.*, 1991b; see above) may indicate that at least part of the Hanborough aggradation incorporates outwash from the Cotswolds glaciation. Maddy *et al.* (1991b) did not address the question of whether Arkell's interpretation of the stratigraphical relations between the Hanborough Gravel and the glacial deposits is correct. This question, which is discussed above and in Chapter 1, remains of paramount importance and is an issue requiring urgent attention.

In Chapter 1, schemes for correlating the Upper and Middle Thames terraces and for relating these to the oceanic oxygen isotope sequence were described. According to these, and if Arkell's interpretation is correct, the relation of the Hanborough Formation to Moreton Drift implies that the Cotswolds glaciation was later than that which diverted the Thames from the Vale of St Albans. If the latter is correctly correlated with Oxygen Isotope Stage 12 (Bowen *et al.*, 1986b), the former may equate with Stage 10 (Chapter 1). If Bowen *et al.* (1989) are correct in correlating the type-Hoxnian with Oxygen Isotope Stage 9, it is possible that the Moreton glaciation is both post-Anglian and pre-Hoxnian (*sensu* Hoxne), although it appears that it might post-date the interglacial sediments at Swanscombe (see Chapter 1).

It remains possible, in the light of the complexity of sedimentary sequences beneath single terrace surfaces implied by the model for terrace formation advocated in Chapter 1, that late Anglian (Oxygen Isotope Stage 12) outwash is included within a range of deposits making up the Hanborough Formation. This would allow the Moreton Drift to be ascribed to the same glacial event as the tills of the London Basin, although there is still the major problem that the glaciation of the Cotswolds appears to occur (or at least persist) after the downcutting to the Hanborough/Boyn Hill terrace level. The flinty gravels described by Gray (1911) and Tomlinson (1929) at Milton and Bledlington (see above) would, according to this view, equate with the gravels underlying the Moreton Drift, but the Hanborough deposits containing the mammalian bones must presumably date from the subsequent cold episode (Stage 10), if the fauna is correctly attributed to Stage 11 (Hoxnian *sensu* Swanscombe). The two sets of gravels would thus represent phases 2 (Stage 12) and 4 (Stage 10) of the model for terrace formation, with phase 3 represented by the *remanié* fauna. Further discussion of the age and stratigraphical relations of the Moreton Drift will be found below, in the Wolvercote report.

Conclusions

The gravels at Long Hanborough were deposited by a braided, gravel-bed river that flowed across a sparsely vegetated, treeless landscape during one or more of the cold-climate phases of the Pleistocene. Since the gravels at Long Hanborough contain the bones of large mammals, of species that preferred warm climates, the deposits were formerly thought to have accumulated during a temperate (interglacial) phase. The discovery of the remains of cold-tolerant snails within the gravels, however, has shown that the deposits were laid down under harsh, periglacial conditions. It seems likely that the bones of the temperate-climate mammals were derived from older, interglacial sediments. It appears that the gravels at Long Hanborough were laid down by an early River Evenlode, which drained a larger area than the present catchment. The precise age of the deposits is difficult to establish. On the basis of correlations with sequences in the English Midlands and elsewhere in the Thames basin, it is likely that the Long Hanborough gravels date back to around 300,000 to 400,000 years BP, somewhat later than the most intense of the Pleistocene glaciations (the Anglian glaciation). The interest of the site is enhanced by a series of infilled pipe structures that penetrate down into the gravels. These are thought to have formed by a combination of periglacial processes and the solution of carbonate-rich sediments, but their precise origin is uncertain.

THE WOLVERCOTE GRAVEL AND WOLVERCOTE CHANNEL DEPOSITS

Although no GCR site exists there, it is necessary, because of its importance to the Quaternary history of the Upper Thames, to discuss the evidence from Wolvercote (type locality of the Wolvercote Gravel and the Wolvercote Channel Deposits) at this point in the text.

During the latter part of the 19th century, a large channel was revealed in a brick pit at Wolvercote (SP 498105), apparently cut through the gravel of the Wolvercote Terrace into Oxford Clay (Figs 2.10 and 2.11). This channel was found to contain a sequence of Pleistocene sediments that have yielded molluscan and mammalian remains, plant macrofossils and the largest Palaeolithic assemblage from the Upper Thames basin (Bell, 1894a, 1904; Sandford, 1924, 1926; Arkell, 1947a; Wymer, 1968; Roe, 1981; Tyldesley, 1986a, 1986b, 1988). The pit is

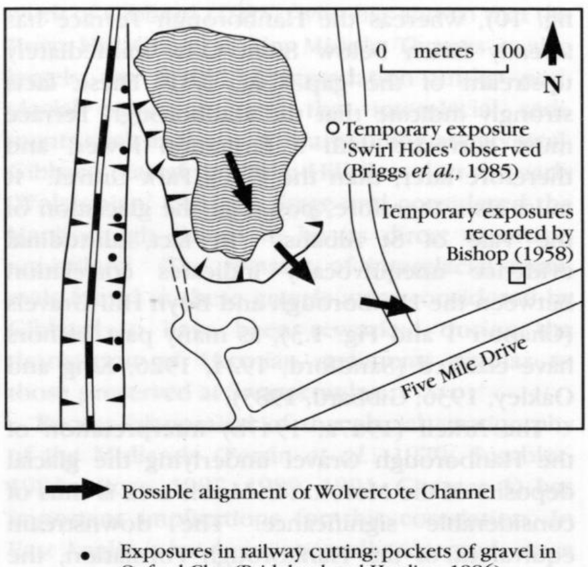


Figure 2.10 Map of Wolvercote brick pit and the surrounding area, showing the possible alignment of the Wolvercote Channel.

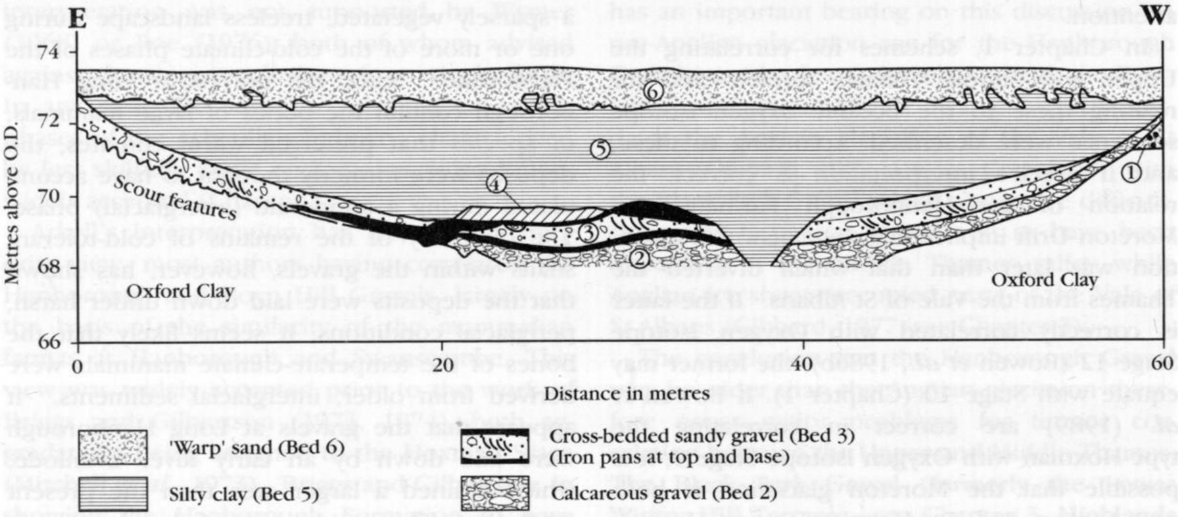


Figure 2.11 Section through the Wolvercote Channel (after Sandford, 1924).

now an ornamental lake surrounded by residential development, making reinvestigation difficult. Temporary exposures in the channel deposits were recently observed on the eastern side of the pit (Briggs *et al.*, 1985; Tyldesley, 1986b), but attempts to locate the channel in a railway cutting immediately to the west revealed only Oxford Clay with pockets of gravel at the surface (Bridgland and Harding, 1986). Work is continuing in open areas close to the brick pit to locate further remnants of the fossiliferous sediments, if any exist. So far no GCR site has been identified at Wolvercote, but it is hoped that future investigations will reveal Wolvercote Channel Deposits at a potentially conservable location.

Sections were open in the Wolvercote brick pit until the 1930s, but the lack of later opportunities to study the site has led to contrasting interpretations in the ensuing years, with both Hoxnian and Ipswichian ages being proposed for the channel deposits (Bishop, 1958; Wymer, 1968; Evans, 1971; Shotton, 1973a; Roe, 1981; Briggs *et al.*, 1985).

Many of the Wolvercote palaeoliths are of a highly distinctive, technologically advanced type, a fact that has caused some authors to argue for a Late Pleistocene age (for example, Roe, 1981), irrespective of the position of the Wolvercote Formation within the Upper Thames terrace sequence. The Wolvercote Terrace deposits have generally been attributed to the Saalian Stage (Bishop, 1958; Tomlinson, 1963; Shotton, 1973a; Briggs and Gilbertson, 1974, 1980), an interpretation based on the supposed first appearance in these gravels of material (in particular, fresh flint) from the 'Chalky Till' glaciation of the Cotswolds (Bishop, 1958; Goudie and Hart, 1975). It has been suggested recently that the 'Chalky Till' of the Cotswolds area might be of Anglian age (Bowen *et al.*, 1986a; Rose, 1987), raising the possibility that the Wolvercote Gravel is pre-Saalian and adding further fuel to the controversy over the age of the Wolvercote Channel.

The sequence at Wolvercote

It is difficult to determine the precise location of the Wolvercote Channel deposits from the early descriptions of the brick pit (Bell, 1894a, 1904; Pocock, 1908; Sandford, 1924, 1926), although they were clearly present in the southern and eastern faces. However, Bell (1894a, 1894b, 1904) provided detailed descriptions of the sections, including several illustrations, and Sandford (1924) provided an east-west section through the channel that has been repeatedly reproduced in subsequent publications (Sandford, 1926; Dines, 1946; Wymer, 1968; Roe, 1981; Tyldesley, 1986a) and which forms the basis for Fig. 2.11. Recent summaries have been provided by Wymer (1968), Roe (1981) and Tyldesley (1986a). The sequence at Wolvercote can be summarized as follows:

		Thickness (where known)
'warp sand'	6. Clayey gravelly sand, yellow-brown, in involutions	1–2 m
Wolvercote Channel Deposits	5. Silt and clay, laminated	up to 4.5 m
	4. Peat, thin and localized within base of bed 5	
	Iron-pan	
	3. Sandy gravel, current-bedded, with shells	
	Iron-pan	
	2. Calcareous gravel containing bones and artefacts	
Wolvercote Gravel	1. Bedded gravel, truncated by the channel deposits	
Oxford Clay		

Fresh flint, derived from the Cotswolds glaciation, is claimed to be present in beds 1–3.

According to the published records, the channel deposits overlie, at their margins, a gravel (bed 1) attributed by Sandford (1924) to the Wolvercote Terrace, although Bishop (1958) considered this to be part of an older aggradation (see below). The basal channel deposits comprise calcareous gravels (bed 2), containing bones and artefacts, that fill and overlie small hollows in the surface of the Oxford Clay. First described by Bell (1904), these features have been interpreted as potholes or 'swirl-holes' (Sandford, 1924; Arkell, 1947a). This appears to be an early record of scour features similar to those described recently beneath Pleistocene gravels (1) overlying London Clay at Stoke Newington (Harding and Gibbard, 1984), (2) overlying Pleistocene silt (Lower Loam) at Swanscombe and (3) overlying Thanet Sand at Globe Pit (see Chapter 4). Sandford (1924) noted that many of the large vertebrate bones were obtained from gravel within these scour features.

Above the basal gravel a series of ferruginous, cross-bedded sands and gravels was recorded (bed 3). Certain layers, predominantly at the base and top of the bed, were cemented into iron-pans. Between the lower and upper iron-pans, Sandford (1924, 1926) recorded shelly sands and a lens of clay containing shells and organic material. In the most comprehensive record, Kennard and Woodward (1924) recorded seventeen molluscan species from these beds. These gravelly deposits were separated by an erosive contact from the main infill of the channel, which comprised laminated silty clay (bed 5). A peat horizon (bed 4), which occurred locally at the base of this deposit, yielded plant fossils and beetles (Bell, 1894a, 1904; Reid, 1899; Blair, 1923; Duigan, 1956).

The channel sequence was capped by an upper sand (bed 6), up to 2 m thick, which, with the top of bed 5, was deformed by cryoturbation. This sand, with only a small clay component (Spiller, in Sandford, 1924), has generally been called 'warp sand'. It has also been recognized above the Wolvercote Terrace gravel away from the channel. Most authors have attributed this bed, directly or by implication, to solifluction, although Sandford (1925) thought it might result partly from the decalcification of the underlying sediments. It is also possible that an input of wind-blown, originally fluviatile, sands occurred. Spiller (in Sandford, 1924) showed from its heavy-mineral content that the 'warp sand' has closer affinities to the local fluvial deposits than to the bedrock.

Most of the palaeoliths from the Wolvercote site came from the basal gravel (bed 2) of the channel-fill or from the overlying cross-bedded ferruginous gravel. Some artefacts are considerably stained by iron, suggesting derivation from in or near one of the iron-pans (Sandford, 1924). The assemblage comprises mainly pointed hand-axes of a particularly well-made and characteristic type, although there is a fair representation of both primary and finishing flakes. About two-thirds of the material is in an unpatinated sharp or mint condition, suggesting that it was knapped at the site (Wymer, 1968). Palaeoliths have also been found in the Wolvercote Terrace gravel, both here and at Pear Tree Hill (SP 494111) to the north (Bell, 1904; Wymer, 1968). These are predominantly heavily abraded and patinated hand-axes, of the pointed type.

The Wolvercote Gravel (bed 1) is preserved, in the area of the Wolvercote brick pit, predominantly in pockets in the surface of the Oxford Clay, described as 'somewhat flask-shaped holes' by Bell (1904, p. 126). These were noted particularly on the western side of the pit (Pocock, 1908) and have been observed at the top of sections in the adjacent railway cutting (Bridgland and Harding, 1986). According to Sandford (1926), the terrace gravel was better represented in temporary sections to the south and east than in the brick pit. Bishop (1958) described temporary sections to the south-east of the pit in deposits that he ascribed to the Wolvercote Terrace and from which he obtained molluscs and ostracods.

Stratigraphy, age and correlation of Wolvercote deposits

Bell (1894a, p. 198) noted that the gravel of the Wolvercote area was older than the 'Summertown and Oxford gravel'. Pocock (1908) classified the former under the title 'Third Terrace', part of a sequence of four terraces numbered topographically upwards. Sandford (1924, 1926) redefined this as his Wolvercote Terrace. The deposits forming this terrace are here classified as the Wolvercote Gravel Formation, of which the Wolvercote Channel Deposits are a member.

The stratigraphical position of the Wolvercote Channel, particularly in relation to the Wolvercote Terrace gravel, has been a topic of a prolonged controversy. According to Sandford (1924, 1926), the Wolvercote Channel cuts through gravel of the Wolvercote Terrace, a view accepted by most authors. As the Wolvercote Gravel has generally been correlated with the Saalian, the temperate-climate channel deposits have been ascribed to the Ipswichian Stage

(Shotton, 1973a; Roe, 1981). A conventional interpretation of terrace stratigraphy in the Upper Thames basin would place the Wolvercote Terrace and Channel earlier than the Summertown-Radley Terrace (Figs 2.2 and 2.3), which has also yielded temperate-climate fauna and flora (see below, Stanton Harcourt and Magdalen Grove). A similar conclusion was reached, following the interpretation of molluscan faunas from various sites in the Upper Thames, by Kennard and Woodward (in Sandford, 1924). Despite this, Sandford (1925, 1926, 1932) concluded that the Wolvercote Channel Deposits post-date the temperate-climate sediments representing the upper part of the Summertown-Radley aggradation (the Eynsham Gravel – see below, Stanton Harcourt and Magdalen Grove), although he considered that both originated in the same interglacial. His correlation table (Sandford, 1932, p. 10) makes it clear that he considered this warm interval to immediately pre-date the last glaciation, implying correlation with the last interglacial (Ipswichian), but he also suggested that the lake beds at Hoxne, later to become the type site of an earlier interglacial in Britain (Mitchell *et al.*, 1973), were of equivalent age. This led some later authors, notably Bishop (1958), to claim that Sandford regarded the channel as Hoxnian.

Sandford's view, that the Wolvercote Channel Deposits post-dated the upper Summertown-Radley aggradation, was later consolidated by Dines (1946) and Arkell (1947a), although the latter placed both in the 'Great Interglacial' (Hoxnian Stage). Most subsequent authors who have concurred with Sandford's stratigraphical interpretation (Shotton, 1973a; Briggs and Gilbertson, 1974) have considered the Wolvercote Channel sequence to belong to the Ipswichian Stage. Evidence for climatic cooling, from plant macrofossils in the peat (see below), implies that the latter part of an interglacial is represented. The stratigraphical relations of the Wolvercote Channel have become a major point of controversy, however, since Bishop (1958) suggested that the channel deposits were older, rather than younger, than the Wolvercote Gravel. He believed the channel-fill to be of late Hoxnian to early Saalian age, an interpretation that also found favour with Wymer (1968).

Briggs (1976b) presented a summary of the various possible stratigraphical interpretations of the Wolvercote Channel Deposits. These are: (1) the channel post-dates the Wolvercote Gravel but pre-dates the Summertown-Radley Formation (the view of Kennard and Woodward (in Sandford, 1924)); (2) the Wolvercote Channel Deposits immediately post-date the upper Summertown-Radley aggradation (the later suggestion by Sandford (1925, 1926, 1932)); (3) the Wolvercote Channel is a pre-Wolvercote Terrace feature (the interpretation of Bishop (1958)) and (4) the Wolvercote Channel Deposits are contemporaneous with the upper Summertown-Radley aggradation, but laid down in a steeply sloping tributary valley and, therefore, at a greater elevation. The last view corresponds with the idea of formation in a 'hanging' tributary valley, possibly an early River Ray, suggested by Arkell (1947a). Whereas the earlier reconstructions (1 and 2) implied an Ipswichian age, Bishop (1958) interpreted the channel as Hoxnian. Briggs (1976b) favoured the first or third of the above hypotheses, considering that deposition of the Wolvercote Channel Deposits before the Summertown-Radley sediments, in line with conventional terrace stratigraphy, was inherently more likely than alternative models requiring complex sequences of erosion and aggradation. The larger number of climatic fluctuations now recognized in the late Middle Pleistocene allows a more straightforward interpretation of the Wolvercote sediments, as in option 1 above; they do not necessarily correlate with any other interglacial sediments recorded from the Upper Thames basin (see below, correlation).

Palaeontological evidence

Information on the faunal content of the Wolvercote Gravel and Wolvercote Channel Deposits is rather sparse. The Wolvercote Gravel has yielded scanty remains of mammals; the only such records appear to be horse, from Spelsbury (Sandford, 1924, 1926, 1939), and a wolf's tooth from Pear Tree Hill (Bell, 1904), where the gravel was regarded by Sandford (1924) as part of the Wolvercote Terrace (although the provenance of the tooth must be regarded as dubious). The fauna from the Wolvercote Channel Deposits comprises *Palaeoloxodon antiquus*, *Dicerorhinus hemitoechus*, *Bos primigenius*, *Cervus elaphus* and *Equus caballus* L., with bison, reindeer and bear recorded with less certainty (Sandford, 1924, 1925, 1926). Molluscan faunas were recorded from both the channel deposits (Kennard and

Woodward in Sandford, 1924) and the Wolvercote Gravel (Bishop, 1958), in each case dominated by *Trichia hispida*. None of the species recognized give a useful indication of climate (Bishop, 1958), although Gilbertson (1976) claimed that the fauna from the channel showed greater temperate affinities than that from the terrace gravel; however, he considered it unlikely that either represented exceptionally cold conditions. The source of the molluscan fauna attributed by Bishop (1958) to the Wolvercote Terrace lies less than 200 m from the brick pit and, although the deposits recorded there by Bishop were dominated by gravel, it seems likely that they represent a continuation of the channel-fill rather than the cold-climate terrace deposits (Fig. 2.10).

Plant macrofossils (Bell, 1894a, 1904; Reid, 1899; Duigan, 1956) and beetle remains (Blair, 1923) from the peaty horizon (bed 4) at the base of the silty clay (Fig. 2.11) indicate cool-temperate conditions (Duigan, 1956), probably colder than during the deposition of the gravels (beds 1–3) (Briggs *et al.*, 1985; Briggs, 1988). This interpretation is based on the presence of the arctic-alpine plant *Draba incana* L. (Duigan, 1956), the northern weevil *Notaris aethiops* (Fabricius) and a number of mosses of cold-climate affinities (Bell, 1904). Confirmation of progressive cooling during the infilling of the Wolvercote Channel was recently obtained from sparse pollen, probably from bed 5, from temporary sections near the eastern edge of the pit (Briggs *et al.*, 1985; Briggs, 1988). These showed a change from pine-dominated forest to open conditions, a sequence suggestive of the later part of an interglacial cycle. None of the palaeontological data provides any clear indication of the age of the channel-fill, except that the mammalian and molluscan species indicate deposition during the late Middle Pleistocene or Late Pleistocene.

The archaeological evidence

Both Wymer (1968) and Roe (1981) singled out Wolvercote brick pit as the most important Palaeolithic site in the Upper Thames valley. It is, in fact, the only locality in this region to have yielded a large collection of well-made Lower Palaeolithic tools, fashioned from good quality flint (presumably imported from the Chilterns), in a condition suggesting the proximity of a working site. Moreover, the site is of great Palaeolithic and Pleistocene significance as the source of an industry that is possibly unique in Britain. This claim is based on the characteristic and unusual form of certain of the best-made artefacts within the assemblage, which have been compared with some of the most recent hand-axe industries on the continent (Roe, 1981; Tyldesley, 1986a). Not all of the Wolvercote material is flint; artefacts made from quartzite and greywacke are included in the collections (Wymer, 1968; Roe, 1976, 1981; Tyldesley, 1988).

Summaries of the Palaeolithic assemblage from Wolvercote have been provided by Sandford (1924), Roe (1964, 1976, 1981), Tyldesley (1986a) and Wymer (1968). The typological harmony of the unabraded implements suggests that a single industry is represented, supporting the notion that a working site existed in the vicinity (Wymer, 1968; Roe, 1981). These hand-axes are characteristically large, finely made tools, showing evidence for soft-hammer working and often with a markedly plano-convex cross-section. This type of implement from Wolvercote, sometimes referred to as 'tongue-shaped' (Evans, 1897) or 'slipper-shaped' (Sandford, 1924, 1926), has been compared to the continental Micoquian industries, which are generally attributed to the last glaciation or the last interglacial (Sandford, 1924, 1925; Roe, 1981). Tyldesley (1986a) noted that classic 'Wolvercote Channel style' hand-axes formed a small proportion of the assemblage from the brick pit, eight specimens in all, but that there was a considerable cluster of other implements sharing many of the 'classic' features.

In his analysis of British hand-axe assemblages on the basis of implement typology, Roe (1964, 1968a) allocated the Wolvercote collection to a group of its own, it being the only British assemblage dominated by plano-convex bifacial tools, which Roe thought likely to be of relatively late inception. Wymer (1968), on the other hand, considered the Wolvercote industry to be broadly comparable to that from the Swanscombe Middle Gravel, both sites lacking ovate hand-axes and Levallois flakes and cores. Wymer recognized that the large plano-convex implements from Wolvercote were exceptional, but was prepared to accept the conclusion of Bishop (1958) that the Wolvercote Channel was pre-Saalian (see above). Roe (1981) disputed Wymer's view both of the affinities of the implement assemblage and of the likely age of the channel deposits. He cited the occurrence of typologically comparable Micoquian hand-axe assemblages at continental sites such as La Micoque in France and Bocksteinschmiede in Germany, both attributed to the last interglacial/glacial cycle. For the Wolvercote Channel Deposits to be as late as these continental industries, they would have to post-date much, if not all, of the Summertown-Radley Formation. This view, advocated by Roe (1981) and tentatively supported by Tyldesley (1986a, 1986b), would appear to conform with the later stratigraphical interpretation of Sandford (1925, 1932).

A detailed study of the Wolvercote Palaeolithic collections has been completed recently by Tyldesley (1986a, 1986b, 1988). Amongst her observations, she noted that the characteristic Wolvercote implements could be the work of a single craftsman who, given the limited size of the assemblage, could have made all the surviving artefacts in a single day. She also noted that tools similar to the characteristic Wolvercote types occurred within some French Micoquian industries, although they formed a less important part of these assemblages than at Wolvercote. She found that German Micoquian industries generally lacked such forms, however, and concluded (1986a) that the similarity of the Wolvercote hand-axes to the French material could have resulted from coincidence.

Briggs *et al.* (1985) questioned the value of typological refinement as an indication of a relatively recent age for the Wolvercote Channel Palaeolithic assemblage. This reflects recent thinking amongst archaeologists, which results largely from the recognition, at sites such as Boxgrove (Sussex), that relatively advanced knapping techniques were used in Britain in the early Middle Pleistocene (see Chapter 1). It is therefore apparent that the Palaeolithic assemblage from Wolvercote brick pit, though forming an important part of the scientific interest at the site, is of little value for relative dating.

Correlation

Since they lack diagnostic biostratigraphical evidence, determination of the age of the Wolvercote deposits relies heavily on the interpretation of the Upper Thames sequence as a whole. It is now widely believed that the deposits underlying the Summertown-Radley Terrace contain evidence for two separate interglacials, correlated with Oxygen Isotope Stages 7 and 5 (Briggs and Gilbertson, 1980; Shotton, 1983; Briggs *et al.*, 1985; Bowen *et al.*, 1989; Chapter 1; see also below, Stanton Harcourt and Magdalen Grove). These deposits are lower within the Upper Thames terrace sequence, and therefore younger, than the Wolvercote Gravel. According to the climatic model for terrace formation favoured in this volume, this implies that the Wolvercote Formation represents an earlier climatic cycle (cold-temperate-cold) than any part of the Summertown-Radley Formation (see Chapter 1). This model holds that the time interval represented by a typical terrace aggradation straddles a temperate climatic half-cycle, so that interglacial sediments, where preserved, are commonly underlain and overlain by deposits representing different cold episodes. The later, overlying, cold-climate sediments (phase 4 of the climatic model) are usually dominant, if only because they are the last to be deposited prior to rejuvenation. At Wolvercote, however, the pre-interglacial (phase 2) cold-climate aggradation appears to dominate (according to Sandford's interpretation of the relations between the Wolvercote Channel and Wolvercote Gravel). It is likely that a post-interglacial (phase 4) part of the Wolvercote aggradation was deposited elsewhere, although it will be impossible to distinguish it from the earlier phase 2 gravels in the absence of intervening interglacial (phase 3) sediments.

It is apparent that the 'Chalky Till' glaciation of the Cotswolds occurred prior to the deposition of the Wolvercote Channel sediments, since it supplied the fresh flint clasts that occur in the underlying Wolvercote Gravel. The glaciation therefore provides a maximum age for the Wolvercote Channel Deposits (it does not, however, indicate that the Wolvercote Gravel is of similar age to the Cotswolds glaciation – see Long Hanborough and Chapter 1). If the reinterpretation of this glaciation as an Anglian event (Rose, 1987, 1989) is accepted, it is possible to accommodate the Wolvercote Channel in one of two temperate episodes between the Anglian (Oxygen Isotope Stage 12) and the older of the two Summertown-Radley interglacials (Oxygen Isotope Stage 7). Correlation of the Wolvercote Channel Deposits is possible, on this basis, with either Stage 11 or Stage 9 of the oxygen isotope record. However, mammalian bones reworked into the Hanborough Gravel have been attributed to the Hoxnian Stage *sensu* Swanscombe, which is correlated with Oxygen Isotope Stage 11 (Table 1.1), and the Hanborough Gravel itself to Stage 10. Since the Wolvercote Formation clearly post-dates the rejuvenation event that followed the deposition of the Hanborough Gravel, correlation of the Wolvercote Channel Deposits with Oxygen Isotope Stage 9 (rather than 11) is strongly indicated. The stratigraphical correlations advocated here are summarized in Table 2.2.

The correlation of the Wolvercote Formation with the terrace sequence in the London Basin has been attempted by relatively few authors. Both Sandford (1932) and Arkell (1947a) suggested a correlation of the silty infill of the Wolvercote Channel (bed 5) with the Crayford 'brickearth', implying correlation with the Taplow aggradation. Evans (1971) similarly correlated the Wolvercote Terrace and Wolvercote Channel with the Taplow Terrace, considering them to have aggraded in his cycle 4W (equivalent to Oxygen Isotope Stage 7). This correlation was largely based on projection of the terraces through the Goring Gap. Gibbard (1985), using the same method, proposed the same correlation. However, the deposits in the Reading area, immediately downstream from the gap, that were ascribed by Gibbard to the Taplow Formation are reinterpreted in this volume (Chapter 1) as degraded Lynch Hill Gravel, thus implying a correlation between the Wolvercote and Lynch Hill Formations. In the scheme for terrace correlation presented in Chapter 1, the equivalence of the Wolvercote and Lynch Hill Formations was proposed (Fig. 1.3). This provides further support for correlation of the Wolvercote Channel sediments with Oxygen Isotope Stage 9, since the Lower Thames equivalent of the Lynch Hill Formation, the Corbets Tey Gravel, incorporates bodies of temperate-climate sediment at a number of sites that are also ascribed to this stage (Table 1.1; Chapter 4).

Attribution of the Wolvercote Gravel to the Anglian Stage, as suggested by Bowen *et al.* (1986b), is rendered untenable by the correlation of the Wolvercote and Lynch Hill Formations. The projection of the long-profile of this formation downstream into the London Basin (Chapter 1 and Fig. 1.3) shows the Wolvercote/Lynch Hill Gravel to be considerably lower (and therefore later) within the terrace sequence than either of the two Anglian formations, the Winter Hill and Black Park Gravels. Bowen *et al.*'s suggestion was based on the assumption that the Wolvercote Gravel was fed by flint-rich outwash from the Cotswolds

Table 2.2 Stratigraphical interpretation of the Upper Thames deposits advocated in this volume.

Temperate	Stage 7	Stanton Harcourt Channel Deposits
Cold	Stage 8	Basal Stanton Harcourt Channel Deposits and equivalents Wolvercote Gravel (phase 4) Uppermost Wolvercote Channel Deposits
Temperate	Stage 9	Wolvercote Channel Deposits
Cold	Stage 10	Wolvercote Gravel (phase 2) Hanborough Gravel Moreton-in-Marsh glaciation?
Temperate	Stage 11	Mammalian fauna (derived) in Hanborough Gravel
Cold	Stage 12	Hanborough Gravel (pre-bones)? Moreton-in-Marsh glaciation?

glaciation, as suggested by Tomlinson (1929) and Bishop (1958). This assumption, although almost universally accepted in recent years, has now been seriously challenged by Maddy *et al.* (1991b). They have reviewed the published clast-lithological data from the Wolvercote and Hanborough Gravels, which is in any case rather scanty, and concluded that there is no unequivocal indication of an input of flint into the Upper Thames system between these two formations. They found that, in comparison with other material foreign to the modern catchment, the highest percentage of flint actually occurred in a sample of Hanborough Gravel. This led them to suggest that the observed paucity of flint in the Hanborough Gravel, in comparison with the Wolvercote Formation, is the result of the greater incorporation of local limestone material in the older gravel. This evidence, as well as historical records of fresh flint in gravels later ascribed to the Hanborough Formation (Gray, 1911; Tomlinson, 1929; see above, Long Hanborough), suggests that the Cotswolds glaciation occurred during or before the aggradation of the Hanborough Gravel and, therefore, significantly earlier than the deposition of the Wolvercote Gravel. As stated above (see Long Hanborough), the outstanding problem is the relation of the Hanborough Gravel to the Moreton-in-Marsh glacial deposits; however, the dating and correlation of the Wolvercote Formation is in no way affected by the continuing dispute over this relation and the age of the Cotswolds glaciation.

It is widely agreed that a modern study of the Wolvercote deposits is urgently required before a complete understanding of the site's chronostratigraphical position within the Pleistocene can be achieved. Given that Wolvercote brick pit has yielded the largest collection of artefacts from any site in the Upper Thames, and it is the only locality in that area to have yielded Palaeolithic material in association with a temperate fauna, the importance of the site cannot be questioned. The interpretation, presented here, of the temperate-climate deposits at Wolvercote and their included fossils and palaeoliths as representing Oxygen Isotope Stage 9 has been argued almost entirely from stratigraphical evidence derived from other sites in the Thames sequence. A new opportunity for an examination of the Wolvercote Channel Deposits themselves must be awaited in order to test this hypothesis.

STANTON HARCOURT GRAVEL PIT (SP 415052) and MAGDALEN GROVE DEER PARK (SP 520065)

Highlights

These are important sites for interpreting the stratigraphically complex sequence of deposits forming the Summertown-Radley Terrace of the Upper Thames basin. This formation shows evidence of having aggraded during two full climatic cycles, thereby encompassing two major warm episodes, as well as one complete cold episode and parts of two others. Faunal evidence from Stanton Harcourt has been critical in demonstrating that the earlier of these temperate intervals represents an additional, as yet unnamed interglacial in the British Pleistocene – a terrestrial correlative of Oxygen Isotope Stage 7 (*c.* 200,000 years BP) of the deep-sea record. Formerly attributed to the last interglacial (Ipswichian Stage), the Magdalen Grove site now appears to represent further evidence for this newly recognized Stage 7 interglacial.

Introduction

The Summertown-Radley Terrace of the Upper Thames basin is formed by a complex sequence of sediments (the Summertown-Radley Formation) representing periods of both temperate and cold climate. The terrace is widely preserved in the Thames valley downstream from the confluence with the Windrush, but is not well represented in any of the tributaries (Fig. 2.1). The deposits forming this terrace have been well exposed in the past, notably at Eynsham, Summertown, Radley, Cassington, Stanton Harcourt and a number of exposures within the urban area of Oxford (Pocock, 1908; Sandford, 1924, 1926; Dines, 1946). Aggraded to 6–10 m above river level in the Oxford area, the Summertown-Radley Terrace was first named by Sandford (1924), although it had previously been described as the '2nd' or '20 ft' Terrace (Prestwich, 1882; Pocock, 1908).

Sandford (1924, 1926) considered that gravels forming the upper part of the Summertown-Radley aggradation contained the remains of interglacial mammals and molluscs, whereas the underlying lower part of the sequence yielded a mammalian fauna of cold-climate character. In recent years the occurrence of an interglacial deposit clearly stratified beneath Sandford's lower, cold-climate Summertown-Radley gravel has been revealed in a pit to the south of Stanton Harcourt, in the main valley of the Thames (Briggs and Gilbertson, 1980; Briggs *et al.*, 1985; Briggs, 1988). This discovery led to the recognition of a tripartite sequence of deposits beneath this terrace, indicative of a succession of climatic episodes, from temperate to cold (periglacial) and returning again to temperate (Fig. 2.12). The earlier of these two temperate episodes has been widely attributed to a hitherto unrecognized interglacial between the Hoxnian and Ipswichian Stages (Briggs and Gilbertson, 1980; Shotton, 1983; Briggs *et al.*, 1985; Bowen *et al.*, 1989). Reappraisal of the stratigraphy of the Summertown-Radley Formation suggests, however, that the sequence is even more complex, perhaps representing five separate climatic episodes (Table 1.1).

It has generally been assumed that the cold-climate gravels at Stanton Harcourt are equivalent to those described beneath the upper fossiliferous (temperate-climate) Summertown-Radley deposits in early records. Briggs *et al.* (1985) proposed the name Stanton Harcourt Gravel for this unit. However, the upper interglacial sediments have never been observed at Stanton Harcourt, so the full tripartite stratigraphy of the Summertown-Radley aggradation has never been recorded in superposition. Recent new exposures in this terrace have consistently failed to reveal temperate deposits overlying cold-climate gravels, in the relationship described by Sandford, and none of the sites featuring in the early records have been available for study for some years. Attempts were therefore made as part of the GCR site selection programme to relocate some of the early sections, with the result that the deposits at Magdalen Grove (Fig. 2.13), originally described by Sandford (1924, 1926), were re-excavated (Bridgland, 1985a; Briggs *et al.*, 1985). Briggs *et al.* (1985) followed Sandford in attributing the deposits at Magdalen Grove to the (interglacial) upper part of the Summertown-Radley Formation, which they termed the Eynsham Gravel. Detailed consideration of the altitudinal position and fauna from this and other fossiliferous sites in the Summertown-Radley Formation raises serious doubts about this interpretation, suggesting instead that the Magdalen Grove deposits (and certain others formerly attributed to the Eynsham Gravel) were deposited during the earlier (Stage 7) temperate episode.

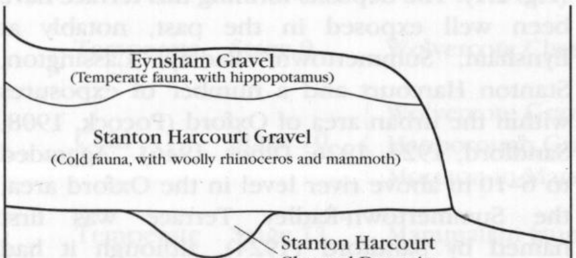


Figure 2.12 Idealized section through the Summertown-Radley Formation.

Description

Lithostratigraphical classification of the Summertown-Radley terrace deposits has already been established in Chapter 1 (Table 1.1), as follows:

Formation	Member	Climate
	Unnamed upper gravel at Eynsham	Cold
	Eynsham Gravel	Temperate
Summertown-Radley	Stanton Harcourt Gravel	Cold
	Stanton Harcourt Channel Deposits	Temperate
	Unnamed lower gravel at Summertown	Cold

This sequence has been determined from records of exposures over a lengthy period. At sites revealing only cold-climate gravels, individual members cannot be identified and the term Summertown-Radley Gravel Formation should be applied.

Descriptions of Summertown-Radley Terrace deposits appeared in the literature long before the definition of the terrace by Sandford (1924). Prestwich (1882) and Pocock (1908) both recorded various fossils from this formation, but it was Sandford (1924, 1926) who first noted that the fauna allowed a bipartite division of the aggradation. According to Sandford, bones from the lower part of the sequence (= Stanton Harcourt Gravel) were of cold-climate mammals, dominated by *Mammuthus primigenius*, with *Coelodonta antiquitatis* (Blumenbach) and *Bison priscus* (Bojanus). *Equus ferus* and *Ursus* sp. (cited as *Ursus anglicus*) were added to the faunal list by Sandford (1954).

Stratigraphically above the lower, mammoth-rich gravel, Sandford described deposits, usually finer and less ferruginous, that yielded *Palaeoloxodon antiquus*, *Dicerorhinus hemitoechus*, *Hippopotamus amphibius* L., *Bos primigenius*, *Cervus elaphus*, *Equus ferus* and other species typical of temperate environments, as well as molluscan faunas that frequently included the southern bivalve species *Corbicula fluminalis* (Müller). If the records of Sandford (1924) and Dines (1946) are combined, this upper temperate-climate deposit has been recorded at ten

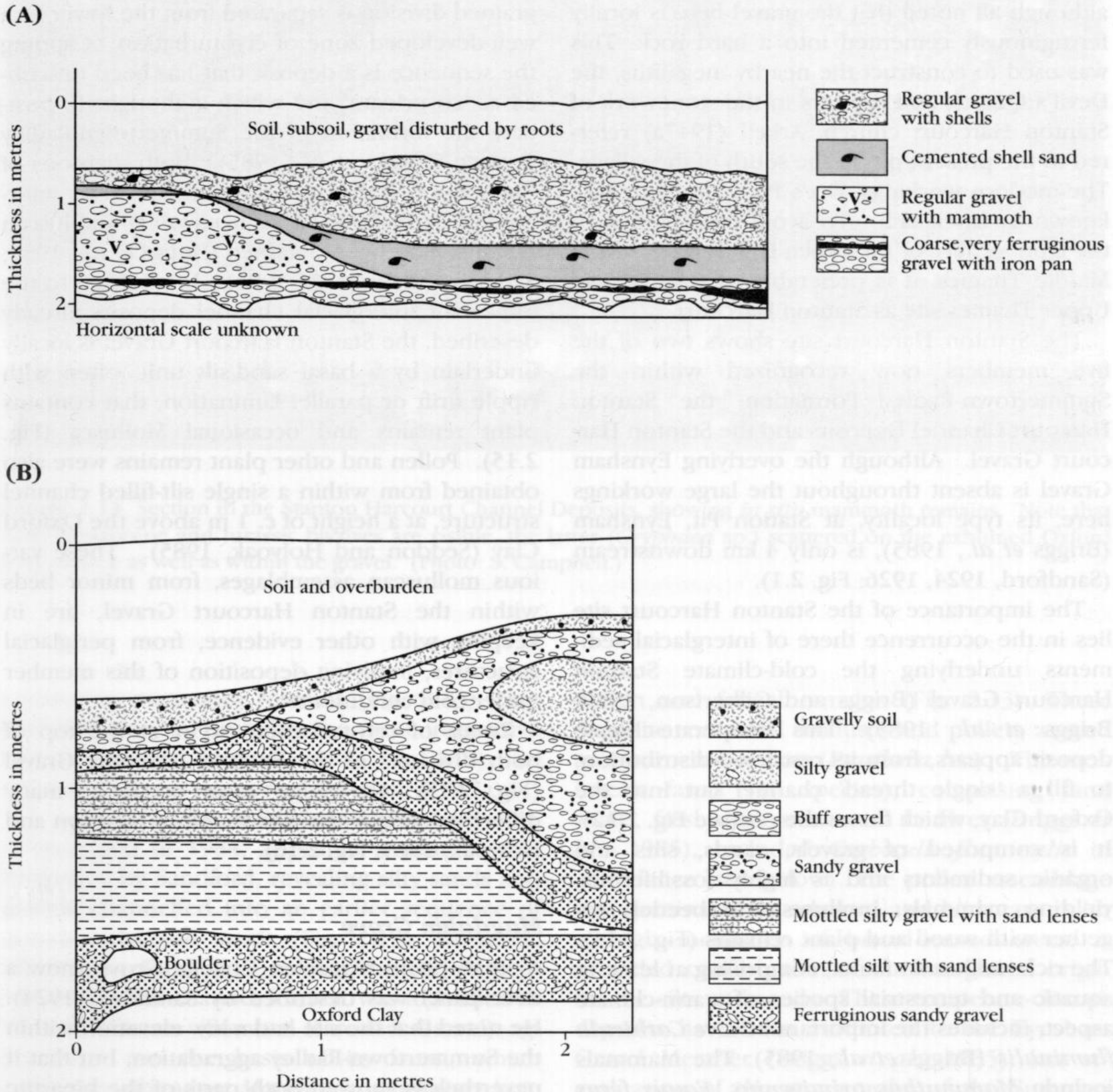


Figure 2.13 A comparison of sections recorded at Magdalen Grove, by (A) Sandford (1924) and (B) Briggs *et al.* (1985).

sites (Briggs *et al.*, 1985), of which the most important were Eynsham (Station Pit, SP 429088), Magdalen College (Magdalen Grove GCR site), Summertown (Webb's Pit, SP 503086) and Radley (Silvester's Pit, precise location uncertain). These were assigned by Briggs *et al.* (1985) to their Eynsham Gravel.

Stanton Harcourt

Erstwhile workings at Stanton Harcourt have been recorded in the various Geological Survey memoirs for the area (Pocock, 1908; Sandford, 1926; Dines, 1946). None of these authors provided any detailed description of the site, although all noted that the gravel here is locally ferruginously cemented into a hard rock. This was used to construct the nearby megaliths, the Devil's Quoits, and appears in the stonework of Stanton Harcourt church. Arkell (1947a) referred to the present pit, to the south of the village. The modern workings, Dix's Pit, exploit an area known as Linch Hill. To avoid confusion with the type locality of the Lynch Hill Terrace of the Middle Thames, it is preferable to refer to this Upper Thames site as Stanton Harcourt.

The Stanton Harcourt site shows two of the five members now recognized within the Summertown-Radley Formation: the Stanton Harcourt Channel Deposits and the Stanton Harcourt Gravel. Although the overlying Eynsham Gravel is absent throughout the large workings here, its type locality, at Station Pit, Eynsham (Briggs *et al.*, 1985), is only 4 km downstream (Sandford, 1924, 1926; Fig. 2.1).

The importance of the Stanton Harcourt site lies in the occurrence there of interglacial sediments underlying the cold-climate Stanton Harcourt Gravel (Briggs and Gilbertson, 1980; Briggs *et al.*, 1985). This temperate-climate deposit appears, from its restricted distribution, to fill a 'single thread' channel cut into the Oxford Clay, which floors the pit (see Fig. 2.12). It is composed of gravels, sands, silts and organic sediments and is highly fossiliferous, yielding mammals, molluscs and beetles, together with wood and plant remains (Fig. 2.14). The rich molluscan fauna, comprising at least 34 aquatic and terrestrial species of warm-climate aspect, includes the important bivalve *Corbicula fluminalis* (Briggs *et al.*, 1985). The mammals include *Mammuthus primigenius*, *Equus ferus* and *Panthera leo* (L.) The first two of these species were also found *in situ* near the base of the overlying Stanton Harcourt Gravel, in company with a small horn core and skull fragment from a bovid, probably *Bison* sp. (Seddon and Holyoak, 1985).

The exposures of Stanton Harcourt Gravel at the type locality (Dix's Pit) have been described in varying detail on a number of occasions (Briggs, 1973, 1976a; Goudie and Hart, 1975; Gilbertson, 1976; Briggs and Gilbertson, 1980; Bryant, 1983; Briggs *et al.*, 1985; Seddon and Holyoak, 1985). Two divisions have been recognized at Stanton Harcourt (Fig. 2.15) within this cold-climate member (Stanton Harcourt Gravel). The lower is coarser and has a maximum thickness of 1.5 m. The higher, finer-grained division is separated from the lower by a well-developed zone of cryoturbation. Capping the sequence is a deposit that has been described as 'coverloam' and which is thought to post-date the formation of the Summertown-Radley Terrace (Briggs *et al.*, 1985). Both divisions of the Stanton Harcourt Gravel contain thin, intermittent sand and silt beds from which molluscan remains have been obtained (Briggs *et al.*, 1985; Seddon and Holyoak, 1985). In addition to the important interglacial channel deposits already described, the Stanton Harcourt Gravel is locally underlain by a basal sand/silt unit, often with ripple drift or parallel lamination, that contains plant remains and occasional Mollusca (Fig. 2.15). Pollen and other plant remains were also obtained from within a single silt-filled channel structure, at a height of *c.* 1 m above the Oxford Clay (Seddon and Holyoak, 1985). These various molluscan assemblages, from minor beds within the Stanton Harcourt Gravel, are in keeping with other evidence, from periglacial structures, implying deposition of this member under cold conditions.

Zones of cryoturbation occur at the top of both divisions of the Stanton Harcourt Gravel (Fig. 2.15). Ice-wedge casts occur at many different levels within the member (Seddon and Holyoak, 1985; Fig. 2.16).

Magdalen Grove

A small pit in Magdalen College Grove (now a deer park) was described by Sandford (1924). He noted that the site had a low elevation within the Summertown-Radley aggradation, but that it nevertheless showed both parts of the bipartite sequence he had established, with a later warm-climate gravel channelled into an earlier deposit

Figure 2.14 Section in the Stanton Harcourt Channel Deposits, showing *in situ* mammoth remains. Note that both Pleistocene and Jurassic bivalves are visible, the latter (*Gryphaea* sp.) scattered on the exhumed Oxford Clay surface as well as within the gravel. (Photo: S. Campbell.)

containing mammoth remains (Fig. 2.13). He regarded this as 'probably the most instructive section as yet opened' (1924, p. 142), an opinion that was supported by Arkell (1947a).

A section at the Magdalen Grove GCR site, re-excavated in 1984, appeared similar to that illustrated by Sandford, revealing silty sands and gravels channelled into an earlier sequence of gravels, silts and sands (Fig. 2.13). However, whereas in Sandford's section the earlier deposit, below the channel feature, was identified as the cold-climate (Stanton Harcourt Gravel) aggradation (on the basis of its fauna, which comprised abundant *Mammuthus primigenius*), the beds in the same stratigraphical position in the 1984 section yielded temperate-climate pollen and faunal remains (Fig. 2.13). These deposits contained molluscs and pollen, as well as a humerus of lion (*Panthera leo*). The molluscan fauna (27 species), comprising land snails, freshwater snails and bivalves (Briggs *et al.*, 1985), included *Corbicula fluminalis* in abundance (see below). The pollen assemblage was dominated by arboreal and herb taxa, with a high incidence of broad-leaved trees; it provided confirmation of an interglacial origin for the silts and sands. These temperate-climate deposits have been attributed to the Eynsham Gravel Member (Briggs *et al.*, 1985), but re-evaluation of the stratigraphy of the Summertown-Radley Formation suggests that this may be incorrect (see below).

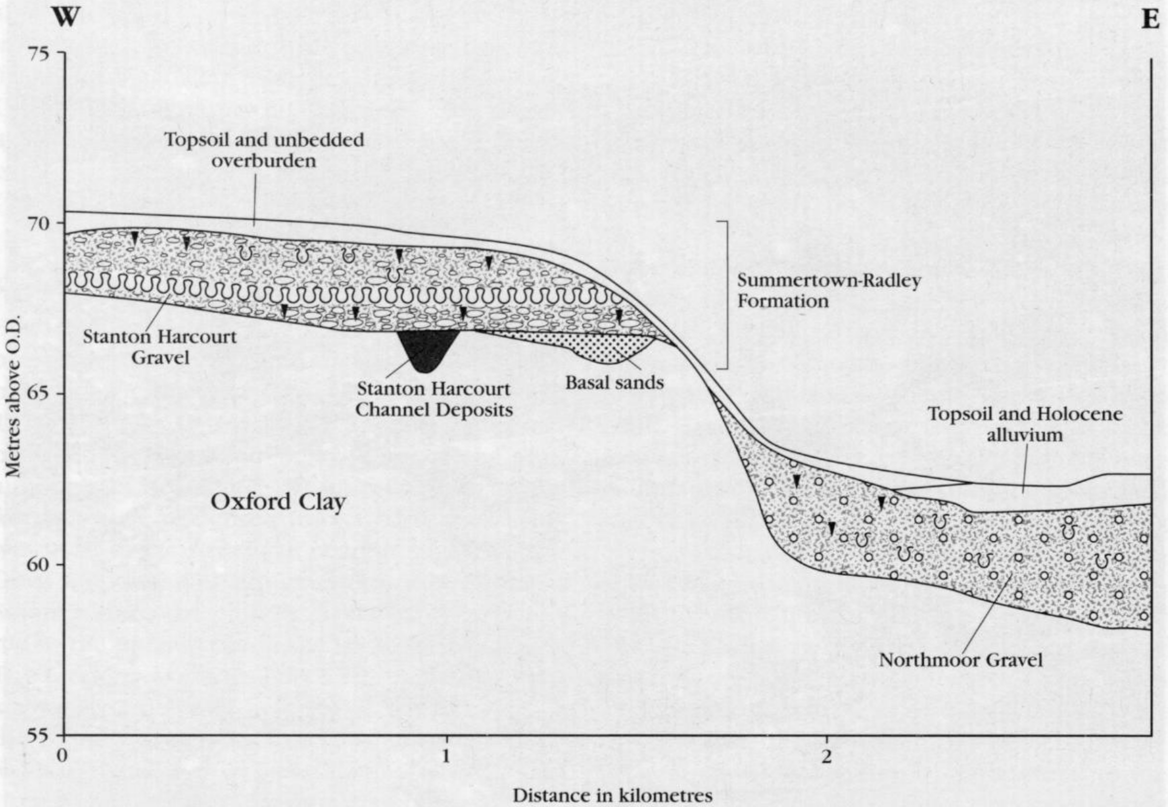


Figure 2.15 Composite section through the deposits at Stanton Harcourt (after Briggs *et al.*, 1985).

Interpretation

The combination of the geological evidence from sites such as Stanton Harcourt and Magdalen Grove, in conjunction with mapping of the distribution of the Summertown-Radley deposits and observations of their stratigraphy throughout their outcrop, has allowed a tripartite sequence to be established (Briggs *et al.*, 1985; Fig. 2.12), as follows:

3. Eynsham Gravel (temperate)
2. Stanton Harcourt Gravel (cold)
1. Stanton Harcourt Channel Deposits (temperate)

Before assessing this sequence, it is necessary to examine the bipartite division of the Summertown-Radley Terrace deposits, proposed by Sandford (1924, 1926), in which only members 2 and 3 (above) were recognized. It is important to establish that the cold-climate gravel that underlies the Eynsham Gravel is the same deposit that overlies the more recently discovered interglacial channel-fill at Stanton Harcourt. This stratigraphical relationship is fundamental to the interpretation of the Stanton Harcourt Channel Deposits as the product of a post-Hoxnian but pre-Ipswichian temperate episode.

Sandford's (1924) distinction of a lower, cold-climate aggradation (the Stanton Harcourt Gravel of Briggs *et al.*, 1985) was further underlined by the discovery, at the base of Summertown-Radley Terrace deposits at Dorchester (SU 569948), of an organic layer that yielded fossil plants indicative of a cold climate (Duigan, 1955).

One of the more significant advances stemming from recent research in the Upper Thames is the realization that the various gravels have predominantly accumulated under periglacial conditions. Earlier models tended to regard cold intervals as periods of erosion and to attribute the bulk of the deposits to interglacials, a view backed up in this region by the relatively

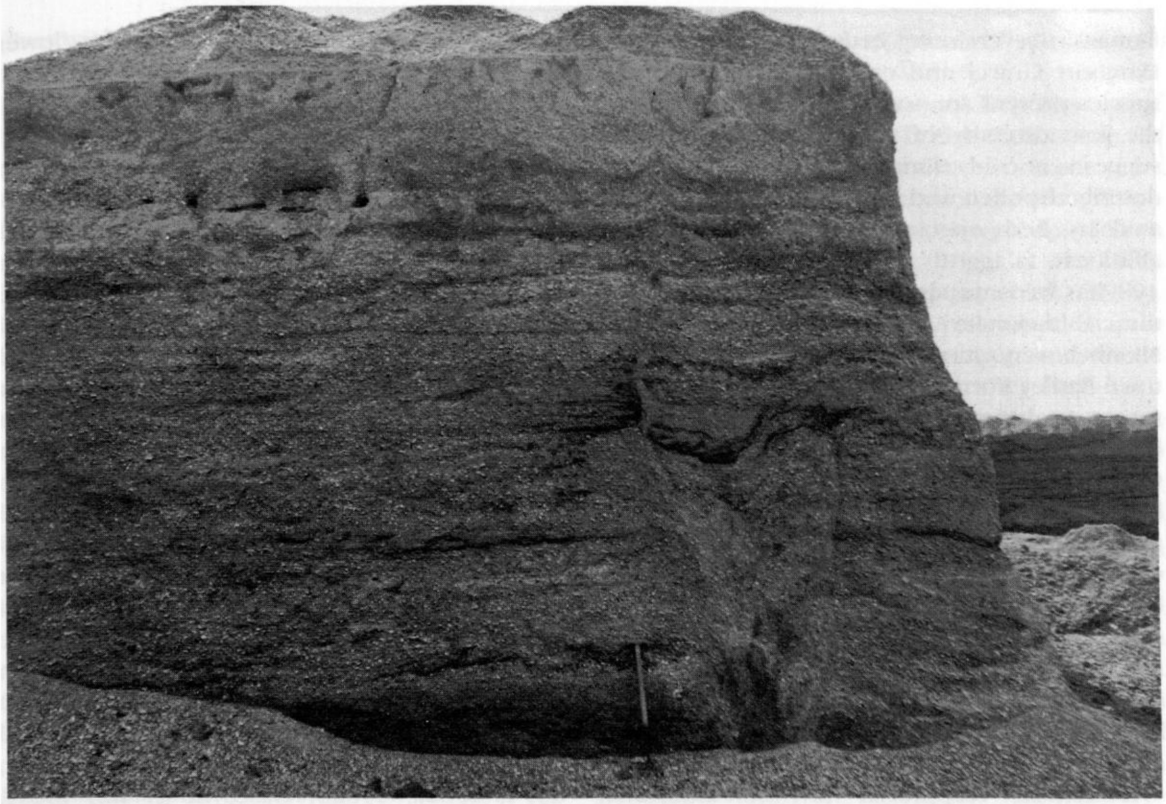


Figure 2.16 Section at Stanton Harcourt, showing an intraformational ice-wedge structure in the Stanton Harcourt Gravel. The complexity of this feature is typical of such structures at this site (see text). (Photo: D.J. Briggs.)

frequent occurrence of warm-climate faunas in the gravels. A significant move away from this view was promoted by Briggs and Gilbertson (1973), who demonstrated that the gravels underlying the Hanborough Terrace were laid down under cold conditions and concluded that the warm-climate mammalian fossils they contained were reworked (see above, Long Hanborough). Following this work, it was suggested by Goudie and Hart (1975) that a large part of the Summertown-Radley Formation was deposited under a 'fluvio-periglacial regime'. This view was based on observations at Standlake and at the present Stanton Harcourt site, which showed that at least the upper 3.5 m of the gravel is of similar character to the Hanborough Formation, suggesting a braided river origin, and that intraformational ice-wedge casts are common. Briggs (1976a) noted that the large complex ice-wedge casts that characterize the gravel at Stanton Harcourt (see Seddon and Holyoak, 1985; Fig. 2.16) are associated with festooning and that, when observed on cleared horizontal surfaces, they form a polygonal 'patterned-ground' effect. Briggs also noted that the ferruginous cementation of the gravels (see above) is typically localized within these ice-wedge cast/festoon features. The braided river origin of the gravels at Stanton Harcourt was confirmed in a sedimentological study by Bryant (1983).

Further support for the interpretation of this gravel as the product of a periglacial environment is provided by a molluscan fauna obtained from an extensive silt band near the base of the succession. This fauna was dominated by the land snail *Oxyloma pfeifferi*, with significant numbers of *Pupilla muscorum* (Gilbertson, 1976; Briggs and Gilbertson, 1980). None of the species present is indicative of particularly cold conditions, but *P. muscorum* requires an exposed, open habitat. This, and the absence of woodland species, leads to the conclusion that this silt accumulated under a climatic regime significantly cooler than that of the present. Seddon and Holyoak (1985) found similar faunas in several silty beds within the Stanton Harcourt Gravel and noted that, although the species present are not good climatic indicators, the low diversity of the assemblages strongly suggests a cold climate. These authors also described pollen and plant assemblages dominated by herb species, mostly of arctic-alpine affinities.

It has become apparent in recent years that the cold-climate Stanton Harcourt Gravel Member very much dominates the Summertown-Radley Formation, certainly in the areas of recent exposure. However, Sandford (1924) considered the upper deposit (the Eynsham Gravel) to be dominant, believing that erosion had removed much of the lower, cold-climate gravel (Stanton Harcourt Member) before the warm-climate deposit was laid down. He noted, however, that the upper deposit was frequently superimposed upon the lower with little sign of any break in the sequence, although occasionally there was evidence of channelling at its base. He illustrated channelling on a large scale at the Magdalen College site (see Fig. 2.13).

A critical reappraisal of the altitudinal relations and faunal content of the various deposits attributed to the uppermost (temperate) Summertown-Radley gravel raises a number of problems that have hitherto largely escaped attention. It appears that many attributions to this member have been erroneous. The original descriptions of the sites (Sandford, 1924, 1926; Dines, 1946) were made long before it was suspected that a further, older interglacial might be represented within the Summertown-Radley Formation (that subsequently identified in the channel deposits at Stanton Harcourt). Faunal records from the various sites in this terrace were merely combined to produce lengthy lists (for example, Kennard and Woodward, 1924) and recent authors have tended to assume, on the basis of the convincing stratigraphical descriptions by Sandford, that these assemblages were entirely derived from the upper deposit, the Eynsham Gravel of Briggs *et al.* (1985).

Eynsham Station Pit is no longer available for study, although degraded faces remain. Excavations here by the GCR Unit in 1984 failed to recover faunal remains (Bridgland, 1985a). Sandford (1924, p. 140) recorded *c.* 3 m of gravel, which was 'noteworthy for the very common occurrence of *Hippopotamus*'. He also noted that teeth of mammoth occurred at the base of the sequence, implying that his 'lower Summertown-Radley gravel' (Stanton Harcourt Gravel) was also represented at the site, making it 'one of the most important in the district' (1924, p. 141). There was faunal evidence for a cold-climate deposit beneath the hippopotamus-bearing levels at Radley and Iffley, as well as at Eynsham. Sandford (1924) also recorded a higher unit at Eynsham, separated from the Eynsham Gravel by an erosional contact, comprising *c.* 1 m of fine pebbly cross-bedded sand. This unit, devoid of fossils, may represent a post-interglacial aggradation (phase 2 of the terrace model – Chapter 1), superimposed upon the Eynsham Gravel during the early Devensian Stage (Table 1.1).

Hippopotamus amphibius is a most important species in the Late Pleistocene of Britain. It is regarded as an indicator for the Ipswichian Stage (*sensu* Trafalgar Square) since, despite the recognition of additional climatic cycles in recent years (Chapter 1), it is thought not to have lived in Britain between the Cromerian and the Ipswichian (Sutcliffe, 1960, 1964; Stuart, 1974, 1982a, 1982b; Gascoyne *et al.*, 1981). This species has been recorded from six sites in the Summertown-Radley Terrace: Eynsham, Wytham, Iffley, Radley, Abingdon and Dorchester (Sandford, 1924, 1965; Briggs *et al.*, 1985).

Many of the sites in the Summertown-Radley Formation, previously ascribed to the Eynsham Gravel Member, have yielded another species of possible stratigraphical significance, the bivalve *Corbicula fluminalis*. It has long been recognized that this mollusc has not lived in Britain during the Holocene, but it is now suggested that it was also absent during the Ipswichian Stage (*sensu* Trafalgar Square), although it has been recorded from many sites formerly regarded as Ipswichian but now considered to be older (Keen, 1990). The principal basis for this view is that there is no reliable record of *C. fluminalis* and hippopotamus occurring together in the same deposit. The Eynsham Gravel would appear to be an exception, but close scrutiny of the records reveals that, of the six sites listed above that have yielded hippopotamus, *C. fluminalis* is recorded only from Radley, where its presence was based on a single abraded fragment (Sandford, 1924; Kennard and Woodward, 1924). It seems highly likely that this was reworked. At other sites, such as Summertown, the species was found in abundance

(Prestwich, 1882; Sandford, 1924), as it is at both the Magdalen Grove and Stanton Harcourt GCR sites. None of these sites has yielded hippopotamus, although numerous other mammalian remains were found. The occurrence of abundant *C. fluminalis* and the absence of hippopotamus from these sites suggests that they represent the earlier of the two temperate intervals recognized from the Summertown-Radley aggradation, that which was first identified from the Stanton Harcourt channel. The true Eynsham Gravel yields hippopotamus but not *Corbicula* (except for derived specimens, as at Radley, reworked from the earlier interglacial member) and is therefore attributable to the Ipswichian Stage (*sensu* Trafalgar Square). It has been recognized unequivocally only at the six sites, listed above, from which hippopotamus is recorded.

Sandford (1924) recognized a lower cold-climate gravel beneath the interglacial beds with *Corbicula* at Summertown and Magdalen College. In both cases this interpretation was based on the occurrence below the *Corbicula* levels of *Mammuthus primigenius*, which is also the most common vertebrate fossil in the Stanton Harcourt Channel Deposits. At Summertown the mammoth was accompanied by horse and ox, which are also present in the Stanton Harcourt Channel Deposits, but neither site yielded woolly rhinoceros *Coelodonta antiquitatis*, the only species that appears, within the Summertown-Radley Formation, to be exclusive to the cold-climate Stanton Harcourt Gravel Member. The elevation of the Summertown site was not recorded, but that at Magdalen Grove (58.8 m O.D.) is at a low level within the altitudinal range of the formation, again suggestive of the lower, rather than the higher, interglacial member. The recorded location of the Summertown pit (see above), in the western edge of the gravel outcrop, suggests that the section there was also relatively low within the formation. These facts seemingly lead to the conclusion that the sites yielding *C. fluminalis* but not hippopotamus represent the earlier of the two Summertown-Radley interglacials and are older than both the Stanton Harcourt and Eynsham Gravels. They also suggest that faunal records from the Summertown-Radley Formation require detailed scrutiny, to determine whether cited upper or lower stratigraphical levels are correct.

The Stanton Harcourt Channel Deposits

The Stanton Harcourt Channel Deposits are of major importance in the British Pleistocene, as they have been repeatedly cited in recent years as providing critical evidence for the recognition of an additional post-Hoxnian/pre-Ipswichian interglacial (Shotton, 1983; Briggs *et al.*, 1985; Bowen *et al.*, 1989; Bridgland *et al.*, 1989). With comparable deposits at Aveley (see Chapter 4), Marsworth (Buckinghamshire) and Stoke Goldington (Buckinghamshire), they have been attributed to a temperate interval at about 180,000 years BP, which has been correlated with Oxygen Isotope Stage 7 (Chapter 1; Shotton, 1983; Bowen *et al.*, 1989).

All these sites have yielded mammalian faunas with mammoth and horse, but lacking hippopotamus, and have insect faunas dominated by the beetle *Anotylus gibbulus* (Shotton, 1983). The sediments at Aveley, Stoke Goldington and Stanton Harcourt have yielded molluscan assemblages that include *Corbicula fluminalis*. A site in the catchment of the Warwickshire–Worcestershire Avon, at Ailstone near Stratford-upon-Avon, has recently been added to this list (Bridgland *et al.*, 1989).

There has not been total agreement with the interpretation of the Stanton Harcourt Channel Deposits as being of pre-Ipswichian age, however. Gibbard (1985) did not accept that they occupy a lower stratigraphical position within the Summertown-Radley Formation. He suggested instead, following Goudie and Hart (1975), that the thick periglacial gravel at Dix's Pit post-dates the interglacial beds recognized by Sandford in the upper part of the formation. The principal reasoning behind this interpretation is that Gibbard, closely adhering to the chronology outlined by Mitchell *et al.* (1973), considered both the Stanton Harcourt Channel Deposits and the Eynsham Gravel to represent the Ipswichian Stage. He claimed support for this conclusion from thermoluminescence dating of silts within the gravel at Stanton Harcourt, which suggested an early Devensian age. This would require the gravel at Stanton Harcourt to be younger than the Eynsham Gravel. Details of two dates obtained by this method, of 91,000 (± 8000) and 93,000 (± 9000) years BP, were provided by Seddon and Holyoak (1985). These authors also cited a radiocarbon date from a similar stratigraphical level, however, that suggested a mid-Devensian age, in the region of 35,000 years BP. This alternative interpretation of the Summertown-Radley sequence raises doubts about the validity of the tripartite sequence established by Briggs and Gilbertson (1980). In support of the view that the Stanton Harcourt Channel Deposits are pre-Ipswichian, in addition to the biostratigraphical arguments already presented, are amino acid ratios recently obtained from specimens of *Corbicula* and *Valvata*. These are comparable to ratios from other sites ascribed to Oxygen Isotope Stage 7 (Bowen *et al.*, 1989).

It is ironical that, whereas the reality of extra climatic cycles within this part of the Pleistocene is now accepted by most workers, the interpretation of the Stanton Harcourt site remains controversial.

The Magdalen Grove deposits

The sediments at Magdalen Grove have provided a wealth of palaeontological information, both from the early collections and from the 1984 re-excavation. The latter provided new information from palynological studies, which have rarely been applied to deposits in the Upper Thames basin. The abundance of broad-leaved trees in the pollen assemblage (see above) argues for a temperate climate, with the occurrence of *Carpinus* and virtual absence of *Betula* suggesting the late-temperate zone (biozone III) of an interglacial (Hunt, 1985). According to Hunt, the absence of *Abies* and the presence of *Picea*, *Acer* and abundant *Carpinus* are features of the Magdalen Grove assemblage that resemble pollen biozone IpIII of the Ipswichian Stage. However, many sites that were once considered Ipswichian, but which are now widely attributed to older, post-Hoxnian but pre-Ipswichian temperate intervals, share these features. As was outlined above, the abundance of *C. fluminalis*, the absence of hippopotamus and the elevation of the deposits at Magdalen Grove suggest that they belong to the earlier of the two interglacials represented within the Summertown-Radley Formation, that correlated with Oxygen Isotope Stage 7.

If this reinterpretation can be corroborated, perhaps by the application of geochronological dating techniques (such as the analysis of the amino acid content of shells – see Chapter 1), Magdalen Grove would be the best reference site for the lower temperate-climate member (the Stanton Harcourt Channel Deposits), since at Stanton Harcourt these are buried beneath several metres of gravel and are therefore inaccessible.

Palaeolithic artefacts from Stanton Harcourt

Palaeolithic implements have been discovered in some numbers in the Summertown-Radley Terrace deposits and offer a possible insight into the approximate age of the aggradation. Sporadic finds of Acheulian hand-axes in these deposits were recorded in the early literature (Evans, 1897; Manning and Leeds, 1921; Almaine, 1922; Smith, 1922; Sandford, 1924). It later became clear that, by Upper Thames standards, a considerable wealth of artefacts occurred throughout the formation, although with the highest concentrations in the cold-climate Stanton Harcourt Gravel (Sandford, 1932, 1939, 1954; Arkell, 1945, 1947a; Wymer, 1968; MacRae, 1991). Both Sandford and Arkell originally considered this to be the earliest appearance of Acheulian implements in the Upper Thames sequence; both thought the prolific Wolvercote Channel to be later than the lower part, if not the whole, of the Summertown-Radley Formation, despite its association with the higher Wolvercote Terrace (see above, Wolvercote). However, one or two hand-axes were later recorded from the Hanborough Gravel (Arkell, 1947c; Wymer, 1968), which is therefore the oldest source of artefacts in the area. Arkell (1945) believed that the numerous worn Acheulian hand-axes found in the Summertown-Radley Terrace deposits were manufactured during a warm period prior to deposition of the cold-climate gravels identified by Sandford. Since no earlier interglacial terrace with such an abundance of artefacts had been identified in the region, he suggested that there might be a third, hitherto undiscovered, earlier division of the Summertown-Radley sequence, of interglacial origin. This suggestion by Arkell pre-empted by more than 30 years the discovery of the lower interglacial channel at Stanton Harcourt and the recognition of the tripartite climatic sequence.

According to Wymer (1968, p. 85) a hand-axe, the largest at that time from west of Oxford, was found in 1962 in the vicinity of the Stanton Harcourt GCR site. This was one of only two discoveries at the locality prior to 1982 (MacRae, 1987). Recent exposures, at Dix's Pit and other nearby workings, have been repeatedly visited by the local archaeologist R.J. MacRae, who has built up a collection of artefacts that includes nearly 50 hand-axes, including (by 1989) 13 made from quartzite (MacRae, 1988, 1989, 1991; MacRae and Moloney, 1988). In the Upper Thames, only the Wolvercote Channel and pits at Berinsfield have yielded larger numbers; those from the latter locality include finds from both the Summertown-Radley and the Northmoor Formations (MacRae, 1982).

The pits at Stanton Harcourt are therefore the most important source of palaeoliths from the Summertown-Radley Terrace. In 1986 a very large hand-axe was discovered there, which, at 26.9 cm long, surpasses the 1962 discovery by 5 cm and is claimed as the third-largest from Britain (MacRae, 1987; Fig. 2.17). Forty-two hand-axes were found at the site between 1984 and the end of 1987, but in the following two years the number retrieved greatly diminished (R.J. MacRae, pers. comm.). According to MacRae, the rate of discovery of mammoth teeth and tusks, which was high from 1984 to 1987, has declined since then in parallel with the artefacts. He reports that this change has occurred as the working faces migrated away from the area of the Stanton Harcourt Channel. This fact, as well as the association of palaeoliths

Figure 2.17 Hand-axe from Stanton Harcourt, discovered by Mr V. Griffin, the excavator driver. Some 26.9 cm long, this is believed to be the third-largest hand-axe discovered to date in Britain (MacRae, 1987). (Photo: R.J. MacRae.)

with mammoth remains (the most abundant vertebrate fossil in the channel deposits), suggests that the incidence of artefacts might be related in some way to the channel. Until recently, all the finds from Dix's Pit were from the Stanton Harcourt Gravel (MacRae, 1985, 1988; MacRae and Moloney, 1988), but a few hand-axes have now been found in the channel deposits (MacRae, 1991). The reinterpretation of the stratigraphy of the Summertown-Radley aggradation, presented above, implies that sediments accumulated during the earlier temperate interval to considerable thicknesses, such as was recorded at Summertown. Subsequently there must have been considerable erosion of these deposits in those areas where the Summertown-Radley Formation is now represented only by later sediments. At Stanton Harcourt, deposits representing the early temperate interval are preserved only as channel deposits incised into the Oxford Clay; these are truncated by the Stanton Harcourt Gravel (Fig. 2.15). The erosive nature of this contact suggests that there may have been considerable reworking of material from the channel deposits into the gravel, perhaps including mammoth remains and artefacts. This might explain a concentration of both in the Stanton Harcourt Gravel in the vicinity of the channel.

Correlation

Attempts at correlating the Upper Thames sequence with the British Pleistocene chronology were, until the new framework based on the deep-sea oxygen isotope record was established (Chapter 1), impeded by the fact that only two interglacials were recognized between the Anglian and Devensian Stages (Mitchell *et al.*, 1973), whereas post-Cromerian interglacial faunas are recorded at four stratigraphical levels within the Upper Thames terraces:

4. Upper Summertown-Radley Formation	(Eynsham Gravel)
3. Lower Summertown-Radley Formation	(Stanton Harcourt Channel Deposits)
2. Wolvercote Channel Deposits	
1. Hanborough Gravel	(derived fauna)

The similarity of the upper Summertown-Radley and Wolvercote Channel interglacial assemblages was stressed by two of the leading authorities on the Upper Thames, Sandford (1924, 1932) and Arkell (1947a). Both authors concluded that these deposits were of comparable ages, despite the fact that they occurred in association with different terraces (see above, Wolvercote). Both also considered the lower cold-climate Summertown-Radley aggradation (Stanton Harcourt Gravel) to pre-date the Wolvercote Channel. Sandford (1924) was impressed with the similarity of the fauna in the upper Summertown-Radley sediments with that from Crayford, implying a correlation with the Taplow Terrace (see Chapter 4, Lion Pit). Sandford (1932) later changed his opinion, correlating Crayford with the Wolvercote Channel Deposits. In this later view, which was supported by Arkell (1945, 1947a), he favoured a correlation of the Eynsham Gravel with the Boyn Hill Terrace at Swanscombe, implying a Hoxnian age. Both Sandford and Arkell were strongly influenced by the first appearance of palaeoliths in the Upper Thames at this level (see above). However, Breuil (Appendix to Sandford, 1932) attributed the upper Summertown-Radley (hippopotamus-bearing) sediments to the 'Riss-Würm interglacial' (= Ipswichian Stage), again proposing a correlation with Crayford. With the recognition, in more recent years, that *Hippopotamus amphibius* was absent from Britain during the Hoxnian, most subsequent writers placed the upper Summertown-Radley deposits in the Ipswichian (for instance, Bishop, 1958; Tomlinson, 1963). Bishop (1958) regarded the Wolvercote Channel as Hoxnian and therefore considerably older. This model was adopted by Wymer (1968), who was then able to claim the Wolvercote Channel as a possible source for the Summertown-Radley implements.

Two recently suggested correlations are worthy of note, being based on attempts to trace the terraces from the Oxford area to the lower reaches of the river. In the first, Evans (1971) linked the Summertown-Radley Terrace with the Upper Floodplain Terrace of the Middle and Lower Thames, claiming support from the occurrence of *Hippopotamus amphibius* in the former; this species occurs beneath the Upper Floodplain Terrace (Kempton Park Formation) at Trafalgar Square (Table 1.1). Gibbard (1985) considered that the Summertown-Radley deposits equated with a variety of deposits downstream of the Goring Gap, ranging in age from late Saalian to Early Devensian. He correlated the terrace not with the Upper Floodplain (Kempton Park Gravel) aggradation, but with his Early Devensian Reading Town Gravel. It is argued in Chapters 1 and 3 that the latter is, in fact, based on a misidentification by Gibbard of the Taplow Gravel in the Reading area. Therefore Gibbard's conclusions actually imply correlation between the Summertown-Radley and Taplow Formations.

The Summertown-Radley sequence provides critical evidence in support of the correlation schemes presented in this volume (Chapter 1) for relating the sequence in the Upper Thames to that elsewhere in the basin and to the deep-sea oxygen isotope record (Fig. 2.18). In these schemes the Stanton Harcourt Channel Deposits are taken as an important stratigraphical marker for Oxygen Isotope Stage 7 and the Eynsham Gravel is assigned to the Ipswichian (*sensu* Trafalgar Square – Substage 5e). Correlation between the Upper and Middle Thames, based on the reconstruction of terrace long-profiles (Fig. 1.3), indicates that the Summertown-Radley Formation is the upstream equivalent of the Taplow Gravel. The latter unit also incorporates temperate-climate sediments attributed to Stage 7, particularly in its Lower Thames equivalent, the Mucking Gravel (see Chapters 1 and 4). As stated above, the Trafalgar Square Ipswichian sediments are found beneath a later aggradation, the Kempton Park Gravel (Fig. 2.18b), that is ascribed to the Devensian Stage (Gibbard, 1985). The Kempton Park Gravel, which gives rise to the 'Upper Floodplain Terrace' of Dewey and Bromehead (1921), cannot be traced further upstream than Marlow (Gibbard, 1985; Chapter 3; Fig. 1.3). This suggests that the rejuvenation event that separated the aggradation of the Kempton Park and Taplow Gravels was restricted to that part of the valley downstream from Reading (Fig. 2.18b). It is interesting to note that Sandford (1965) claimed that the Goring Gap was the site of a major 'nick point', which is the situation now envisaged during the deposition of the Kempton Park Gravel.

This interpretation explains the unusual incidence, in the Summertown-Radley Formation, of two full climatic cycles represented within a single aggradational sequence. The uppermost, unfossiliferous gravel at Eynsham, recorded by Sandford (1924; see above) may represent aggradation at the beginning of the cold half-cycle that followed the Ipswichian (*sensu* Trafalgar Square). The lower gravel at Summertown, underlying deposits containing *Corbicula*, may also represent a cold-climate deposit, presumably representing Oxygen Isotope Stage 8. In terms of the model for terrace formation outlined in Chapter 1, the full Summertown-Radley sequence would therefore be as shown in Table 2.3 (see also Fig. 2.18a).

Rejuvenation to the Northmoor Gravel level occurred during the mid-Devensian (see above, Introduction), perhaps as part of the incision that led to the separation of the Kempton Park and Shepperton Formations in lower reaches of the Thames catchment (Table 1.1). Information regarding the timing of this rejuvenation in the Upper Thames may be obtained in the near future from a recently discovered site in the Northmoor Gravel, at Cassington. Preliminary investigations suggest that organic and shelly channel-fills from the lower part of the sequence here may represent one or more of the interstadial episodes of the early/middle Devensian

Table 2.3 Stratigraphical subdivisions of the Summertown-Radley Formation.

Lithostratigraphical unit	Terrace model (Chapter 1)	Oxygen Isotope Stage
Uppermost gravel at Eynsham	Phase 4	5d-2?
Eynsham Gravel Member	Phase 3	5e
Stanton Harcourt Gravel Member	Phases 2 and 4	6
Stanton Harcourt Channel Deposits	Phase 3	7
Gravel underlying interglacial deposits at sites with *Corbicula*	Phase 2	8

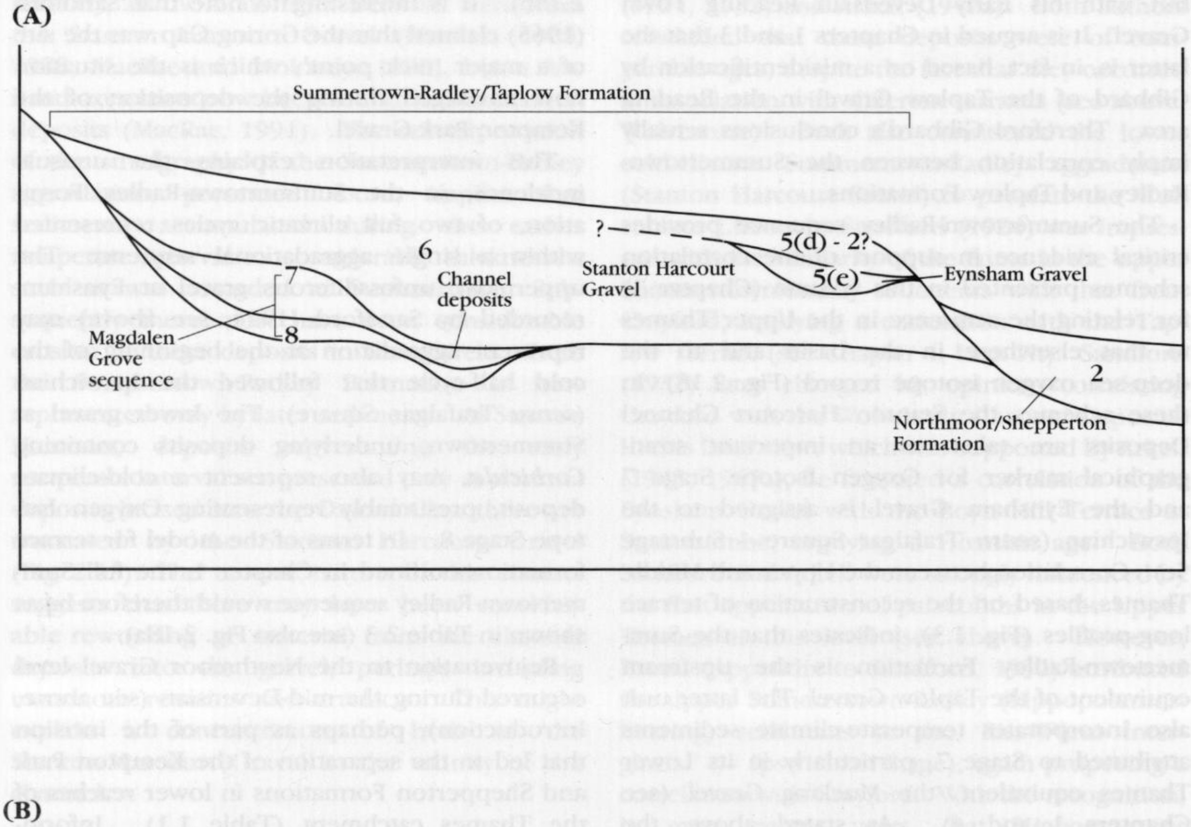


Figure 2.18 Comparison of terrace stratigraphy upstream (A) and downstream (B) from the limit of the Kempton Park Formation. Numbers 2–8 indicate oxygen isotope stages.

(D. Maddy, pers. comm.). This may prove difficult to reconcile with the Middle Thames sequence, in which these temperate episodes are represented within the Kempton Park Formation. It appears that rejuvenations may have occurred at different times in the Upper Thames and Middle Thames valleys.

Summary

The GCR sites at Stanton Harcourt and Magdalen Grove combine to provide coverage of the complex of deposits that underlies the Summertown-Radley Terrace of the Upper Thames. Considerable controversy surrounds the interpretation of this sequence, to the extent that there is disagreement on the subdivision of the deposits and the number of climatic cycles represented. The resolution of these problems is fundamental to an improved understanding of the Upper Thames sequence, which is clearly of considerable importance, given its position between the London Basin and the Midlands. Further research is required to address these difficulties. In particular, additional attempts to date the various sediments would be of value; the cold-climate Mollusca from the Stanton Harcourt Gravel could be suitable for geochronological dating by amino acid analysis. Similar analyses of shells from Magdalen Grove might give support (or otherwise) to the view that the deposits here are of the same age as those from the Stanton Harcourt channel-fill.

Conclusions

The Stanton Harcourt and Magdalen Grove sites provide an insight into a complex sequence of deposits forming a major terrace in the Upper Thames basin (the Summertown-Radley Terrace). The gravels that form the bulk of this sequence were laid down under intensely cold (periglacial) conditions, as is demonstrated at Stanton Harcourt both by structures such as ice-wedge casts and by the shells of cold-climate snails, which occur in silt bands interbedded with the gravels. It has long been recognized, from a number of sites in the region, that parts of the sequence yield interglacial faunas. Early records suggested that they were generally from the upper part of the gravel. They have been widely attributed to the last (Ipswichian) interglacial (around 125,000 years BP), largely on the basis of the occurrence of hippopotamus, which is highly characteristic of that interval.

The more recent discovery of a fossiliferous channel-fill beneath the gravel at Stanton Harcourt has provided critical evidence to show that two separate interglacials are represented within the Summertown-Radley Terrace sequence. This has also been a key site in establishing that the earlier of these interglacials is additional to the sequence of climatic events recognized hitherto in Britain and for its correlation with the oceanic record of Oxygen Isotope Stages, in which it is believed to represent Stage 7 (*c.* 200,000 years BP). The Magdalen Grove deposit has been widely regarded as an example of the upper, last interglacial element of the Summertown-Radley sequence. However, a reconsideration here of the evidence from this and other associated sites now suggests that it is also of Stage 7 age. It is further concluded that five different climate episodes are represented within the Summertown-Radley sequence, respectively cold, warm, cold, warm and cold.