Pleistocene geology of the Palaeolithic sequence at Redhill, Thetford, Norfolk, England

P. L. Gibbard[1], R. G. West[2], A. Pasanen[1,3], †J. J. Wymer[4], S. Boreham[1], K. M. Cohen[5] & C. Rolfe[1]

GIBBARD, P. L., WEST, R. G., PASANEN, A., †WYMER, J. J., BOREHAM, S., COHEN, K. M. & ROLFE, C. 2008. Pleistocene geology of the Palaeolithic sequence at Redhill, Thetford, Norfolk, England. *Proceedings of the Geologists' Association*, **119**, 175–192. The Pleistocene river terrace deposits in the Little Ouse valley at Redhill are described and related to earlier records. Lowestoft Formation (Anglian-age) glacial deposits underlie the interfluve area into which the valley was excavated, whilst the present valley is underlain by Holocene alluvial sediments beneath the modern river floodplain. The sediments beneath the Redhill terrace represent deposition in a gravel-bed braided-type stream. Ground Penetrating Radar (GPR) survey clarifies the internal structure, areal distribution and relation of the sediments to bedrock in the local area. The sediments are overlain by aeolian 'cover sand'. The valley sides provided a source of chalk and flint, the latter exploited locally by Palaeolithic humans, as indicated by the prolific finds of palaeoliths from the sediments. Contemporaneous periglacial conditions are indicated by putty chalk, silty sand and associated sharp flint pebbles and diamicton-like coarse gravel with highly angular clasts, which was interbedded with the fluvial sediment. These materials, together with the artefacts, were soliflucted onto the river braidplain. The Redhill artefact assemblage includes Late Middle Acheulian pointed and sub-cordate hand-axes. Comparison of the artefact and vertebrate assemblages with those from the River Thames' sequence shows a striking similarity to those recovered from the Lynch Hill/Corbets Tey Member (late Middle Pleistocene Wolstonian Stage; Marine Isotope Stages 10–8). This appears to represent a significant period of human occupation of lowland Britain.

Key words: Little Ouse, river, fluvial, Wolstonian, artefacts

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1. INTRODUCTION

Extensive spreads of Quaternary fluvial sediments occur throughout eastern England. Whilst substantial investigations have been undertaken in this region on older pre-glacial formations and, particularly, on valley systems such as that of the River Thames, surprising little is known about the evolution of the extensive post-Anglian-age deposits in the region. The importance of these sequences arises not only from their potential environmental significance but also from their contained archaeology, many localities having yielded abundant artefactual assemblages over the last two centuries. This is the case of the fluvial deposits in the Little Ouse valley in western Norfolk.

In the mid-nineteenth century the valley gravels of the Little Ouse between Thetford and Brandon became well known as a source of some of the earliest finds of Palaeolithic implements in Britain. Here, a series of gravel and sand spreads, underlying terrace surfaces within the Little Ouse valley, are shown on the original Geological Survey map (the area has not been mapped since but is currently being remapped by the British Geological Survey at the time of writing). At least three levels of gravels and sands were identified within the valley, itself cut into Lowestoft Formation glacial deposits which form the interfluves in the district. The valley is floored by alluvial sediments that underlie the modern river floodplain.

The Palaeolithic implements recovered from a number of gravel pits worked on the lower slopes of the valley were summarized by Wymer (1985; 1999). One of the most prolific sites was Redhill, west of Thetford on the north (Norfolk) bank of the river (Fig. 1a). This site, the importance of which is indicated by it having been described in detail by Evans

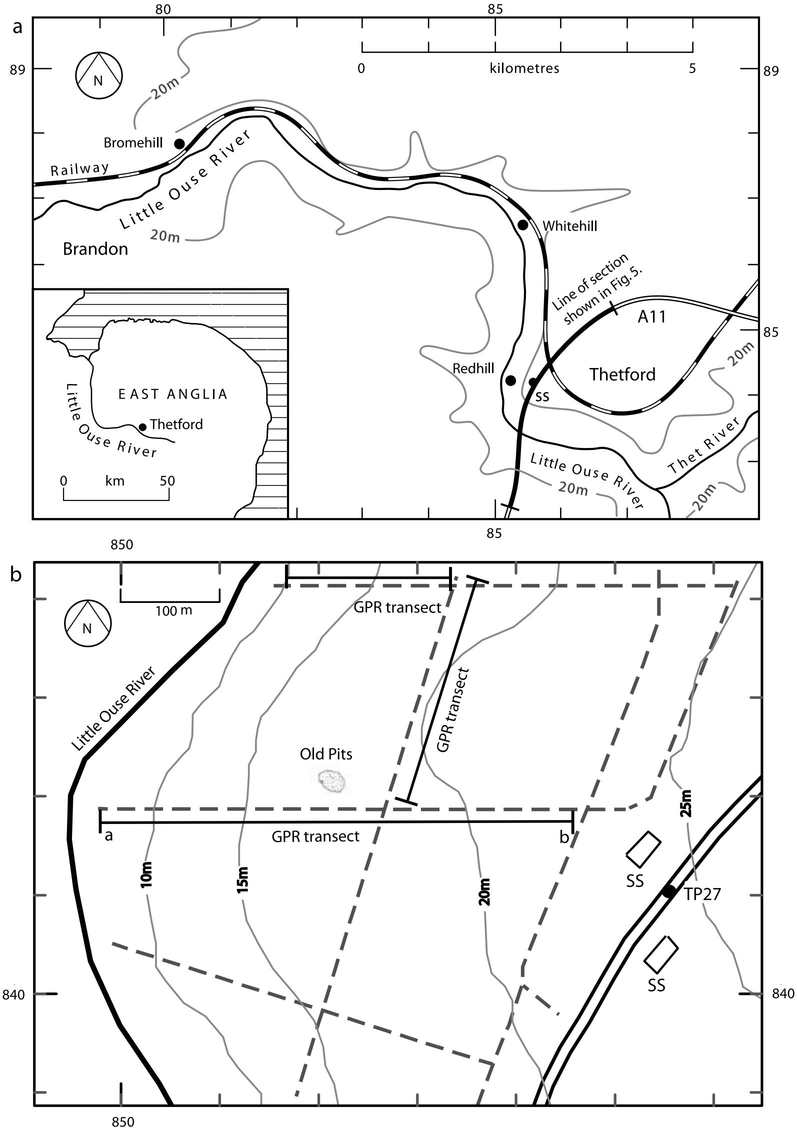


Fig. 1. (**a**) Location map showing localities mentioned in the text; ss, A11 service station. (**b**) Plan of position of levelled profile (a–b) and ground penetrating radar (GPR) transects at Redhill. TP 27, trial pit of A11 site investigations (for details, see Appendix); dashed lines indicate forest rides.

(1897, pp. 551–555) and summarized more recently by Wymer (1985, pp. 113–114) and Roe (1981, pp. 212–213), ceased being worked by the end of the nineteenth century. However, exposures were still available when the site was visited by Paterson in 1934 during investigations for his thesis. In the period intervening between this and Wymer's investigations, the locality became hidden by dense reforestation and this led to the site's position being located elsewhere in Wymer's (1985) review.

The geology and location of this site was given clearly by one of the early investigators of the Little Ouse gravels and their archaeology, the geologist J. W. Flower (1867, 1869). He also gave a section across the Little Ouse valley, showing the terrace resting on Chalk and the position of the Redhill pits in the terrace. H. Prigg (aka Trigg) (1869) also described deposits related to the terrace at Redhill, noting the provenance of palaeoliths in the section he gave. 'No less than 200 have been found at Red Hill alone during the past ten months'.

These early discoveries by Flower and Prigg were reported and discussed by Evans (1897) and described in detail by Wymer (1985). T. T. Paterson (1942) made

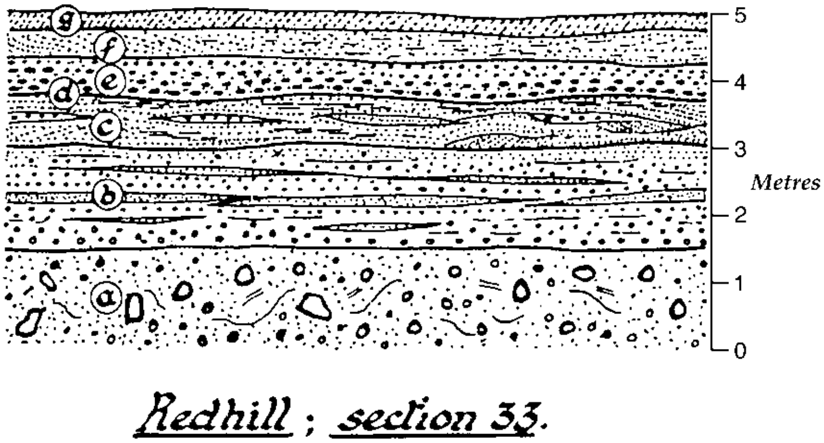


Fig. 2. Section at Redhill in the 1930s, drawn by T. T. Paterson (1942). See text for details.

an extensive survey of the Pleistocene geology of the Breckland, including an account of the stratigraphy at Redhill. He noted that Flower's terrace extended downstream from Thetford for almost 1.5 miles. He commented that the terrace

> lies 25 to 30 feet above the river and is easily seen from behind the golf club house on the west side of the river. Below it, there runs a narrow 10 foot terrace some 30 to 40 yards wide, and higher, a kind of shelf about 40 to 50 feet above the river is cut into the Chalk. This shelf is not continuous but is well marked behind the Heath Strip a mile form Thetford Bridge.

In relation to the Redhill gravel pits, Paterson wrote that

> These pits have been long disused and though they were originally dug to 15 feet, only about 8 feet can now be seen. The following section is a combination of those recorded by Flower and Prigg, which are in accord, and the present exposures:

(h) Dirty white and greyish brown soil.
(g) Podsol.
(f) On top of a well-marked junction a fine gravelly wash with white pebbles, up to 2 feet.
(e) Heavy gravel band of fairly large white flint pebbles with coarse sand and some few pebbles up to three feet. This deposit is very like low terrace gravels in most parts of the river systems of this countryside.
(d) A junction well-defined owing to the sudden change in character of the deposits, possibly a disconformity.
(c) Current-bedded yellow sand, with lenses of gravel and seams of fine clay, 5 to 7 feet. Bunter erratics.
(b) Gravel with rolled and subangular flints in an ochreous sandy matrix, beds and lenses of sand and silt, chalky, 6 to 9 feet. In a sandy bed Evans (1897) recorded shells of *Helix*, *Bythinia*, *Cyclas, Pisidium, Ancylus and Succinea* and also that bones of mammoth, ox, horse and stag have also been recorded. The exact provenance of these fossils in relation to the present exposures is unknown.
(a) Basal conglomeratic layer with large angular cobbles of flint and masses of chalky stuff, interstitial chalky sand stained ochreous, 6 to 9 feet. This description is strongly reminiscent of that of a solifluxion deposit. Most of the worn artefacts come from this layer.

Paterson's drawing of the section is shown in Figure 2.

In the course of an extensive field survey of the Little Ouse river by the authors, relying on descriptions of sites by nineteenth-century authors, in particular Flower's (1867) accurate description of the location of the Redhill pits, led to their rediscovery in 2004 in the southern part of Abbey Heath. A re-investigation of the stratigraphy at one of the pits and its relation to the local geology is reported in this paper, together with comments on the emplacement of the palaeoliths and their association with the evolution of the Little Ouse valley. This is followed by a provisional attempt to place the extensive Lower Palaeolithic artefact assemblage from the Redhill site into its local geological context and to determine its significance to the Quaternary stratigraphical sequence in the region.

2. GEOLOGY

The Pleistocene deposits at Redhill are today exposed in a series of overgrown shallow pits (3–4 m deep) that now occur within the Forestry Commission plantation ([TL 851 842]; Figs 1a, b). An initial exploratory borehole (1) was put down adjacent to the pits. This borehole proved a sequence of horizontally bedded medium sand in the basal 35 cm overlain by orange stratified sand with small flint fragments up to 5 cm in

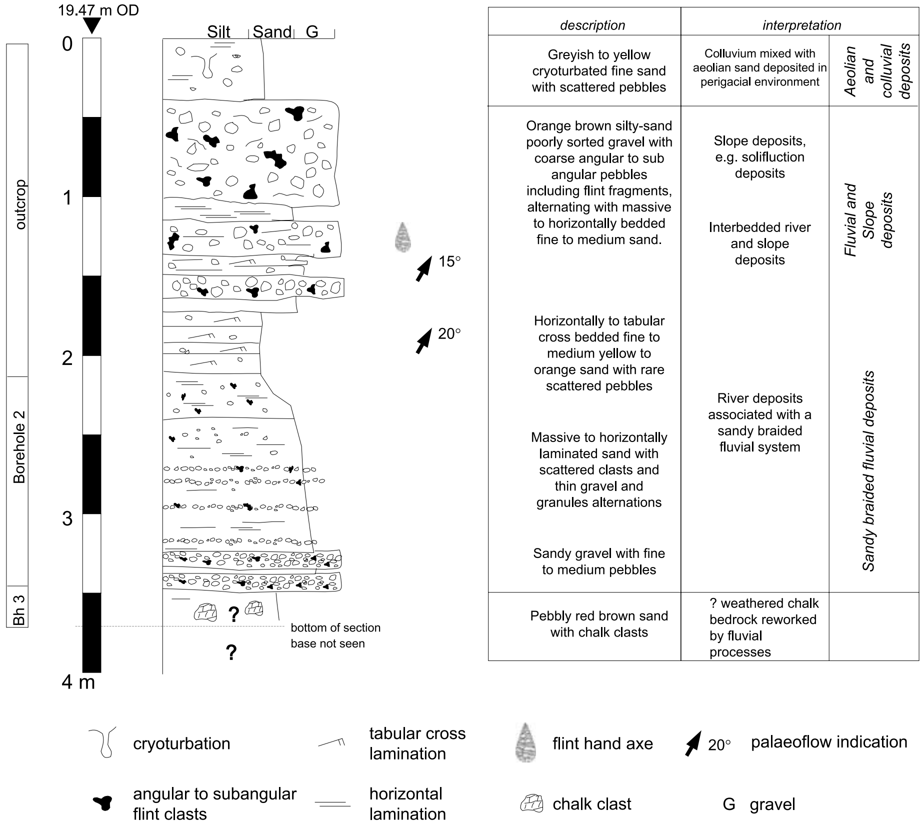


Fig. 3. Composite sediment log showing the stratigraphy and interpretation at the Redhill site in November 2004.

diameter continuing up to the surface, i.e. 40 cm and overlain by red stone-free medium sand 43 cm thick. The boring was stopped on large angular flints at 118 cm. (for details see Appendix).

Subsequent hand excavation within the largest of the pits [TL 8520 8422] in November 2004 exposed 2.30 m of *in situ* deposits (Fig. 3). The sequence was extended a further 1.40 m by boring (borehole 2) in the base of the excavations, but was not bottomed onto bedrock. However, borehole 3, 7 m west of borehole 2, reached sediment containing abundant chalk at 160 cm below the base of the pit. The lowermost sediment encountered in this borehole consisted of over 30 cm of pebbly red brown sand with occasional chalk clasts, beneath 30 cm of orange fine to medium gravel predominantly of angular flint in a very coarse sand matrix, the clasts ranging predominantly from *c.* 0.5–1 cm in diameter (in borehole 2). This is overlain by orange iron-stained poorly sorted massive to horizontally laminated silty fine sand that contains scattered small pebbles. It is overlain by horizontally to tabular cross-bedded medium sand, the tabular cross-bedded units each *c.* 10 cm thick. Palaeocurrent measurements from the sand indicate flow towards 020°. This unit is truncated by a yellow pebbly coarse gravel supported in a medium sand matrix, 13 cm thick. Next a complex unit of tabular and horizontally cross-bedded medium gravel is present, with isolated large clasts in a sand matrix that passes upwards into tabular cross-bedded silty sand with isolated pebbles. Here palaeocurrent measurements indicate a flow towards 015°. This sand is again truncated by 14 cm of diamicton-like medium to coarse gravel in an abundant sand matrix with large, highly angular flint clasts; a hand-axe was recovered from these sediments at 125 cm. Horizontally bedded sand 13 cm thick is conformably draped over the underlying gravels and this is unconformably overlain by a further 60 cm of coarse angular to subangular poorly sorted gravel similar to that beneath. The sequence is capped by 40 cm of cryoturbated greyish-yellow silty sand with occasional scattered flint pebbles that rests on a sharply defined unconformable base. This material, interpreted as colluvium, may be partially of anthropogenic origin since it was absent from the adjacent borehole 1.

These descriptions closely resemble those by previous workers – Prigg, Flower, Evans and Paterson. Of particular interest is the section from one of the pit exposures illustrated by Paterson (1942, section 33: Fig. 2). The figure clearly illustrates that the strata

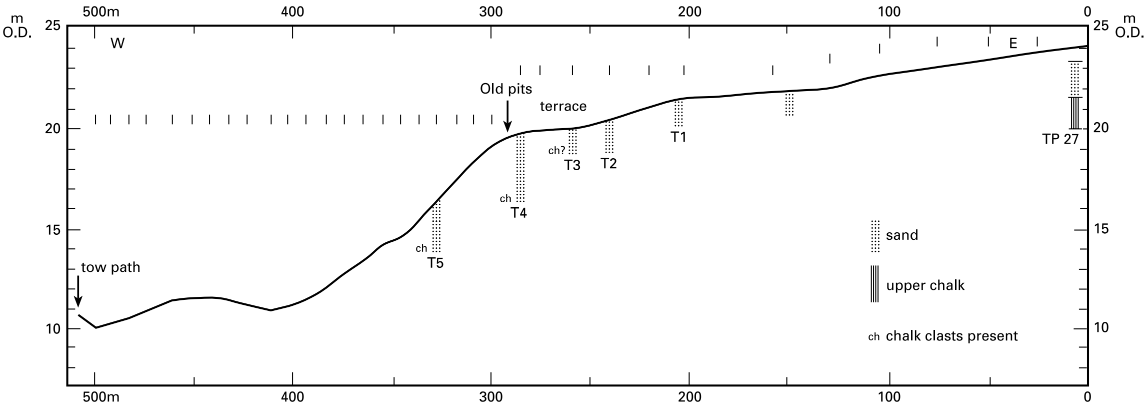


Fig. 4. Profile at Redhill along line a–b (Fig. 1b), levelled to Environment Agency Gauging Station at No. 2 Staunch, Little Ouse River, showing position of nineteenth century pits. TP 27, trial pit of A11 site investigations; ch, chalk.

were variable in three dimensions. The units he illustrates, especially unit b, clearly show horizontally bedded gravels with interbedded sand-filled channel-like forms of a scale similar to those encountered in the 2004 exposures (i.e. 5–10 cm thick). The overlying unit c also shows typical channel-like features, again of sand and interbedded gravel, showing tabular cross-bedding structures indicating a predominantly northward flow direction. It is interesting to note that, unlike the 2004 exposure, the deposits continue to the surface as predominantly horizontally bedded stoneless sand, as encountered in the exploratory borehole 1.

These old records unequivocally demonstrate that the sequence, although somewhat variable internally, is broadly consistent across the immediate terrace spread. In order to confirm this conclusion, a transect of boreholes was put down along the forest-ride track close to the small workings in July 2005 (Fig. 1b). These boreholes, labelled T1–5 (Fig. 4 and Appendix) prove that the gravel and sand sequence rests on Chalk bedrock but at variable level. In boreholes T1–T3 the Chalk is encountered consistently at 19.18 m, 18.95 m and 18.83 m OD, respectively, but in boreholes 4 and 5 the base falls to below 16.24 m and 13.71 m OD, respectively. The latter two localities are sited on the valley slope and therefore the effect of bedrock dissolution and post-depositional slippage of sediments must be borne in mind. The former bedrock surface levels at *c.* 19.00 m OD indicate that the general total thickness of the gravel and sand unit is *c.* 4–5 m where it has not been modified by later post-depositional slope processes.

The sedimentary sequences proved in boreholes T1–5 all show similar details to those recorded in the exposures, with considerable internal variability of interbedded bedded gravel and sand sequences, but of consistently similar bed thickness, scale, texture and sedimentary structure. Of particular interest is the repeated occurrence of 'putty chalk', granular, crumbly chalk clasts in a putty-like matrix of small granular chalk, often with an admixture of sand and/or flint clasts. This material, often in the form of thin beds or laminae (1–30+ cm thick) was repeatedly met in the basal portions of the borehole sequences close to the Chalk bedrock base. Isolated chalk clasts were also recorded in gravel or sand, e.g. in the lower 65 cm of borehole T1. Repeatedly capping the sections is a medium sand, often red brown to orange brown in colour and containing varying numbers of angular, granular flint clasts. This sand, exactly similar to that found in the exploratory borehole 1 and presumably in previous sections such as Paterson's (1942, section 33, beds f/g; Fig. 2), appears to underlie the entire area and may be associated with local subdued 'dune-like' landforms. It may represent a later reworking of the surface material by subaerial, almost certainly aeolian processes.

A remarkably similar sedimentary sequence is also shown by the commercial boreholes undertaken for the Thetford Bypass road construction where the pebbly silty sand seen in the section occurs beneath a degraded terrace surface at *c.* 25 m OD, north of the River Little Ouse valley (Fig. 5). Here the intermediate position of the terrace sequence is clearly seen resting on Chalk. A thick sequence of Anglian glacial diamicton and associated sorted sand and gravel (Lowestoft Formation) underlies the interfluve area at the extreme northern end of the section (Fig. 5), whilst the present valley is underlain by alluvial sediments beneath the modern river floodplain. The whole sequence rests on bedrock Chalk throughout.

3. PEBBLE LITHOLOGY

A sample was taken for a pebble lithological count from level 106–130 cm in the section (Fig. 3 and Appendix) to characterize the gravel component assemblage. The count, based upon (16–8 mm size range: 454 pebbles), comprises 96% local-district

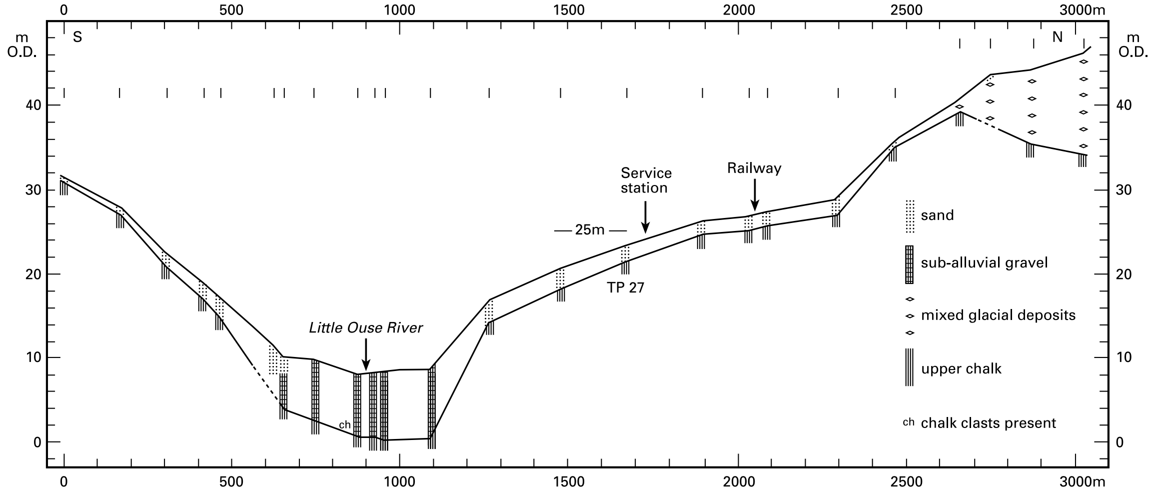


Fig. 5. Transect across the Little Ouse valley, west of Thetford, based on exploration boreholes and trial pits for the A11 Thetford bypass route. The position of these is shown in Figure 1b. The data are taken from the Site Investigation Report (May Gurney Technical Services Ltd, 1983).

lithologies (i.e. 91.6% angular flint, 2.2% nodular flint, 0.4% chalk, 1.1% sandstone, 0.4% mudstone, 0.4% concretions) and 4.0% extra-regional exotics, (i.e. 2.0% quartzite, 1.3% quartz and 0.7% igneous and metamorphic rocks). The latter, and potentially a proportion of the former, are almost certainly derived by reworking of local glacial sediments. The remainder derives from local bedrock or pre-existing fluvial deposits.

4. GROUND PENETRATING RADAR INVESTIGATION

Ground penetrating radar (GPR) is a powerful, non-intrusive electromagnetic technique for revealing sedimentary structures in the shallow subsurface. The physical basis of the GPR method is given by Annan & Davis (1976) and Davis & Annan (1989) among others. The propagation and reflection of the electromagnetic waves is similar to acoustic waves. Therefore, a similar approach to that for seismic stratigraphy (Roksandic, 1978; Sangree & Widmier, 1979) can be used for GPR interpretation. Radar stratigraphy is based on the recognition and interpretation of the radar surfaces (bounding surfaces), radar facies (bed assemblages) and radar packages (geometry of the deposits) (Neal *et al.*, 2002). The principles of radar stratigraphy are given by Gawthorpe *et al.* (1993) and later reviewed by Neal (2004).

The GPR studies undertaken in the Red Hill area were performed in May 2007 and comprised three GPR transects (cf. Fig. 1b). The data collection parameters and post-processing steps used for the GPR transect a–b are shown in Table 1. The radar equipment used is incapable of common mid-point survey. Therefore, the relative dielectricity value used for the depth conversion was estimated by fitting the borehole data to major radar surfaces. Two boreholes, T1 and T5, were feasible for the estimation. The boreholes do not continue to the Chalk bedrock and, therefore, the estimated relative dielectricity value used in the depth conversion is valid only for sediments above the Chalk bedrock. The radar equipment did not have a measuring wheel either and, therefore, a time trigger was used in the data collection. When using a time trigger, the towing speed of the radar antenna should be constant. Minor variations in the towing speed causes the topographical correction and borehole locations to be inaccurate and that is thought to explain why the radar reflections do not show similar sequences to those encountered in borehole T4. However, a similar sequence can be found 10 m further west in the radar transect showing multiple diffraction hyperbolae which are thought to be caused by gravel clasts also recorded at the bottom of borehole T4.

The processing parameters (cf. Table 1) were chosen by using the well-established parameters for a 100 MHz antenna and subsequently adjusting them to give the best possible view of the radar reflections. Migration was not used in post-processing because of the estimated large difference in relative dielectricity values between the Chalk bedrock and the sediments above it. In addition, diffraction hyperbolae were left in the radargram to aid the identification of clasts in the sediment and interpretation of the depositional environment.

The GPR transect a–b and its interpretation are presented in Figure 6. The transect is 500 m long and it follows the levelled profile a–b seen in Figures 1 and 4. Seven different radar facies (RF) and one major radar surface (RS) were interpreted from the GPR transect a–b and are described in Table 2. Other radar surfaces above RS 1 and only major radar surfaces below RS 1

Table 1. Ground penetrating radar data collection information and processing steps.

Data collection parameters	
Transect	a–b
Figure	6
Location	Red Hill, Thetford, Norfolk
GPR unit	Malå Geoscience, Ramac X3M
Data logging	Panasonic Toughbook CF-29 with Malå Geoscience GroundVision software
Survey type	Common offset
Antenna centre frequency	100 MHz
Antenna separation	1 m
Mode of data collection	Continuous, time trigger, radar was towed by foot
Stacking	2
Post-processing steps	
1. Data editing	x
2. Relative dielectricity value for depth conversion	12
3. Topography correction	Levelling
4. Set time-zero	x
5. Amplitude zero-level correction	x
6. Background removal (scans)	400
7. Vertical low-pass boxcar filter	268 MHz
8. Vertical high-pass boxcar filter	50 MHz
9. Linear and exponential gain control	
exponential gain	14
linear gain 1	1
linear gain 2	5
maximum amplitude	400

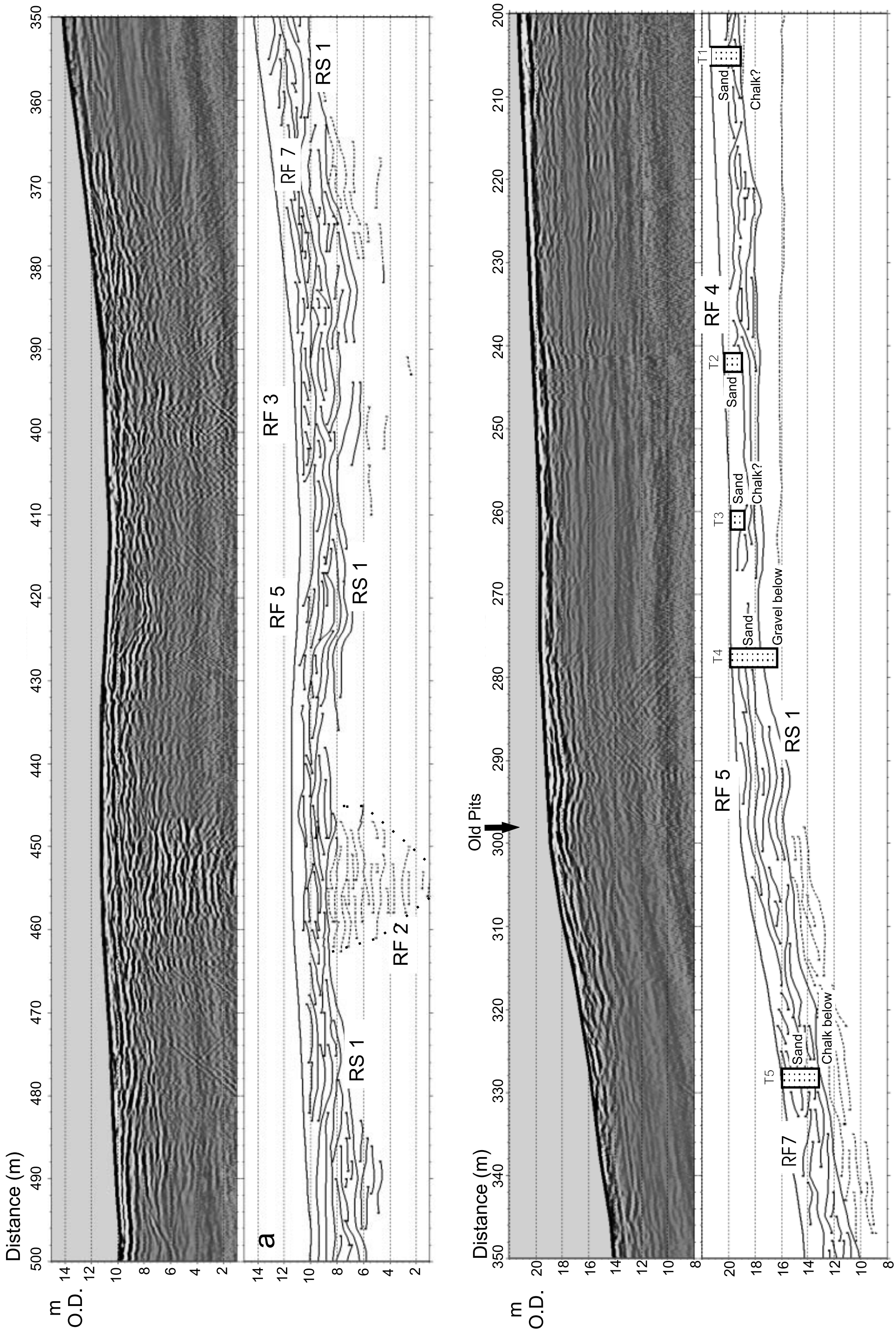
are drawn in the interpretation in Figure 6. However, no RS codes are given to them because of the clarity of the interpretation.

RS 1 is seen at an altitude 17–21 m OD in between 0 m and 280 m and at an altitude 6–16 m OD between 280 m and 500 m. The surface is continuous between 0 m and 390 m. After 390 m it is difficult to track its continuity in places because of the hyperbolae reflections of the clasts in upper layers. RF 1 can be seen between 0 m and 280 m below RS 1. RF 2 is seen between 445 m and 463 m below an altitude of 9 m OD. RF 3 is seen between 7 m and 16 m at an altitude of 23 m OD, 194 m and 200 m at an altitude of 20 m OD and at 388–406 m at an altitude of 10 m OD. RF 4 is seen at 39–51 m at an altitude of 22–23 m OD and between 232 m and 240 m at an altitude of 18–19.5 m OD. RF 5 can be seen throughout the radar transect. The most notable occurrences are between 94 m and 108 m at an altitude of 21–22 m OD, 279–301 m at an altitude of 16–19 m OD and between 417 m and 426 m at an altitude of 8.5–10 m OD. RF 6 can also be seen throughout the radar transect. The most notable occurrence is between 0 m and 39 m at an altitude of 22 m OD where another channel is cut into an older filled channel at 16 m. RF 7 can be seen between 306 m and 400 m. Between 370 m and 390 m the facies is overlain by RF 5, which has an onlapping lower boundary and between 390 m and 400 m by RF 3, where the upper contact of RF 7 seems to be erosional.

The description and geological interpretation of the radar facies presented below can be found in Table 2. RF 1 is interpreted as bedding planes in the Chalk bedrock. An alternative interpretation is that it represents layers of flint nodules within Chalk. However, flint nodules should generate diffraction hyperbolae, which are not seen in the radargram. The apparent dip of the bedding planes is estimated to be towards the southeast based on the data combined from all the radar transects in the area. RF 2 is interpreted as an infilled solution hollow in the Chalk bedrock (cf. Culshaw & Waltham, 1987). Such hollows in the Little Ouse valley related to Chalk were described originally by Evans (1868). It is characterized by reflections of the fill sediments which end abruptly and have diffraction hyperbolae dipping outside the reflections. The abrupt end of the reflections show the lateral discontinuity of the fill sediments at the almost vertical walls of the solution hollow. The high-amplitude reflections can be seen at a lower altitudinal level (4 m OD) than other reflections in the radargram. The high-amplitude reflection configuration, moderately good penetration depth and lack of hyperbolae reflections suggest that the solution hollow is filled with sandy sediments, probably of fluvial origin. RF 3 is interpreted to represent point bars. They form on the inside of a bend in the channel where the stream velocity was lower (cf. Miall, 1977) and the channel was migrating. RF 4 is interpreted as a mid-channel bar (cf. Miall, 1977; Ashmore, 1991). RF 5 is interpreted as fluvial channel fill (cf. Vandenberghe & van Overmeeren, 1999) and RF 6 is interpreted as channel-floor scours. They represent abandoned and filled channels that have been cross-cut subsequently by other channels (cf. Vandenberghe & van Overmeeren, 1999). RF 7 is interpreted as colluvial deposits, which consist of reworked fluvial deposits as well as reworked Chalk bedrock. RF 5 seems to gradually change to colluvial deposits in approximately 300 m.

The sediments above RS 1 can be divided into three separate depositional facies based on the GPR survey.

(1) 0–300 m, shallow (1–3 m) and relatively wide (10–20 m) cross-cutting channels with point and mid-channel bars suggest a shallow gravel-bed braided river facies (Miall, 1996).
(2) 300–400 m, a complex series of dipping reflectors, where the dip direction is mostly downslope, suggests a mass-movement facies.



(3) 400–500 m, a complex series of channels, channel fills (cf. Vandenberghe & van Overmeeren, 1999), mid-channel bar and interfingering colluvial deposits suggests a floodplain facies of the modern

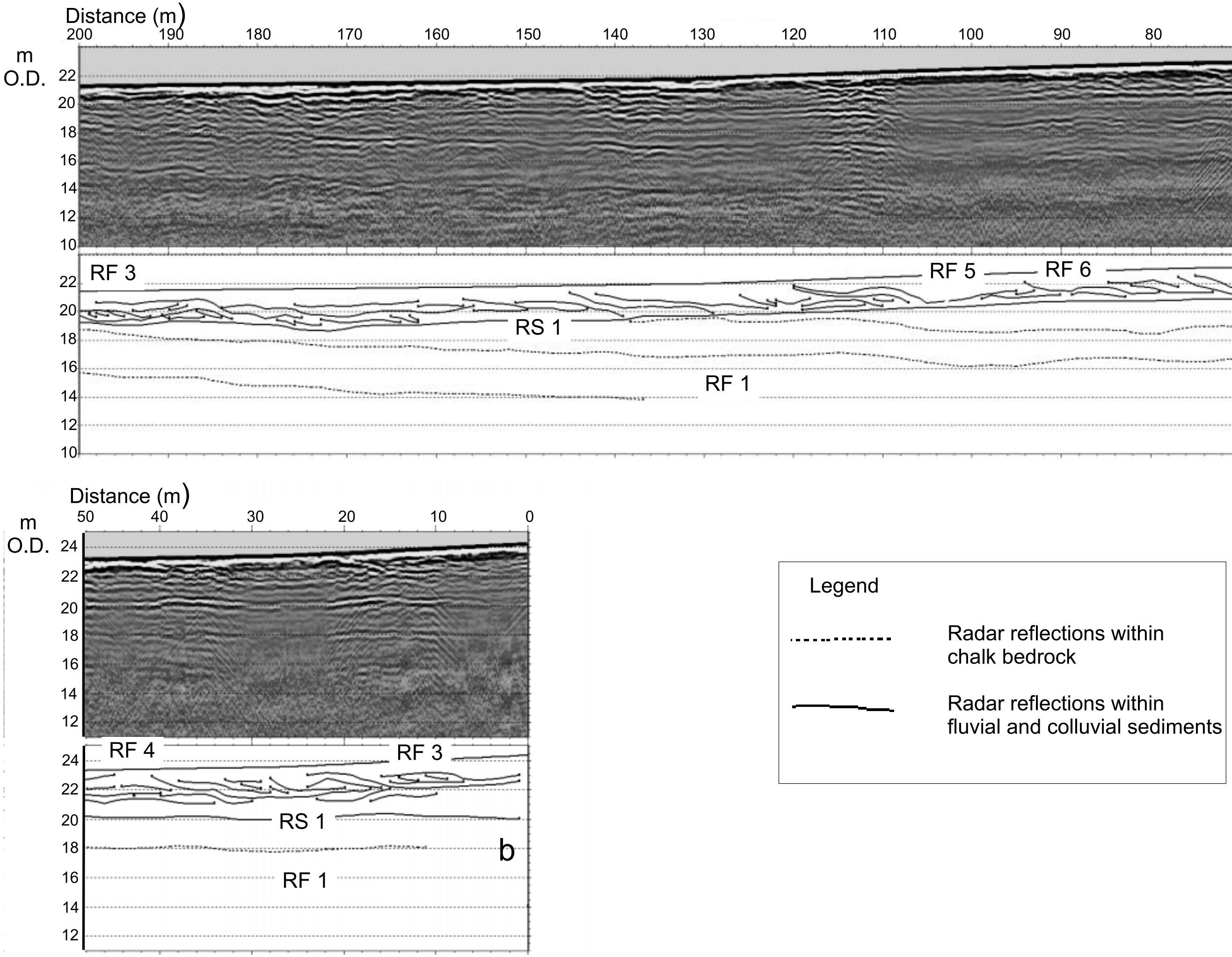


Fig. 6. A 500 m long GPR profile a–b and boreholes (Fig. 4) from Redhill shown in Figure 1b. The upper profile shows the processed GPR data and the lower profile the interpretation. Facies codes used in the profile are explained in Table 2 and in the text. The radar facies (RF) and the principal radar surface (RS 1) are shown. The possible infilled solution hollow can be seen between 445 m and 463 m; the interpolated margins of this structure are dotted (for discussion see text).

Table 2. Radar facies codes, facies description and geological interpretation.

	Description	Geological interpretation
Radar facies 1 (RF1)	Series of mildly sinuous, parallel, mildly dipping reflections which are laterally continuous. Upper boundary of the facies is erosionally truncated by RS1. The reflections dip towards b (east) at the transect.	Bedding planes in chalk bedrock.
Radar facies 2 (RF2)	Complex series of sinuous, subparallel and moderately continuous reflections which are toplapped by RS1.	Solution hollow filled with sandy, possibly fluvial, sediments.
Radar surface 1 (RS1)	Laterally continuous, sinuous, partly horizontal and partly dipping reflection.	Bounding surface between chalk bedrock and river deposits
Radar facies 3 (RF3)	Sigmoidal, strongly dipping, parallel and continuous reflections which have a toplapping upper contact. The dip direction of the reflections vary depending of the position of the facies.	Point bars.
Radar facies 4 (RF4)	Planar, horizontal, subparallel continuous to moderately continuous reflections.	Mid-channel bar.
Radar facies 5 (RF5)	Planar or mildly sinuous, continuous to moderately continuous, horizontal and parallel reflections.	Fluvial channel fills.
Radar facies 6 (RF6)	Series of cross-cutting reflections which are mostly concave and partly sinuous, subparallel and moderately continuous.	Channel floor scours, characterized by a complex series of cross-cutting strata with numerous bounding surfaces.
Radar facies 7 (RF7)	Complex series of mildly sinuous, subparallel and moderately continuous to discontinuous reflections. Most of the reflections dip towards the downslope but some are horizontal.	Colluvial deposits in fluvial sediments and chalk bedrock.

The distribution of these facies is shown in Figure 6.

river. The point bars beneath the higher terrace surface suggest that the channels were migrating towards the east, whereas in the floodplain the channels were migrating towards the modern river in the west.

5. NOTE ON STRATIGRAPHICAL TERMINOLOGY

In the following discussion the standard formal chronostratigraphical classification for British terrestrial and related deposits, originally proposed by Mitchell *et al.* (1973), is adopted. Although some workers have discontinued using this scheme (e.g. Bowen, 1999), the authors consider it the most appropriate for classification of the deposits described in this article. In this scheme the term Wolstonian was applied to the predominantly 'glacial' (cold) stage time-interval intermediate between the Hoxnian and Ipswichian temperate Stages (Shotton & West, 1969; Mitchell *et al.*, 1973; Gibbard & Turner, 1988, 1990, p. 40). This definition is adopted here.

6. ARCHAEOLOGY AND FAUNAL REMAINS

The occurrence of palaeoliths at the Redhill site is described in detail by Evans (1897, pp. 551–555) and summarized by Wymer (1985, pp. 113–114) and Roe (1981, pp. 212–213). According to Evans, the majority of the implements came from coarse gravels at the base of the exposures, although some are dispersed in gravel higher in the sequence (Prigg, 1869).

Pointed and sub-cordate forms predominate at Redhill (Fig. 7), whilst flakes, some showing secondary working, were also recovered from the site, according to Evans (1897). A few fresh flakes, a side-scraper 'in fresher condition' and a possible Levallois flake from the site also occur in various museum collections (Wymer, 1985, pp. 113–114). During excavation of the section at Redhill, a single hand-axe was identified by JW from the sediments at a depth of 125 cm (Fig. 3). The hand-axe, a partly rolled, sub-cordate form with an untrimmed butt of natural cortex (type G in Wymer's (1968; 1985) typological classification), is in John Wymer's collection in the care of Andrew Lawson (Wessex Archaeology, unpublished; no accession number at time of writing).

According to Wymer (1999, pp. 137–141), the valleys of the rivers Little Ouse and Lark include more Palaeolithic sites than anywhere else in East Anglia. The majority of hand-axes marked 'Thetford' in museum collections are probably from Redhill (Wymer, 1985, p. 114; 1999, p. 141). In addition, like Prigg (1869), Wymer considered that the sediments exposed at the Whitehill site, 1.25 km north of Redhill

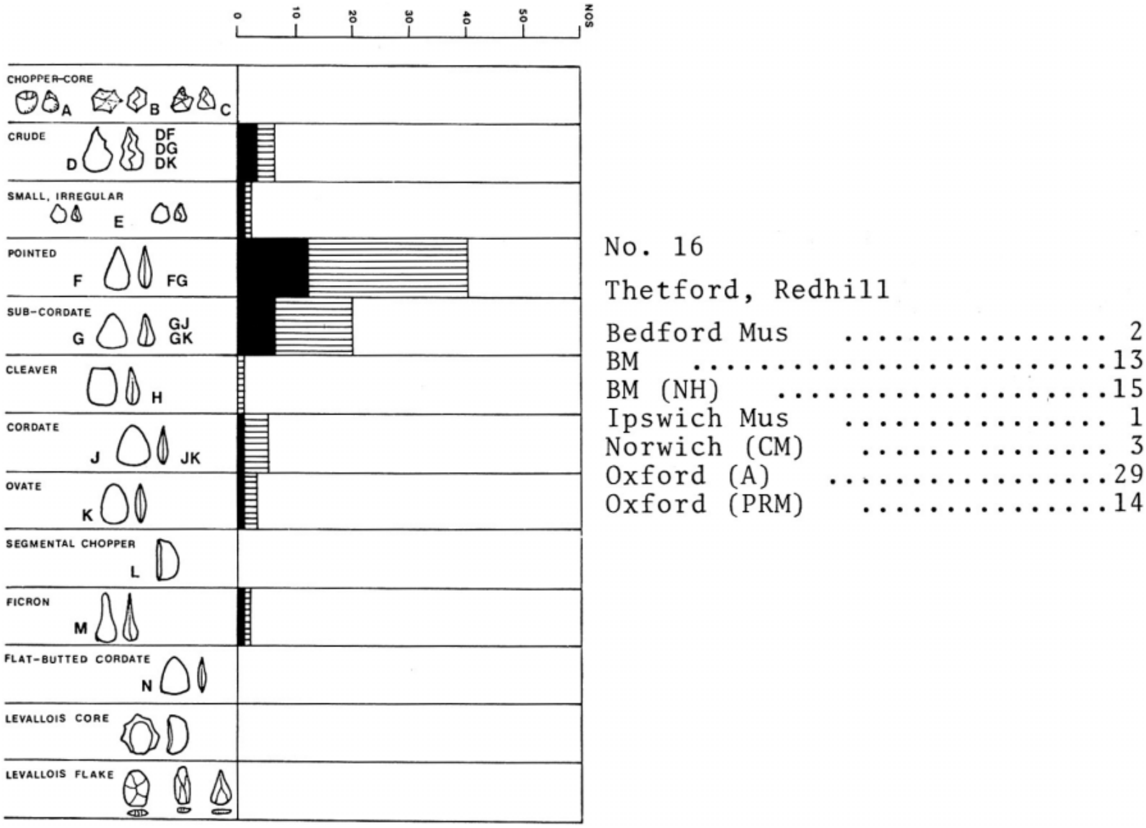


Fig. 7. Artefact typology chart from the Redhill site, showing the individual class characters and the number of artefacts in museum collections. Modified from Wymer (1985, p. 6). Fresh artefacts are represented by solid black, rolled ones by bars with horizontal lines. The numbers in each category are represented by the length of each bar. Abbreviations: Bedford Mus, Bedford Museum; BM, British Museum; BM(NH), Natural History Museum; Ipswich Mus, Ipswich Museum; Norwich (CM), Norwich Castle Museum; Oxford (A), Oxford Ashmolean Museum; Oxford (PRM), Oxford Pitt Rivers Museum.

([TL 855 864]; Fig. 1a) are a continuation of the same spread as that at Redhill. Three implements recorded from here, one of which is illustrated by Evans (1897, fig. 432), include a hand-axe (type FJ) with a worn, white patina and a slightly rolled crude ovate (cf. Wymer, 1985 for full details). A similarity to finds from the lower-level terrace gravel spread at Bromehill (or Broomhill [TL 801 877]), 7 km to the NW in the Little Ouse valley was noted by Wymer (1985, pp. 103, 113), who thought that they 'agree so well geologically and archaeologically that it would seem that one episode is represented at both'. However, re-examination of the valley terrace spreads, the deposits in which the Redhill excavations occur, demonstrate that the Redhill terrace sediments are higher and therefore probably older than those at both Whitehill and Bromehill. This implies that the finds at these sites could have been derived from reworking of Redhill gravel or local valley-side materials.

The artefact assemblage from Redhill is dominated by Late Middle Acheulian forms (Fig. 7). It is a mixed assemblage which Roe (1981, pp. 212–213) included in his Group VII sites dominated by his 'pointed tradition' group assemblage. Clactonian material is apparently lacking, but one questionable Levalloisian flake might be included. Although the latter may be from the gravel body at Redhill, it could potentially be derived from the gravel surface underlying the considerably younger 'cover sand' that caps the sequences in the local area. This division was unrecognized by earlier workers.

The typology chart (Fig. 7) is based on those used by Wymer (1968; 1985, p. 391, chart No. 16). Wymer's (1968; 1985, p. 2, fig. 1) typological classification scheme for flakes and hand-axes is based on the recognition of 13 form categories. This allows comparison of assemblages from sites and their grouping into industries. Whilst the identification of a stone industry is necessarily subjective, for comparative purposes this classification works well. Full discussion is given in Wymer (1968, 1985).

In his masterful summary of southern British Lower

Table 3. Artefact typological assemblages from the Lynch Hill (Middle Thames valley) and laterally equivalent Corbets Tey (Lower Thames valley) members compared to that collected from the Redhill gravel exposures (cf. Fig. 7), using Wymer's (1968; 1985) classification, modified from Gibbard (1985, 1994).

Typology	Lynch Hill Gravel	Corbets Tey Gravel	Redhill
A	+		
B	+	+	
C	+		
D	+	+	+
E	++	++	+
F	+++	+++	+++
G	+	+	++
H	+	+	+
J	+	+	+
K	+		+
L	+		
M			+
N			
Levallois core	+		
Levallois flake	+		+

+, present;++, frequent;+++, very common.

Palaeolithic assemblages, Wymer (1999) did not mention Redhill specifically, but included the Thetford assemblages in his broad time intervals 'Periods 2 and 3'. These periods he defined as:

- Period 2, 'from the beginning of the Hoxnian Interglacial to the latter part of the glacial stage prior to the Stanton Harcourt Interglacial=OIS 11 to the latter part of OIS 8';
- Period 3 extends 'from the latter part of the glacial stage prior to the Stanton Harcourt Interglacial to the advent of modern humans at about 40,000 BP' (Wymer, 1999, p. 4).

The key distinction between these two periods is the occurrence of Levalloisian technology and possibly small ovate or cordate hand-axes. However, although the single Levallois flake from Redhill might suggest that the assemblage could potentially be classified in 'Period 3', on the basis of the abundance of hand-axes and the questionable stratigraphic position of the flake, a 'Period 2' assignment appears considerably more appropriate.

Comparison of the Redhill assemblage with those recovered from the well-established Thames' sequence (Table 3) shows a striking similarity to those from the Lynch Hill/Corbets Tey Member gravels (Wymer, 1968, 1999; Gibbard, 1985, 1994), also included in Wymer's (1999) 'Period 2'. The latter are characterized by fine, large ficron hand-axes (type F) and big transverse cleavers (type H), specific forms that are not found in the earlier, Swanscombe sequence nor the Boyn Hill Member (Roe, 1981; Cranshaw, 1983). The Redhill finds, although limited in number in comparison to the substantial assemblages from the Lynch Hill/Corbets Tey unit, differ in that the small-irregular type E implements are rare at the former, whilst the sub-cordate forms (type G) appear more common. The significance of these differences is not certain. The subsequent Thames' Taplow Member gravels contain very few palaeoliths, most are in rolled condition and probably derived from the Lynch Hill/Corbets Tey sediments, while Levalloisian material is present (Wymer, 1968, 1999; Gibbard, 1985). The latter represent the first of Wymer's (1999, p. 49) Middle Palaeolithic 'Period 3' assemblages. The Lynch Hill/Corbets Tey Member is assigned to the late Middle Pleistocene Wolstonian Stage by Gibbard (1985, 1994, 1999) and equated to Marine Isotope Stages (MIS) 10–8 by Bridgland (1994; 2006). The abundance and regional distribution of finds from this mid-Wolstonian interval implies that they represent a significant period or periods of human occupation that occurred either during the times that these terrace sediments were being laid down or else immediately before.

Prigg (1869) and Evans (1897) recorded the bones of elephant, horse, bison and deer from the Redhill sediments. These finds also correspond to those recovered from the Lynch Hill/Corbets Tey Member in the Thames' sequence (Gibbard, 1985; 1994) and reinforce the broad temporal equivalency of this and the Redhill unit.

As noted above, Paterson (1942) repeated Evans' (1897, p. 551) record of freshwater mollusc shells *Helix*, *Bythinia*, *Cyclas, Pisidium, Ancylus and Succinea* from a sand bed (cf. above) at Redhill. Since the exact provenance of these fossils is unknown, and no fossils were recovered during the 2004 excavations, the significance of these finds cannot be determined.

7. INTERPRETATION OF THE SEQUENCE

There can be no doubt from the historical descriptions, supported by the modern observations reported here, that the gravel and sand sediments represent deposition by flowing water. Comparison of the facies described with facies models leave little doubt that the sediments were laid down by a gravel-bed stream of variable flow energy and abundant sediment supply. The small scale of the bedforms, lack of characteristic fining-upward sequences, predominance of horizontal bedding and lack of fine-grained sediment units overall indicate deposition in a braided-type stream active over most of the width of the valley. Streams characteristically adopt this mode during cold periods of the Pleistocene in lowland Britain when the streams are of niveofluvial type (cf. Gibbard, 1985; 1994; Bridgland, 1994; Brown, 1995; Van Huissteden *et al.*, 2001). Therefore, this sand and gravel sequence corresponds closely to those from other river systems.

The relationship of the sediments to the bedrock, the occurrence of a diamicton-like large highly angular (unrolled) flint clasts within a silty sand matrix and the abundance of chalk clasts and 'putty chalk' lenses within the basal part of the sequence indicate that following active vertical and lateral incision into the bedrock, the river was being supplied by material flowing, slumping or falling into the channel from the valley sides where bedrock Chalk was exposed. The valley sides, to the immediate east and north of the channel (Figs 1a, b) would have been exposed during accumulation of the gravels and would have provided not only a source of chalk but also a source of the accompanying flint which was being exploited by Palaeolithic humans in the immediate vicinity, as indicated by the prolific finds of palaeoliths from the sediments. The occurrence of putty chalk and associated highly angular, sharp flint pebbles – materials typically resulting from repeated freezing and thawing of saturated bedrock Chalk – strongly implies that the local environment was subjected to contemporaneous periglacial conditions. This observation is further reinforced by the association of this material with regolith transferred by mass-flow processes, such as solifluction, onto the braidplain of the river valley. Again this corresponds closely with observations from other river valleys in the region (Ballantyne & Harris, 1994; Rose, 1995; Van Huissteden *et al*., 2001).

This intermediate position of the Redhill terrace sediments, flanking the Little Ouse valley, indicates that they postdate the Anglian Stage glacial deposits. The latter cap the interfluves (Fig. 5) and their emplacement was later followed by a phase of fluvial incision. The deposition of the terrace sediments by fluvial activity, potentially during the Wolstonian Stage, records a phase of Little Ouse braidplain lateral expansion. Later a similar order of events apparently produced the low-level 10 ft (3 m) terrace. The age of the sediments upon which this low terrace is developed is uncertain. Thereafter (probably during the Devensian, by analogy with other valleys in the region), downcutting proceeded to the base of the modern valley and a similar order of events explains the distribution of the modern late Devensian and Holocene floodplain sediments. Aeolian 'cover sand' caps the fluvial sediments at the Redhill site and was deposited during the late Devensian (Bateman, 1995; Bateman & Godby, 2004; cf. Clarke *et al*., 2001). In the Holocene, podsolic soil formation occurred until Roman and mediaeval agricultural practices locally triggered renewed aeolian shifting of the cover sand, on the Red Hill terrace and throughout the district.

The remarkable similarity between the artefact and, indeed, the vertebrate assemblages from Redhill terrace sediments and the Lynch Hill/Corbets Tey Member of the Thames' sequence reinforce the view that the two sequences are potentially broad time equivalents (Period 2). They represent deposition during or immediately following a significant period of occupation of the region by Palaeolithic humans in the late Middle Pleistocene Wolstonian (=Saalian) Stage (Gibbard, 1985, 1991). Moreover, the Lynch Hill Member predates the glaciation of Midland, Northern England and the Continent during this stage (Gibbard, 1985, 1991), as do the earliest artefact assemblages including the later Levalloisian industry in the southern North Sea region.

Supporting evidence that these assemblages predate the late Wolstonian/late Saalian glaciation (*s.s.*) is available from the Netherlands. Here, as in southern Britain, the Redhill-type ('Period 2') artefact industry predates the earliest finds of Levalloisian-bearing assemblages ('Period 3'). In the Netherlands, the latter is known as the 'Rhenen' industry, after implements found locally reworked into a Rhine–Meuse channel deposit that is incorporated in Saalian-age ice-pushed ridges in the Central Netherlands (Utrecht and Wageningen ridges; Stapert, 1987; van Balen, 2006; van Balen *et al*., 2007). Dating by the optically stimulated luminescence (OSL) technique indicates the deposition of the Rhine–Meuse sediment unit at 180–160 ka BP and the ice-pushing event at 160–140 ka BP (Busschers, 2007). The latter unequivocally immediately predates the last (Eemian Stage) interglacial (de Gans *et al*., 2000). This evidence is fully consistent with that from the Thetford area in indicating that the Redhill assemblage ('Period 2') should therefore represent an older event within the Wolstonian than the 'Levallois–Rhenen' implements. It also confirms that both industries predate the Saalian 'Drenthe' Substage glaciation in the Netherlands ($\equiv$Wolstonian glaciation in Britain).

The Wolstonian Stage has been noted repeatedly to be a critical interval in the landscape evolution of eastern England, during which the modern drainage system was established after both the Anglian glaciation and the immediately following Hoxnian Stage interglacial (West, 1963, 1968; Gibbard, 1991). Subsequent Ipswichian Stage (last) interglacial sequences occurring at or close to modern floodplain level in river valleys throughout the region confirm that the modern drainage system was established by this time. The occurrence of glaciation in the Fenland, postdating the Hoxnian temperate Stage, is attested by the sequence at Tottenhill, West Norfolk (Gibbard *et al*., 1992), 35 km NW of Redhill. The relation between this event and the Little Ouse sequence is the subject of a separate report to be published shortly.

8. CONCLUSIONS

A number of conclusions can be drawn from this investigation.

(1) The Pleistocene deposits in the Little Ouse valley at Redhill represent a degraded river terrace sequence resting on Chalk.
(2) The gravel and sand sediments beneath both the Redhill and low-level terraces represent deposition in a gravel-bed stream of variable flow energy and abundant sediment supply. The sedimentary structures indicate deposition in a braided-type stream. The facies identified by the GPR survey confirm

these conclusions. Both gravel and sand aggradations are overlain by aeolian 'cover sand'.

(3) The valley sides, to the immediate east and north of the river valley, were exposed during aggradation of the gravels and would have provided not only a source of chalk but also of the accompanying flint, the latter exploited by Palaeolithic humans in the immediate vicinity, as indicated by the prolific finds of palaeoliths from the sediments.

(4) The occurrence of putty chalk, silty sand and associated highly angular, sharp flint pebbles – materials typically resulting from repeated freezing and thawing of saturated bedrock Chalk intermixed with regolith – strongly implies that the local environment was subjected to contemporaneous periglacial conditions. Diamicton-like coarse gravel, with the highly angular clasts, was interbedded with the fluvial sediment. These materials, derived from the valley side, were soliflucted onto the braidplain of the river valley system; the interdigitation of colluvial and braidplain sediments are confirmed by the radar survey. Artefacts may have also entered the deposits from the valley sides by this process.

(5) The rich artefact assemblage from the Redhill sequence is dominated by Late Middle Acheulian pointed and sub-cordate hand-axes, although flakes, a side-scraper and a possible Levallois flake are also known from the site. This mixed assemblage is included in Roe's (1981) Group VII sites dominated by his 'pointed tradition' group assemblage.

(6) A single Levalloisian flake might not be derived from the gravel body at Redhill, but from the gravel surface underlying the considerably younger 'cover sand' that caps the sequences locally.

(7) On balance, the artefact assemblage appears to fall into Wymer's (1999) 'Period 2', i.e. MIS 11 to the latter part of MIS 8.

(8) Comparison of the artefact and vertebrate assemblages with those from the Thames' sequence shows a striking similarity to those recovered from the Lynch Hill/Corbets Tey Member. The latter has been assigned to the late Middle Pleistocene Wolstonian Stage and equated to Marine Isotope Stages (MIS) 10–8.

(9) The Little Ouse Redhill terrace sediments postdate the Anglian Stage Lowestoft Formation deposits, which cap the interfluves. They are preserved flanking the valley of the predominantly incising post-Anglian Little Ouse. Fluvial incision was followed by the deposition of the Redhill, and subsequent Whitehill and terrace sediments by the Little Ouse, which occurred during stadials within the Wolstonian Stage. Their precise ages within the Wolstonian Stage and their relation to nearby glaciation have yet to be determined, but evidence from the Netherlands implies that the Redhill sediments and equivalents predate the glacial event. Renewed downcutting to the base of the modern valley was followed by floodplain aggradation probably in the late Devensian and Holocene.

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APPENDIX. BOREHOLE AND SECTION DESCRIPTIONS

Borehole 1

30 September 2004; drilled using Eikelkamp dutch auger. Top 19.47 m OD – auger hole.

0–5	humus
5–40	red sand
40–43	red sand, small angular flints
43–50	orange sand, small flints
50–67	orange stratified sand, very small flint chips. Darker red fine sand on millimetre scale
67–83	ditto, with some 2–3–5 cm angular flints
83–103	ditto, fewer flints, bedded sand with ferruginous horizons which appear to be of finer sand
103–118	ditto, one 8 cm shattered flint
103–119	Stopped by stones, still in bedded sand

Section and borehole on east side of pit [TL 8520 8422]

22 November 2004. Section, measured from top of borehole in base of dug section to top. Total depth section and borehole is 3.73 m. Top at 18.78 m OD.

213–243	soil, slope wash (colluvium)
203–213	cryoturbated red-brown, slightly silty sand becoming greyish yellow sand downwards.
143–203	medium coarse gravel, erosional base, sandy matrix (Gm) with large angular sharp (frost-shattered) flints and some quartzites
130–143	horizontally bedded sand, draped over underlying gravel
106–130	medium coarse gravel, erosional base, sandy matrix (Gm). Hand-axe with orange sand attached from 125 cm, i.e. *in situ*. Gravel sample here
91–106	cross-bedded sands, dipping at 15° N, similar to below, isolated pebbles at base
87–109	orange brown granular sand, with horizontal bedding
82–87	medium sand, horizontally bedded
77–82	orange brown pebbly sand lens, 5 cm thick at N end, thinning to 2 cm at south end (edge of channel)
70–77	medium sand, tabular cross-bedding
60–70	pebbly coarse gravel, sandy matrix, coarse flints, nested, one quartzite, one very large flint, thinning to south, as 77–82 cm, erosional contact at base
45–60	pebble-free sand, erosional base, gradational at top, 2 cm thick
0–45	rusty orange brown silty fine sand, tabular cross-bedded units, c. 10 cm thick each, dipping to 20° N
At 0	pebbly red sand

Borehole 2

At base of dug section in pit; drilled using Eikelkamp dutch auger.

0–80	fine yellow, horizontally bedded medium sand (150–210 μm)
80–90	coarsens (210–300 μm)
90–100	coarser poorly sorted, to 2 mm grains
100–110	even coarser orange, small flint gravel to 5 mm–1 cm, medium sand, rusty
110–120	orange, finer, silty pebbles, small angular gravel
120–130	orange gritty sand, to 600 μm, admixed with very coarse sand 130–140 cm angular flint gravel, clasts to 4 cm
15.08 m OD	Stopped by stones

Borehole 3

In base of pit, *c*. 7 m west of section; drilled using Eikelkamp dutch auger. Top 16.07 m OD, base 14.47 m OD. Through brown sand, small flints, more flints near base, probably made ground, hit white chalky sediments 160 cm, possibly top of underlying Chalk recorded in old reports.

Borehole transect

Redhill (boreholes T1–5). 22 July 2005 (for location, see Fig. 4); drilled using Eikelkamp dutch auger. Just south of the ride along which the levelling transect was made in January 2005, at points on this transect, west of garage (service station on eastern side of bypass road.

Borehole T1. At cross ride at 204 m on transect; 21.48 m OD.

0–30	soil, fine to medium sand
30–40	red sand
40–50	as above, granules, small flints
50–60	change to orange brown sand, base of soil B horizon.
60–90	lighter sand (soil C horizon), small flints
90–105	as above, gritty, small flints
105–115	as above, more loamy
115–125	greyer at base, fine sand, (cover sand ?)
125–130	fine sand
130–165	fine sand, gritty, small flints, red-brown
165–170	as above, but with chalk fragments
170–190	many chalk fragments, marly paler sand

190–200	light brown very sandy loam, chalk fragments
200–210	cleaner fine to medium sand with chalk pebbles, at 205 cm back to marly sand
210–230	putty chalk 1 cm thick with marly sand above and below
At 230	2 cm putty chalk, marly sand, i.e. near Chalk
	Base at 19.18 m OD

Borehole T2. At 241 m on transect; 20.35 m OD.

0–65	soil, then red sand with small flints
65–80	horizon with small flints
80–95	with flints up to 5 cm
95–100	fine to medium red brown sand
100–120	finer clean sand
120–130	bedded ? sand, granules, iron stained layers, coarser sand horizons
130–140	as above, more gritty, loamy at base, red, flints, at base 3 cm putty chalk, sandy, flints
	Base at 18.95 m OD

Borehole T3. At 260 m on transect; 19.99 m OD.

0–20	soil, red fine to medium sand
20–40	red sand, soil B horizon
40–50	as above, flints present
50–60	as above, angular flints
60–70	red-brown sand, many angular flints, granules
70–73	cleaner loamy sand
73–75	putty chalk
75–80	sandy putty chalk
80–90	as above, fresh chalk fragments
90–116	putty chalk, flints
	Base at 18.83 m OD

Borehole T4. At 276 m on transect; immediately south of pit excavation, 19.89 m OD.

0–20	soil
20–25	sand with flints
25–30	orange-brown paler sand, flints, granules
30–40	as above, larger flints
40–50	cleaner sand, slightly silty, flints to 7 cm at base
50–60	very loamy, signs of chalk
60–70	sandy putty chalk
70–75	redder med sand, chalky patches (soil formation?)
75–100	as above, coarse sand, small angular flints
100–120	coarse sand
120–125	more loamy, indeed clayey/silty, at base
125–130	very silty, as base of above
130–140	into 2 cm marly putty chalk and sand
140–150	red sand and chalky marl
150–160	clean yellow sand, fresher (140–160 cm fining up)
160–170	as above, with clayey horizon at 168
170–180	laminated clay and sand (fluviatile below *c.*165 cm)
180–190	sand, 0.5 cm clay at 185 cm, weathered sand above
190–200	coarsening with depth, stratified with clay (fines)
200–210	coarse sand, fresh
210–250	coarser, gritty, small flints
250–260	finer fresh sand
260–280	coarser sand, coarser at base
280–295	gravelly sand, coarse, granules, rounded clasts
295–320	sand, basal 3 cm with chalk pebbles, granules
320–330	fine to medium sand, coarse granular horizons, finer below
330–355	coarse clean sand, as above, 2 cm flints, some chalk granules
355–360	as above, but stones at base
360–365	slightly rounded flints, coarse sand, stopped on gravel
	Note: Chalky base not reached, cf. borings 1, 2, 3. Base at 16.24 m OD

Borehole T5. At 328 m on transect; 16.36 m OD.

0–40	soil, gravelly brown sand
At 40	medium sand, and medium flints
40–60	medium brown sand, granules, cleaner
60–90	medium brown sand, stony with flints, silty. To here, all slopewash
90–120	chalky sand, granules, chalk pebbles, small rounded flints, slope wash
120–130	brown sand
130–145	coarse gritty sand, sampled
145–160	as above, small rounded flints
160–170	fresher cleaner sand
170–200	as above, at base very coarse chalky sand
200–210	as above, interbedded with sand
210–245	gritty sand with small pebbles
245–255	as above, with basal 2 cm chalk pebbles
255–260	brown sand, small gravel, chalky at base
260–265	small gravel, sandy
	boring abandoned at 13.71 m OD, i.e. below level of possible chalk in borehole 3, at base of pit (14.47 m OD) of 22 November 2004

Trial Pit (TP) 27

Figures 1b, 4. 23.32 m OD; dug using mechanical excavator.

0–25	a	brown sandy topsoil
25–40	b	orange brown fine to medium sand and a little gravel
40–180	c	light brown variably chalky sand, with some fine to coarse gravel and weathered flint fragments at base.
	d	as c, but becoming brown medium sand.
180–350	e	off-white grade IV Chalk with flints becoming
	f	off-white grade III Chalk

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