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CROMERIAN INTERGLACIAL DEPOSITS AT SUGWORTH, NEAR OXFORD, ENGLAND, AND THEIR RELATION TO THE PLATEAU DRIFT OF THE COTSWOLDS AND THE TERRACE SEQUENCE OF THE UPPER AND MIDDLE THAMES

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Excavation for the Abingdon bypass road revealed at Sugworth, SW of Oxford, a dissected terrace feature, the Sugworth Bench, covered by a pebbly clay resembling the ‘Plateau Drift’ or ‘Northern Drift’ of the Cotswolds. This rested on Kimmeridge Clay or upon a number of sand and gravel-filled channels cut into the Kimmeridge Clay. These channels are considered to be ancient meanders of an old River Thames with a flow probably seven times that of the present river. One of these channels provided a fauna and flora that indicate a Cromerian III b age. The essential facts leading to this conclusion are given here, but detailed discussion of the vertebrates, beetles, ostracods, molluscs and palaeobotany are given in a series of separate papers.

Mainly to the NW of Sugworth, extending as far as the Oolite scarp of the Cotswolds, occur isolated patches of what has been called Plateau Drift, with its coarser constituents dominantly of pebbles from the Triassic Bunter Pebble Beds of the west Midlands and with a much smaller content of flint. These sediments have been examined from the aspects of topographical position, pebble content and heavy mineralogy. The following conclusions are drawn:

1. Much of the Plateau Drift is water-deposited, but where it was originally gravel, decalcification by solution of limestone clasts, together with cryoturbation, may give it a spurious resemblance to till. This interpretation does not preclude the original occurrence of some true till.
2. The lowest occurrences of ‘Plateau Drift’ along the Evenlode Valley lie on a surface that is a continuation upstream of the Sugworth Bench.
3. The high level occurrence of Plateau Drift represents the original incursion of west Midland erratic material on to the Cotswold Scarp and its dip plane to the southeast and must be ascribed to glacial action, though it is probable that the more easterly outcrops represent fluvioglacial outwash rather than till.
4. Intermediate levels of Plateau Drift are suggested to be the result of redistribution of original material at various times between the early glaciation and the stage of the Sugworth Bench (i.e. Terrace).

Correlation is attempted with the pre-Boyn Hill terraces and summit deposits of the Thames below the Goring Gap. The Sugworth Terrace, initiated in Cromerian III b time and probably completed in the Anglian, is correlated with the Winter Hill Terrace, possibly only with the Lower Winter Hill. The highest Plateau Drift is equated with the high level Westland Gravels of Hertfordshire, which show the first introduction of Bunter pebbles to the Middle Thames. Only the broadest of correlations can as yet be made between those deposits of intermediate level in the Middle Thames and the Evenlode.

Both Hey and Turner, from evidence in eastern England, have suggested a Baventian Glaciation. The high level Plateau Drift Glaciation may also be of this period, but there is as yet no better estimate of its age than that it preceded Cromerian III b by a considerable period.

1. Broad elements of the geology

Excavations for the A34 Abingdon Bypass during 1972–3 revealed, southwest of Oxford, over a total length of 1700 m, a number of sediment-filled channels cut into Kimmeridge Clay (Goudie & Hart 1975; Briggs *et al.* 1975). These channels occurred along three stretches of the cutting:

(*a*) for 250 m immediately east of the crossing of the motorway and the old A34 road (referred to hereafter as the Lodge Hill channel);

(*b*) from 250 m south to 125 m north of the lane by Sugworth Farm (Sugworth Lane channels);

(*c*) from 20 m to 150 m north of the lane near the south boundary of Bagley Wood (Bagley Wood channel).

These occurrences are broadly indicated on the locality map, figure 1.

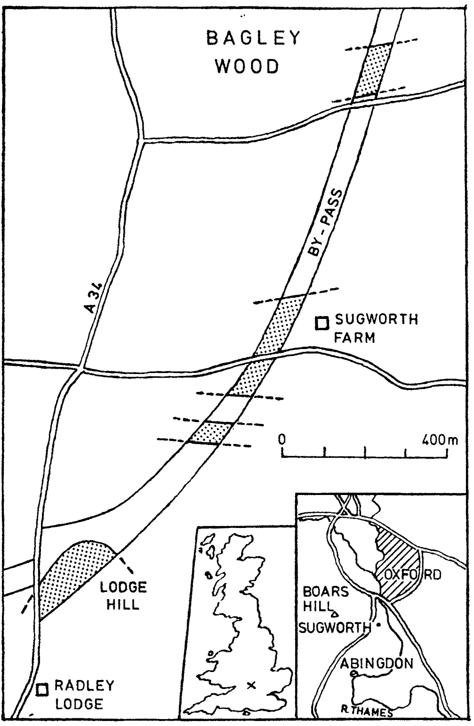

Figure 1. Location map of the Sugworth area.

There is no reason for regarding these channels as belonging to more than one geological episode, though they may not all have been exactly synchronous. Being filled chiefly with sand and gravel, they may be interpreted as intersections on an old meandering river channel, an ancient River Thames flowing roughly from north to south. At all three sites, the channels and the containing walls of Kimmeridge Clay are overlain by a thin layer of pebbly sediment that varies somewhat in its character at the three localities, as will be described later. It forms an old surface, which may be termed the Sugworth Bench, now deeply dissected by recent erosion, as the surveyed section shows (figure 2), with its top at about 95 m above O.D. at Bagley Wood, 92–91 m at Sugworth, and 89 m at Lodge Hill.

It was apparent that these sections had unique implications for Midland Quaternary stratigraphy, involving the age relation of the channels to the overriding pebbly clay and sand, to the numerous occurrences of Plateau (or Northern) Drift in the neighbourhood and to the well established sequence of river terrace deposits of the Oxford district (Sandford 1924, 1926, 1932, 1965). The highest of these usually recognized, the Hanborough Terrace, is mapped over three areas spaced over more than 2 km north from St Peter's College, Radley, and only about $\frac{1}{2}$ km east of Sugworth Farm, on surfaces that are about 13 m lower than the tops of the three bypass sections. The sediments there must then be older than the gravels of the Hanborough Terrace that were originally ascribed to the Hoxnian, but which Briggs & Gilbertson (1973), on the basis of molluscan faunas, now tentatively regard as early Wolstonian. Hence the youngest age that could possibly be given to the channels is Hoxnian, but there is a considerable probability that they are older.

2. Details of the channels

The Bagley Wood and Lodge Hill channels were not well exposed and were not so extensive or informative as those at Sugworth, so they will be described briefly first.

(a) *The Bagley Wood channel*

When first observed, much of the exposure had already been covered with topsoil, but enough could still be seen to indicate that it descended to about 5 m below ground level and that it was probably completely filled with poorly bedded yellow and orange sand. Its top appears to have been eroded, for it now occupies an interfluve ridge and the channel sands are covered by a variable thickness, up to 1 m, of 'Plateau Gravel', here a clayey sand with pebbles, lying on an almost flat surface that transgresses both sides of the channel on to Kimmeridge Clay. The continuations of the channel away from the bypass have been largely destroyed by the later erosion of two valleys (see figure 2) that descend from Boars Hill to the west.

(b) *The Lodge Hill channel*

The Geological Survey Sheet 253 (Drift edition) shows a strip of 'sand and gravel of unknown age', 200 m wide, stretching east–west across the old Oxford–Abingdon road, just south of where the bypass crosses it; the northern edge of this strip was exposed in some of the boreholes and the south side of the cutting east of the bridge. When examined, much of the section had been obscured by earthworks, but that which could still be seen and the borehole information both indicate that the channel is at least 3 m and, probably, about 5 m deep. Sandy gravel was observed in the channel fill and it is overlain by 'Plateau Gravel', here less than 0.5 m thick and not so sharply separated from the underlying channel fill as at the other exposures on the bypass.

This site is right at the edge of the Sugworth Bench, before the ground drops down steeply to the next terrace.

(c) *The Sugworth Lane channels*

The Sugworth exposures revealed a complex series of channels visible on both sides of the cutting over a length of 375 m and attaining their greatest depth under the bridge, where they were well exposed in the abutment works.

It has not proved possible to trace these channels for any appreciable distance away from the

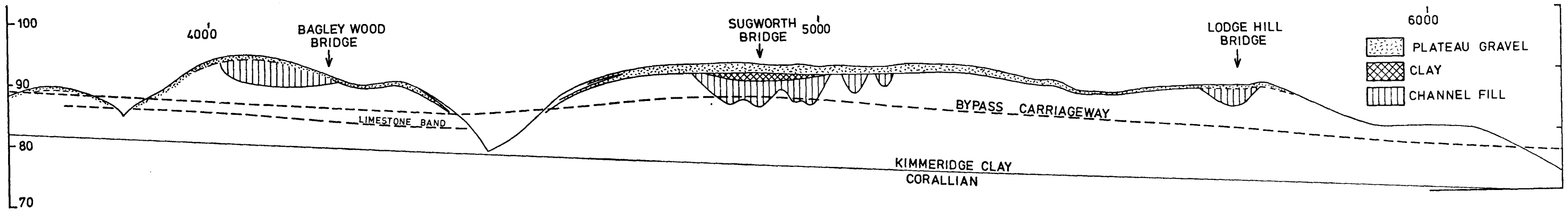

Figure 2. Section revealed on the east side of the cutting. (Vertical exaggeration × 10. Vertical and horizontal distances in metres.)

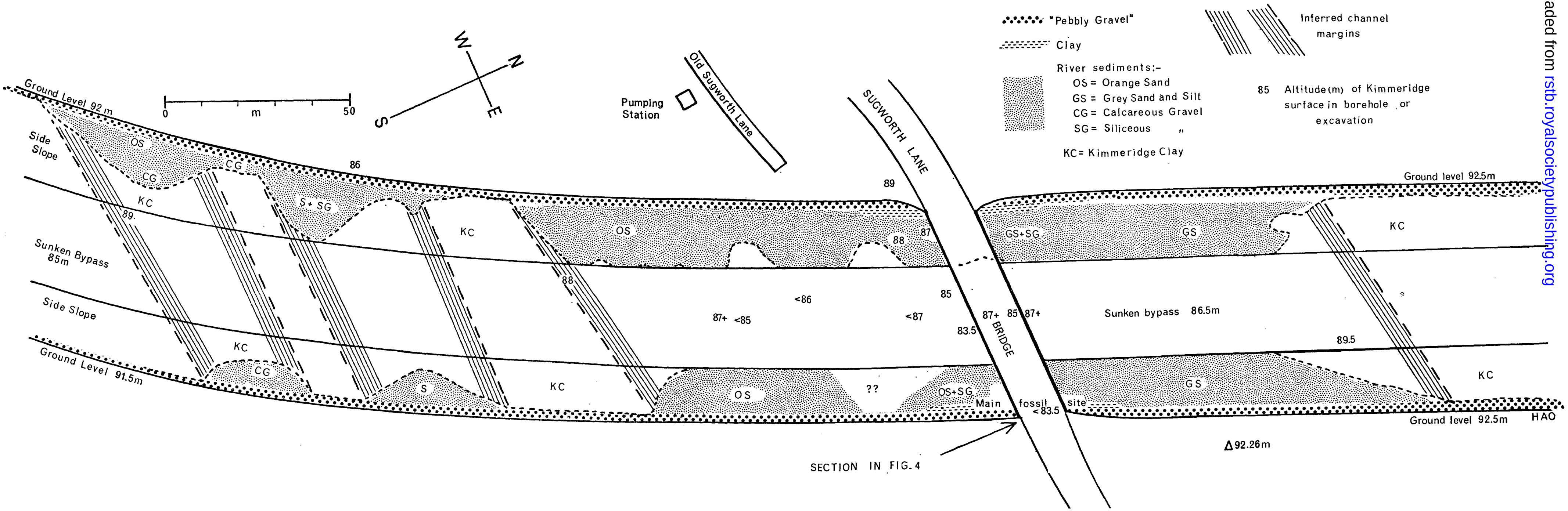

Figure 3. Detail of the Sugworth group of channels crossing the motorway cutting.

cutting. Hand augering through the very pebbly 'Plateau Gravel' is not practicable; aerial photographs and a proton magnetometer survey revealed nothing conclusive.

The sediments of the Sugworth Channels

The dominant type of sediment in all the channels is medium to coarse orange-coloured sand. In the main channel under the road bridge there are a few strings of gravel, which become more important on the south flank of this channel and also in the other channels of the Sugworth group to the south. A very important departure from this generalization is the occurrence, in the middle of the main channel, of a zone of dark grey silts and clayey sands with a considerable content of organic debris. It was the discovery in this of mammal bones, a horn core, molluscs and wood, by members of a field party of the Quaternary Research Association, led by A. S. Goudie, that suddenly gave this section great potential stratigraphical significance. By good fortune, this critical part of the section coincided with the bridge across the bypass, so that, on both sides, good, clean vertical sections at the bridge abutments were available for study. Although some collecting was done from the west side of the cutting, detailed work was concentrated on the east side, and it is to this that the following description applies.

The important part of the section was precisely surveyed by Bristol University Geography students under H.A.O., using a 1 m grid of strings to plot the sediment variations. The most critical part, a width of 10 m is shown in figure 4. On the extreme right (south), only two thin bands of grey clay interrupt the succession of red, orange and yellow sands overlying gravel, but grey sediments and the development of clay and silt increase rapidly to the north. So sudden is the change that initially the organic sediments were thought to be the infill of a channel cut into the sands, but clearly this is not so and changes from ferruginous sand to grey silt or clay are the result of lateral passage. There is a down-faulted trough which may perhaps result from differential shrinkage and compaction of the different types of sediment, the throw of the northern side of which is about $\frac{1}{2}$ m; but there is no difficulty in tracing certain horizons across the faults. This main channel differed from others in that the varied sequence of sands and gravels was overlain by a little over 1 m of uniform, unstratified grey and orange clay, devoid of obvious organic matter. This, in turn, was overlain by the sandy, clayey gravel of 'Plateau Drift' type that covers all the other channels.

3. THE PALAEOHYDROLOGY OF THE CHANNELS

What follows is a brief summary of a much fuller analysis by H.A.O. (in preparation).

The dimensions and sediments of the channels provide some information about the conditions of their formation, but also raise some major problems. The river that occupied the Sugworth channel was larger than the present Thames, but estimates of its actual width and depth are subject to some uncertainty because the angle at which the exposure intersects the channel is not clear and because it is arguable whether or not there were gravelly deposits on the Sugworth Bench then, overlying the Kimmeridge, but a width of 140 m and a mean depth of 7 m at bank-full stage seem probable. The latter figure is also supported by the sizes of the very few dune structures in the sediments. These dimensions indicate a bank-full discharge of *at least* 1000 $m^3 s^{-1}$, seven times that of the modern Thames nearby, thus supporting Dury's views (1965) that many rivers in Britain and elsewhere had much higher discharges during the Quaternary than they have now. Most of the sediments are in fact plane-bedded, which is in

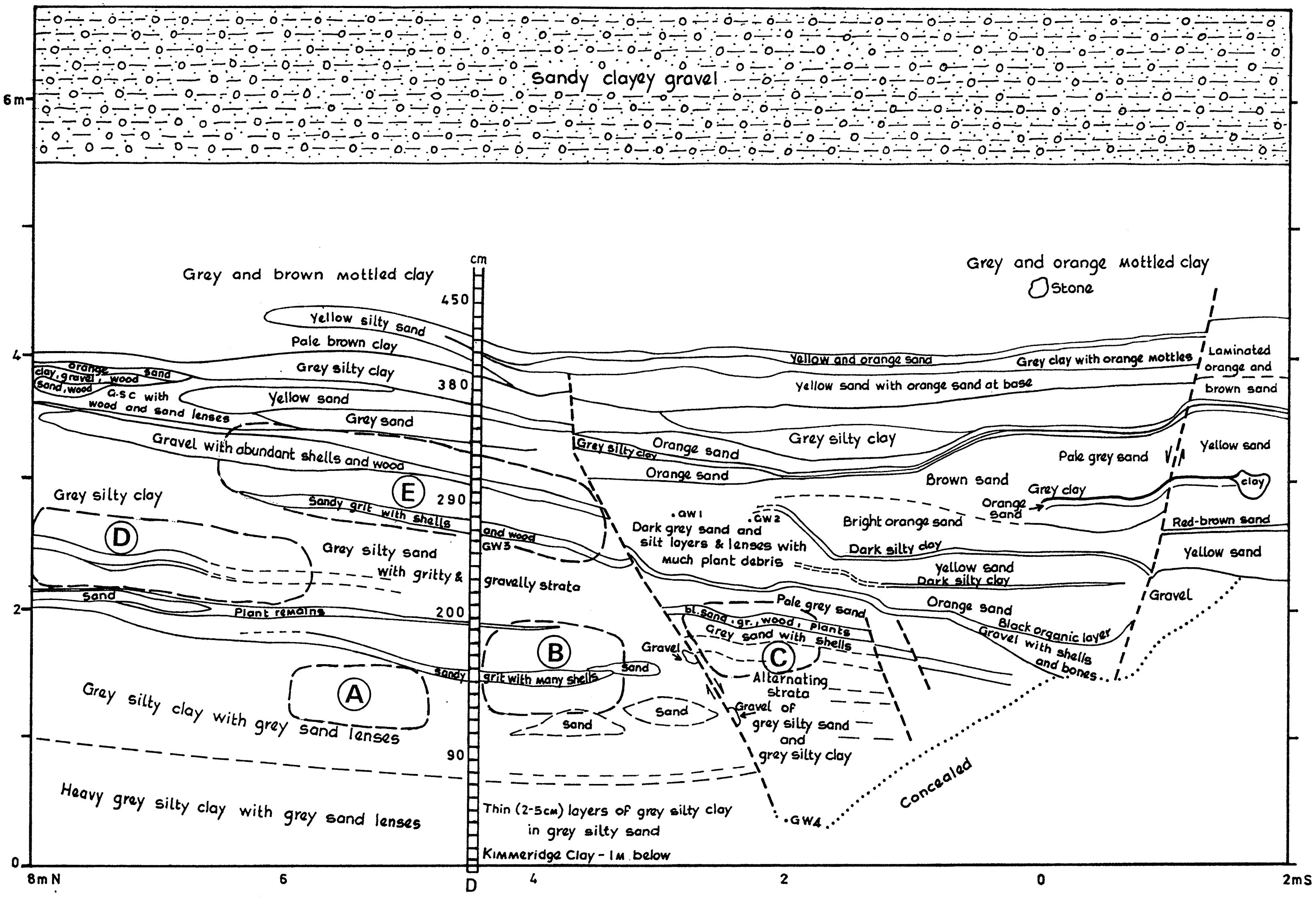

FIGURE 4. Detail of 10 m length of cutting exposed at the Sugworth Lane east bridge abutment. The arbitrary base (85.25 m above O.D.) for height measurements is shown and D marks the position of the profile from which most of the samples were collected. The base of the top pebbly clay is drawn diagrammatically. The boxed areas Ⓐ–Ⓔ enclose locations from which vertebrate remains were picked out.

accordance with the velocity to be expected in a channel of this size and slope, but unfortunately reduces the information available about flow direction.

Thus the general picture is of a swiftly flowing, large river, with meandering, but occasionally braided, channels incised into the Kimmeridge Clay, carrying a moderate load of sand and gravel, but with occasional pools and backwaters where organic debris would settle. The climate was warm and moist; the banks were well vegetated and fairly stable. Occasionally a new channel would be cut, and an old one silt up leaving a shallow pool that would then be filled with mud washed into it by rain or floods: hence the clay capping on the main Sugworth exposure. The relation of the channels to the Sugworth Bench and to the overlying Pebbly Clay permits more than one explanation. Possible interpretations will be considered later.

Evapotranspiration was no less than at present; so, if greater rainfall was the cause of the high discharges, an increase of *at least* 1.5-fold and probably 5-fold, is indicated.

4. THE AGE OF THE CHANNEL SEDIMENTS

The visible abundance of organic remains, the occasional large animal bone, pieces of wood, and Mollusca, among which *Unio crassus* was very evident, left no doubt that much biological information was there to be interpreted. A concerted programme of sample collection was therefore undertaken. Along the line marked D on figure 4, small samples were taken at 30 cm intervals for pollen analysis and a continuous series of 10 cm bulk samples, to be examined for insects. Alongside this line, eight bulk samples were taken for analysis of plant-macro remains, at irregularly spaced intervals, where the sediment looked most promising, and another series, for the same purpose and for pollen analysis, were collected from a profile labelled B, 12 m to the north of D, but these proved unproductive. Large bones were picked out where visible and were augmented later from the washings of the systematically collected bulk samples. These samples also provided ostracods and an abundance of molluscs.

The authorities that have studied and reported on the various sorts of biological material are Mary Pettit (plant-macro remains), the Commonwealth Forestry Institute (wood), P. L. Gibbard (pollen), A. J. Stuart (vertebrates), D. D. Gilbertson (molluscs), J. E. Robinson (ostracods) and P. J. Osborne (beetles). The conclusions that they have each reached on age, ecology and climate are important in their own right, and the last four people have provided papers under their individual authorship. Mary Pettit and P. L. Gibbard have published elsewhere (Gibbard & Pettit 1978). In this paper we are concerned essentially with stratigraphy and the interpretation of the Middle and Lower Pleistocene in the Midlands, and so will restrict ourselves to the minimum of facts that establish the age of the channel deposits. It may be stated at once that there is unanimity in ascribing the channel sediments to an Interglacial. The important stratigraphical question is: which Interglacial?

(*a*) *Vertebrates* (A. J. Stuart)

Critical records are *Dicerorhinus etruscus*, restricted in this country to the Cromerian and probably Pastonian; *Mimomys savini*, characteristic of Cr II and Cr III before being replaced by *M. cantiana*; and teeth of *Sorex*, which compare with those of *S. savini* from the Cromerian of West Runton. In addition, *Pliomys episcopalis* (known from Westbury-under-Mendip but not Cromer) and *Beremindia fissens* occur at several European sites of early Middle Pleistocene age.

(*b*) *Ostracods* (J. E. Robinson)

The fauna is consistent climatically with the middle period of an interglacial. The occurrence in abundance of *Scottia browniana* s.s. limits the age to Hoxnian or earlier, and the assemblage of rarer constituents is matched in the late Beestonian of Cromer and the Cromerian of Süssenborn. Although not conclusive, the ostracods suggest a Cromerian age.

(*c*) *Molluscs* (D. D. Gilbertson)

The balance of available evidence points to a Cromerian age. *Nematurella runtoniana* is known only from the Cromerian interglacial and *Valvata goldfussiana* appears no later than the Cromerian interglacial in Britain, while the following taxa present at Sugworth have not yet been identified in deposits older than the Cromerian in Britain: *Valvata naticina*, *Bithynia inflata*, *Marstoniopsis scholtzii*, *Unio crassus*. There are no indications of the more open, less temperate landscapes of Zones Cr I and Cr IV. The general decline in number of species per sample and species numbers per sample suggests that the deposit post-dates any climatic optimum. Therefore, the site is best referred to Cromerian Substage Cr III, probably Cr III b.

(*d*) *Coleoptera* (P. J. Osborne)

The beetle fauna clearly indicate an interglacial environment. A climate at least as warm as that of today is suggested and species are present that are associated with deciduous trees. No comparison with a Cromerian fauna is possible, as none has been investigated to date. Hoxnian faunas that have been examined, though again indicating a temperate climate and the presence of deciduous woodland, have few actual species in common with Sugworth, particularly among the exotic members. The nearest match to Sugworth so far known is with the Ipswichian deposits from Trafalgar Square, London (G. R. Coope, personal communication). A number of exotic species are common to both sites, including one species that has defied identification, even to family level. As stratigraphy forbids an Ipswichian date, this resemblance must be due to a similarity of climate resulting in the same type of environment in the Ipswichian and a pre-Hoxnian period. Ascription to the Cromerian, in the absence of any insect fauna of this age for comparison, must be resolved from other biological groups.

(*e*) *Palaeobotany* (Mary Pettit and P. L. Gibbard)

The flora indicates Stage III (Late Temperate) of the four stages that characterize any Interglacial that follows one glacial period and is succeeded by another (Turner & West 1968). As to which Interglacial, Mary Pettit draws attention to similarities to both Hoxnian and Cromerian, but, on the basis of the occurrence of *Potamogeton* '*distinctus*', regards Cromerian as more probable. Gibbard's analysis of the pollen does not really permit him to distinguish between Cr III and Ho III, so that it is on the basis of conclusions reached by those working on fauna and of Mary Pettit's work, that he accepts a Cromerian age, in which instance it will be Subzone III b.

Pieces of wood were scattered throughout the gravels; a number of these were submitted to the Commonwealth Forestry Institute at Oxford for identification. They comprised 16 samples of *Ulmus*, recorded abundantly as pollen but not as macro-remains by Gibbard & Pettit; 14 of *Quercus*, similarly recorded by Gibbard & Pettit; and 6 of probable *Crataegus*, absent from the pollen records of Gibbard, but present as twigs from the macro-remains.

Conclusion

After assessment of all the approaches summarized above, it may be stated that the Sugworth channel deposits are Cromerian III b in age.

5. The Plateau Drift of the Oxford region and the Cotswold scarp

(*a*) *History of research*

The earliest sediment of Pleistocene age that has hitherto been recognized in the Oxford region is that which occurs as small patches in summit positions over the Jurassic limestones and clays of the Cotswold dip slope and in small hills of the Corallian ridge to the southeast of Oxford itself. It is a deeply weathered mixture of clay, sand and pebbles, of which those of quartzite and vein quartz are dominant, though there is usually a smaller, but persistent, content of flint. The fact that the pebbles of quartz and quartzite appeared to be derived from the Bunter Pebble Beds (and there is still no evidence to controvert this view) and that this Triassic formation outcrops in Worcestershire and northwards, led to the early use of the term 'Northern Drift' (Buckland 1823).

Figure 5 shows all the occurrences of 'Plateau Drift', 'Northern Drift' and 'Unbedded Drift' that have been mapped on Sheets 236, 253 and 254 of the Geological Survey of England and Wales. Further to the west, interest has long been attracted to the occurrence, on high positions close to the watershed and even on summits such as Painswick and Cleeve Cloud detached into the Severn drainage basin, of Bunter pebbles and sometimes flint. Rarely do these spreads merit being mapped as discrete outcrops, but many are mentioned in Geological Survey publications. They appear to be remanié deposits of the formation, or formations, that appear as mappable areas to the southeast. These also are shown on figure 5.

One of the first workers after Buckland to refer to the 'Northern Drift' was Hull (1855, 1857), but his accounts are confused by his adherence to the theory, then held, of a great marine submergence and the development of a high-level beach, and also by his inclusion in the Northern Drift of any deposit that contained pebbles derived from the Bunter Pebble Beds. This led to remanié patches on Cotswold summits, river terraces of the Avon and the Pleistocene deposits of the Moreton-in-Marsh area all being grouped into one category.

Lucy (1872, 1880) made the first map of the distribution of Northern Drift over the Cotswolds, and although there was still confusion with some river terrace deposits, he did establish that several summit areas carried spreads that included Bunter Pebbles and, sometimes, rarer flints. Often, these occurrences were nothing more than scattered pebbles of quartz and quartzite, but they still were the relics of more extensive deposits that must have been laid down after transport to their now elevated position by some natural agency. Lucy accepted a glacial origin. James Geikie (1877) also attributed the Northern Drift to a glacial agency in his 'Great Ice Age'.

Callaway (1905) described the section at Tangley at about 650′ (198 m) as an undoubted boulder clay and listed the erratics therein, while Gray (1911, 1920) described other occurrences of Northern Drift in the Cotswolds. It has to be remembered that Gray and Callaway worked in an atmosphere of monoglacialism. While Gray accepted the chalky till of the Vale of Moreton as glacial, he was reluctant to accept the high level plateau deposits (e.g. at Tangley) as due to a glacier, certainly not the glacier that filled the Vale of Moreton. He does, however, make a

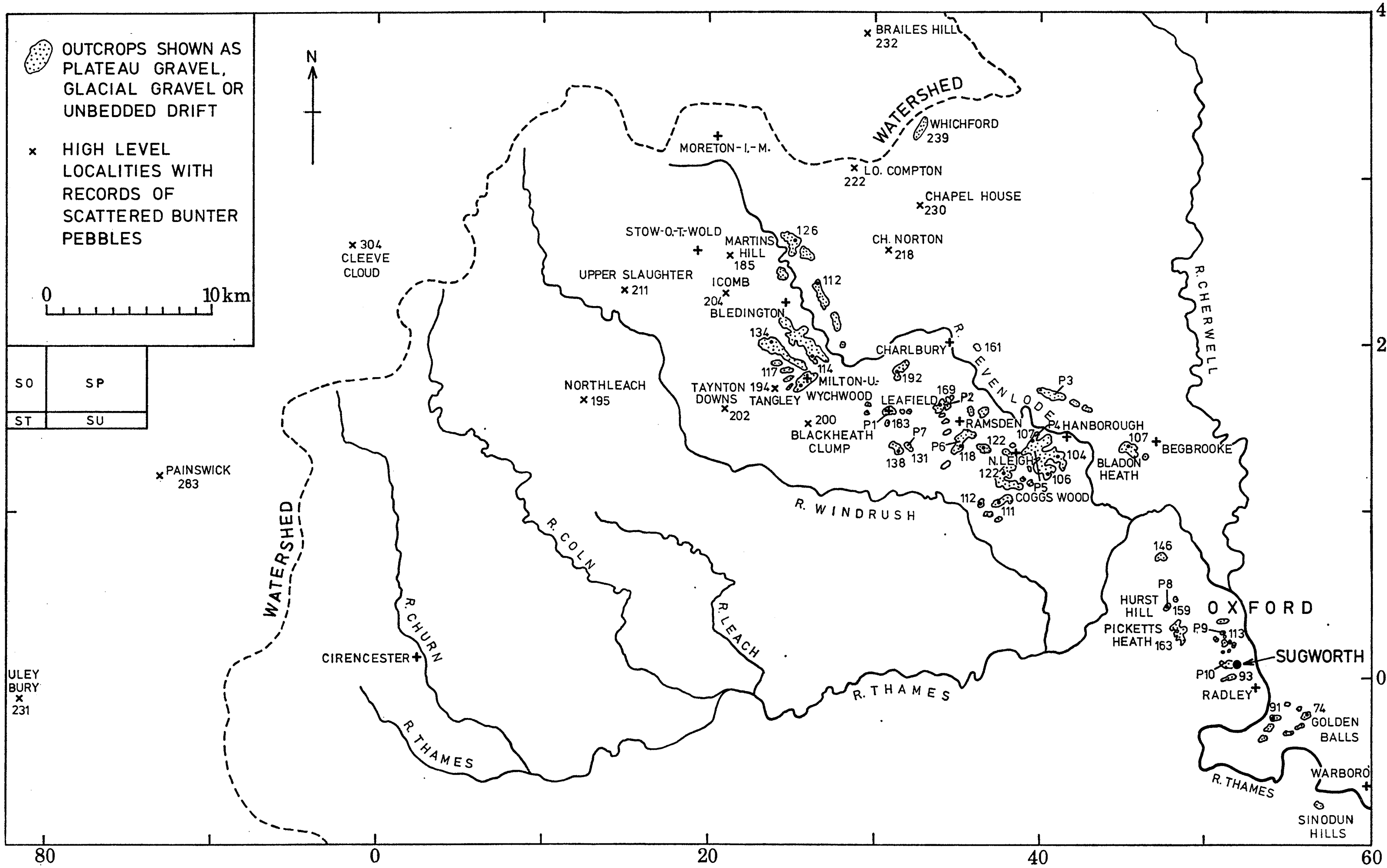

FIGURE 5. Deposits mapped as Plateau or Northern Drift, and high land with scattered Bunter pebbles, northwest of Oxford. The locations of the pebble samples of table 2 and the heavy mineral samples of table 4 are indicated. (Numbers shown are heights in metres.)

prescient observation: 'The Drift material [at Tangley] . . . is probably the oldest on the Cotteswolds and appears to consist of the remnants of Tertiary river gravels . . . but it is just possible that it may be due to a glaciation of much greater antiquity than that credited with the transport of the Vale of Moreton gravels'.

Richardson (1926) and Dines (1928) mentioned other occurrences of Northern Drift and, with the coming of Geological Survey memoirs on the sheets around Oxford (236, 253, 254 and special Oxford Sheet), the position of the Northern Drift (or Unbedded Drift, as Dines preferred to call it) as the oldest Pleistocene deposit of the area was generally accepted. It was also generally believed that it was the result of glaciation. Sandford, who referred to the Plateau Drift, as he preferred to call it, in several papers (1924, 1926, 1929, 1965), in 1926 described it thus: 'It is bedded only rarely and then but crudely; it consists of red-brown clay loam, occasionally with some sand; pebbles of all sizes and boulders are set in it without arrangement and locally with their longer axes pointing downwards. As we now see it, clearly it is not a normal fluviatile deposit'.

Such a description does not necessarily imply that the Plateau Drift is a till. Some of its occurrences (e.g. the sands in Bagley Wood (*q.v.*) or the gravels at Freeland, south of Long Hanborough (Arkell 1947)) do not conform to Sandford's description and are more easily regarded as fluviatile in origin. Even in those instances where Sandford's description applies, it is impossible to believe that any agent of transport, marine, fluvial, glacial or soliflual, could traverse a large expanse of Jurassic rocks and fail to incorporate limestones as clasts in its deposits. Yet the Plateau Drift does not include limestone and so there must have been decalcification with consequent destruction of any original stratification and haphazard rearrangement of the insoluble pebbles of quartzite, quartz and flint. It is a striking fact that when the gravels of the Hanborough Terrace, in which oolite pebbles greatly outnumber Bunter and flint pebbles, are decalcified in pipes, as can be seen in Long Hanborough quarry, the resulting reddish-brown, pebbly clay closely resembles Plateau Drift. So, at this point in the argument, the question of the origin of the Plateau Drift can remain open for later discussion.

As to the age of the Plateau Drift, this has been assumed to be Anglian and it is so classified by Shotton in Mitchell *et al.* 1973. The deposit that lies above the Cromerian Sugworth channel is shown on geological maps as within an outcrop of Plateau Drift and certainly conforms in its lithology to this ascription. It must date from a period between Cromerian IIIb and the ?Early Wolstonian Hanborough Terrace and so falls naturally into the Anglian; but the first cursory inspection of the gravel in the Cromerian Sugworth channel revealed that its dominant pebbles were precisely those that characterize the Plateau Drift. This fact immediately raised the possibility that what has been grouped together as Plateau Drift, Northern Drift or Unbedded Drift may be of at least two ages, one post-Cromerian, the other pre-Cromerian.

The idea that the scattered outcrops may not be all of the same age is not new. Arkell (1947), in his study of a length of the Evenlode valley, claimed to distinguish three components of the Plateau Drift: a 'Northern Drift' which he accepted as a glacial deposit, gravels of the Coombe Terrace, which he regarded as water-redistributed Northern Drift, and gravels of the Freeland Terrace. The latter he described as standing above and separated by a step of 30 ft (9.14 m) from the Hanborough Terrace, and therefore older than it, but he also described the Freeland Terrace as similarly separated from the older Coombe Terrace and Northern Drift. Nevertheless, he was content to encompass everything from the entry of the Northern Drift ice lobe to the erosion following the Freeland gravels within his Berrocian Glaciation. In modern terminology (Mitchell *et al.* 1973) this would be equated with the Anglian stage.

In an attempt to clarify the age relation of what has been grouped into Plateau Drift, three lines of investigation were followed: the topographical situation, the characteristics of the contained pebbles, and the mineralogy of the sediments.

(*b*) *Topographical relations of the Plateau Drift*

The scattered outcrops of Plateau Drift comprise a number at high level, two of them up to 304 m and 283 m if the westerly occurrences of Cleeve Cloud and Painswick are accepted, and, further east, about a dozen between Northleach and Brailes Hill (figure 5), lying in the range of 185 to 239 m. These lie along a belt that is in a direction (NE–SW) close to the strike of the Jurassic rocks which controls the preservation of summits in the more resistant limestones.

Eastward of these higher level occurrences, the numerous patches of the deposit occupy a belt, as Arkell (1947) pointed out, that is about 13 km wide and extends between the Moreton Gap and the Goring Gap, a probable old line of consequent drainage into the London Basin. The River Evenlode and the Thames below Oxford still occupy this line (figure 5). It is this distribution that has prompted those who regard the Plateau Drift as an ancient till to speak of an ice lobe pushing southeastward from the Moreton Gap.

Figure 6 is a plot of the heights of all the locations shown in figure 5, projected onto a line running W 40 °N, the general course of the Evenlode. The propriety of doing this for the widely scattered high level occurrences between Northleach and Brailes is questionable, but, fortunately, any other method of plotting would not seriously affect the argument that follows.

It can be seen that there are also high level outcrops at Leafield (183 m), WSW of Charlbury (192 m) and, 23 km further downstream, at Pickett's Heath (163 m) and Hurst Hill (159 m). The rest of the outcrops are at diverse lower levels, but, with one exception, they all lie on or above the line drawn on figure 6, which slopes at 1 in 1800. The exception is at Golden Balls. We have no ready explanation for this, though it might be due to solifluction or be a remnant of a lower terrace. It is perhaps significant that, at Pear Tree Hill (SP 493110), a small outlier of Wolvercote Terrace shown as such on Geological Survey Sheet 236 (Witney), reprinted 1947, was shown on the combined Oxford Sheet published in 1908 as Plateau Gravel. Presumably, this was because it is largely decalcified. Had it been accepted as Plateau Drift, it would have appeared on figure 6, 30 m below the general run of the lowest outcrops, and would have defied all explanations except an incorrect one.

It should be noted that the Sugworth channel covering of 'Northern Drift' is part of a small mapped outcrop that lies on this apparent base line curve. It also appears to cap an erosion bench some 13 m above that of the Hanborough Terrace. So it would serve as a working hypothesis to picture (*a*) the Plateau Drift as having been deposited in pre-Cromerian times on a high level surface little dissected; (*b*) one or more periods of erosion along the Evenlode (and doubtless the Windrush) and the Thames, down to the base level of the Sugworth channels; and (*c*) redistribution of the Plateau Drift on to this bench and also at intermediate heights along tributaries to the main rivers.

This theory leaves for the moment the question of what agent could cause this postulated redistribution, and this will be examined when the results of the other two methods of investigation have been discussed.

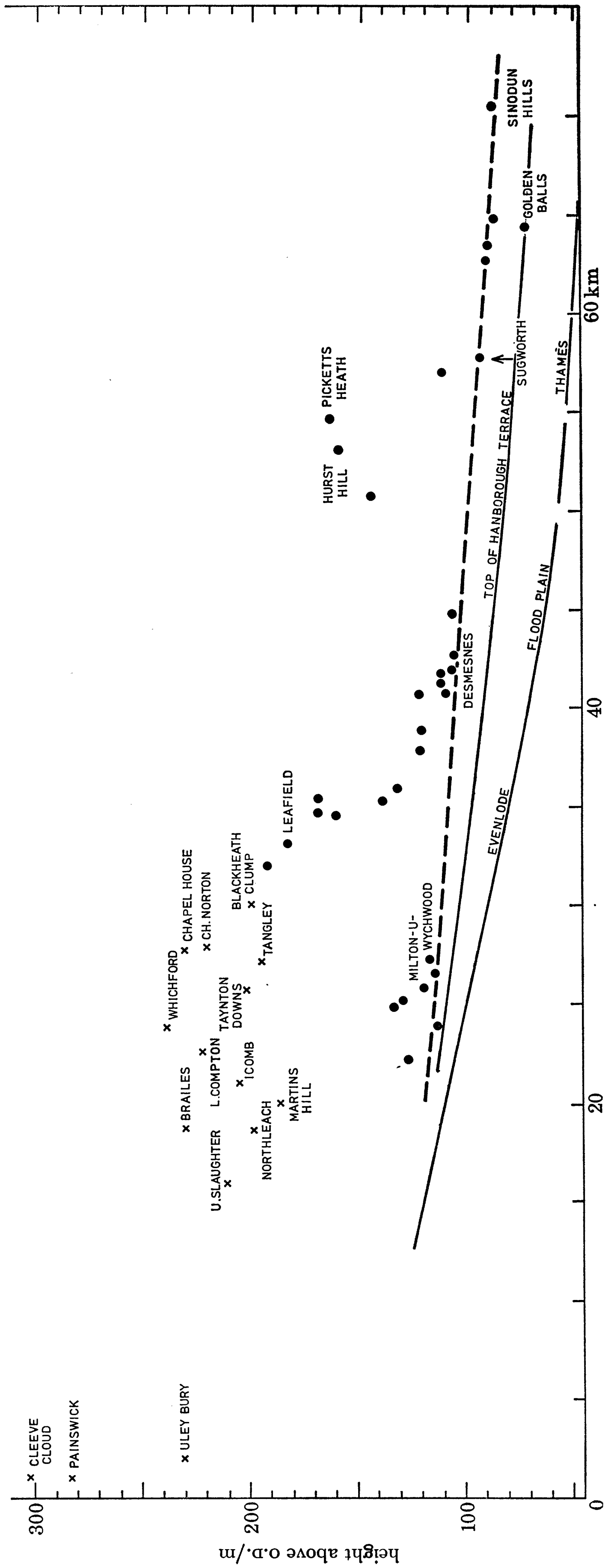

FIGURE 6. The levels of deposits called Plateau Drift, from the Cotswold scarp, down the Evenlode to the Thames at Oxford.

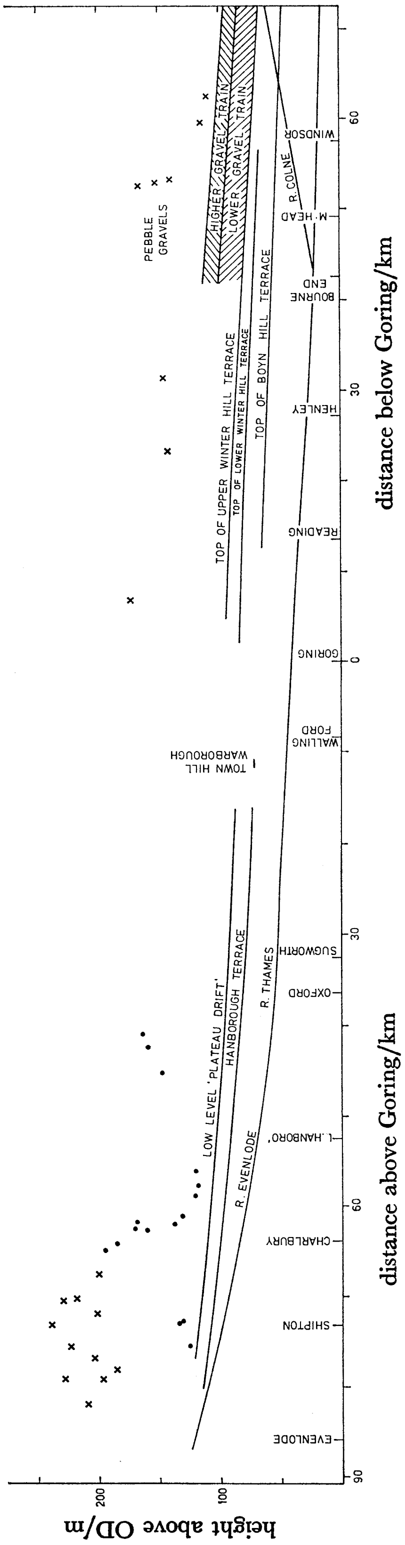

Figure 9. The higher terraces and earlier high level deposits bordering the Middle Thames and the Evenlode.

(c) *The pebble content of the Plateau Drift*

Normally, the Plateau Drift does not include any pebbles of limestone. It is impossible to believe that a deposit that has relics over a length of about 80 km of Jurassic outcrops, whether it be of glacial, fluvioglacial, periglacial or fluvial origin, could fail to include some Jurassic limestone in its composition. So we must assume that the Plateau Drift is decalcified and that what we now see in it are its insoluble relics.

Sandford (1929) listed the rock types that had been identified in the drifts of the Oxford district, but included some from sites as far afield as Buckingham, Bicester, Moreton-in-Marsh, and near Aylesbury. These localities have Pleistocene deposits very different in nature and date from the Plateau Drift, and to include them in a study of that deposit was misleading. Sandford acknowledged that pebbles from the Bunter Pebble Beds of the West Midlands were overwhelmingly dominant and, with a much smaller content of Cretaceous flint, made up virtually the whole of the pebble content, but he still regarded a small minority of the pebbles as ice-floated erratics from almost all the points of the compass. Study of the Midland Bunter has shown that its pebbles include many rare types, such as quartz porphyry, chert, gneiss, microgranite, schorl and a wide variety of tourmalinized rocks (see Smith 1963), that resemble those claimed as distant erratics by Sandford. Sandford's explanation of the origin of the Plateau Drift as being deposition from ice floating in a lake or sea, from such diverse sources as Norway, Scotland, East Anglia, southwest England and the West Midlands, is not now accepted. Almost all the pebbles, with the exception of flint, can be matched in the Bunter Pebble Beds and most are still recognizable by the retention of some part of the perfectly rounded exterior produced by Triassic transport.

In recent years more quantitative studies of pebble types have been undertaken. The procedure followed for this paper was to sort the pebbles into the broad categories proposed by Hey (1965), but, although quartz was counted separately from combined quartzite and sandstone, the figures were later recombined as 'Bunter pebbles'. Although there were wide variations in the ratio of quartz to quartzite plus sandstone (from 1/0.6 to 1/3.3), equally large, or larger, variations are to be found in undisturbed Bunter Pebble Beds of the Midlands. This is apparent in a study by Thomson (1953) on the Pebble Beds of the West Midlands.

We have disregarded all of Thomson's localities that were originally wadi gravels contaminated by a large proportion of Palaeozoic limestone and/or Permian breccia fragments from the western mountain edge of the Triassic cuvette; this leaves 40 other localities, where Thomson worked out the proportions of different pebble constituents with the following results.

Table 1.

	quartz	quartzite	sandstone	tourmaline rock	chert	igneous	metamorphic	Permian breccia	others
mean (%)	16.8	64.6	7.6	1.7	4.2	0.2	0.23	4.4	0.25
range (%)	3.0–43.6	37.4–81.0	0–25	0–4.4	0–15.2	0–1.1	0–2.4	0–14.3	0–4

An extremely wide variation in the quartz:quartzite ratio must result from these figures. Inasmuch as Thomson based his counts on weight rather than on number of pebbles and also pointed out that quartz pebbles were usually smaller than the other constituents, it would follow that quartz:quartzite ratios based on numbers would be even more divergent and well outside the proportions arising from the counts of the high level Plateau Drifts. Since there is no doubt that many of the quartz, quartzite and sandstone pebbles are derived from the Bunter, there seems good reason to accept that so are they all and that the quartz:quartzite ratio at any one site has no significance. So the sum of the means in the first three columns of table 1, i.e. 89.0 %, is to be compared with the figures shown for 'Bunter Pebbles' in subsequent tables. We may go a little further. If we assume that the 4.4 % of weathered pre-Cambrian material from the Permian breccias that still show in Thomson's figures would not survive another phase of transport, then 89.0 % recalculates as 93.1 %. It is this latter figure that should be compared with the analyses of Plateau Drifts and of other deposits that follow. This does not mean that other very minor constituents (except flint), e.g., chert, igneous and metamorphics, could not also have originated in the Bunter Pebble Beds.

The Plateau Drift sites where pebble counts were made by A.G. included only two high level localities, Leafield at 183 m and Shipton Downs at 200 m. However, Hey (1965) had already examined three other high level sites at Waterman's Lodge (192 m), Ramsden Heath (169 m) and Picketts Heath (Boars Hill), (163 m) and all five sites are included in table 2 (group A). Figure 5 shows their location.

TABLE 2. PEBBLE COMPOSITION OF HIGH AND LOW LEVEL PLATEAU DRIFT

	group A					group B			
	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	(*g*)	(*h*)	(*i*)
Bunter pebbles	77.9	97.0	97.5	93.0	95.5	94.1	87.4	87.8	76.1
flint	17.7	1.7	1.8	1.8	1.5	2.9	6.3	9.8	21.6
limestone	—	—	—	—	—	—	—	—	—
chert	2.2	1.9	0.5	3.0	1.0	—	1.9	—	1.3
basic igneous	1.5	—	—	0.6	1.5	1.0	1.0	1.2	0.6
metamorphic	0.5	—	0.3	1.3	0.5	2.0	3.4	1.2	0.4

	location	grid reference	height above O.D./m	
(*a*)	Shipton Downs	SP 267153	200	A. Goudie coll.
(*b*)	Waterman's Lodge	SP 326183	192	R. Hey coll.
(*c*)	Leafield	SP 316154	183	A. Goudie coll.
(*d*)	Ramsden Heath	SP 345158	169	R. Hey coll.
(*e*)	Picketts Heath	SP 485031	163	R. Hey coll.
(*f*)	The Demesnes	SP 399136	107	A. Goudie coll.
(*g*)	Bagley Wood	SP 515016	100	A. Goudie coll.
(*h*)	Sinodun Hills	SP 568926	91	A. Goudie coll.
(*i*)	Warborough, Town Hill	SU 600946	71	A. Goudie coll.

In this and subsequent tables, figures are expressed as percentages of the totals except where otherwise stated.

Four of the five columns of group A are remarkably similar and indicate almost complete derivation from the Bunter Pebble Beds. Flint is quite rare. The Shipton Downs locality (*a*) is anomalously high in flint, which is difficult to explain, particularly since it is the most westerly of the examined sites; but the derivation of most of the pebbles from the Trias is still very clear.

In group B of table 2, sites of 'low level' Northern Drift have been put together. Neglecting, for the moment, site (*i*), Warborough, the other three differ from four of the five sites in group A only in having a little more flint, though none approaches the figure of 17.7 % in the high level Shipton Downs site (*a*). On the basis of pebble content, therefore, low level 'Plateau Drift' cannot be clearly distinguished from that at high level.

Column (*i*) of group B, table 2, relates to Town Hill, north of Warborough. No Pleistocene deposit is shown here on I.G.S. map 255, but one of us (A.G.) was familiar with the scatter of pebbles over the hill top and it was on these that the count was made, resulting in a comparatively large flint figure. It is very doubtful, however, if this occurrence can be claimed as a relic of Plateau Drift. The summit of Town Hill is at 71 m, which is 13 m lower than would be expected if the baseline curve of figure 6 had any validity. It may be significant that 13 m also separates the post-Cromerian 'Plateau Drift' of Sugworth from the top surface of the Hanborough Terrace immediately to the east. The Hanborough Terrace at the type locality stands 25–26 m above river alluvium. About 18 km downstream, the same terrace, east of Sugworth, is 25 m above the river, and, a further 18 km downstream, Town Hill stands at the same distance above the river. It seems likely, therefore, that the spread of pebbles here is the insoluble residue of a patch of Hanborough Terrace. The small outcrop of so-called Plateau Drift at the Golden Balls (see figure 5) may also be a decalcified remnant of the same terrace.

(*d*) *The pebble content of the Cromerian channel sediments and of the Plateau Drift-like deposit that overlies them*

Three samples ((*j*), (*k*) and (*l*)) were collected from the coarser beds of the channel fill. Each contained an appreciable or even major content of limestone pebbles derived from the Jurassic. Rolled and broken Mesozoic corals and molluscs were abundant, large shells of *Ostrea delta* being particularly conspicuous at the base of the channel on the west side of the cutting, and Dr S. McKerrow kindly identified the following species:

Ostraea delta from the Lower Kimmeridge Clay;
Exogyra nana from the Corrallian or Kimmeridge Clay;
Isastraea sp., *Thecosmilia* sp., and *Lopha gregaria*, from the Corallian;
Gryphaea dilata and *Belemnites oweni* from the Upper Oxford Clay; and
Belemnites biloba from the Lower Oxford Clay.

All these fossils could have been eroded from outcrops crossed by the river of the Sugworth channels at moderate distances upstream and their presence could have been expected. Table 3 gives the proportions of various types of clasts in samples (*j*) (*k*) and (*l*), and (**j**), (**k**) and (**l**) are recalculated percentages of the non-limestone components. This second set of figures can only be explained on the supposition that both Plateau Drift and the Jurassic strata were exposed to erosion in Cromerian time, i.e., that part or all of the Plateau Drift is pre-Cromerian. The proportion of flint appears to be a little higher in the channel gravels than in the Plateau Drift, but this may reflect the greater propensity of flint pebbles to become fractured during recycling.

The pebbly sandy clay that transgresses the Sugworth channels was sampled at five places, and the results of pebble counts are also shown in table 3. Unlike the channel gravels, the pebbly sandy clay has no, or very little, limestone and in its composition it is not distinguishable from the Plateau Drift samples of table 2. This could be explained on the assumption that during its formation it in some way avoided incorporating the Jurassic limestones that contributed to the earlier channel gravels, but this problem is more fully discussed later.

(*e*) *Comparative data for Thames Terrace deposits*

The *Hanborough Terrace* (Terrace IV of the Geological Survey), which occurs near Oxford at about 26 m above the level of the Thames floodplain, is very different in lithology from the Plateau Drift, being dominated by flat, rolled oolitic debris with only a small proportion of exotic materials. A count at Church Hanborough (418138) gave the following percentages: Bunter pebbles, 9.6; limestone, 88.2; ironstone, 1.9. No flint was noted in this sample, but, if the Bunter pebbles are derived from Plateau Drift, then, with their percentage standing at 9.6, associated flint might only be expected to make up a fraction of 1% and so might not have figured in the sample. When this limestone-rich gravel is completely decalcified, as it is in the filling of numerous pipes, the resultant brown-red clay with Bunter Pebbles closely resembles some of the Plateau Drift.

TABLE 3. PEBBLE COMPOSITION OF GRAVEL LAYERS IN THE SUGWORTH CHANNELS ((*j*)–(*l*)) AND OF THE OVERLYING PEBBLY CLAY ((*m*)–(*q*))

	(*j*)	(*k*)	(*l*)	**(j)**	**(k)**	**(l)**	(*m*)	(*n*)	(*o*)	(*p*)	(*q*)
Bunter quartzite and vein quartz	63.0	34.2	66.8	69	79	85	88.6	93.1	87.6	87.5	84.6
flint	26.2	6.5	11.3	29	15	14	10.3	4.7	8.4	10.4	11.4
limestone	8.9	56.9	21.0	—	—	—	—	—	1.24	0.46	—
chert	0.23	—	0.61	0.25	—	0.77	0.54	0.73	0.62	0.69	0.88
basic igneous	0.23	1.31	—	0.25	3.04	—	0.54	0.36	1.24	0.23	2.64
metamorphic	1.41	1.09	0.30	1.55	3.60	0.38	—	1.09	0.93	0.69	0.44
$n =$	427	459	328	389	198	259	185	275	323	432	227

(*j*) Sugworth channel, gravel layer
(*k*) Sugworth: small channel cut in Kimmeridge Clay on Abingdon side
(*l*) Sugworth: gravel layer in main section, 1 m above datum
(j), **(k)**, **(l)** above figures recalculated after elimination of limestone
(*m*) Sugworth, cover of Plateau Drift type, Abingdon side of trench
(*n*) Sugworth, 'Plateau Drift', farm trench
(*o*) Sugworth, 'Plateau Drift', depot
(*p*) Sugworth, 'Plateau Drift', lane
(*q*) Sugworth, 'Plateau Drift', Abingdon side of lane

The *Wolvercote Terrace*, approximately 15 m above the Thames, has at its type locality, according to Bishop (1958), 9.1–19.7% flint, 4.5–15.45% Bunter and 46.9–76.0% Jurassic material. The origin of these pebbles is, however, very different from that for the Hanborough Terrace or the Plateau Drift, since the flint and Bunter pebbles emanate from the Wolstonian drifts north of Moreton-in-Marsh and derive from northeast of Leicestershire.

The extensive *Summertown–Radley Terrace*, 7–8 m above the river, is even more dominated by Jurassic material, with flint up to 10.6% and Bunter pebbles below 3.8%, according to samples counted at Kirtlington and Begbroke.

(*f*) *The shape of Plateau Drift and Sugworth channel pebbles*

Standard examination of pebble shape by means of Cailleux's indices was carried out on two samples from the Sugworth channel, four from the overriding pebbly clay, all close to Sugworth, and two accepted Plateau Drift samples from the Demesnes and from Shipton Barrow. The determinations were carried out on Bunter quartzite pebbles of 2–12 cm length, so that there was as much lithological comparability between sites as possible. The index of flattening, $100(w+1)/2t$, is similar for all samples (range 168.2–198.3), as is the index of asymmetry (range 559–656). The index of rounding, however, shows a greater range (322.5–480.4). There is nothing in these figures that differentiates between the three types of deposit, nor perhaps should that have been expected. Such perfect rounding was imposed on these pebbles during Triassic times, that rederivation in the Quaternary could only impair that rounding, not add to it.

(*g*) *The heavy minerals of the Sugworth deposits and the Plateau Drift*

Although investigation of the pebble content of the drifts helps to determine the relation between the coarser fractions of the deposits, it does not explain the nature of the fine fractions, which may retain the accessory minerals of calcareous rocks whose pebbles have disappeared, by solution. For this reason, heavy mineral analyses were carried out by D.J.B. on samples collected from the Sugworth channels and overlying pebbly clay, and from the drifts of neighbouring areas.

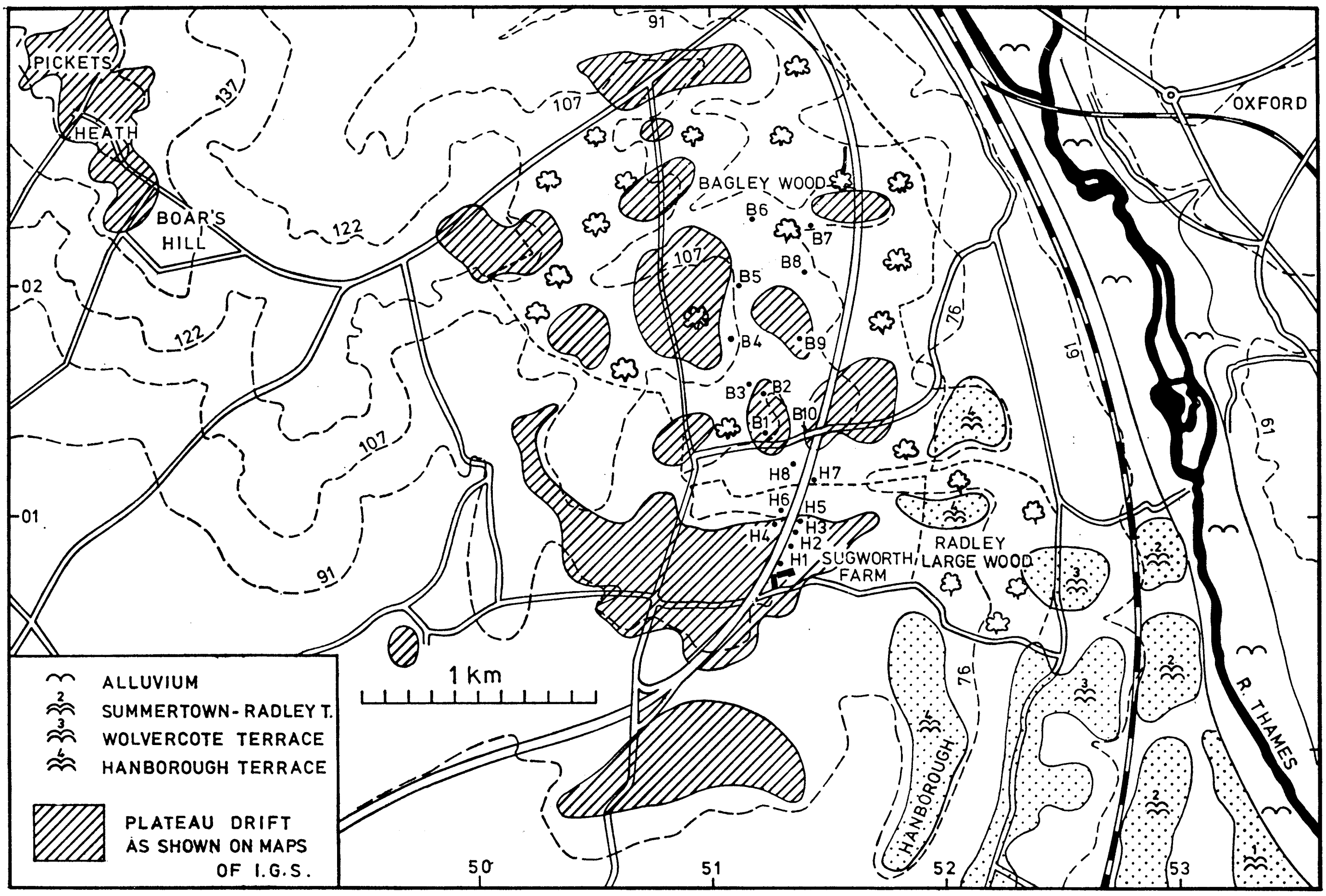

Figure 7. The position of heavy mineral samples in the Pebbly Clay around Sugworth Farm and in the Bagley Wood Sands.

The samples were analysed by standard methods, following Müeller (1967). The material was sieved to obtain the fine sand fraction (63–250 μm) and this was treated with warm aqua regia to clean the grains and to destroy soluble constituents. Of the insoluble residue, 50 g was then floated in bromoform (relative density 2.86) and the heavy minerals collected and mounted on permanent slides. All the non-opaque grains were then identified by standard microscope methods and counted.

Twelve samples were taken from ten localities (excluding Sugworth itself and Bagley Wood to the north of it) mapped as Plateau Drift by the Geological Survey. At two of these localities,

Table 4. Heavy mineralogy of the Plateau Drift

	(A) high and medium level					(B) low level								
	P1	P2	P7	P8	$\bar{X}$†	P3	P4a	P4b	P5a	P5b	P6	P9	P10	$\bar{X}$†
colourless zircon	51.4	65.0	67.0	62.1	61.4	45.1	49.0	35.0	67.8	64.0	64.8	42.0	63.5	53.9
pink zircon	0.0	0.7	0.0	1.7	0.6	0.6	0.2	1.4	0.7	0.2	0.6	1.7	0.2	0.7
colourless angular garnet	0.9	0.4	0.0	0.0	0.3	3.1	1.9	0.0	0.7	0.7	1.0	6.3	1.8	1.9
colourless rounded garnet	0.0	0.0	0.0	0.0	0.0	1.7	0.6	0.4	0.3	1.0	0.0	2.3	0.2	0.8
pink garnet	0.5	0.2	0.0	0.3	0.3	1.7	0.0	0.7	0.0	0.2	0.2	2.3	0.0	0.6
total garnet	1.4	0.6	0.0	0.3	0.6	6.5	2.5	1.1	1.0	1.9	1.2	10.9	2.0	3.4
brown tourmaline	30.6	4.8	10.5	15.4	15.3	25.1	23.6	40.4	10.7	12.4	4.7	19.0	13.6	18.7
other tourmaline	0.9	0.7	0.0	3.6	1.3	1.1	4.7	1.1	0.4	1.0	1.6	2.9	1.8	1.8
total tourmaline	31.5	5.5	10.5	18.0	16.6	26.2	28.3	41.5	11.1	13.4	6.3	21.9	15.4	20.5
red rutile	0.9	0.7	2.0	0.8	1.1	0.8	0.6	1.1	0.7	0.9	0.5	1.1	1.1	0.85
yellow rutile	4.6	12.6	7.0	5.8	7.5	5.9	7.8	4.0	7.7	8.4	12.7	4.6	6.1	7.15
brown rutile	1.9	9.3	7.5	3.1	5.5	6.2	5.2	4.7	6.8	6.0	6.7	5.2	6.3	5.9
total rutile	7.4	22.6	16.5	9.7	14.1	12.9	13.6	9.8	15.2	15.3	19.9	10.9	13.5	13.9
angular staurolite	4.6	2.6	3.0	3.3	3.4	3.7	5.0	3.6	2.2	1.9	3.9	6.3	1.4	3.5
rounded staurolite	0.0	0.0	0.0	0.3	0.1	1.4	0.2	2.9	0.3	0.0	0.6	0.6	0.5	0.8
kyanite	1.4	2.2	2.0	2.8	2.1	1.4	0.4	3.2	1.6	2.6	2.3	5.2	1.8	2.3
other	2.3	0.9	1.0	0.6	1.2	2.2	0.9	1.4	0.1	0.7	0.3	0.6	1.6	1.0

† $\bar{X}$, Mean.

P4 and P5 of table 4, the deposits were thick enough to justify a sample from near the top of the section (a) and from near the base (b). The localities are indicated on figure 5.

Eight points were sampled in the post-channel pebbly clay at or close to the main motorway section, two of these having upper (a) and lower (b) samples, and their position is shown on figure 7. Their heavy mineralogy is given in table 5. Bagley Wood to the north of Sugworth, though not greatly higher topographically than Sugworth, is largely covered by sand that has nevertheless been interpreted as still another occurrence of Plateau Drift. On the special geological map of the Oxford area published by I.G.S., a number of isolated patches in the wood are shown as Plateau Drift, and these boundaries have been retained on figure 7. Nevertheless, the sampling boreholes that were made in the wood show that the Bagley Wood sands do not conform to the mapped boundaries. The location of ten boreholes on the eastern half of the wood, yielding eleven samples (two from B9) is shown on figure 7 and the heavy minerals are listed in table 6.

TABLE 5. HEAVY MINERALOGY OF THE SUGWORTH PEBBLY CLAY

mineral	H1a upper	H1b lower	H2	H3	H4	H5	H6	H7	H8a upper	H8b lower	$\bar{X}$†
colourless zircon	34.4	40.0	52.8	34.1	30.7	35.9	35.7	34.4	54.6	40.5	39.3
pink zircon	0.0	1.4	0.9	1.1	0.0	1.0	0.2	0.4	1.1	1.1	0.7
total zircon	34.4	41.4	53.7	35.2	30.7	36.9	35.9	34.8	55.6	41.6	40.0
colourless angular garnet	29.2	9.8	16.8	8.0	11.3	25.2	22.4	20.4	3.8	19.0	17.6
colourless rounded garnet	5.2	7.9	1.2	8.1	6.6	6.0	6.6	8.6	0.4	2.6	5.3
pink garnet	1.9	6.1	2.1	4.5	4.0	3.0	2.5	2.4	0.4	4.1	3.1
total garnet	36.3	23.8	20.1	30.6	21.9	34.2	31.5	31.4	4.6	25.7	26.0
brown tourmaline	14.9	12.6	9.3	15.3	28.0	11.0	13.1	14.8	18.3	11.5	14.9
other tourmaline	1.3	1.2	0.5	0.5	2.0	1.3	1.6	1.1	1.8	1.1	1.2
total tourmaline	16.2	13.8	9.8	15.6	30.0	12.3	14.7	15.9	20.1	12.6	16.1
red rutile	0.6	1.6	0.2	0.8	2.0	0.3	0.9	0.6	0.7	0.4	0.8
yellow rutile	1.3	4.4	3.0	3.6	4.0	2.3	4.5	2.4	4.8	4.8	3.5
brown rutile	3.9	3.5	4.0	3.3	2.6	3.3	4.8	4.1	4.3	1.9	3.6
total rutile	5.8	9.5	7.2	7.7	8.6	5.9	10.2	7.1	9.8	7.1	7.9
angular staurolite	3.2	5.1	3.0	3.8	4.0	4.3	2.7	4.7	3.7	1.9	3.6
rounded staurolite	0.6	0.5	0.5	0.5	2.0	1.0	0.5	0.4	1.0	5.2	1.2
kyanite	1.9	2.6	4.2	3.6	1.3	4.0	4.1	3.7	3.2	5.2	3.4
other	1.3	3.3	1.4	3.0	1.3	1.7	0.5	2.1	1.9	0.7	1.7
number of grains	154	428	640	150	301	442	535	835	835	269	4589

† $\bar{X}$, Mean.

Finally, the heavy mineralogy of the Channel Sands at Sugworth is shown in table 7. It is clear from all these tables that the variety of heavy minerals in all deposits was similar. The dominant non-opaque mineral in nearly all samples was zircon, which occurred both as rounded, rod-shaped colourless grains and as euhedral colourless prisms. Rarer, coloured varieties (pink and mauve) also occurred.

Tourmaline was similarly abundant in most samples. This was mainly present as large (*ca.* 200 μm diameter), rounded 'potato'-shaped grains, showing strong pleochroism from brown to colourless, yellow or grey. Smaller quantities of green, blue and bicoloured varieties were also found. Almost all the tourmaline appeared to be schorl.

TABLE 6. HEAVY MINERALOGY OF THE BAGLEY WOOD SANDS

mineral	B1	B2	B3	B4	B5	B6	B7	B8	B9a upper	B9b lower	B10	$\bar{X}$†
colourless zircon	63.2	60.3	51.1	48.4	65.2	41.7	52.5	26.0	31.0	50.3	57.5	49.7
pink zircon	1.0	1.2	1.2	0.6	1.0	1.9	1.4	0.0	1.2	1.3	0.9	1.1
total zircon	64.2	61.5	52.3	49.0	66.2	43.6	53.9	26.0	32.2	51.3	58.4	50.8
colourless angular garnet	3.0	3.7	4.6	3.1	0.6	3.2	3.3	1.4	2.0	4.4	0.7	2.7
colourless rounded garnet	1.0	2.2	0.7	1.2	0.0	1.3	1.4	1.9	0.4	2.8	0.0	1.2
pink garnet	0.8	1.8	2.7	0.6	0.0	3.5	3.2	2.9	1.2	2.8	0.0	1.8
total garnet	4.8	7.7	8.0	4.9	0.6	8.0	7.9	6.2	3.6	10.0	0.7	5.7
brown tourmaline	15.2	13.8	17.4	31.7	18.0	27.9	21.2	42.9	40.9	22.8	15.7	24.3
other tourmaline	1.8	1.2	1.5	0.0	1.0	0.0	0.7	1.9	1.2	1.3	1.8	1.1
total tourmaline	17.0	15.0	18.9	31.7	19.0	27.9	21.9	44.8	42.1	24.1	17.5	25.4
red rutile	0.8	1.5	1.0	0.6	0.6	2.9	0.4	1.0	2.0	0.9	0.7	1.1
yellow rutile	3.3	3.4	5.3	2.5	1.9	2.9	2.6	2.9	0.8	2.5	6.3	3.1
brown rutile	5.6	4.0	5.6	1.2	4.0	6.1	4.2	3.9	6.3	3.4	4.9	4.5
total rutile	9.7	8.9	11.9	4.3	6.5	11.9	7.2	7.8	9.1	6.8	11.9	8.7
angular staurolite	2.0	3.7	3.9	4.3	4.7	7.1	3.7	5.8	7.5	4.4	4.0	4.7
rounded staurolite	0.0	0.9	0.5	1.2	0.3	0.3	1.9	4.3	1.2	1.6	0.9	1.2
kyanite	1.8	1.5	2.7	1.9	2.2	1.3	2.6	3.4	4.0	1.6	1.6	2.2
other	0.5	0.6	1.9	2.5	0.6	0.0	0.9	1.9	0.4	0.0	0.8	0.9
number of grains	394	325	413	161	322	312	570	208	252	320	427	3704

† $\bar{X}$, Mean.

TABLE 7. HEAVY MINERALOGY OF THE CHANNEL SANDS

mineral	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	$\bar{X}$
colourless zircon	51.2	36.2	44.6	53.9	52.0	49.4	10.7	29.4	29.1	44.9	32.7	47.2	33.2	60.2	34.4	40.6
pink zircon	0.0	2.4	0.8	5.2	1.6	0.0	0.0	1.0	1.7	2.6	0.4	0.0	1.0	0.0	0.0	1.1
total zircon	51.2	38.6	45.4	59.1	53.6	49.4	10.7	30.4	30.8	47.5	33.1	47.2	34.2	60.2	34.4	41.7
colourless angular garnet	12.5	16.0	15.2	11.9	17.8	14.1	8.3	8.6	14.7	6.2	7.5	12.2	7.9	7.9	6.3	11.0
colourless rounded garnet	2.2	4.7	1.6	0.2	1.2	2.7	9.5	9.2	1.4	11.1	11.1	10.0	5.4	6.7	14.4	6.1
pink garnet	1.9	1.6	1.5	3.2	1.0	3.9	8.9	8.6	3.8	5.9	9.3	5.6	3.0	1.2	5.0	4.3
total garnet	16.6	22.3	18.3	15.3	20.0	20.7	26.7	26.4	19.9	23.2	27.9	27.8	16.3	15.8	25.7	21.4
brown tourmaline	9.0	19.4	13.7	9.6	3.4	14.9	29.8	17.8	26.7	10.6	13.3	7.5	29.2	11.5	20.0	15.8
other tourmaline	0.8	1.0	2.6	0.0	0.1	1.3	1.8	0.3	1.0	1.5	0.4	0.3	0.5	1.0	0.0	0.8
total tourmaline	9.8	20.4	16.3	9.6	3.5	16.2	31.6	18.1	27.7	12.1	13.7	7.8	29.7	12.5	20.0	16.6
red rutile	1.2	0.8	0.9	0.7	0.7	1.1	1.2	2.0	2.1	2.5	4.4	1.9	1.0	0.8	1.9	1.5
yellow rutile	7.4	2.9	4.6	2.3	8.0	2.3	1.8	3.3	2.7	2.9	1.3	5.6	1.0	2.0	2.5	3.4
brown rutile	6.3	4.4	3.1	2.8	7.2	3.4	3.0	3.6	4.1	4.1	4.0	1.9	5.4	3.4	0.6	3.8
total rutile	14.9	8.1	8.6	5.8	16.3	6.9	6.8	9.0	9.3	11.4	7.2	8.5	7.4	6.2	5.0	8.7
angular staurolite	3.9	4.6	4.3	5.3	1.6	3.6	11.9	8.6	6.5	1.8	7.1	5.0	6.4	1.4	6.9	5.3
rounded staurolite	0.3	0.3	0.9	0.0	0.3	0.0	4.2	1.3	1.4	2.1	4.4	0.8	2.0	1.0	0.0	1.3
kyanite	2.3	3.6	3.6	2.5	3.1	3.6	6.0	3.6	3.8	3.8	4.0	1.4	4.0	1.4	3.1	3.3
other	1.1	2.1	2.7	2.4	1.8	0.4	3.0	2.6	1.0	1.2	0.0	0.6	0.0	1.6	5.0	1.7
number of grains	640	614	745	562	734	538	168	303	292	341	226	360	202	505	160	6390

† $\bar{X}$, Mean.

Garnet (almandite) showed a less regular distribution, being abundant in the channel sands and the pebbly clay but rare in the Plateau Drifts both from Bagley Wood and from elsewhere in the area. The main forms were colourless and either angular, euhedral or rounded in shape, but a significant quantity of salmon pink garnet occurred in most samples.

The other main constituents of the heavy mineral fractions were rutile, staurolite and kyanite. Rutile was present as small, brown and yellow grains, generally ovate or spheroidal in shape, but occasionally euhedral and showing knee twinning. Larger, rounded, red grains also occurred. Two forms of staurolite were widely found. The most abundant was angular, small, and pale yellow in colour; the less common form was larger (150–200 μm), rounded, strongly pleochroic and frequently showing extensive alteration to iron. Kyanite occurred mainly as large, flat prismatic grains, often with somewhat rounded corners and, on occasions, displaying simple twinning.

In all the samples, a small number of ancillary minerals were found. Individually, these generally accounted for less than 0.1 % of the total non-opaque assemblages. The most common ancillary minerals were epidote, muscovite, monazite, sphene, chloritoid, topaz, hornblende and glauconite. In addition, a small proportion of non-opaque minerals could not be identified either because of their small size or because of extensive alteration. These were not included in the heavy mineral counts.

(*h*) *Discussion of the heavy mineral analysis results*

It has already been stated that the variety of heavy minerals is essentially similar in all four deposits studied. The proportions of individual minerals, however, vary both within individual deposits (from sample to sample) and between deposits. From a superficial inspection of the results, the most obvious examples of the former situation are zircon and tourmaline. Zircon, for example, ranges from 10.7 to 60.2 % in the channel sands, while, in the same deposits, tourmaline varies from 3.4 to 31.6 %. Garnet, on the other hand, provides an example of a mineral that is reasonably consistent within a single group of deposits, but differs widely between each group. Nevertheless, it is clear from the bivariate scattergram (figure 8), which plots total zircon against total garnet, that the deposits divide conclusively into two distinct groups. Characterized by a small garnet content and a high zircon figure are the high level Plateau Drift (zircon averaging 62 %, garnet 0.6 %), the low level Plateau Drift (zircon 54.6 %, garnet 3.4 %) and the Bagley Wood Sands (zircon 51.1 %, garnet 5.7 %). These three are widely separated from the Channel Sands (zircon averaging 41.7 %, garnet 21.4 %, including one sample, C7, with anomalously low zircon). They differ even more from the Pebbly Clay (zircon 40.0 %, garnet 26.0%), even though the latter has one very anomalous result, H8a, which agrees well with the low level Plateau Drift and also falls within the field of the Bagley Wood Sands. It should be pointed out that this sample was taken from the top of borehole H8, and that one from the bottom of the same hole (H8b) gave zircon and garnet figures that almost coincide with the mean for the Pebbly Clay. Borehole H8 is also the northernmost sample of the Pebbly Clay and adjoins the holes sampling the Bagley Wood Sands, so that there is the possibility that at this point Bagley Wood Sands rest upon Pebbly Clay.

Confirmation of this separation into two groups is given by statistical analysis of the data. In this instance, the non-parametric Kruskal–Wallace one way analysis of variance must be used since the data do not show a normal distribution. The result of doing this on four groups of deposits (high level and low level Plateau Drift being grouped together for this purpose) is given in table 8.

These results emphasize that there is a very significant difference between the Pebbly Clay and the Plateau Drift and equally between the Channel deposits and the Plateau Drift. The Bagley Wood Sands are closer to the Plateau Drift than to the Channel Sands or the Pebbly Clay. On the other hand, the closest similarity between two separate deposits is that between the Channel Sands and the Pebbly Clay that overlies them. This analysis agrees well with the similar graphical analyis on figure 8.

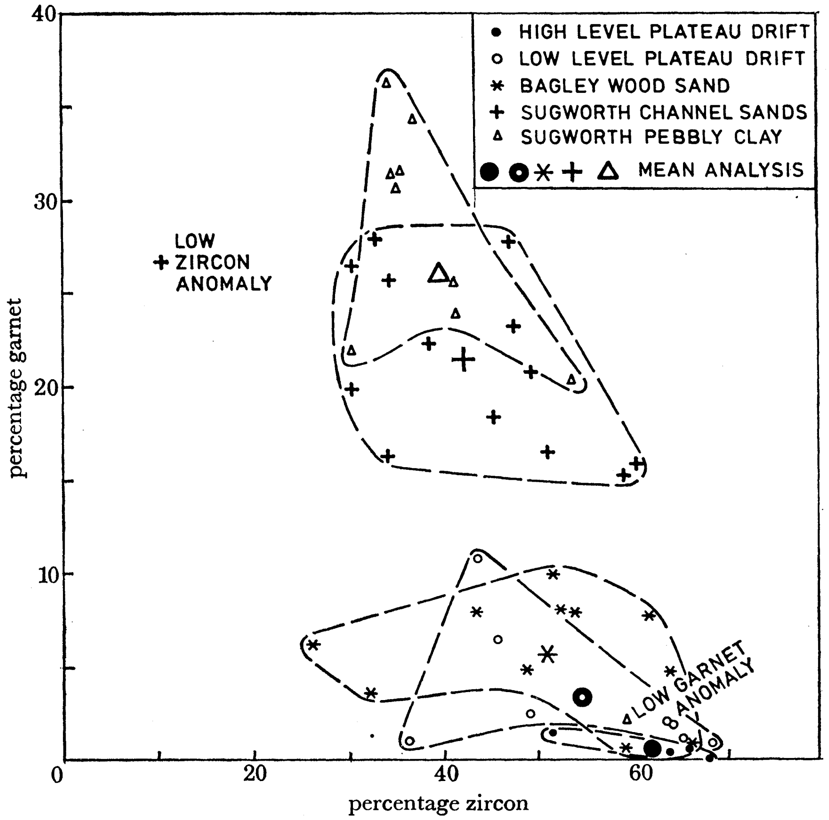

Figure 8. Scattergram of zircon and garnet content of various deposits once ascribed to the Plateau Drift.

Table 8. Percentage heavy minerals : levels of rejection of H_0 in Kruskal–Wallace one way analysis of variance

	Channel *v.* Pebbly Clay	Channel *v.* Bagley Wood	Channel *v.* Plateau Drift	Pebbly Clay *v.* Bagley Wood	Pebbly Clay *v.* Plateau Drift	Bagley Wood *v.* Plateau Drift
zircon	0.90	0.10	0.001‡	0.10	0.01‡	0.30
pink garnet	0.60	0.02†	0.001‡	0.10	0.001‡	0.02
colourless garnet	0.02†	0.001‡	0.001‡	0.001‡	0.001‡	0.05†
brown tourmaline	0.99	0.05†	0.70	0.01‡	0.80	0.10
other tourmaline	0.10	0.30	0.10	0.90	0.90	0.80
rutile	0.95	0.70	0.01‡	0.50	0.001‡	0.01‡
staurolite	0.40	0.99	0.10	0.30	0.20	0.10
kyanite	0.60	0.05†	0.02†	0.05†	0.05†	0.95

† Significant differences at the 0.05 level.
‡ Significant differences at the 0.01 level.

Before discussing the implications of the different approaches to the origin of the various deposits, it is clear that the Jurassic rocks that outcrop so prominently to the northwest of Sugworth, and possibly the Upper Greensand that underlies the Plateau Drift of Picketts Heath, could have affected the composition of the Quaternary sediments. Indeed, it has already been demonstrated that Jurassic clasts, from the Oxford Clay, Corallian and Kimmeridge Clay, are present in the gravels of the Channel sediments. Neaverson (1925) has published results for the Kimmeridge Clay that show the similarity of its heavy mineralogy to that of the Channel Sands.

Table 9. Heavy mineralogy of the Kimmeridge Clay (K.C.) and Upper Greensand (U.G.)

	K.C. bulk sample from Sugworth	U.G., Picketts Heath
colourless zircon	35.1	59.6
pink zircon	0.7	1.6
colourless angular garnet	15.6	0.7
colourless rounded garnet	0.4	0.6
pink garnet	1.8	0.2
total garnet	17.8	1.5
brown tourmaline	20.6	6.7
other tourmaline	4.0	0.4
total tourmaline	24.6	7.1
red rutile	0.4	2.6
yellow rutile	4.7	2.1
brown rutile	4.0	5.4
total rutile	9.1	10.1
angular staurolite	7.2	3.4
rounded staurolite	0.4	3.6
kyanite	2.9	10.6
others†	2.2	2.5
number of minerals counted	276	475

† Mainly chloritoid, topaz, sphene and epidote.

Although frequency was expressed in comparative terms, the four minerals (apart from opaque ones) listed as 'abundant' were garnet, rutile, zircon and tourmaline; staurolite and kyanite were 'common', and all others were rare or absent. D.J.B. analysed a bulk sample of Kimmeridge Clay and also of the Upper Greensand of Picketts Heath, and the results, shown in table 9, confirm the general tenor of Neaverson's work on the heavy minerals of the Kimmeridge Clay and show the similarity of the Kimmeridge Clay to the Channel Sands. At the same time it can be seen that the Upper Greensand in no way resembles the analyses of either the Channel Sands or the overlying Pebbly Clay, and that it cannot have contributed in a significant way to their formation.

6. Relative and actual ages of the Plateau Drift

What has up till now been grouped together under the headings of 'Northern Drift', 'Plateau Drift' or 'Plateau Gravel' is a series of outcrops, at widely varying heights, but all characterized by a dominance of pebbles derived from the Bunter Pebble Beds of the West Midlands, with flint in much smaller amounts. The channels at Sugworth show, by their constituents, that at their time of formation Jurassic rocks (from the Oxfordian to the Kimmeridgian) and Plateau Gravel were available for erosion. So some Plateau Gravel must be older than Cromerian III b. Yet the Pebbly Clay that caps the Cromerian channels, has also previously been included in the outcrops of Plateau Gravel, which it certainly closely resembles in appearance and pebble composition, and it unequivocally post-dates the Cromerian III b sediments of the channels, though not necessarily by a long time interval. Moreover, this pebbly clay covers an erosion bench that lies above the level of the Hanborough Terrace and that must continue upstream. Figure 6 suggests very strongly that it is represented by the low level occurrences of so-called Plateau Drift along the Evenlode valley, including also the Bagley Wood Sands. It is predictable that future exavations, on the scale of the motorway cuttings, will reveal additional Cromerian deposits beneath some of these low level 'Plateau Gravels', though it must not be forgotten that at Sugworth such deposits occurred under only 45% of the visible length of pebbly clay cover, and those with a recognizable fauna and flora, under only about 5%. So the chances in the near future of another discovery similar to Sugworth are slender; but they are still there.

The explanation advanced above involves the redistribution of pre-Cromerian Plateau Drift to lower levels of erosion. Deposits such as the Bagley Wood Sands and the sands and gravels of Arkell's Coombe and Freeland terraces (Arkell 1947) are certainly explicable by fluvial processes and there are many other instances for which a similar explanation would apply; but the pebbly clay that caps the Sugworth channels does not resemble a normal water-lain sediment and demands a different explanation.

The views so far advanced must also explain the evidence of the heavy mineralogy, and here we encounter a difficulty that does not weaken the arguments advanced above but nevertheless requires a satisfactory explanation. The high level Plateau Drift is almost devoid of garnet. Whether or not it reached its position on the Cotswolds by means of a glacier, it is still largely composed of Bunter sediments, and it is a feature of these Triassic rocks that they contain a considerable amount of garnet. Fleet (1927) gives average figures for the Bunter Pebble Beds of Warwickshire that, if recalculated to eliminate opaque minerals that are not considered in our tables 4–9, amount to: zircon, 47.8%; tourmaline, 9.6%; rutile, 9.0%; garnet, 9.0%; staurolite, 7.7%; anatase, 1.7%; and apatite, 15.4%. To bring the Plateau Drift from the Midland Trias to its present position on the Cotswolds, the transporting agent would have to traverse a succession of Jurassic rocks from the Lower Lias to the Kimmeridge Clay, and in so doing would be expected to pick up some of their heavy minerals. This is supported by the fact that the Plateau Drift contains kyanite, which is a mineral not recorded until the Jurassic.

Skerl (1927) listed the minerals of the Northampton Ironstone of mid-Northants in order of abundance, as follows: pale garnet, zircon, staurolite, chloritoid, kyanite, spinel and tourmaline. We have already quoted the relative abundance, given by Neaverson (1925), of heavy minerals in the Kimmeridge Clay and the absolute figures of a local sample in table 9. So it appears that the early, high level Plateau Drift must have originally contained considerable garnet. The counts of table 4(A) and figure 8 show that this is not now so, and that garnet is very rare or absent.

It seems unlikely that selective sorting during transport could have led to this loss of garnet, for no clear relation exists between the frequency of garnet and the texture of the samples. Selective abrasion is similarly an inadequate explanation, since garnet is generally considered to be highly resistant to mechanical wear. The possibility remains that chemical weathering of the high level Plateau Drifts, after deposition, has removed the garnet. Although considerable differences of opinion exist, it is argued by some workers that garnet is readily removed in acid, humid conditions (Hutton 1950; Raeside 1959). This is an interesting possibility, for it would also explain the absence of Jurassic limestone clasts which might be expected in the Plateau Drifts, and strengthen the view that these deposits have been decalcified. It would also imply that they have experienced longer, or more intense, conditions of weathering than, say, the Cromerian channel sands, which contain a high proportion of garnet and also of Jurassic limestone clasts. This may reflect the greater antiquity of the high level Plateau Drift.

In the area of study there is no evidence for the actual age of the High Level Plateau Drift except that it is pre-Cromerian, and it could be of great antiquity. Its redistribution, mainly by fluviatile agencies, onto intermediate erosion levels, may also have taken place before the Cromerian, but there is insufficient evidence to confirm this. The low level deposits along the Evenlode, and the Bagley Wood Sands, both hitherto included within the designation of Plateau Drift, but apparently related to a river bench above the Hanborough Terrace, are best regarded as Anglian. The Pebbly Clay of Sugworth itself, previously included within the Plateau Drift, is more probably Anglian, by its relation to the Hanborough Terrace and its superposition on the Cromerian channel deposits.

7. Origin of the Pebbly Clay capping the Cromerian channels

After discarding (for lack of other evidence of glaciation) the possibility that the Pebbly Clay represents a till emplaced by ice subsequent to the Cromerian channels, it is still possible to present two alternative explanations for its origin.

(*a*) That it was derived from earlier, already decalcified, Plateau Drift, at higher altitudes in the neighbourhood, that was soliflucted across the already formed bench and channels during a subsequent (i.e. post-Cromerian IIIb) periglacial period. The most likely source is that of Picketts Heath (Boar's Hill) 3–4 km to the NW, rather than the sandy material of Bagley Wood to the north, which appears to have insufficient pebbles to produce a solifluction product like that of the capping to the channels. Indeed, the sands proved by borings on the east side of Bagley Wood (see figure 7) are at levels consistent with their being constituents of the Sugworth Bench and they may be alluvial deposits not overrun by the solifluction that occurred lower downstream.

Between the western side of Bagley Wood and Picketts Heath, the Geological Survey has mapped a number of patches ascribed to Plateau Drift (reproduced on figure 7), that can be explained as relic areas of a solifluction sheet that descends with more or less uniform slope from Picketts Heath. It is true that no similar relics occur directly between Picketts Heath and the large patch of 'Plateau Drift' that includes Sugworth, but, if the approximate contours on the base of the preserved relics of this postulated sheet solifluction are extrapolated across this area, it is evident that more recent stream erosion will have entirely removed the evidence.

If sheet solifluction is the correct explanation, it must account for the fact that the Pebbly Clay contains few or no limestone clasts (average, 0.37%; see table 3), like the high level Plateau Drift, but unlike the Channel Sands. It also has to explain why this alleged solifluction has a high content of the heavy mineral garnet, which is poorly represented in the postulated Plateau Drift parent source. Neither of these features controverts the solifluction hypothesis. The fossiliferous limestones occurring in the Channel Sands derive from the Lower Kimmeridge

Clay, the Corallian and the Upper and Lower Oxford Clay (p. 71), which entails transport by the ancient river from many kilometres upstream from Sugworth. If, however, the Pebbly Clay is pictured as sludging down from Picketts Heath, it would have no contact with either Corallian or Oxford Clay, only with an outcrop of Upper Greensand and a wide expanse of Kimmeridge Clay. The latter is predominantly a formation of clay, shale and mudstone, with limestone subordinate, and so incorporation of limestone in the solifluction sheet could be minimal. Incorporation of additional argillaceous material would have to come from the Kimmeridge Clay. The single heavy mineral analysis of table 9 and Neaverson's observations indicate how the high garnet figures of the Pebbly Clay could have arisen, thus providing its main point of difference from the high level Plateau Drift.

(*b*) An alternative hypothesis seeks to explain the similarities and differences between the Pebbly Clay and the channel fill by supposing that the Pebbly Clay was deposited as a calcareous terrace gravel, containing some Bunter pebbles, at the same time as the Bench was formed, either previously to or contemporaneously with the incision of the channels. The channel fill was derived partly from the same source as the terrace gravels, partly by direct erosion of those gravels. Subsequently, the gravel was soliflucted from the sides over the top of the partially filled channels, and was progressively decalcified and cryoturbated so that we see now only an unstratified remanié, yet resembling the channel fill in its Bunter content, its garnet content and the occasional presence still of calcareous gravel at its base.

This hypothesis is satisfactory in ascribing the cutting of the erosion surface across the Kimmeridge Clay to the same time as covering gravels were being deposited, and it explains the similarity in heavy mineralogy between the channel sediments and the covering Pebbly Clay. It has to explain, however, why the latter was virtually completely decalcified while the underlying, highly permeable gravels of the channels were unaffected and also why, if channels and bench cover were contemporaneous, the channels are so decisively truncated by the Pebbly Clay. Whichever of these hypotheses is accepted (and some intermediate views are also tenable), it is of course clear that the final emplacement of the Pebbly Clay over the channels was post-Cromerian IIIb, although its original deposition in the neighbourhood may, on the second hypothesis have been Cromerian.

8. Relation of the Plateau Drift to the higher terraces of the Thames below the Goring Gap

Much work has been done on the spreads of gravel related to the Middle Thames below Goring since Sherlock (1924) suggested that the river originally had its course in places north of its present day position (Wooldridge 1938, 1958; Hare 1947; Sealey & Sealey 1956; Hey 1965; Walder 1967; Green & McGregor 1978). The sequence of terraces or, in the instance of the higher levels, rough terrace surfaces underlain by gravels is as follows:

(*a*) High level Pebble Gravels, including the Westland Green Gravels;
(*b*) Higher Gravel Train;
(*c*) Lower Gravel Train or Harefield Terrace;
(*d*) Upper Winter Hill Terrace;
(*e*) Lower Winter Hill Terrace;
(*f*) Boyn Hill Terrace;
(*g*) Lower terraces that need not be specified.

The Chalky Till of the Vale of St Albans antedates the Hoxnian deposits of Hadfield and also presumably the Boyn Hill Terrace sequence, and is therefore classed as Anglian (Kellaway *et al.* 1973). The Winter Hill Terraces are clearly older than the Boyn Hill Terrace in the type area for the latter, near Maidenhead. Kellaway *et al.* placed the Winter Hill Terrace also in the Anglian, although they did not separate the two stages. On the other hand, Evans (1971) equated the Winter Hill Terrace(s) with the Cromerian.

This situation clearly invites comparison with Sugworth, where late Cromerian channels are truncated by an erosion bench that is in turn covered by a possible solifluction. Whichever of the two possible explanations advanced, on pp. 81–82, for this upper layer is preferred, there is no question that it antedates the Hanborough Terrace, and so it may reasonably be referred to the Anglian cold period. Hence, the apparently opposed views of Evans and of Kellaway *et al.* on the Winter Hill Terrace may both be correct. It is useful to examine the disposition of Pleistocene deposits down the Evenlode, from its source, and along the Middle Thames; this is done in figure 9. The levels of the Pebble Gravels (including the Westland Green Gravels) and of the Higher and Lower Gravel Trains (which collectively include the Leavesden Gravels) in the Vale of St Albans, are taken from Green & McGregor (1978). The two Winter Hill Terraces and the Boyn Hill Terrace are interpreted from the map in Sealey & Sealey (1956). There is a gap in terrace representation in the steeper sided valley from Goring to Reading. Above Goring can be plotted the Hanborough Terrace, continuing up the Evenlode according to the levels shown by Arkell (1947), and above this is reproduced the baseline of figure 6 of this paper, which carries all the lowest occurrences of so-called Plateau Drift, including the pebbly clay cover of the Sugworth bench. (Figure 9 appears on p. 68.)

It appears that the Hanborough Terrace is represented downstream by the Boyn Hill Terrace, a correlation that has often been made previously and that does not preclude each of these terraces having a complex history within the Hoxnian and early Wolstonian. The lowest occurrences of so-called Plateau Drift lying above the Hanborough Terrace, on what might be called the Sugworth Terrace, would appear to correspond to the Lower Winter Hill Terrace, but not necessarily to its higher member. Its date at Sugworth is late Cromerian followed by Anglian solifluxion and this could reconcile the views of both Evans and Kellaway *et al.* Of the gravel deposits in the Middle Thames area that antedate the Winter Hill Terrace, the oldest must be the 'Pebble Gravel', which has a pebble content almost wholly of flint. Its age is problematical but it could be as old as Pliocene. In the Westland Green gravels of Hertfordshire, pebbles from the Bunter Pebble Beds are, for the first time, substantially present, and this is true also of the Leavesden Gravels, Higher Gravel Train and Lower Gravel Train (see Green & McGregor (1978) for pebble counts). Flint is still usually the most important component, but this would be expected in gravels that lie east of the Chalk outcrop. All who have worked recently on this problem, however, are agreed that these gravels are fluviatile in origin (some have argued for a fluvioglacial origin) and that the Bunter pebbles must have been transported from the Upper Thames through what is now the Goring Gap. The Plateau Drift is thus the only available source.

Two important conclusions then follow:

(*a*) that the oldest, higher level Plateau Drift must be at least as old as the Westland Green Gravels;

(*b*) that, since the Middle Thames shows at least three stages of erosion and deposition subsequent to the Westland Green Gravels before the Cromerian stage, a similar sequence of stages should be embodied in the varied levels of Plateau Drift northwest of Oxford, which antedate the Sugworth deposits.

9. THE ORIGIN OF THE EARLIEST PLATEAU DRIFT

There is ample evidence that much of what has been called Plateau Drift is water-deposited as, for example, the Coombe and Freeland terraces of Arkell (1947), or the Bagley Wood Sands. A section at the Desmesnes, SP 401138, opened up for inspection in April 1976, showed:

Rusty-red unbedded sandy clay with many pebbles, mainly Bunter, rare flint	0–2.4 m
Sand with beds of silt, occasional pebbles. (Largely proved by augering).	2.4–4.6+ m.

The upper 2.4 m is till-like, but could also be a decalcified gravel originally with a large content of limestone pebbles. The lower 2.2(+) m is certainly water-deposited.

This is one of the low level occurrences at a surface height of *ca.* 110 m above O.D., i.e. 38 m above the Evenlode alluvium, and so might be expected to have been redistributed from an earlier deposit. The difficulty of interpreting the overlying clayey gravel brings up the problem encountered whenever an unstratified deposit of Plateau Drift is considered. We have quoted Sandford's arguments (p. 66) for a glacial origin but it also must be acknowledged that, if 'Plateau Drift' was originally limestone-rich, its decalcification would produce a lack of regular bedding, stones standing at high angles, a concentration of clay material and a general resemblance to till. If we add to these factors the near certainty of solifluction, it is going to be very difficult to identify any pebbly clay deposit as a till, though easy to assert that a particular sand or clean gravel is not one. So attention must be turned to more abstract arguments.

The highest residual patches of Plateau Drift occur on the Great Oolite escarpment at heights up to 230 m or even 300 m if we accept Painswick and Cleeve Cloud as pieces of the escarpment recently detached. As for source areas of pebbles from the Bunter, there is a stretch from Hartlebury to Bridgnorth, 60–85 km to the northwest, the Birmingham area, 60 km to the north, and Cannock Chase, about 90 km to the north. At the present day, only the last-named location is marginally higher than the Cotswold Scarp; the others are lower. Even though one may claim that erosion must have lowered the general surface since Plateau Drift time, the fact still remains that the Bunter outcrops were exposed for erosion and the Great Oolite was exposed for reception of the Plateau Drift, so that all the intervening strata, including the Keuper Marl and Lias, must also have outcropped. It is unreasonable to think that the unresistant Keuper Marl and Lower Lias did not form a strike valley between the Lower Trias and the Oolites, as it did some time later, in pre-Wolstonian and even pre-Anglian times (Shotton 1953). So it seems impossible to reconstruct a system of fluvial drainage from the Trias areas to the Oolites, and for that reason, a glacier, the only agency of uphill transport, must be invoked for the earliest Plateau Drift. The limit of this glacier need not be far extended on to the Cotswolds, and high level occurrences of gravels, such as those at Leafield and Picketts Heath, may be outwash. Once the earliest drift deposits were in position, all lower outcrops can be explained by fluvial processes or solifluction. There are problems inherent in this explanation. The postulated glacier would need a head of ice to impel it over the Cotswold edge and there is no suitably high accumulation ground nearer than the Welsh Mountains or the north of England and Scotland, and the apparent virtual absence of anything but Bunter pebbles poses the question of where other erratics have gone. Undoubtedly, decalcification has occurred and this would dispose of the Jurassic limestone clasts, while Keuper Marl and Lower Lias would constitute the fine matrix of any till; but there seems to be no sign of Palaeozoic sediments or igneous rocks. It may be that some of the small fraction of cherts are directly from the Carboniferous Limestone of the north, rather than secondhand from the Bunter, where they also occur. Some of the igneous rocks might also be far-travelled, but these two types together do not add up to a large amount (see table 2). Hey (1965) also suggested that some of the quartz clasts, particularly those that were not well rounded, may have originated in the north of England (presumably from veins), and these could make a much more significant addition to the total of distant erratics. The flint content poses another problem, but, with one exception, this material occurs only in very small amounts. It is normally yellow or brown, deeply patinated and unlike the flint from the English Chalk that is abundant in some later tills. It does not seem necessary to invoke a second ice tongue merging from the northeast, with all the geographical problems that this involves, for similar flint ascribed to the Irish Sea floor occurs as a rare constituent both in the late-Devensian till of the Staffordshire and Cheshire lowland (Morgan 1973) and in drifts ascribed to the Anglian in the Birmingham area (unpublished).

If one accepts that at least the high level Plateau Drift represents a glaciation, there is no firm evidence to date it. Turner (1975) has advocated a Baventian glaciation based on palaeobotanical evidence in East Anglia, and Hey (1976) would concur with this on the grounds of composition of the older gravels. Whether between the Baventian and the Cromerian enough time is available to explain the higher terraces of the Middle Thames is arguable; but of positive evidence to date these events there is really none.

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REFERENCES

Arkell, W. J. 1947 The geology of the Evenlode Gorge, Oxfordshire. *Proc. Geol. Ass.* **58**, 87–113.

Bishop, W. W. 1958 The Pleistocene geology and geomorphology of three gaps in the Midland Jurassic Scarp. *Phil. Trans. R. Soc. Lond.* B **241**, 255–305.

Briggs, D. J. & Gilbertson, D. D. 1973 The age of the Hanborough Terrace of the River Evenlode, Oxfordshire. *Proc. Geol. Ass.* **84**, 155–173.

Briggs, D. J., Gilbertson, D. D., Goudie, A. S., Osborne, P. J., Osmaston, H. A., Pettit, M. E., Shotton, F. W. & Stuart, A. J. 1975 New interglacial site at Sugworth. *Nature, Lond.* **257**, 477–479.

Buckland, W. 1823 *Reliquiae diluvianae.* London: J. Murray.

Callaway, C. 1905 The occurrence of glacial clay on the Cotteswold Plateau. *Geol. Mag.* **12**, 491.

Dines, H. G. 1928 On the glaciation of the North Cotteswold area. *Mem. geol. Surv. Summ. Prog.* (for 1927), pp. 66–71.

Dury, G. H. 1965 General theory of meandering valleys: theoretical implications of underfit streams. *Prof. Pap. U.S. geol. Surv.* no. 452-C.

Evans, P. 1971 Towards a Pleistocene time-scale. Part 2 of The Phanerozoic time-scale – a supplement. *Spec. Publ. geol. Soc. Lond.*, no. 5, pp. 123–356.

Fleet, W. F. 1927 The heavy minerals of the Keele, Enville 'Permian' and Lower Triassic rocks of the Midlands and the correlation of these strata. *Proc. Geol. Ass.* **38**, 1–48.

Funnell, B. M. & West, R. G. 1962 The Early Pleistocene of Easton Bavents, Suffolk. *Q. Jl geol. Soc. Lond.* **118**, 125–141.

Geikie, J. 1877 *The Great Ice Age.* London: W. Isbister.

Gibbard, P. L. & Pettit, M. 1978 The palaeobotany of interglacial deposits at Sugworth, Berkshire. *New Phytol.* **81**, 465–477.

Goudie, A. S. & Hart, M. G. 1975 Pleistocene events and forms in the Oxford region. In *Oxford and its region: geographical essays*. (ed. C. G. Smith & D. I. Scargill), pp. 3–13. Oxford University Press.

Gray, J. W. 1911 The North and Mid Cotteswolds and the Vale of Moreton during the Glacial Epoch. *Proc. Cotteswold Nat. Fld Club* **17**, pt 2, 257–274.

Gray, J. W. 1920 Notes on the Cotteswold–Malvern region during the Quaternary Epoch. *Proc. Cotteswold Nat. Fld Club* **20**, 99–141.

Green, C. P. & McGregor, D. F. M. 1978 Pleistocene gravel trains of the River Thames. *Proc. Geol. Ass.* **89**, 143–156.

Hare, F. K. 1947 The geomorphology of a part of the Middle Thames. *Proc. Geol. Ass.* **58**, 294–339.

Hey, R. W. 1965 Highly quartzose pebble gravels in the London Basin. *Proc. Geol. Ass.* **76**, 403–420.

Hey, R. W. 1976 Provenance of far travelled pebbles in the pre-Anglian Pleistocene of East Anglia. *Proc. Geol. Ass.* **87**, 69–82.

Hull, E. 1855 On the physical geography and Pleistocene phenomena of the Cotteswold hills. *Q. Jl geol. Soc. Lond.* **11**, 477–496.

Hull, E. 1857 Superficial accumulations and Pleistocene deposits. In The geology of the country around Cheltenham. *Mem. geol. Surv. U.K.* pp. 85–98.

Hutton, C. O. 1950 Studies of heavy detrital minerals. *Bull. geol. Soc. Am.* **61**, 635–710.

Kellaway, G. A., Worssam, B. C., Holmes, S. C. A., Kerney, M. P. & Shephard-Thorn, E. R. 1973 South-east England. In A correlation of Quaternary deposits in the British Isles (ed. G. F. Mitchell, L. F. Penny, F. W. Shotton & R. G. West). *Geol. Soc. Lond. spec. Rep.* **4**.

Lucy, W. C. 1872 The gravels of the Severn, Avon and Evenlode and their extension over the Cotteswold hills. *Proc. Cotteswold Nat. Fld Club* **5**, 71–142.

Lucy, W. C. 1880 On the extension of the Northern Drift and Boulder Clay over the Cotteswold range. *Proc. Cotteswold Nat. Fld Club* **7**, 50–61.

Mitchell, G. F., Penny, L. F., Shotton, F. W. & West, R. G. (eds) 1973 A correlation of Quaternary deposits in the British Isles. *Geol. Soc. Lond. spec. Rep.* **4**.

Morgan, A. V. 1973 The Pleistocene geology of the area north and west of Wolverhampton, Staffordshire, England. *Phil. Trans. R. Soc. Lond.* B **265**, 233–297.

Müeller, G. 1967 *Methods in sedimentary petrology*. New York: Hafner.

Neaverson, E. 1925 The petrography of the Upper Kimmeridge Clay and Portland Sand in Dorset, Wiltshire, Oxfordshire and Buckinghamshire. *Proc. Geol. Ass.* **36**, 240–256.

Raeside, J. D. 1959 Stability of index minerals in soils with particular reference to quartz, zircon and garnet. *J. sedim. Petrol.* **29**, 493–501.

Richardson, L. 1926 Excursion to the North Cotteswolds. *Proc. Cotteswold Nat. Fld Club* **22** (2), for 1925.

Sandford, K. S. 1924 The river gravels of the Oxford district. *Q. Jl geol. Soc. Lond.* **80**, 113–179.

Sandford, K. S. 1926 In The geology of the country around Oxford (ed. J. Pringle). *Mem. geol. Surv. U.K.*, pp. 118–172.

Sandford, K. S. 1929 The erratic blocks and the age of the southern limit of glaciation in the Oxford district. *Q. Jl geol. Soc. Lond.* **85**, 359–388.

Sandford, K. S. 1932 Some recent contributions to the Pleistocene succession in England. *Geol. Mag.* **69**, 1–17.

Sandford, K. S. 1965 Notes on the gravels of the Upper Thames floodplain between Lechlade and Dorchester. *Proc. Geol. Ass.* **76**, 61–75.

Sealey, K. R. & Sealy, C. E. 1956 The terraces of the Middle Thames. *Proc. Geol. Ass.* **67**, 369–392.

Sherlock, R. L. 1924 The superficial deposits of south Buckinghamshire and south Hertfordshire and the old course of the Thames. *Proc. Geol. Ass.* **35**, 1–28.

Shotton, F. W. 1953 The Pleistocene deposits of the area between Coventry, Rugby and Leamington and their bearing upon the topographic development of the Midlands. *Phil. Trans. R. Soc. Lond.* B **237**, 209–260.

Shotton, F. W. 1973 English Midlands. In A correlation of Quaternary deposits in the British Isles (ed. G. F. Mitchell, L. F. Penny, F. W. Shotton & R. G. West). *Geol. Soc. Lond. spec. Rep.* **4**.

Skerl, J. G. A. 1927 Petrography of the Northampton Ironstone. *Proc. Geol. Ass.* **38**, 375–393.

Smith, W. Campbell 1973 Description of the igneous rocks represented among pebbles from the Bunter Pebble Beds of the Midlands of England. *Bull. Br. Mus. nat. Hist.* C **2**, no. 1.

Thomson, W. M. 1953 The origin of the Bunter Pebble Beds of the Midlands. Unpublished M.Sc. thesis, University of Birmingham.

Turner, C. 1975 The correlation and duration of Middle Pleistocene interglacial periods in North-west Europe. In *After the Australopithecines; stratigraphy, ecology and culture change in the Middle Pleistocene* (ed. K. W. Butzer & G. L. Isaac), pp. 259–308. The Hague: Mouton.

Walder, P. S. 1967 The composition of the Thames gravels near Reading, Berkshire. *Proc. Geol. Ass.* **78**, 107–119.

Wooldridge, S. W. 1938 The glaciation of the London Basin and the evolution of the lower Thames drainage basin. *Q. Jl geol. Soc. Lond.* **94**, 627–667.

Wooldridge, S. W. 1958 Some aspects of the physiography of the Thames valley in relation to the Ice Age and early man. *Proc. prehist. Soc.* **23**, 1–19.