PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The Pleistocene Deposits of the Area between Coventry, Rugby and Leamington and their Bearing upon the Topographic Development of the Midlands

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Phil. Trans. R. Soc. Lond. B 1953 **237**, 209-260
doi: 10.1098/rstb.1953.0004

THE PLEISTOCENE DEPOSITS OF THE AREA BETWEEN COVENTRY, RUGBY AND LEAMINGTON AND THEIR BEARING UPON THE TOPOGRAPHIC DEVELOPMENT OF THE MIDLANDS

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(*Communicated by W. B. R. King, F.R.S.—Received* 4 *December* 1952—*Read* 30 *April* 1953)

CONTENTS

The sequence of drift deposits in an area between Leamington and Warwick has been established by mapping following an extensive programme of auger drilling. There is a broad differentiation into Older Drift now capping the higher land and Newer Drift forming terraces along the upper Avon and Leam. The Older Drift includes relics of an ancient glaciation correlated with the First Welsh (Berrocian) or Mindel phase, and thick deposits belonging to the Great Eastern and Second Welsh (Catuvelaunian) or Riss episode. Details of the lithology, disposition and fauna of both the Older and Newer Drifts are given.

Suggested correlations with neighbouring areas are made. The deposits of the Catuvelaunian episode are shown to be largely of clay or sand laid down in a lake whose extent is traced over a wide area of the Midlands. To it the name 'Lake Harrison' has been given. It is shown that it formed in a great pre-glacial valley of very gentle slope which ran from the region of Bredon Hill down towards Leicester, forming part of the Trent system, and which was impounded at each end by Welsh and north-eastern ice respectively. The lake was eventually overridden by the north-eastern ice which went as far south as Moreton-in-the-Marsh. Not until this ice retreated was the Avon river system developed. Associated with this great and very recent change of drainage pattern are others of less importance affecting the Tame and Soar basins.

1. History of previous research

The area whose Pleistocene geology is shown on figure 9, is one for which, for the most part, no 'drift' map has hitherto been obtainable, for it covers a part of east Warwickshire which lies in the Old Series Sheet 53 N.W. of the Geological Survey, produced in 'solid' edition only in 1855. Overlap with previously published maps showing superficial deposits is made, however, on the north and west sides and south-west corner. The memoir of the Geological Survey of the Coventry District (Eastwood, Gibson, Cantrill & Whitehead 1923) describes Sheet 169 whose southern limit lies roughly along grid-line 775, though the edge of the six-inch to the mile sheets used in its preparation carries the boundaries of the Government survey down to grid-line 768. It will be seen that I have made a number of alterations in the mapped lines and ascribed various ages to deposits previously included under one lithological description. The western edge of figure 9 covers ground included in an earlier paper of mine (Shotton 1929), though again I have made substantial modifications of the earlier interpretation. In the south-west corner where the rivers Avon and Leam join, my work joins on to that of Tomlinson (1935).

Apart from the three contacts mentioned above, literature relating to the superficial deposits is very scanty. William Buckland, 130 years ago, gave an important account of the finding of vertebrate remains at Kings Newnham (Buckland 1823), though without discussion of the stratigraphical context of the finds; J. M. Wilson (1869, 1870) furnished descriptions of the superficial geology around Rugby which are still of value despite their lack of maps; and L. Richardson (1928) put on record a number of well sections which are useful. In general, however, this portion of the Midlands may be regarded as one of the blanks in the interpretation of British Pleistocene geology.

2. The general nature of the Pleistocene succession

In my 1929 paper, dealing with the southern end of the Warwickshire coalfield and therefore largely but not wholly west of the area which I am now considering, I had postulated the following members of the Pleistocene succession, in descending order of age:

(*a*) Five river terraces. (These are valid and their extent has been traced much farther up the main rivers, though it will be seen later that there has been modification in nomenclature and in evaluation of the terraces' extent and height above alluvium.)

(*b*) A higher ('80 ft.') terrace, which has now been discarded.

(*c*) A series of fluvioglacial gravels, mainly along Finham Brook, Kenilworth.

(*d*) A 'Newer Boulder Clay'.

(*e*) An underlying series of sands above and gravels below which collectively I referred to as 'Interglacial gravels'.

(*f*) An 'Older Boulder Clay'.

Of these, formations (*d*) to (*f*) formed an Older Drift, since they appeared to cap the higher land and to have been left as outliers by the downcutting of the Avon river system with its successive terraces forming Newer Drift. It was in 1946 that I decided to extend the mapping of the Warwickshire Pleistocene eastward, and though in the 17 years which had elapsed since my 1929 paper I had not changed the broad features of the succession beyond suspecting that (*b*) was merely an outlier of (*e*), I had become painfully aware of the inaccuracy of many of my mapped boundaries. This inaccuracy largely resulted from my inexperience in recognizing the extent of solifluxion on the slopes. This can result in gravels being mapped at levels much below that of their true occurrence; more seriously gravel material creeping downhill over outcrops of Keuper marl or Upper Carboniferous clays can produce in shallow exposures what appears to be pebbly clay, and since the glacial clays are also red and are in fact very largely reconstituted Keuper marl, such exposures may be interpreted as boulder clay. Much of the boulder clay marked either as 'unspecified in age' or 'older clay' in my 1929 paper results from this error.

There is also in the east Warwickshire succession another possible source of error working in the opposite way from the one described above. Much of the clay of the Older Drift is not boulder clay—it can be quite stoneless and so closely resembling Keuper marl that I have sometimes stopped auger holes in the belief that the Pleistocene had been bottomed, only to have occasion later to deepen the holes and to run into sand, gravel or boulder clay beneath the believed Keuper marl. This similarity between solid formation and stoneless clay drift could clearly lead to further mapping inaccuracies. I therefore decided that before a reliable map could be produced, it was necessary to establish the details of a firm succession by boring along selected traverses.

In all, I put down ninety-one holes to an aggregate depth of 917 ft., generally using a 3 in. diameter bucket auger and occasionally a 6 in. tool, so that good samples even of coarse beds could be obtained. The greatest depth of any hole was 27 ft. In addition, I was generously given access to the results of thirty-seven holes put down by Mr W. Yardley of the Coventry Sand and Gravel Company and of six holes sunk by Messrs Baillie, Brind and Co. Ltd, so that the area discussed in this paper has the backing of 134 exploration boreholes averaging a little over 10 ft. each in depth.

My auger holes were sited along lines deliberately selected to yield the greatest amount of information about the Older Drift, and the heights of all boring sites were surveyed instrumentally. The first line was at Wolston (section S_1–S_1' of figures 9, 10), and I have used this locality to name certain divisions of the sequence. The working pit of the Wolston Gravel Company shows gravel overlain by sand (the 'Interglacial' series of my 1929 paper, now to be called respectively the Baginton-Lillington gravels and the Baginton sand), and on top of this no more than the bottom 4 ft. of the 'Newer Boulder Clay' of my earlier paper. By augering the steep hill of Brick Kiln field adjoining the pit, the sequence for 64 ft. above the Baginton sand was established. Without at the moment going into the details of the formations proved, it may be stated that most of the hill consists of a tripartite series, here called the Wolston Series, with a thick sand layer separating two beds of clay. The whole is capped by a thin gravel, the edge of a sheet which covers a great area farther east and is named the Dunsmore gravel.

The long section across Ryton Wood (S_3–S_3'), involving twenty-six holes, proved the succession above the lower (Baginton-Lillington) gravels which are so abundantly exposed in the pits of Baillie, Brind and Co. Ltd where they can be seen resting on Keuper marl (Map Reference 3773). Even the lower auger holes had to stop when they had entered a few inches of these gravels, so that the thickness of the latter shown on section S_3–S_3' on figure 10, is problematical; it is confidently expected to be less than the 14 ft. of the gravel pits. Above this level, however, the same succession as at Wolston was proved, though the middle sand of the Wolston Series had thinned from 17 to 10 ft.

The mile-long traverse of thirty-two holes across Waverley Wood (S_2–S_2') revealed two new features of importance. It had become obvious from mapping that in coming south from Bubbenhall, the lower gravels were being overlapped until the Baginton sand became the local base of the drift. This in its turn appeared to thin towards the starting point of the auger line, so that it was no surprise when this proved the Baginton sand to be the bottom member of this drift sequence (the Bubbenhall clay (see below) is here neglected), and with a thickness of only 7 ft. compared with 21 in section S_3. Farther along line S_2–S_2' it will be seen that even the Baginton sand has been overlapped. This section confirms one of the basic conclusions derivable from the mapping—the successive overlap of the members of the older drift sequence.

The second important feature of section S_2 is the existence of a much older clay drift than anything seen in S_1 or S_3. The first and lowest hole proved undoubted Keuper marl near to the Passage Beds horizon, but the next two, after penetrating a solifluxion layer of pebbly loam, went into a red stoneless silty clay which, because of its great plasticity, silt content and absence of green blotches, did not suggest Keuper marl. In the fourth hole at 800 ft., a thin layer of similar material intervened between sand and normal Keuper marl. It therefore becomes necessary to postulate a small pocket of drift clay older than the Baginton sands. A larger pocket of these older clays occurs between 3800 and 5200 ft. on the section. In the hole at 5030 ft., red plastic clay containing scattered pebbles of Bunter quartz and quartzite cannot be confused with the green mottled Keuper marl upon which it rests. The three holes from 3940 to 4250 ft. all show stoneless plastic clay, which in the lowest is visibly laminated in the manner of varved clay and so clearly distinguishable from Keuper marl. The significance of these oldest drifts will be discussed later. Since future work might make such a term as 'oldest' misplaced, these deposits will be called the Bubbenhall clay.

Two other facts proved by the augered sections are worthy of mention. The hill slopes are usually covered by a layer of orange loamy gravel varying in its proportions of clay, sand and pebbles, typically 2 to 3 ft. thick, and clearly post-dating the present valley topography. It is interpreted as the result of solifluxion, probably during the cold period represented by No. 2 river terrace or the end stage of No. 4 terrace. From a mapping point of view it can be a great nuisance by obscuring the outcrops of the layers in the older drifts—it is even now impossible to detect the Wolston sand at the surface across Brick Kiln Field (section S_1), though the auger has proved a layer 17 ft. thick to be there.

The other feature common to all sections is some degree of disturbance at the outcrops of sands or gravels—often a gentle camber, sometimes a buckled edge, and in both cases ascribed to gravity flow of the contiguous clays. In no case, however, is the effect large enough to affect mapped boundaries by more than a few feet of height.

The full sequence of quaternary deposits can be listed in descending order of age as follows below. The terraces are placed in their sequence as topographical features, without implying that the gravels which underlie them follow a similar age-succession:

Modern alluvium

NEWER DRIFT. River terraces, Avon No. 1 (often divisible into a lower 1*a* and an upper 1*b*)
Avon No. 2
Avon No. 3
Avon No. 4

Long time interval

OLDER DRIFT. Dunsmore gravel
Wolston Series { Upper Wolston clay, Wolston sand, Lower Wolston clay }
Baginton sand
Baginton-Lillington gravel

Long time interval

Bubbenhall clay

3. Description of members of the Pleistocene succession: the Older Drift

(*a*) *The Bubbenhall clay*

Most of what I regarded as 'Older Boulder Clay' in my earlier paper (Shotton 1929) I now think was a misinterpretation of Enville clays or Keuper marl rendered pebbly at surface by hill creep. It is possible that, by the very restricted recognition of Bubbenhall clay which figure 9 shows, I have erred too far in the other direction; but it is very difficult to map a deposit which so closely resembles the solid formation it rests upon and which is only now preserved in small pockets.

The two patches proved in section S_2 consist largely of stoneless red silty clay, non-calcareous and, in one auger-hole at least, clearly laminated. This material, largely reworked Keuper marl, must have been deposited in still water. Sometimes, however, the Bubbenhall clay contains pebbles, as it did, though not abundantly, in one hole of section S_2. A section now grassed over was revealed 20 years ago near Bubbenhall (M.R. 357718) and showed 4 ft. of red sandy clay with scattered small Bunter pebbles, resting on 3 ft. of Keuper sandstone. The only other occurrence of Bubbenhall clay in which I can feel confidence was again seen in a temporary section in Coventry, now lost to view but fortunately recorded at the time (Shotton 1932). Widening of the main London road opposite Humber Road (M.R. 357770) revealed 15 ft. or so of sand with pebbly layers (= Baginton sand), resting at one end of the section on Keuper sandstone but at the other on at least 5 ft. of stiff red clay with pebbles. This clay had earlier been recognized and mapped by the Geological Survey. Lying, as it does, beneath sands which go down to 250 ft. O.D. and so must be Baginton sands (see p. 216), and overstepped by the latter, it must be placed as Bubbenhall clay.

It is not clear whether any of the Bubbenhall clay is true till. The stoneless and laminated clays clearly are not, and even where pebbles occur they could be explained by floating bergs. At the time when I saw the Coventry exposure, I regarded it as a till, but I am less certain now. In the light of the evidence which will be presented below to show that the Wolston Series was largely the product of a very extensive ice-dammed lake, it is possible that the geography of Bubbenhall clay times lent itself to a similar ponding. The preservation of these earliest clays is now so reduced, however, that it is impossible to make sound generalizations about their former nature and extent. It is probable that they were laid down upon a surface not much different from that which underlies the Baginton-Lillington gravels or newer members of that drift series, though greatly differing from the present-day topography. The original extent and thickness may well have been considerable, but afterwards, and before the Baginton-Lillington gravel phase of deposition, there must have been a long period of erosion to leave behind only such disconnected small relics.

The pebbles in the Bubbenhall clays appear to be entirely derived from the Bunter pebble beds. There is no evidence of flint, chalk, or Jurassic rocks, and the clay is always red and non-calcareous where I have tested it. In this part of England where eastern and western ice jockeyed for position, it would be usual to speak of such a deposit as Western Drift, but perhaps Northern Drift would be a more appropriate term. It is as devoid of true western erratics, such as Welsh lavas and ashes or Uriconian rocks, as it is of Mesozoic rocks from eastern England.

(*b*) *The Baginton-Lillington gravels*

There is a reason for combining two place-names in the nomenclature of this gravel. The lithology at Baginton (Shotton 1929, p. 212) is different from that at Lillington (Shotton 1929, p. 206), and anyone examining sections at the two places would be justified in doubting that they represented one formation. It is important, therefore, to demonstrate this identity.

In the Binley-Baginton-Wolston area, where a number of pits work (or have recently worked) the gravels, the deposit is uniform in type. It consists of rounded pebbles, mainly below 3 in. in diameter, but exceptionally up to 6 in., in a rusty brown sandy matrix and occasionally with thin intercalations of sand. At Brandon Grounds Farm, midway between Brandon and Willenhall, a number of borings done by the Coventry Sand and Gravel Company proved the gravels under deposits of No. 4 terrace (the two formations being easily distinguishable because of the high flint content of the latter) and showed that up to $5\frac{1}{2}$ ft. of sand could occur below the main gravel. This development of sand is, however, abnormal, and in most places coarse pebble beds form the base of the deposit. Bedding is fairly regular, in view of the high velocity of the water which must have transported the pebbles. The perfect rounding of the pebbles is not an indication of distant transport, for they are almost entirely derived second- or third-hand from the Bunter pebble beds; pebbles which chanced to be split before incorporation in the gravels have not lost much of their reimposed angularity. The dominant rock types amongst the pebbles are naturally fine quartzite and white vein quartz, but in accord with the known composition of the Bunter conglomerate in the Midlands, one also commonly finds tourmalinized rocks and less frequently quartz porphyries and cherts. Only when one knows the composition of the Bunter does one realize that hardly any of the unusual rock types have significance as glacial erratics. I can, indeed, only mention two constituents of the gravel which are obviously not derived from the Bunter, and both are extremely rare. By diligent searching it is possible to find a brown chert-like flint (a fraction of 1 % only). This does not imply any connexion with an eastern glaciation, for the great rarity and the nature of the flint suggests a material which is found occasionally in Welsh and Irish Sea drifts much farther west and which is ascribed to Cretaceous rocks from Ireland or the Irish Sea. One other most interesting constituent is represented by a single semi-angular pebble about 4 in. in size from the main pit on the north side of the road at Baginton. It is a porphyritic and flow-banded andesite with epidote and garnets up to 2 mm. It is undoubtedly a Lake District rock (Hartley 1932), and, indeed, is identical in every respect with a specimen collected from Oxendale. The chief interest of this erratic is its hint of derivation from a deposit of an earlier glaciation, to which the Bubbenhall clays would also presumably belong.

For all practical purposes, however, the Baginton-Lillington gravel found north of grid-line 71 may be regarded as wholly made of Bunter pebbles.

If the outcrop of Baginton-Lillington gravels which lies east of the Avon is followed south-westward, it is found to thin rapidly and disappear just south of Bubbenhall. The overlying Baginton sand in its turn thins southward, and at about map reference 354709 is overlapped by the Lower Wolston clay. This overlap is the result of deposition against a buried pre-glacial hill which underlies Waverley and Weston Woods and which is crossed by the auger traverse S_2 of figure 9. It is an isolated hill and not the eastern boundary of the gravels, for these are found again on the other side of the buried feature, having been well proved by trial holes put down by the Coventry Sand and Gravel Company near Weston Fields Farm (M.R. 366708). At this point the gravel is still wholly Bunter in type, the Baginton facies. From here the Baginton sand above the gravels can be traced continuously as a girdle encircling the spur dividing the Leam from the Avon, via Cubbington, Campion Hills and Lillington and so north-eastward until it disappears against the south-west side of the buried Waverley Wood hill. Beneath the Baginton sand lies the Baginton-Lillington gravel, at first south of Weston Fields Farm, somewhat discontinuous, but soon becoming a continuous outcrop which can be followed completely around the spur back to its overlap against the buried hill. Above both sand and gravel, the Wolston clays with their intercalated Wolston sand lie with unbroken regularity.

It has been necessary to demonstrate that the gravels of Lillington and Cubbington are stratigraphically the same as those at Baginton, Ryton and Wolston, because of the striking change of pebble content in the southern localities. At Lillington and Cubbington (Shotton 1929, pp. 206–9), although Bunter pebbles still form an important part of the gravel, there is also a very high proportion of Jurassic material represented by rolled *Gryphaea arcuata* and belemnites from the Lias, pieces of compact white limestone (White Lias) and grey limestone (Lower Lias), oolite (Middle Jurassic) and limonitic ironstone which probably originates in the clay ironstone nodules of the Lias. The deposit is therefore a 'Jurassic gravel' similar to that described by Tomlinson (1935) from Snitterfield and other places farther to the south. At neither Pratt's Pit, Lillington nor at Cubbington did I record any flint, nor did I note it at the Manor Pit, Lillington (M.R. 332671), opened up after my 1929 paper but now almost filled by tip. It is, however, an occasional constituent, for I have seen it in a pipe trench a mile west of Cubbington village, near the village itself, and in an exposure at 335666 near Redhouse Farm Cottage.

The above-mentioned trench, which was cut in 1947 from the summit of Cubbington Hill (336684) west-north-westward along the Welsh Road to West Hill (325690), went through the gravels in the valley near the cross-roads at 329688 and showed them to be only about 5 ft. thick, overlain by Baginton sands and floored by Keuper marl. The section was particularly important in being the most northerly known occurrence of the Jurassic gravel facies. The bottom 2 ft. and the upper foot or so of the gravel were, however, pure Bunter gravels of Baginton facies, and only the middle part contained, in addition to Bunter pebbles, fragments of limestone, gryphaeas and belemnites and a small amount of flint. This intercalation of Lillington type in Baginton gravels is further evidence, if it were needed, of the identity in age of the two types of gravel.

The thickness of the gravel varies, as might be expected in the basal member of a series deposited on an irregular land surface. In the Wolston pits the variation is obviously controlled by a very channelled floor, for tests of the thickness have shown figures between 5 and 16 ft. with an average of about 9 ft.; but elsewhere the thickness appears to be more regular, and the chief variation is brought about by thinning as the gravel laps against the old land surface which forms its floor. The greatest development is about 14 ft. at the pits of Baillie, Brind and Co. Ltd, south-west of Ryton on Dunsmore. Other figures are: Baginton, 10 to 12 ft.; Brandon Grounds, 13 ft. including $5\frac{1}{2}$ ft. of basal sand; Willenhall, probably about 3 ft.; Weston Fields (364711), up to 6 ft.; trench 1 mile west-north-west of Cubbington, 5 ft.; Pratt's Pit, Lillington (328675), 6 ft.; Manor Pit, Lillington (332671), 8 ft.

(*c*) *The Baginton sand*

The junction between this and the underlying gravels is sharp enough for mapping and for recognition in auger holes, but when examined on clean faces at such pits as Wolston, Binley, Baginton or Lillington, it is found to be a transition. Beds of sand occur in the underlying gravels, and the main sands have thin and inconstant strings of pebbles. There is no reason to suspect any unrepresented time interval between the two deposits.

Table 1

	ft.	in.
clean brown sand	0	5
clayey red sand	0	1
clean brown sand	3	6
fine loamy brown sand	0	11
clean brown sand	3	6
clean brown sand with occasional small Bunter pebbles	4	6
black sand	0	7
sand with small pebbles	0	1
medium-coarse brown sand with occasional streaks of small pebbles	7	0
	20	7

The sand is typically rusty brown in colour, rarely more than half a millimetre in grain size and usually without much interstitial clay; it is liable to have beds of argillaceous sand, particularly in the upper part. Black-stained layers occur irregularly. Probably the best section that can be given is the combination of two adjacent auger holes of the Ryton (S_3) section, where the total thickness was nearly 21 ft., a maximum for the district (table 1). There is, of course, no regularity over any considerable distance of either the argillaceous layers or the black sands.

From this maximum value, the thickness of the Baginton sands declines in all directions, even in those places where it is still underlain by the Baginton-Lillington gravel and so has its full depositional thickness. North and north-eastward it is 18 ft. at Ryton cross-roads (384736), 14 ft. at Wolston, 13 ft. at auger holes in Brandon Wood (399765), 12 ft. at Baginton, 9 ft. at Binley and 9 ft. at Willenhall. Southward, in the pits at Lillington and Cubbington, it is about 10 ft. thick, rising occasionally to 12 ft.

The Baginton sand is extremely cross-bedded over most of its thickness. This false-bedding seems to be a combination of foreset delta deposition with scour and fill channels. In the pit at Ryton cross-roads I took dip measurements on this false-bedding, attempting to avoid repetition of readings in any single depositional wedge and also trying to omit obvious channels. From the thirty-two results it was hoped that a dominant direction would be apparent, but although there was some preponderance around bearings of 125° and 180 to 200°, it does not appear to be statistically significant, and I do not feel that the false-bedding can yet be interpreted in terms of direction of derivation.

It is common to find that the upper few feet of the sands are level bedded, and the junction with the overlying Wolston clay is quite undisturbed. When I thought of the Wolston clay as the till of a glacier, it was necessary to imagine freezing of the sands below to prevent any disturbance of the junction; but since I have come to regard most of the Wolston clay as a deposit of ponded water (see later), such an explanation now becomes unnecessary. When level bedded sands occur at the top of the Baginton sand series—as they do strikingly at the Wolston pits, with intercalated beds of silt and clayey sand—it would appear that ponded water conditions had already set in.

(*d*) *Pre-Wolston clay deposits at Kings Newnham and Little Lawford*

Examination of figure 9, will show that there is a patch of sandy deposit existing north-east of Kings Newnham (*ca.* 465780), which, though it is separated from other outcrops of Baginton sand, is in the same position as the latter in relation to the Wolston clay. Although it has at its base up to 3 ft. of gravel, it is in all not more than 9 ft. thick, and so I have indicated both sand and gravel by the Baginton sand symbol. The Geological Survey shows the edge of this deposit on Sheet 169, but on its unpublished '6 in.' sheet which extends farther south, gives it much too great an extent by joining the outcrop to the flint-bearing terrace gravels (No. 2) which lie west of Little Lawford. It is not of great significance whether the basal gravel is equivalent in age to part of the Lillington-Baginton gravels as well as to the Baginton sand, for it is clearly older than the Wolston clay. The real importance of the deposit is that it yielded, about 130 years ago, the great series of mammal remains described by Buckland (1823), Cuvier (1822) and Owen (1846). These are the specimens usually noted in literature as coming from 'Lawford, near Rugby', and it is first necessary to prove that they came from the outcrop in question and, in more detail, from the overburden of an old pit in the Lias which still exists, though it is half-flooded and partly filled by tip, at M.R. 465777, adjacent to the farm Fennis Fields.

This pit must once have been an exceedingly large working in the Lower Lias. The worked area covers about 10 acres and its depth must have been considerable for, at the north end, there is still over 20 ft. of face above deep flood water. There is, moreover, a shaft presumably leading to underground workings in the White Lias, and the activity was sufficient to justify the construction of more than half a mile of canal leading as an arm from the Oxford Canal to a loading wharf. These facts indicate that it was by far the largest of the now disused Lias pits of the district, and also suggest that its heyday of activity was in pre-railway times. It lies in the parish of Kings Newnham, but the stream which forms the eastern boundary of the pit and has broken into it, is the parish boundary. It is thus actually 0·88 mile from Kings Newnham village, but only 0·39 mile from Little Lawford, 1·08 miles from Long Lawford and 1·17 miles from Church Lawford. Workers from Rugby would never touch Kings Newnham but would leave the road at Little Lawford to take a path leading to the quarry. It is therefore not surprising that the locality became spoken of as 'Lawford', and all the mammal remains in the Oxford geological museum and most in Warwick Museum carry this label. Fortunately Buckland, in his *Reliquae diluvianae* (1823), leaves no doubt about the origin of the actual specimens now at Oxford, for although he on at least two occasions gives Lawford as the locality, his only detailed reference runs as follows (p. 176): 'At Newnham, in Warwickshire, near Church Lawford, about 2 miles west of Rugby, two magnificent heads and other bones of the Siberian rhinoceros and many large tusks and teeth of elephants, with some stag's horns, and bones of the ox and horse, were found in the year 1815, in a bed of diluvium, which is immediately incumbent on stratified beds of lias, and is composed of a mixture of various pebbles, sand, and clay; in the lower regions of which (where the clay predominates) the bones are found at the depth of 15 feet from the surface.'

As the pit under discussion is the only one in Kings Newnham parish, or indeed anywhere near, which has something like 15 ft. of superficial deposits above the Lias, it alone can be the source of the bones. Additional confirmation is given by Cuvier (1822), who, in his reference to bones of *Rhinoceros* and *Elephas* respectively, speaks of 'Newnham, near Rugby'; by two humeri of *Rhinoceros* in Warwick Museum (G 624 and 625), which, unlike the other vaguely labelled bones, carry the inscription 'Newnham lime quarries, Warwickshire, 15 ft. below surface'; and by the rhinoceros head in the library of the Geological Society, mentioned by Buckland and labelled as presented by him in 1820, from Kings Newnham, Church Lawford, Warwickshire.

The most complete section now visible in the pit is as follows:

(*a*) Clay top obscured by slip	4 ft.	(Wolston clay)
(*b*) Orange sand	$7\frac{1}{2}$ ft.	(Baginton sand)
(*c*) Clayey gravel with fragments of ironstone, Lias limestone and Bunter pebbles	$1\frac{1}{2}$ ft.	(Baginton sand or Baginton-Lillington gravel)
Total of drift	13 ft.	
(*d*) Lias clay, seen to	9 ft.	

Another section, farther round the pit, shows a very coarse deposit of local angular blocks at the base of the drift, as follows:

(*a*) Pebbly sandy clay	3 ft.	(Wolston clay)
(*b*) Red sand	4 ft.	(Baginton sand)
(*c*) Sandy gravel with small pebbles of Lias and Bunter	2 ft.	(Baginton sand or Baginton-Lillington gravel)
(*d*) Coarse gravel, with large angular blocks of Lias limestone in coarse yellow sand	1 ft.	
(*e*) Lias clay, seen to	10 ft.	

These sections, particularly the first, closely conform to Buckland's description, and as a final confirmation there is with the large series of remains in the Oxford museum a sample of 'sand from the Elephant Bed'. It is a ferruginous sand mixed with much Lias clay, containing a Bunter pebble, a fragment of a belemnite and another of *Ostrea* and many bits of compact grey Lias limestone, and is identical with bed (*c*) of the first section above. Exactly similar material also fills cavities in a lower jaw of *Rhinoceros* in Warwick Museum.

(*e*) *Fauna of the Baginton sands and Baginton-Lillington gravels*

I have included the two formations together, because I believe one follows the other with no break in time, though there is only a single record—a bone of *Equus caballus* from the Manor Pit at Lillington—which comes unequivocally from the sand. The numerous other finds at Lillington were in the gravel, usually at its base when their position is known. Having demonstrated the stratigraphical position of the Kings Newnham finds, they may be added to the list (table 2) which otherwise comes largely from Lillington. These latter comprise the specimens in Warwick Museum labelled 'Pleistocene gravels, Lillington' (Shotton 1929, p. 209 footnote), finds at Pratt's Pit (Shotton 1929, p. 209, plus another mammoth tooth and a tooth of *Elephas antiquus* not there recorded) now in Leamington Spa Museum, and from Manor Pit, collected by the late Dr C. A. Matley and now in the Birmingham University Geological Department. The only finds at Baginton are eight associated teeth of *Equus caballus*, also now at Birmingham University.

TABLE 2. FAUNAL LIST

	Kings Newnham ='Lawford'	Baginton	Lillington in general	Pratts Pit, Lillington	Manor Pit, Lillington
Elephas primigenius	×	—	×	×	×[1]
Elephas antiquus	—	—	—	×	—
Bos primigenius	×[2]	—	×[3]	—	×[2]
Equus caballus	×	×	×	×	×
Rangifer tarandus	—	—	×[4]	—	—
Deer, indet.	×	—	—	—	—
Tichorhinus antiquitatus	×	—	×	—	×[5]
Sus scrofa	—	—	?[6]	—	—
Hyaena crocuta	×	—	—	—	—
Goose (?)	×[7]	—	—	—	—

Notes

1. No teeth found, strictly *Elephas* sp.
2. Bones which might equally be of *Bison*.
3. Teeth, previously labelled *Cervus elaphus*, identified as *Bos* sp. by Dr A. T. Hopwood.
4. A piece of antler, previously labelled ? *Cervus*, identified as reindeer by Dr A. T. Hopwood.
5. A single metatarsal, only identifiable as *Rhinoceros* sp.
6. Single canine tooth, source queried because of high state of preservation.
7. Mentioned and figured by Buckland (1823, p. 26), but I have not traced the specimen.

In this fauna, the three dominant species numerically are *Tichorhinus antiquitatus*, *Elephas primigenius* and *Equus caballus*. *Bos* (or perhaps *Bison*) is less abundant and the reindeer is rare. It is represented only by one piece of antler in Warwick Museum, previously labelled (?)*Cervus*. *C. elaphus* is not now listed, for specimens in Warwick Museum previously placed under this heading have been transferred to other species. Buckland's general reference to 'stag's horns' cannot be specifically identified, since no specimens appear to have been preserved, but they too may have been reindeer. It is significant that Boyd Dawkins (1869, p. 197) on the authority of the Oxford Museum and Sir P. Egerton, gives *C. tarandus* and not *C. elaphus* under the Lawford heading.

The fauna is very definitely a 'cold' one, but the abundance of horse with mammoth and woolly rhinoceros indicates a cold steppe rather than a tundra biotope (Zeuner 1945, p. 255).

Two species in the list are of more than usual interest. The *Hyaena crocuta* from Kings Newnham is the one described by Buckland (1823, p. 26) as found in 1822—the associated remains of a single large and old individual. Buckland figured the lower jaw, right ulna and right radius (all preserved at Oxford), and mentioned also foot bones. Very soon after the complete cranium was also found, and it too is in the Oxford Museum, labelled as presented by J. Keele in August 1823. Both halves of the skull were figured on a plate published by J. Murray in 1825.* As far as I know, this is the only record of pre-Chalky Boulder Clay hyaena in the Midland counties.

The other species worthy of special mention is *Elephas antiquus*, usually regarded as a 'warm' animal. The single tooth, a lower last molar, from Pratt's Pit, Lillington, upon which this identification is based, was found at the base of the gravels very soon after the publication of my 1929 paper. Both Dr K. S. Sandford and Dr A. T. Hopwood have seen this tooth, and they are agreed that it represents a perfectly normal *antiquus*.

This tooth was found in the same gravel that yielded mammoth of normal Siberian type, and there is no doubt that the latter animal is contemporary with gravel deposition. Just before the *antiquus* molar was discovered, there had been found two upper first molars of mammoth, opposed teeth of exactly the same size and state of wear and very probably belonging to one animal. A small tusk found at the same time almost certainly pertains to the same individual. In contrast to this evidence of contemporaneity, an isolated tooth must always be suspected as derived. The tooth of *E. antiquus* has certainly lost more of the dentine from between its plates than have the *primigenius* teeth; but it is otherwise whole, is unrolled, and is no more stained or mineralized than the mammoth teeth. The balance of evidence is in favour of this particular *E. antiquus* existing with *E. primigenius* (and the rest of the cold fauna). Zeuner (1945, p. 254) points out that there is no objection to contemporary overlap of the species, even though one is normally 'colder' than the other, provided that the two habitats of steppe and forest intermingled.

Although I have not listed *E. antiquus* from Kings Newnham, since Buckland makes no reference to anything except 'Siberian elephant' and all the teeth in the Oxford and Warwick Museums belong to *primigenius*, it is notable that Boyd Dawkins (1869) lists it from this locality—suggesting that since Buckland wrote, evidence for its occurrence had come to light.

There is no evidence of *Hippopotamus* from the Baginton-Lillington gravels. When I recorded a complete skull from Coventry (1929, p. 213), I suggested that the containing sands might, because of their height, belong to the same series as at Lillington, in which case they would have to underlie the boulder clay mapped here by the Geological Survey (M.R. 323794); but I also raised the possibility that the skull came from a terrace deposit. Excavations which I have since seen on the property of the National Benzole Company show boulder clay resting directly on Corley Beds of the Upper Carboniferous, and there is no possibility of a thick sand series underlying the boulder clay. The *Hippopotamus*-bearing sand must be banked against these other deposits and therefore be a terrace of the River Sherbourne (see p. 231).

* I am indebted to Mr R. W. Stott, of Rugby School, for bringing this illustration to my notice.

(*f*) *Conditions of deposition of the Baginton-Lillington gravels and the Baginton sands*

These were laid down in a broad valley which traverses the whole of the mapped area in a general north-north-east direction. The eastern flank of this valley is made by the Upper Keuper marl or White Lias, and the original boundary of the gravel and sand beds can be traced with considerable accuracy (figure 1). Near Princethorpe the Baginton

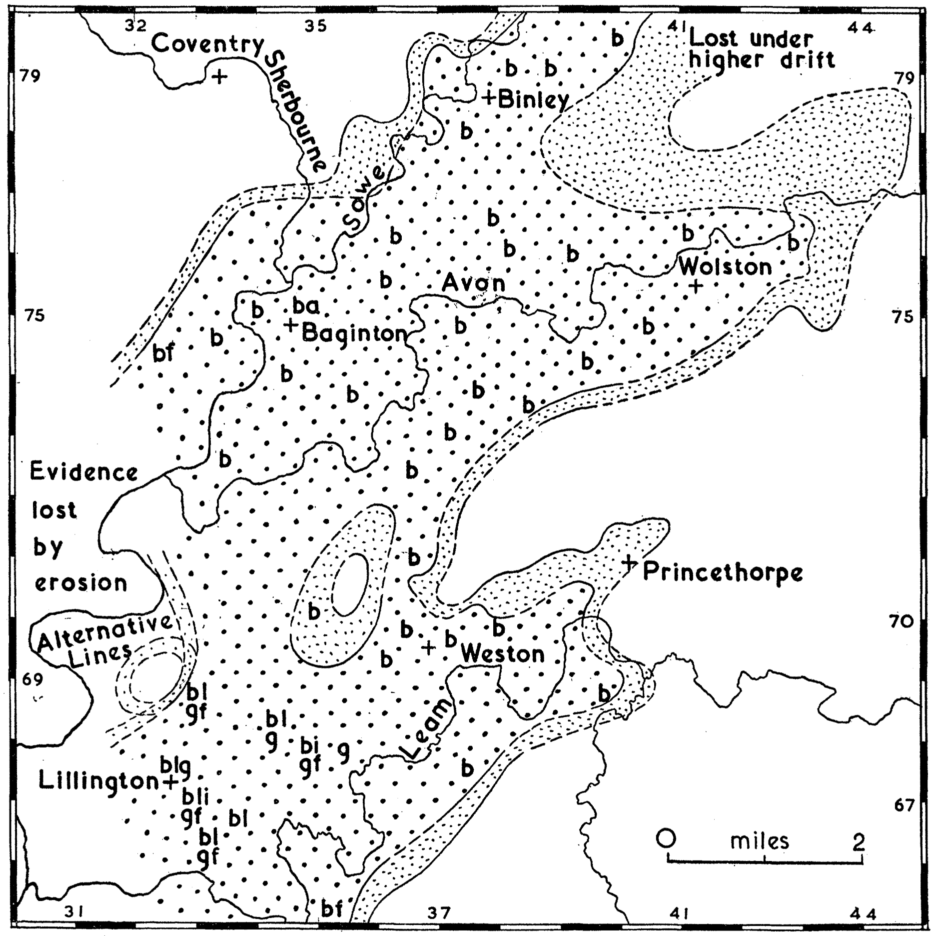

FIGURE 1. The original extent of the Baginton-Lillington gravels and Baginton sand, compared with the present-day river system. Heavy dots represent the gravel resting on solid formations and overlain by Baginton sand; fine dots indicate where the Baginton sand, having overlapped the gravel, rests directly on solid; over the undotted area, the basal member of any Older Drift deposits is younger than the Baginton sand. Letters indicate observed constituents of the gravel (and in one case of pebbly layers in the sand) as follows: *b* = Bunter pebble bed material; *a* = garnetiferous andesite (a single pebble): *l* = Lias or Oolite limestone; *i* = ironstone; *g* = rolled *Gryphaea arcuata* and/or Jurassic belemnites; *f* = flint.

sands end against a steep escarpment of White Lias which modern erosion has once more succeeded in revealing, so that the outcrop of sand diverges for a distance from the overlying Wolston clay. The original western edge of the deposits can also be deduced very closely in the Coventry district, where they bank against higher-standing Upper Carboniferous beds. The floor of this wide valley appears to slope down gently to the north (see also figure 11, and discussion, p. 248), in contrast with the Avon system which flows south-westward. One obvious result of this opposition of slope is that to the north the sands and gravels disappear from view beneath higher drifts, whereas to the south-west they have been largely eroded and it is difficult now to reconstruct the original boundaries accurately. For example, the trench running west from Cubbington (p. 215) proved the downward succession of Wolston clay, Baginton sand and Baginton-Lillington gravels with the base resting on Keuper almost in the bottom of the valley at a level of 270 ft. (M.R. 329688). As the trench followed up the hill, farther west, the Pleistocene sequence might have been expected to repeat in reverse order, but actually Keuper sandstone and Keuper passage beds were present. There must clearly be an edge to both the sands and gravels here, but I am uncertain whether it is the original western edge or due to an 'island' similar to that which certainly exists west of Weston. Both possibilities are shown in figure 1.

From the main pre-gravel valley ran two salients which have been re-excavated by the rivers Avon and Leam. The Avon arm might have been drawn longer to include the beds at Kings Newnham (p. 217), but as these are separated by a length of outcrop devoid of sands and gravels, it is more likely that the Newnham deposits belong to another tributary whose extent is largely buried under higher drift.

Figure 1 shows the distribution of pebble types, and it is notable that the Jurassic-rich gravels are confined to the south. The pure Bunter gravels of Wolston and Baginton appear likely to have come into the valley from the east, though a westerly origin cannot be excluded; but the Bunter gravels near Weston can only be of eastern origin, in view of the distribution of Jurassic material near Lillington. This derivation of Bunter pebbles from the east may appear anomalous, since all outcrops of the Bunter Pebble Beds lie west of the area we are considering. The explanation doubtless lies in the erosion of the Bubbenhall clay, which must have extended far east of the area. Hollingworth & Taylor (1946) have indicated the existence of a glacial clay rich in Bunter pebbles and considerably antedating the Chalky Boulder Clay in Northamptonshire.

The gravels around Cubbington and Lillington would be explained by another feeder from the south, deriving most of its material from the Lias scarps. Even in the limited area covered by figure 1 it is necessary, therefore, to postulate at least three feeding streams. An additional problem is provided by the record of flint in the King's Hill outlier at 326745. Its presence is only deduced from the extensive scatter of pebbles on the fields which lie immediately west of the well-exposed summit patch of Baginton sand, but it certainly appears to be present in appreciable amount. There is, however, no suggestion of flint in the next outlier to the east on Coventry golf course (334747). This unexpected appearance of flint raises the possibility of some connexion with the flint-bearing gravels of Kenilworth (so-called fluvio-glacial gravels, Shotton 1929, p. 213), but as I do not understand all the implications of space and time raised by the latter, it may be better to leave the problem undiscussed for the moment.

Whether or not the flint at King's Hill requires still another tributary into the main valley, there is already enough evidence of separate feeders to suggest that normal land streams should be visualized, rather than outwash from the advancing front of the Chalky Boulder Clay ice. These would still belong to the cold phase immediately preceding the glaciation. Not merely is the fauna indicative of cold climate, but there is clear evidence of solifluxion festooning within the period of gravel deposition at Lillington (Shotton 1929, p. 208, fig. 5, though I did not originally invoke a solifluxion explanation for this phenomenon).

The Baginton sands I regard as representing a continuation of sedimentation in the same major valley, the inflowing streams being occasionally strong enough to transport fine gravel but being in general of reduced power, due partly to diminution in gradient and partly perhaps to decline in volume of water as the ice enlarged and its front came nearer. The end stage of the sands, level bedded and with intercalated silts, indicates that the ice front was already impounding the lake which was to become so important during the Wolston clay period.

(g) *The Wolston Series*

Above the Baginton sand lies upwards of 50 ft. of deposits which I have in my earlier paper called boulder clay. Except for the few feet at the bottom, which are seen as overburden in pits working the Baginton sand, the formation is most inadequately exposed. In the upper part are many old pits, but they date from the time when it was customary to 'marl' the sandy fields of the Dunsmore gravel outcrop and they are now overgrown. In such old pits it is not possible to assess whether pebbly clay layers intercalate with non-stony clays, whether clays are laminated, nor if there are thin interbedded sands. The only consistent evidence of the nature of the deposits comes from the auger holes.

It has already been pointed out that the bottom foot of the Wolston clay is usually stoneless and appears to be a still-water deposit. The next 3 ft. or so, seen in pits, contain scattered pebbles, and although by no means a typical boulder clay, might be interpreted as till of an unusually clayey character. In the bulk of the succession, however, there is little evidence of till. The dominant materials of the auger holes were either a red or pinkish grey stoneless, very plastic clay or a similar material with rare small scattered stones. The first can only be interpreted as laid down in quiet water, the second as a similar deposit receiving an occasional contribution from a melting iceberg. Varved clays might in such circumstances be expected, but the auger, though it gives a good bulk of sample, brings it up in curled shavings, and it is difficult to be certain when they represent laminated clays. Only in a limited number of cases was I confident that varved clays were present. It was therefore of great interest when Mr D. R. Hughes drew my attention to a temporary excavation in the grounds of King Henry VIII's School, Coventry (M.R. 330781, surface level 330 ft. O.D.), which, under 5 ft. of soil and red clay, showed 2 or 3 ft. of finely laminated brown silt and chocolate clay.

Apart from the main bed of Wolston sand which splits the series, thin bands of rather clayey sand occur in the clays. The relative importance of the different types of lithology encountered in the Wolston Series (but omitting the Wolston sand) can be judged from table 3, which takes account of the thicknesses penetrated in all the auger holes of sections S_1, S_2 and S_3.

Most of this material can only be interpreted as due to the settling of fine detritus in a lake ponded in the valley whose bottom was filled by the Baginton-Lillington gravels and Baginton sands. Its extent was considerable, so that the Wolston Series overlaps the earlier sands and gravels on to the solid formations of the east and west sides of the valley

TABLE 3

Possibly to be interpreted as boulder clay			
(*a*)	Very stony clay	4 %	6 %
(*b*)	Sandy clay or clayey sand with stones	2 %	
Interpreted as deposits of a lake			
(*c*)	Laminated clay and silt	4 %	94 %
(*d*)	Stoneless plastic clay	49 %	
(*e*)	Plastic clay with rare scattered stones	37 %	
(*f*)	Sandy clay and clayey sand	4 %	

and before the eastern margin of figure 9, is reached (e.g. around Dunchurch) it has itself died out (figure 2). It can be seen almost at its minimum at Thurlaston, in an old pit at 473713, which shows:

Surface level *ca.* 380 ft. O.D.

Sandy gravel with flint and Bunter pebbles (Dunsmore gravels)	6 ft.
Red clay with some Bunter and flint pebbles, almost stoneless at base (Upper Wolston clay)	3 ft.
Dark grey Lias clay	2 ft.

The interpretation of the Wolston Series as lake deposits is supported by the widespread occurrence of its middle member, the Wolston sand. This barely reaches to the southern edge of figure 9; it is thin though traceable north of Cubbington, but on the spur south-west of that village it has only been mapped over a very limited area. I have no doubt that it is present under most of the hill, for it occurs in the borehole of the Leamington Corporation near Lillington (M.R. 332681; Richardson 1928, p. 117) as $4\frac{1}{2}$ ft. of sand between the levels of 306 and 310·5 ft. O.D. Northward it becomes thicker—10 ft. in the Ryton auger traverse (S_3) and 17 ft. at Wolston (S_1), and if followed out of the area towards Hinckley, ultimately attains to about 50 ft. With this thickening, it also takes on a more pebbly character and becomes a sandy gravel. The general distribution of this sand is shown in figure 8, and its origin is discussed on p. 253; but its occurrence as a regular layer over an area of at least 250 square miles is suggestive of deltaic deposition and therefore of the existence of a sheet of water. It will be noted also how, in both sections S_1 and S_2 (figure 10), the Wolston sand in places interfingers with plastic clays.

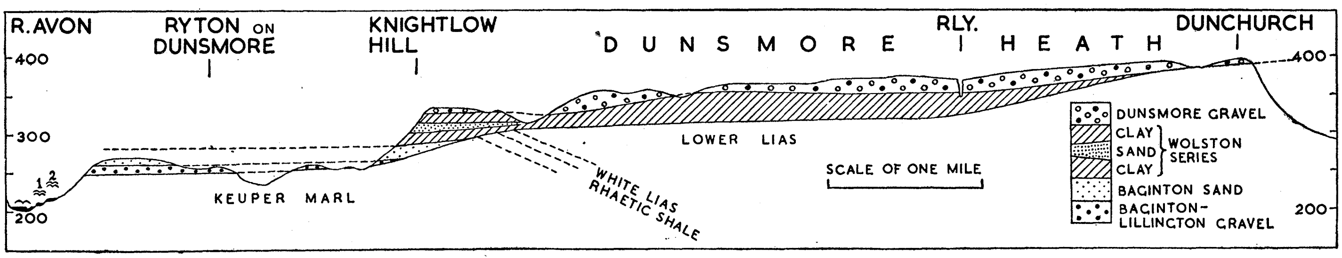

FIGURE 2. Section along the line of the Coventry-London road, from the River Avon at Ryton Bridge to Dunchurch. Vertical exaggeration 26·4.

So much of the Wolston clay of the auger traverses is a lake deposit that it might be permissible to regard the small amount of very pebbly clay there occurring as moraine dropped from bergs. Such an explanation would not alter the fact, however, that in other parts of the area mapped in detail (figure 9), true till does occur. To quote only a few examples, recent trial boreholes for a reservoir on the Campion Hills, Leamington, at 332667, showed brownish grey calcareous clay with many small pebbles of siltstone (Keuper), Bunter quartzite and limestone of Lias type with the unsorted character of true boulder clay. In an auger traverse at Radford Semele (around 350644 and so just south of the edge of figure 9), two beds of undoubted Chalky Boulder Clay were interbedded with red plastic lake clays (section on figure 10). Other examples will be quoted later when the general implications of the postulated lake are discussed, but it is clear that the lake facies of the Wolston clay is equivalent to Chalky Boulder Clay and also to the red boulder clays of the west of the area, and that the glacier which helped to pond the water also advanced spasmodically over the deposits of its own lake.

Pebbles occurring in the clays, in a thin gravel which forms the base of the Wolston sand, and also in the Dunsmore gravel which overlies the Wolston Series, were retained from the auger samples and classified with the results shown in table 4.

TABLE 4

	Upper Carboniferous sandstone (%)	Bunter pebble beds (%)	Keuper sandstone (%)	Lias or Rhaetic limestone (%)	brown flint (%)	white or grey flint (%)	chalk (%)	others (%)	no. of pebbles
Dunsmore gravel	$3\frac{1}{2}$	29	—	—	15	34	—	19	196
Upper Wolston clay	6	39	9	2	9	28	$\frac{1}{2}$	7	166
Wolston sand	15	49	$18\frac{1}{2}$	$2\frac{1}{2}$	$9\frac{1}{2}$	—	—	$5\frac{1}{2}$	125
Lower Wolston clay: upper half	6	$44\frac{1}{2}$	$26\frac{1}{2}$	—	7	13	—	$2\frac{1}{2}$	153
lower half	—	60	32	2	1	1	—	$4\frac{1}{2}$	107

The figures for flint in the Lower Wolston clay are a little misleading—in fact, the lower part is normally devoid of flint, and it was the upper half only which yielded this material and then only in abundance at Wolston; but numerically the sample here was rather large, with a consequent effect on the average obtained from all the holes.

The general trend is clear—the Wolston clay commences with little but Bunter pebbles and Keuper sandstone as erratics, and ends with these much reduced and flint equal in importance to the Bunter material. The Dunsmore gravel continues the trend, with Keuper sandstone reduced to vanishing point, Bunter pebbles down to half their original importance, and flint now dominant. These figures show how a northern ice (it can hardly be called 'western'), rich in Bunter and Keuper detritus, was gradually pushed aside by an eastern ice with flint as the main transported material.

Along with this change in pebble content, the Wolston clays change, as one would expect them to, in colour and content of calcium carbonate. At the base of the series they are deep chocolate red and non-calcareous—merely redistributed Keuper marl—but at the end of the period they are pinkish grey or pink, full of race concretions and highly calcareous. Surface decalcification is such, however, that no sample can be expected to show calcium carbonate unless it comes from at least 5 ft. down, and weathered outcrops appear red rather than pink or grey.

There are a number of less common erratics which can be found scattered over the fields where the Wolston clay outcrops and in the pits which show the bottom of the formation. Some of these are of important directional significance, in particular the Leicestershire igneous rocks which appear to be present throughout the whole mapped area, for I have found them in pits near Ryton-on-Dunsmore, Willenhall, Binley, Brandon and Wolston and also scattered on the fields south of Church Lawford. The commonest is the granophyric monzonite of Croft, and it is this which accounts for most of the large boulders which occur sparsely in the area (Shotton 1931, 1950); also recognizable are markfieldite and Mount Sorrell granite. In the Coventry district and as far south as Brandon I have found camptonite from Nuneaton, but this erratic does not seem to occur in the east of the mapped area. The table given above suggests that neither chalk nor Lias rocks are important in the Wolston clay (except as ground-up material making the clays calcareous), but this is not true to the east where both 'blue' and 'white' Lias limestones occur frequently. Chalk (as distinct from flint) is rather sporadic, occurring near Rugby and also at Radford Semele, south-east of Leamington. In east Coventry, also, at the G.E.C. works (M.R. 3678), the Wolston Clay revealed by excavations contained chalk and yielded a well-preserved specimen of *Actinocamax quadratus* (Shotton 1936, p. 139) which must have originated at least 100 miles away.

(*h*) *The Dunsmore gravels*

One of the most striking topographical features of the area is the flat-topped plateau which lies between the Avon and Leam rivers. Anyone who traverses the London-Coventry road will be conscious of this almost horizontal surface from Dunchurch westward until he drops below it at Knightlow Hill, south of Wolston. This plateau has actually a very gentle slope to the west-north-west and reaches its lowest point (320 ft. O.D.) south-south-east of Wolston. It is everywhere capped by gravel which, owing to dissection by streams, forms a number of tongues roughly radiating from the Blue Boar. Each of these arms was in ancient times a heath, as the place-names clearly testify, and I have chosen one of these, Dunsmore, as the label for the formation.

Dunsmore gravels only cap the high land between the two rivers to a point about a mile west of Princethorpe, and on the south-westerly continuation of this high land, to Cubbington and Lillington, they have not been preserved though they may well have originally existed there. A number of small outliers occur near Birdingbury and Kites Hardwick, and there are also small patches between the Leam and the Itchen at Offchurch and near Hunningham.

The formation consists of gravel with pebbles up to about 3 in. in size, interbedded with subordinate beds of sand. It is very ochreous and there is a significant proportion of argillaceous matter. Flint is the dominant material, with Bunter pebbles important, a fair proportion of limonitic ironstone (which might derive from the clay ironstones of the Coal Measures or the Lower Lias) and rarer pieces of Carboniferous sandstone and the Leicestershire igneous rocks. All constituents except the Bunter pebbles are subangular. Owing to the ochreous clay, the gravels have been little exploited, and the only working of any importance now in operation is the Frog Hall pit at 415738, where nearly 20 ft. can be seen. The bedding here is as regular as one would expect to find in any deposit of this coarse character, and the whole sheet of Dunsmore gravels is clearly due to water deposition. The climate existing when the gravels were laid down cannot yet be indicated by a fauna, for the only fossil I have obtained is a metatarsal of *Equus caballus* from Frog Hall.

It is not known how far south relics of this gravel sheet may be found, but an understanding of its northward continuation is important to an appreciation of its mode of origin. It is naturally missing where the Avon valley runs between Rugby and Willenhall, but on the higher ground to the north, the deposit might be expected to reappear. All the earlier divisions of the Older Drift can certainly be recognized and mapped in turn as the slope is ascended, and east of Harborough Magna, where the ground level rises above 400 ft., there is much flint on the fields, suggesting the possibility that the Dunsmore gravels form an outlier. The soil here, however, is heavily argillaceous and far more suggestive of boulder clay (which is how I have interpreted it). Immediately north of the limit of figure 9, there is much ground above the 400 ft. contour, but as far as I can see no sign of true Dunsmore gravel. Instead is found true eastern boulder clay, and it can be seen from the borehole sections in figure 5 that this lies upon the Wolston Series and that there is no place for the Dunsmore gravel. Eastern boulder clay and Dunsmore gravel appear to be mutually exclusive, each forming in its own area the end-member of the Older Drift sequence. I regard them as equivalent, the first being the ground moraine of the eastern ice and the second its plain of outwash gravels.

4. Description of the Newer Drift—river terraces and alluvium

(a) *General*

Tomlinson (1925, 1935) has mapped the terraces of the Midland Avon from its junction with the Severn at Tewkesbury up to Warwick, and Wills's work on the Severn (1938) has allowed the features of the two rivers to be correlated. In figures 3 and 10, can be seen how these terraces continue along the two main branches into which the Avon system divides above Warwick—the Avon and Sowe to the north and the Leam and Itchen to the south.

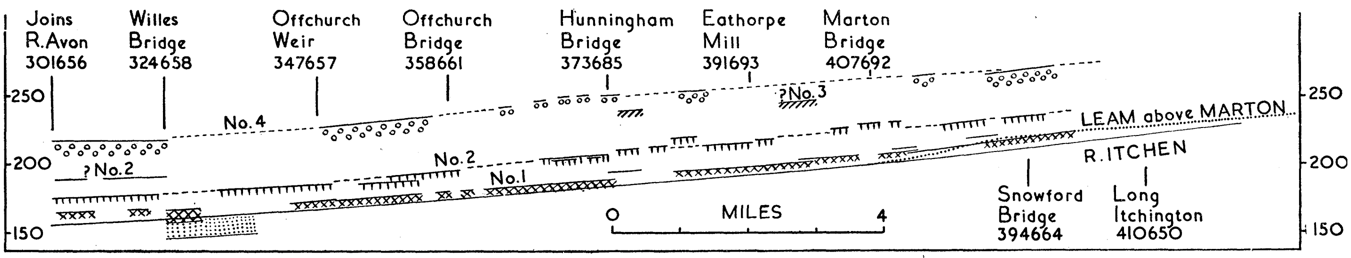

Figure 3. Profile of terraces along the River Leam and River Itchen.

Tomlinson distinguished five terraces, to which she gave the numbers 1 to 5, No. 1 being the lowest. No. 5 was not detected north of Stratford-on-Avon, and I have found no hint of it in my area; but the other four can all be traced by well-developed features, excellently preserved because of the much greater width of the ancient floodplains compared with that of the modern alluvium. This striking difference, a feature of all our rivers, is obvious throughout the area here considered, and No. 4 floodplain generally had a width seven or eight times that of the modern alluvium.

Because the Avon system has cut down through the eastern boulder clay and the Dunsmore gravels, its terraces are dominantly flinty, though Bunter pebbles are always also present. There is, indeed, no obvious lithological criterion by means of which one terrace can be separated by mapping from another or from the Dunsmore gravels, and such distinction has to be made on considerations of height. Fortunately, No. 4 terrace, even as far upstream as Rugby, is still clearly below the Dunsmore gravels. On considerations of height alone, however, there could be confusion with the Baginton-Lillington gravels, and it is fortunate that the pebble content of these (whether they be the pure Bunter type of Baginton or the Bunter-Jurassic development of Lillington) immediately allows separation from the flint-rich terraces. Only the River Sherbourne, flowing from the north-west, lacks flint in its poorly developed terraces, and in this respect resembles the River Tame to the west of the Warwickshire coalfield.

Perhaps the most striking feature of the system of terraces is that their height distribution is completely at variance with that of the Older Drifts. This arises from the fact (which will be amplified later) that the Older Drifts fill a pre-glacial valley which slopes down to the north-east, whereas all the terraces conform with the present Avon in falling in level to the south-west. This has the effect that the long profile of a terrace such as No. 4 crosses the plane of the base of the Older Drifts. In the Lower Avon mapped by Dr Tomlinson, No. 4 terrace is scores of feet below the older series, and even at Warwick its top is 40 ft. below the base of the Baginton-Lillington gravels. Upstream from here it approaches towards the older series and first rests on the Baginton-Lillington gravels at Baginton on the Sowe and near Willenhall on the Avon; from these points it creeps progressively over the subdivisions of the Older Drifts and near Coombe and Rugby is banked against the Wolston clay. One may guess that, near the source of the Avon, No. 4 terrace will grade into the Dunsmore gravels or the Chalky Boulder Clay, from which it derived its material by erosion.

(*b*) *No.* 4 *terrace*

No. 4 terrace is well developed as a topographical feature along the Avon-Sowe and also the Leam-Itchen system. Up the Avon from Brandon to Rugby, however, the very level surface of the terrace passes on its outer edge into gravel spreads which climb gently to heights which may be 20 ft. above the main flat, as though fan gravels bordered the ancient alluvial plain. Wherever possible, I have taken the flat surface as the level to be plotted on the long profile (figure 10), but if this has been removed by erosion and only the gravel slope remains, it is impossible to select a height which does not appear to cause an irregularity on the terrace gradient.

Four separated but very distinct patches of flinty gravel in the hollow north-west of King's Hill, Finham, between the points 321713 and 330755 are evidently, from their height, relics of No. 4 terrace. They would appear to indicate a deserted loop of the Sowe running from Baginton, north and west of King's Hill to the Finham brook at 320742. From this point the ancestral Sowe may have followed the lower part of Finham brook to join its present course at 336738. The long-profile of No. 4 on the Avon from Warwick upwards shows a convergence to the profile of the present-day floodplain, and from being 65 ft. above the river at the confluence of the Leam with the Avon, it has dropped to 40 ft. at the point between Ryton and Brandon bridges, $14\frac{1}{2}$ miles upstream. From there onwards it seems to remain more or less parallel to the river.

The behaviour of the terrace along the Leam is different. It can be traced easily up to where the River Itchen joins it, but from there upwards I can find no trace of it along the few miles of the upper Leam which I have examined; wide spreads do, however, continue parallel to, but east of the Itchen, as far as Snowford Bridge on the profile and certainly considerably farther south beyond the limit of my mapping. There is no doubt that, at the time when No. 4 terrace was a floodplain, the northward-flowing Itchen and south-westward running lower Leam was the important river, and it is possible that the upper Leam did not exist.

In its height relationships, also, No. 4 behaves differently on the Leam-Itchen compared with the Avon. There is little evidence of convergence towards the present-day floodplain profile within the stretch I have examined—at Snowford Bridge the terrace is 57 ft. above the Itchen, whereas at the corresponding distance along the Avon it is only 40 ft. up. The full significance of this difference in behaviour must await the outcome of work which Dr G. H. Dury is doing on the River Itchen, there being little doubt that this river has played an important role in the development of the upper part of the Avon system.

The composition of No. 4 terrace, or at least of its top portion as spread out liberally on the ploughed fields, is dominantly of flint with a good proportion of Bunter pebbles, of a size up to several inches. Pits in the terrace are few and mostly old and unworked, with the consequent obscurity that goes with these conditions, but in the process of developing a new pit near Brandon (386758) Jas. Turner and Son, Ltd have constructed a loading bay, and in doing so have revealed a temporary section covering the whole sequence of the terrace, as shown in table 5.

Table 5

1.	Soil	1 ft.
2.	Gravel, pebbles typically about 3 in. in size, angular flint and Bunter. Usually without obvious bedding, but with occasional thin sand bands	2 to 4 ft.
	Irregular channelled base	
3.	Coarse brown sand with rare small pebbles, false-bedded and with black streaks	3 to 4 ft.
4.	Red clayey gravel, pebbles to $\frac{3}{4}$ in., mainly Bunter, flint rare	4 in.
5.	False-bedded brown sand with streaks of small pebbles and clay layers	2 ft.
6.	Poorly bedded gravel, very clayey, pebbles mainly below 1 in. chiefly Bunter, some Keuper sandstone and clay pellets, flint rare	3 ft. 6 in.
7.	Very fine gravel	1 ft.
8.	Coarse, false-bedded, pale or deep red sand	1 to 4 ft.
9.	Fine gravel with clay matrix, pebbles mainly below 1 in., chiefly Bunter, some Keuper sandstone, rare flint	6 ft.
	total about	21 ft.
10.	Red and green Keuper marl	

This section reveals clearly that the deposits of No. 4 terrace are composite, bed 2 being separated by an important time-break from the lower parts of the succession. In addition to the marked change in pebble size seen at the junction of beds 2 and 3 and the channelled base of 2 (facts not necessarily of great significance), there are two other facts which are more obviously indicative of a time-break. There is a great change in the nature of the constituent pebbles, flint being rare below bed 2 but dominant within it; and bed 3 is 'cryoturbate', the bedding being warped into strong solifluxion festoons, whereas bed 2 is quite unaffected. It can safely be said that a period of cold periglacial climate occurred some time after the deposition of beds 10 to 3, and before bed 2.

The composite nature of No. 4 terrace is hinted at by some of the sections in the lower Avon and Warwickshire Stour described by Tomlinson (1925, particularly the Ailstone section, p. 143), whilst in its correlative of the River Severn, the Kidderminster terrace, Wills (1938, pp. 181–4) has described at least two sections where the same conclusion can be drawn. At Highnam Court, 6 ft. of Bunter gravels with flint lie with a channelled surface on Jurassic gravels, and at Yates's pit, Kidderminster, 3 ft. of horizontal and quite undisturbed sand rests upon gravels whose top 6 ft. are violently disturbed by solifluxion. The implications of this structure will be discussed further after consideration of No. 3 terrace.

(*c*) *Fauna and implements of No.* 4 *terrace*

I can add nothing to the rather meagre faunal list which characterizes No. 4 terrace lower down the Avon (Tomlinson 1925, 1935) and which I discuss later (p. 233). Very important from the point of view of dating, however, are the implements from Baginton (Shotton 1930, 1937).

From what I called the village pit (347747) where the Baginton-Lillington gravels but no terrace gravels occur, came a single chipped pebble (Shotton 1937, p. 39, Pl. IV, fig. 1) not found *in situ*. It might be a crude core-implement of ancient date but might equally well be a core from surface soil in which Bronze Age flints are not uncommon. Such a crude artifact picked up from the floor of the pit cannot be used stratigraphically. Apart from this, all the other Baginton implements came from the river pit at 339751 where No. 4 terrace was plastered on a spur of Baginton-Lillington gravels. Eight specimens comprise two quartzite hand axes, parts of two flint hand axes, and four flint flake-implements. All were picked up from gravel heaps.

I described these artifacts under the belief that they came from the Baginton-Lillington gravels, basing that belief on what I considered to be a paucity of flint in the gravel heaps. It is not easy to form a reliable impression of such a factor when gravel-winning methods are mixing up two deposits, and it should be said that Dr Tomlinson, who found one of the quartzite hand axes, has always held the other view that the artifacts came from the terrace gravel. Dr W. J. Arkell has also maintained privately that only this explanation would lead to a satisfactory stratigraphical conclusion. It may be said now that I am fully converted to this view. There are the negative points that implements came abundantly from the one pit where No. 4 terrace lay on Baginton gravels, only when that end of the pit with terrace gravels was being worked, and no trace of artifacts has yet been found, despite intensive search, in the vast pits such as at Wolston and near Ryton (376740) where Baginton-Lillington gravels alone are being worked. More important is the typology of the implements and of one in particular, an unworn trimmed flake (Shotton 1937, p. 39, Pl. IV, fig. 2). Of this, Mr M. C. Burkitt wrote 'this is probably Levalloisian in culture—contemporary with the late Acheul stage—although the striking platform actually is not multiple-faceted'. Dr K. P. Oakley has expressed to me his opinion that this is 'certainly later than anything in the Middle Gravel of Swanscombe'. Faced with this relatively late dating, it would seem to be impossible to place the implement in the Baginton-Lillington gravels, which we know antedate the Great Chalky Boulder Clay of the Midlands. By elimination, therefore, the Acheulian implements of Baginton must be ascribed to No. 4 terrace, which becomes dated as very late Acheulian or Levalloisian.

This conclusion brings the finds into line with others made in Warwickshire. From 5 ft. down in No. 4 terrace at Barford-on-Avon, A. Jack obtained a rather worn hand axe which is Acheulian, though more precise dating cannot be attempted (Jack 1922). The numerous implements, mainly quartzite hand axes, described by Mrs E. M. Clifford from Little Alne (1943), were picked up from fields on an outlier of gravel which Tomlinson (1935, Pl. XXVII) shows as the equivalent of Avon No. 4 terrace on the Arrow-Alne system. Of the two flint implements, one is a trimmed flake (Clifford 1943, p. 52, No. 8 and p. 54, fig. 7), quite unworn, and very similar to the Baginton flake mentioned above. Mrs Clifford suggests comparison with le Moustier technique, and it is certainly the latest in type of the Alne specimens. It leads to a most satisfactory correlation with Baginton.

(*d*) *No.* 3 *terrace*

This terrace, within the area of my mapping, occupies the same rather unsatisfactory position as it does lower down the Avon (Tomlinson 1925, 1935). No. 4 terrace is established on numerous flats of gravel which connect with each other by well-defined long profiles along the Avon, Leam, Itchen and other tributaries. No. 2 terrace is even more clearly defined; but between the two occur only a few patches of gravel which cannot be distorted into either long profile and yet are of terrace form. Two such occurrences are shown on the Avon diagram (figure 10) at 14 and 15 ft. below the level of No. 4 terrace, and two on the Leam profile (figure 3), 9 and 10 ft. below the height of No. 4. By analogy with the Avon below Warwick, these patches belong to No. 3 terrace.

One other piece of No. 3 terrace is shown on figure 9, M.R. 323791, on the River Sherbourne,* and the reasons for ascribing it to this level need to be fully stated, since it was from here that the complete skull of *Hippopotamus* now in Coventry Museum was obtained (Shotton 1929, p. 212). This came from an excavation for an underground petrol tank, but was only brought to the notice of anyone capable of appreciating its significance after the tank had been concreted and all spoil removed. It was stated by the excavators to have been found in sand which occupied the 16 ft. of excavation apart from made ground at the top. Because of its height and immediate proximity to a mapped outcrop of boulder clay shown to the east on Sheet 169 of the Geological Survey, I suggested in my 1929 paper that the deposit might belong to the sands and gravels which I call in this paper the Baginton series, lying immediately beneath the boulder clay. I also pointed out, however, that the possibility of a river terrace was not excluded. Since that time I have been able to see excavations at the depot of the National Benzole Co. at 324794 (see figure 4*b*), where 2 ft. of red boulder clay rested directly on sandstones and clays of the Corley beds, so that the possibility of the *Hippopotamus*-bearing sand lying beneath the boulder clay is ruled out. These sands must be banked against the rising ground to the east and thus be part of the river terrace sequence.

It was not possible to sink an auger hole at the spot where the skull was found, owing to a concreted pavement. A suitable place was, however, found about 60 ft. to the west, and here and at a spot 14 ft. farther west, two holes were drilled. Under about $3\frac{1}{2}$ ft. of made ground, each proved unconsolidated silts or silty clays before the Corley beds of the Upper Coal Measures were reached. The detail of these holes is shown in figure 4*a*; the drop in

* The paucity of terrace deposits on the Sherbourne from this point downstream to near the junction with the Sowe may be merely due to inability to recognize them on the heavily built up and modified town area.

the base of the quaternary deposits, amounting to 1 ft. 5 in. in 14 ft., would if continued as a plane allow about 13 ft. to exist where the skull was found, so that the description of 'about 16 ft. of sand' could be more or less correct. These silts and/or sands must occupy a well-defined channel.

The significance of this channel can be better understood when it is realized that, about a quarter of a mile to the west, there is a well-marked terrace remnant. Though not indicated as such on Sheet 169 of the Geological Survey, its nature cannot be doubted, for it combines the typical appearance of a terrace with very sandy soil rich in Bunter pebbles.* This terrace is 30 ft. above alluvium level. Farther downstream in Coventry

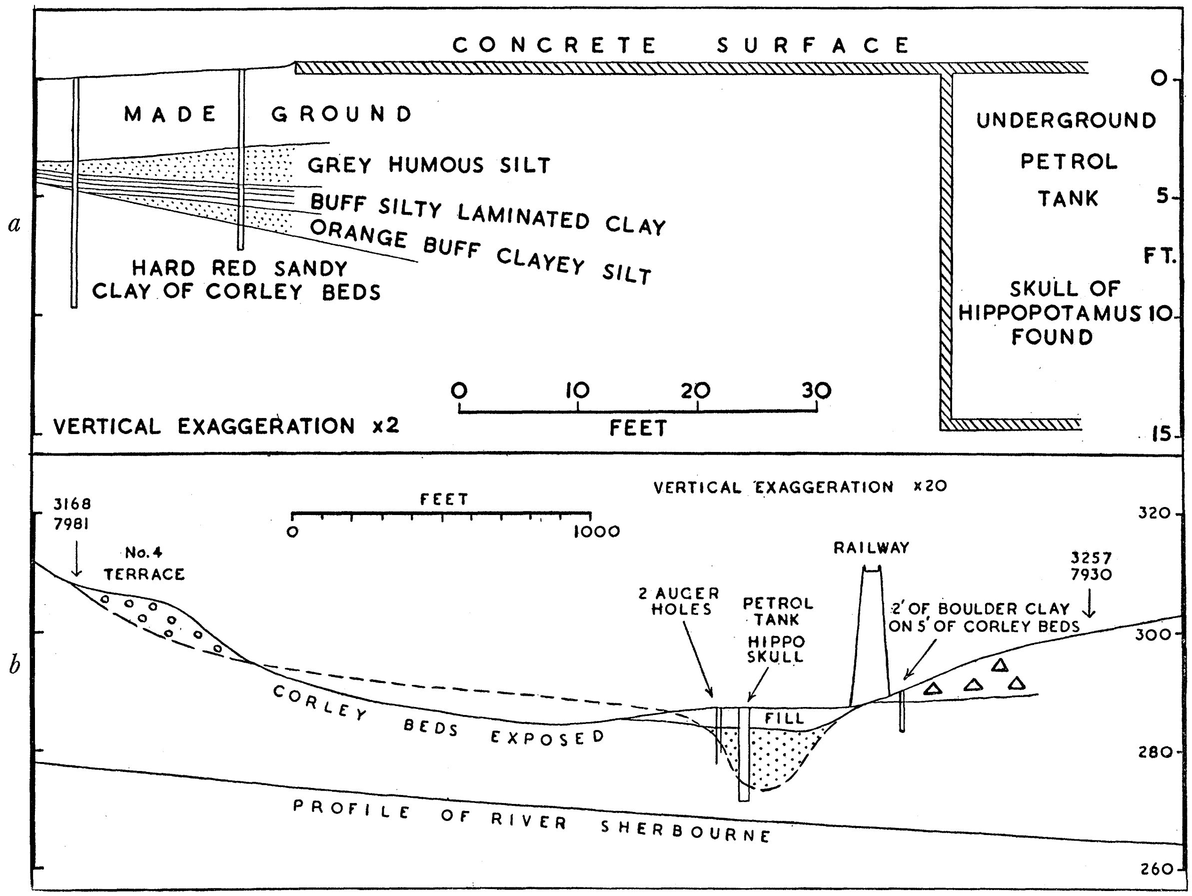

FIGURE 4. *a* (above), relation of auger holes to excavation which yielded a skull of *Hippopotamus* in Coventry. *b* (below), possible relation of *Hippopotamus*-bearing channel to adjacent drift deposit.

at Greyfriars Green (332786) excavations have revealed several feet of loose sand on a flat which is 33 ft. above alluvium. The two occurrences give a gradient which joins No. 4 terrace on the River Sowe, and they can be confidently referred to this. The preserved top of the channel deposits that yielded *Hippopotamus*, however, only lies 16 ft. above the Sherbourne alluvium, suggesting a correlation with No. 3 terrace. I would not expect No. 2 terrace to be as high as this, so far up a minor tributary, and in any case the

* The Sherbourne, flowing from the west from the high land of the Warwickshire Coalfield, with its western drift, would be expected to produce terraces of Bunter pebbles, like the Tame system, and not flint-bearing gravels as the Avon does.

occurrence of *Hippopotamus* is in violent contradiction to the abundant 'cold' fauna of No. 2. If, however, the channel is referred to No. 3 terrace, it falls into line with other records of *Hippopotamus* along the Avon.

In figure 4*b* I have suggested a relationship between No. 4 terrace and the channel which makes the deposits of the latter older than No. 4 and laid down where a channel might be expected, on the outer bend of an old loop of the Sherbourne. An alternative explanation clearly could give the opposite age relationship, with the channel cutting through the deposits of No. 4 terrace.

(*e*) *No.* 2 *terrace*

No. 2 terrace is a conspicuous feature along all the rivers except the Sherbourne. The wide spreads of it at Leamington and Warwick are by no means level in cross-section, and the height above alluvium may be estimated between 20 and 30 ft. in different places. Upstream from here there is the same difference in behaviour between the Avon-Sowe on the one hand and the Leam-Itchen on the other as there was with No. 4. In the first case, the terrace approaches the alluvium towards the river's source, and at Rugby it is only 12 ft. high and not easily separable from No. 1, whereas in the second case it keeps almost parallel to the alluvium and is still 25 ft. above it at Snowford Bridge on the Itchen.

At no place is No. 2 terrace worked for gravel, so that I can add no new facts concerning either the thickness of the deposit or its fauna. The latter, of course, is conspicuously 'cold', and from many places between the Severn and Leamington has yielded *Elephas primigenius* and *Tichorhinus antiquitatus* abundantly and *Rangifer tarandus* sparingly.

(*f*) *The relationship of No.* 3 *terrace to No.* 2 *and No.* 4

Two opposed suggestions have been made concerning the relative age of the deposits of terrace. Tomlinson (1925, p. 159; 1935, p. 459) suggests that the deposits of No. 3 are older than those of No. 4, both belonging to a continuous warm-climate aggradation. No. 3 has yielded *Hippopotamus*, *Elephas antiquus* (possibly), *Unio littoralis* and *Belgrandia marginata*, while No. 4 (but so far as is known, only the lower part of it) has produced *Unio littoralis* and *Corbicula consobrina*. These gravels were then entrenched with two halt stages, the first producing the terrace feature of No. 4 and the second that of No. 3. By the time of the first pause, the climate had changed to a colder one and there was aggradation of a few feet of gravels which have yielded the Siberian form of *Elephas primigenius* at Barford; the second halt stage was not accompanied by any aggradation beds which have survived. Later than all this was the further entrenching followed by aggradation which resulted in the cold-climate gravels and terrace top of No. 2.

Professor Wills, however (1938, p. 200), inclines to a different sequence. Oldest of the deposits in question are the gravels of No. 4 terrace with a warm fauna, 'at any rate in the upper part'. Then follows excavation to below the level of No. 2, followed by aggradation of cold-climate gravels (deposits of No. 2 terrace) with *Elephas primigenius*, *Tichorhinus antiquitatus* and *Rangifer tarandus*, further aggradation of warmer-climate deposits whose top is No. 3 terrace, and a subsequent excavation to form the terrace feature which we know as No. 2.

I do not understand why the warm fauna of No. 4 is ascribed by Wills to the upper part, for what little evidence there is indicates that the latest deposits of this terrace appertain to a colder climate than the beds below. This, however, is a minor point which in no way weakens the general sequence postulated by Wills. His interpretation differs from Tomlinson's in two important respects. He would have the gravels of No. 2 pass without break upwards into the deposits of No. 3 (the age sequence being 4–2–3), whereas Dr Tomlinson pictures No. 3 passing up into No. 4 the full sequence being 3–4–2; and consequently she visualizes the cold episode of No. 2 terrace separated from the Great Eastern Glaciation by a single extended warm period, whereas Wills interposes it in the middle of the latter.

Along the upper Avon and Leam, the top of No. 3 appears to overlap the base of No. 4, but its base is always separated by a rock step from the top of No. 2. I therefore support the sequence of events suggested by Dr Tomlinson.

(*g*) *No.* 1 *terrace*

Although Dr Tomlinson did not map No. 1 terrace above Hampton Lucy and therefore suggested the possibility that it passed beneath the alluvium, it is in fact apparent along all the Avon from Warwick to Rugby (forming a feature from 5 to 10 ft. above the alluvium) and even more strongly developed on the Leam-Itchen system. Frequently it is in two stages, separated by a small step of 3 or 4 ft., and in such cases I have shown it on figure 9 as 1 *a* and 1 *b*; but I do not think there is any important difference in age between the two levels, which may have resulted from the migration of meanders.

The terrace is not worked in any pits, though its gravels are visible in natural and temporary exposures. Whereas it is separated from No. 2 by a rock step, its gravels abut against the alluvium and indeed go below the level of the top of the latter; but they appear to be wholly earlier than any of the alluvial fill and separated from this last stage by a down-cutting amounting to about 25 ft. (measured from the top of 1 *b*). Several shallow bore-holes recently put down east of Willes Bridge in Leamington (324658) to test the foundations of a possible reservoir were mainly in alluvium, but one started on No. 1 terrace, 4 ft. higher. It proved $2\frac{1}{2}$ ft. of clay underlain by $5\frac{1}{2}$ ft. of coarse flinty and Bunter gravel, before reaching the Keuper. The terrace deposits were thus 8 ft. thick and extended 4 ft. below the present floodplain; but the alluvium of the floodplain was as much as 15 ft. thick, butting against the edge of No. 1 terrace and its underlying solid foundation.

(*h*) *The modern alluvium*

Deposits beneath the present floodplains are entrenched into No. 1 terrace and extend down to a level typically about 14 ft. below flood level. A boring at Blackdown Mill (311691) on the Avon proved 13 ft. of sandy clay resting on 1 ft. of gravel before entering the solid formations. Six boreholes east of Willes Bridge, on the Leam at Leamington (between 324657 and 332656), proved the alluvium to vary between 8 and 15 ft. in thickness. In five of these holes there was a coarse basal gravel of flint and Bunter pebbles, exceptionally 6 ft. 6 in. thick but averaging 2 ft. 2 in., and above this a grey plastic clay weathering brown in its top 3 ft. The sequence therefore was similar to that of Blackdown Mill. The bottom of the alluvial fill represents the lowest base level attained by the Avon system, and may, so far up the river system, correspond to the impressive sunk channel which characterizes the main English rivers (including the Severn) near their mouths.

Dury (1952) has demonstrated that the Itchen, at a point $3\frac{1}{2}$ miles south of the edge of figure 9, has an alluvial fill amounting to 12 ft. and consisting of clay above and silt below, occasionally with flint and Bunter gravel at the base. A list of nine species of shells obtained from both the clay and silt indicates a climate similar to that of Warwickshire at the present day.

(*i*) *Drainage changes near the Leam-Itchen junction*

Following the Leam upstream from Leamington, there is evidence of a large deserted meander east of Weston. This seems to have been the river's course during the time of terraces 3 and 4. During the period of terrace 2 the meander was short-circuited somewhat south of the present river's course, but the old loop was probably also still in use, for as late as terrace 1 *b* it received extensive deposits of gravel. Not until 1 *a* time does the shortened course appear to have become firmly established to the exclusion of the old loop.

The spread of 1 *b* gravels which leaves the Leam up the small stream towards Princethorpe is not another old meander, for levels to the east forbid this, but rather the deposit of the small stream itself. The terrace deposits along this tributary valley are astonishing, particularly at Stretton-on-Dunsmore where wide relics of No. 4 are preserved 45 ft. above the stream. They lie in actual height above the level of the same terrace on the Leam or the Avon and are separated from the second river by the unbroken Dunsmore ridge, so that they cannot be explained by any theory involving an ancient course of either main river. They are, in fact, what they appear to be, the deposits of the tributary which has its source just west of the Blue Boar, the centre of the radiating drainage of the Dunsmore plateau. The terrace gravels must therefore be derived from Dunsmore gravels of the immediate neighbourhood. It is amazing that at a distance of only 2 miles from the source of the stream the gravel plain of No. 4 times must have had a width of 900 yards.

Returning to the Leam it is joined at Marton by the Itchen, and here there is evidence of considerable drainage modification. It has already been pointed out that No. 4 terrace has not been traced up the Leam beyond Marton, but turns south along the Itchen, though it would perhaps be premature to suggest that no upper Leam then existed. This change occurs just in front of the escarpment of the White Lias, which may have been the controlling factor. Actually the terrace patches of No. 4 lie about $1\frac{1}{2}$ miles east of the Itchen and are on the continuation of the upper stretch of that river before it makes a big bend to the west at Long Itchington (just south of figure 9). From that time onwards through the various stages of downcutting and aggradation, there was migration of the lower Itchen westward, culminating in the 1200 yards plain of No. 1 gravels which is so out of keeping with the usual narrow width of this terrace on the other rivers. For a brief period there was a narrow 'short-cut' to the Leam at Eathorpe. I cannot give a satisfactory explanation for this great spread of No. 1 gravels, nor for the even more puzzling occurrence at Marston Moor. This latter spread is too hemmed in at its south end to be part of an old course of the river. It has a resemblance to a lake bed, and its deposits of clays and silts are less like terrace gravels and more like modern alluvium—but from which, at the Leam, they are separated by a clear step. The resemblance to a lake is probably fallacious, for apart from the difficulty of finding a cause for impounding, the surface of Marston Moor has a gentle gradient from south to north.

There is a further point of interest concerning No. 1 terrace. Though it runs up the Itchen, it does not continue up the Leam past a point between Marton and Birdingbury. Levels on the modern alluvium show that here there is a very definite knickpoint (see profile of figure 3). The alluvium upstream from this grades into No. 1 terrace—in other words, the Leam above Birdingbury is the valley of No. 1 times, and the last stage of downcutting which was dealt with in §(*g*) above has nearly but not quite worked back to the river's source—it has stopped at the hard band of the White Lias.

5. Correlation

The correlation of the Pleistocene succession described in the foregoing pages cannot be wholly divorced from the broad palaeogeographical implications of the succeeding section. The existence of a large glacial lake during Older Drift times would control the type of deposit to such an extent that similarity of lithology and succession in themselves become telling arguments for similarity of age. As far as is possible, however, circular arguments will be avoided.

(*a*) *The Leicester area*

The individual members of the older drifts, from the Baginton-Lillington gravel upwards, can be mapped without difficulty on both sides of the upper Avon, towards Rugby. Northwards from here, the older parts of the sequence pass underground as the surface level rises towards the watershed across the eastern half of Sheet 169; but the two divisions of the Wolston clay with their separating Wolston sand are obviously traceable across the watershed to the northern edge of Sheet 169 and on to Sheets 155 and 156. The Lower Wolston clay retains its character of a stoneless or near-stoneless deposit, the Wolston sand thickens to a maximum of 50 ft. near Hinckley (see figures 5 and 8) and becomes gravelly in places, while the Upper Wolston clay is sometimes a lake deposit, sometimes a chalky boulder clay, and in places the second resting on the first. The deeper borings (figure 5) often reveal sandy or gravelly beds near the base of the succession which correspond in position to the Baginton-Lillington series, whilst the basal deposits in some holes are described in records as red pebbly clays (in contrast to the grey chalky boulder clay higher up) indicating the Bubbenhall clay facies.

It is necessary to go some way farther north, and lower topographically in the Trent drainage system, before the rivers once more cut down to expose the base of the Older Drift. Then we encounter the succession described by Fox-Strangways (1900, 1903) around Atherstone and Leicester, a sequence slightly modified from Deeley (1886) and so obviously the repetition of the Rugby-Leamington succession except that Chalky Boulder Clay consistently occurs instead of its outwash equivalent, the Dunsmore gravels, that there can be no doubt of the correlation set out in table 6. In assessing this statement, it should be borne in mind that in §6 I shall draw the picture of a lake impounded by a glacier which subsequently overrode the deposits of that lake. In such circumstances, the junction between a stoneless clay and an overlying boulder clay is not to be regarded as a strict time line over long distances.

The newer drifts which form terraces on the Trent and its tributaries can, as far as they have yet been worked out, be equated with the Avon terraces. Wills (1950, p. 123) has pointed out that the high-level gravels of Hilton and Beeston can be correlated broadly with No. 4 (and perhaps 3). They contain implements ranging up to Levalloisian and late Acheulian. The Hilton sections also show a division into an upper and lower series with solifluxion festooning at the junction and above it (Armstrong 1939).

The Allerton terrace on the Derwent (Arnold-Bemrose & Deeley 1896) suggests, both by its lower level and the occurrence of *Hippopotamus*, that it should be equated with Avon No. 3.

The low terrace of the Trent, dated as Mousterian by Armstrong and yielding *Elephas primigenius* and *Tichorhinus antiquitatus*, seems clearly to be the equivalent of No. 2.

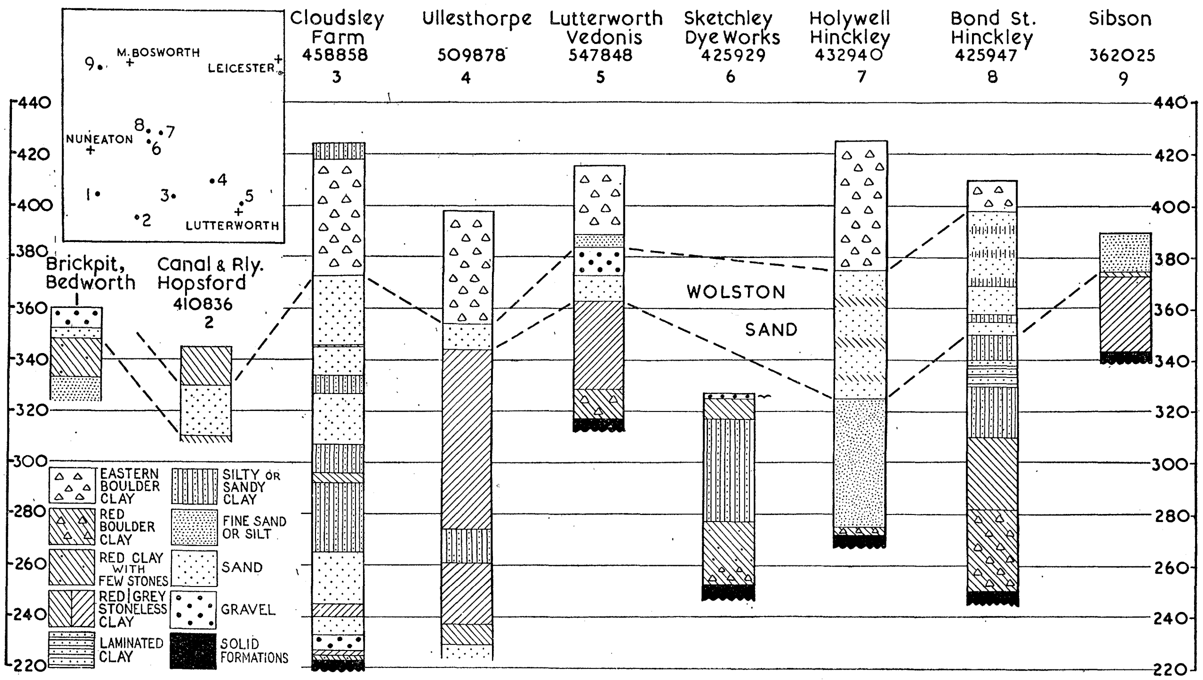

FIGURE 5. The older drifts shown by sections (1 and 2) and boreholes (3 to 9) north and north-east of Coventry.

(*b*) *Birmingham and the Tame Valley*

In the Birmingham district and the upper Tame Valley to the east of it (Sheet 168, Eastwood, Whitehead & Robertson 1925), a generalized succession has so far only been established. There is an older drift, cut through by the present river system and now occurring as hill cappings, just as in the area described in this paper. It rests on a pre-glacial surface in the form of a broad valley ancestral to the present Tame, and it is in this hollow that a thick series of 'bedded gravelly drifts' was deposited. The lowest part of this tends to be coarse gravel and the upper part more sandy, though there is not the same easy distinction for mapping purposes that there is between the Baginton-Lillington gravels and the Baginton sand. Covering and overlapping the bedded gravelly drift is a red clay which is often almost or quite stoneless and may be interpreted as a lake deposit, but which at other places appears to be ground moraine. This is particularly so on the higher ground. The glacial clay steps across the gravels and on the higher ground on both sides of the Tame, i.e. on the south Staffordshire and Warwickshire coalfields, rests directly on the solid foundation. The topographic relationship and the nature of the succession clearly point to a general correlation with the series from the Baginton-Lillington gravel up to the

TABLE 6

Leamington-Rugby	Leicester and Trent	Upper Tame Valley	Northants	north of Stratford-on-Avon
vium	alluvium	alluvium	alluvium	alluvium
on	erosion	erosion	erosion	erosion
1 terrace (1*a* and 1*b*)			10 ft. terrace	
on			erosion	
2 terrace	low terrace	low terrace of Tame	25 ft. terrace	No. 2 terrace
on	erosion	erosion	erosion	erosion
of No. 4 terrace	top of Hilton and Beeston terrace	? high terrace of Saltley	45 to 50 ft. terrace	No. 4 terrace, Kingswood train, low-level eastern and western drift
on and solifluxion	erosion and solifluxion			
of No. 4 terrace	base of Hilton and Beeston terrace			
3 terrace	Allenton terrace			
t erosion	erosion	great erosion	great erosion	erosion No. 5 terrace erosion
smore gravel and alky Boulder Clay	Great Chalky Boulder Clay with beds of sand and gravel	boulder clay, including lake clays of California	Chalky Boulder Clay with associated gravels	silts, clays and moraine gravels of Tattle Bank (high-level western drift)
er Wolston clay	older boulder clay (upper part)			silts, sands and laminated clays (high-level western drift)
ston sand	quartzose sand			
er Wolston clay	older boulder clay (lower part)			
nton sand	older sand and gravel	bedded gravelly drift	mid-glacial gravels	sands of Snitterfield
nton-Lillington gravel				Jurassic gravels of Snitterfield
t erosion		Nechells peaty silts gravels	great erosion	
benhall clay			lower boulder clay	
			pre-glacial sands and gravels	

TABLE 6 (*cont.*)

oreton and River Stour	Evenlode and Oxford	Severn Valley	climate from fauna and lithology	human cultures	continental glaciations
vium	alluvium	alluvium	temperate		
ion	erosion	erosion, buried channel			
		Welsh re-advance and Worcester terrace **Cy.**	cold		
		erosion			
2 terrace	solifluxion (warp)	Main terrace and Irish Sea glaciation **Co.**	cold	Mousterian	Würm, Weichsel, Tubantian
ion		erosion			
	peat and clay of Wolvercote channel	Kidderminster terrace	cold	Levallois, late Acheulian	
	sands of Wolvercote channel		temperate		
aces Nos. 3 and 4	lower gravels of Wolvercote channel and upper gravels of Summertown-Radley terrace		warm	Micoque, late Acheulian	
ion	erosion	great erosion			
5 terrace	base of Summertown-Radley terrace	Second Welsh glaciation **Ca.**	cold		Riss, Saale, Drenthian
ion	erosion				
eton drift (boulder clay)	Wolvercote terrace		cold		
eless clays of Moreton ft			cold		
er mpden nel drift tton sand / Paxford gravel			cold		
	great erosion	great erosion	temperate		
	Hanborough terrace	Bushley Green terrace	warm	early Acheulian	
		erosion			
eau gravels	Freeland and Coombe terraces, unterraced northern drift	First Welsh glaciation and Woolridge terrace **Be.**	cold		Mindel, Elster, Taxandrian

Dunsmore gravel and Chalky Boulder Clay. It is, however, likely that the gravels extend somewhat further back in time than do the Baginton-Lillington group. Thick peaty silts have recently been proved at Nechells, Birmingham, in the middle of the gravels, and they have yielded pollen which, to anticipate the results of work by Miss Duigan and Dr Godwin, indicate a temperate climate—I would suggest the interglacial between the First and Second Welsh glaciations.

River terraces in the Birmingham district are very inadequately known except for the one only a few feet above alluvium which fringes the Tame. This carries remains of mammoth and may be correlated with Avon No. 2. That higher terraces exist is very probable, but their recognition has proved difficult. The Birmingham memoir (Eastwood *et al.* 1925) mentions as a post-glacial deposit the upper 3 ft. of gravel at Saltley, 80 ft. above the River Rea, where 60 years ago Landon found a quartzite hand axe made from a Bunter pebble. In view of similar implements at Baginton and Little Alne (p. 231) I have ventured to suggest an equivalence with Avon No. 4 terrace.

(*c*) *Northamptonshire*

Little detailed work has been published on the area east of Rugby, though the Geological Survey has recently mapped some of it. Hollingworth & Taylor (1946, p. 229; 1951, p. 23) have shown, however, that in Northamptonshire there is the same obvious division into an older drift culminating in the Chalky Boulder Clay, and a newer river drift incised into it. They have also shown that there is an older boulder clay with Bunter and Jurassic but no Cretaceous erratics, in marked contrast to the Chalky Boulder Clay. There would appear to be a long interval between the two deposits, for the older boulder clay is only preserved intermittently in hollows beneath the newer. The correspondence with the Bubbenhall clay and Chalky Boulder Clay of my area is obvious. In addition, there often occurs beneath the upper boulder clay, even when the lower is absent, a series of 'mid-glacial gravels' which contain Bunter and Jurassic pebbles but lack flint. Like the Baginton-Lillington gravels, these would appear to be of local origin, derived from the Jurassic outcrops and the early boulder clay, and the two gravel series may be generally correlated. Northamptonshire also shows sands and gravels below the older boulder clay—a deposit for which as yet I can produce no equivalent.

The river terraces which are mentioned by Hollingworth & Taylor have been placed in table 6 merely in order of height.

(*d*) *North of Stratford-on-Avon*

The areas discussed above all show the older drifts preserved on a scale at least equal to that in the Rugby-Leamington district. As one proceeds westwards down the Avon, however, the river and its tributaries cut increasingly deeper below the Older Drift, leaving those deposits more and more dissected and fragmentary until, by the Ridgeway and the Lenches, they are represented by narrow or small outliers on the higher ground only.

The starting point in the correlation of these older drifts with those of my area must be Hutchins brickyard, Snitterfield (Tomlinson 1935, p. 436). This now shows red and green laminated clays (the most spectacular varved lake deposit in the Avon valley) overlying sand, in turn upon a gravel with Bunter pebbles, ironstone, marlstone, oolite and

Lias fossils (Jurassic gravels). In Lucy's time (1872, p. 92) the visible sequence extended higher with $25\frac{1}{2}$ ft. of clays above the sand, and although he regarded certain beds, including the laminated clays, as boulder clay, it is apparent from the description that none qualifies for this description. Dr Tomlinson and I did, however, auger the sequence from the summit of a bank adjacent to the pit and reproved Lucy's succession. We were agreed that there was no ground moraine—nothing above the sand which was not laid down in still water.

Now the Snitterfield outlier as a whole is only separated from Lillington by 5 miles. It occurs just where it should if the Lillington sheet once extended across the site of the Avon. It has exactly the same sequence of a Jurassic gravel (or Lillington gravel) followed by sand and a thick series of lake clays. Coincidence cannot be stretched to the extent that these are not to be correlated. It would have been essential to do this even if the single tooth of *Elephas antiquus** from Snitterfield had been held to conflict with the cold fauna of the Lillington gravels, but as mentioned earlier (p. 220), *E. antiquus* also occurs at Lillington.

Correlating with these sections are those of Welcombe Hill and presumably Oversley Lodge.

From this point my interpretation would differ from Dr Tomlinson's, for I would regard the ridge-cappings of high-level Eastern Drift of Snitterfield Bushes and Gannaway Wood (R_2) and of Tattle Bank to Shrewley (R_1) as being, with the deposits of Snitterfield (R_3), relics of a once-continuous sheet. This was laid down with progressive overlap on the north-west flank of the same ancient valley whose south-east slope was overlapped by the Wolston Series. The highest deposits would be the newest, so that the lake clays of Snitterfield would be overridden by the Eastern ice which laid down Chalky Boulder Clay at Gannaway Wood and then bouldery moraine gravel at Tattle Bank. The original continuity of the deposits of these three ridges is still preserved at Haseley and south of Snitterfield Bushes (Tomlinson 1935, Pl. XXVII).

Put in another way, I believe that the downcutting of the River Alne, and of the Pinley, Inchford and Sherbourne Brooks, keeping pace with the violent post-Eastern Drift erosion of the Avon, led to a preservation of the high level drifts only on the interfluves (R_1, R_2 and R_3) rather than that these mark successive retreats of the ice initiating the above-mentioned streams as marginal drainage channels. This explanation does not preclude the possibility that the peculiar drainage was initiated by halt stages in the shrinkage of the ice-front eastward, so long as the ridge-cappings of Older Drift are not regarded in any sense as glacier-edge moraines.

Dr Tomlinson's Kingswood drift train is acknowledged by her to be appreciably later than the high-level western drift because of the 60 ft. of erosion which intervened between the two deposits, but she equates the former with the main Eastern Drift. To me, perhaps the most striking feature of Dr Tomlinson's map is the clear separation between older drift (as residual cappings) and valley deposits which include the Kingswood train, the low-level Eastern and Western Drifts and the river terraces. The hill tops may be covered by Eastern or Western Drift but not apparently by both, a clear line of separation can be

* Both Dr Sandford and Dr Hopwood have re-examined the Snitterfield tooth, an upper molar, and are agreed that it belongs to *antiquus*.

drawn between the two types of deposit, but as one crosses this line there is no change in the level at which they are found. All this suggests to me that the two types of drift were laid down simultaneously, and that at the maximum advance of the ice the eastern and western glaciers were in contact along a line slightly west of R_1 of Dr Tomlinson's map. It is on this line that we find the moraine gravels of Tattle Bank, and that is why they can contain large boulders of Welsh rocks in addition to flint and Leicestershire igneous rocks (Tomlinson 1935, p. 433). Being contemporary, the high-level Eastern and Western Drifts have suffered the same subsequent erosional history and so occupy the same position on the hill tops. If, however, we equate the two types of high-level drift, there still remain the various valley deposits to be correlated. Dr Tomlinson has five such deposits earlier than No. 2 terrace—low-level Western Drift (e.g. the sands and gravels of Riley's Pit, Temple Balsall), the Kingswood gravel train, local drift terraces, low-level Eastern Drift gravels as at Hatton station, Bearley station and Preston Bagot, and No. 4 terrace from Little Alne south-westward. The first four she equates more or less, but places the fifth as later; and to explain the fact that the Kingswood gravels and low-level Eastern Drift lie on a long profile which seems to grade into No. 4 terrace lower down the River Alne (1935, p. 458, fig. 8, Pl. XXVII, fig. 2), invokes two phases of erosion and aggradation which happened to finish at the same height. I have in my correlation table suggested that these two phases are really one, coinciding with the formation of No. 4 Avon terrace. This is an appreciable change from Dr Tomlinson's conclusions. The low-level Western Drift north of the watershed at Temple Balsall—which maps like a terrace—would also then be equated with No. 4, and the Acheulian hand axe found loose in Riley's pit (Tomlinson 1935, p. 429; Shotton 1937, Pl. V, fig. 2) would be in accord with the other records from this terrace. Dr R. P. Oakley has expressed the opinion that the implement from Riley's pit 'marches with the implements from the Wolvercote channel'. It will be seen, in table 6, that I correlate this channel with part of No. 4 terrace.

These changes are made with some diffidence, for in effect they abolish the Kingswood gap as an overflow channel and explain it as the result of erosion by two opposed streams. On my correlation, the apparent great width of the Kingswood train so near to the watershed is difficult to account for; on Dr Tomlinson's, it is not easy to explain why going upstream No. 4 terrace ceases to be in evidence at the point where the allegedly older trains on the same profile make their appearance. Though I would regard the correlation of the Kingswood train with No. 4 terrace as no more than a working hypothesis, I should continue to equate the 'low-level Western Drift' of Riley's pit, Temple Balsall, with No. 4 even if I were satisfied that the Kingswood drift was an earlier overflow deposit. The cutting of the Kingswood channel by escaping lake water could not coincide with the cutting of the channel containing the gravels of Riley's pit, which lies beneath the site of the postulated lake.

(*e*) *The Moreton Gap*

The culminating deposit of the 'Moreton drift' (Tomlinson 1929; Dines 1928; Richardson 1929) is a boulder clay with flint and Jurassic material representing perhaps an extreme limit of the Great Eastern glacier. No one has hesitated to correlate it with the Great Chalky Boulder Clay to the north-east. Beneath it may be found gravels, sands, stratified loams and stoneless chocolate clays, still part of the Moreton drift but clearly not deposited directly by ice. The loams and clays were manifestly laid down in still ponded water, and of the clays Dr Tomlinson writes (1929, p. 184): 'I think there is very little doubt that we are dealing with the same deposit and that it may have originated in a lake...which appears to have stood at about 400 feet, since this is the height of all known occurrences of the clay.' This lake can hardly be anything but the one which, standing slightly above this height (see p. 247 later), laid down the Wolston clays until they were overridden by the Great Chalky Boulder Clay glacier. Being marginal, the thin clays at Moreton may be equivalent to much thicker formations in the Wolston area.

Beneath the Moreton drift, the Paxford (= Ditchford) gravels made of locally derived Jurassic material and antedating the advent of flint-bearing ice to the neighbourhood, clearly invite correlation with the Baginton-Lillington gravels, though in the absence of fauna no more than a general correspondence can be suggested.

I would agree with Dr Tomlinson, both in placing the Campden Tunnel drift as earlier than the Moreton drift and in considering that their similar states of weathering and contrast with the old plateau drifts makes these two deposits products of the same glaciation. When Gavey (1853, p. 29) described the tunnel section, he listed a series of sands and gravels plus two beds of red clay with marlstone boulders. The latter might be glacial till, though Gavey's description suggests that the large stones could have come from the adjacent Dovers and Ebrington hills, the deposits then probably being the result of solifluxion. In either case the clays would represent a cold climate. Of the Campden tunnel drift, however, 80 % consists of water-deposited sand or gravel, with Bunter pebbles, dolerites and Welsh rocks ascribed to a Welsh glacier. These gravels fill the col between Dovers Hill and Ebrington Hill, which separates the valley of the Knee Brook from the main Avon valley to the north. According to Dr Tomlinson's map, their highest point is 520 ft. O.D., and the floor of the valley filling, according to Gavey's section, descends to something between 400 and 414 ft. O.D. Other occurrences of Campden Tunnel drift to the south-east are lower than in the col, confirming that they derived from the north-west, i.e. from the direction where we should expect the Welsh glacier to be. To bring these sands and gravels from the north-west by ordinary fluvial processes clearly involves the continuation of a valley, always above 414 ft. O.D., north-westward across where the Avon valley now lies at about 100 ft. O.D., and the relics of the Older Drift in the Avon valley are much too low to allow this. The only alternative is the one which Dr Tomlinson suggests, namely, that the Welsh glacier was plastered against Dovers and Ebrington hills and discharging its melt waters into the old Knee Brook valley. Now it will be shown in the subsequent section that, to explain the extensive deposition of lake clays (Wolston clays), it is necessary to postulate the simultaneous existence of a north-eastern glacier and a Welsh glacier, the latter pushing from the west and blocking the old site of the lower Avon. Part of the Tunnel drifts might, therefore, have been laid down at the same time as the Moreton boulder clay, but there is no positive evidence of this. There is clear evidence at Stretton of Welsh ice leaving its effects before the north-eastern glacier appeared, for sands with Welsh erratics (and therefore part at least of the Tunnel drift) are ravined by Paxford gravels which are overlain by stoneless clays. Apparently the Welsh ice was pressing against the Dovers Hill-Ebrington Hill col before the north-eastern ice had advanced far enough to impound a lake.

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(*f*) *The Evenlode and Oxford*

There have been several differing correlations even between the deposits which lie on either side of the Moreton col. Arkell's latest opinion (1947*a*) differs in several respects from that of Dr Tomlinson, and my suggestions offer a third version which is perhaps nearer to the second-named author.

Arkell has correlated the Hanborough terrace with the Paxford gravels, in general because of the lack of flint in each case, indicating pre-Moreton drift age, and in detail by means of a gradient diagram which shows (1947*a*, Pl. 2) three patches of Paxford gravel in the Stour valley continuing the profile made by the Hanborough-Spelsbury-Bledington terrace. While agreeing with his first point, I cannot accept his second conclusion for two reasons:

(*a*) The various patches of Paxford gravel do not seem to be resting on a surface which slopes down towards the Evenlode but rather on an old landscape which falls in the same general direction as the Stour.

(*b*) The profile of the top of the Hanborough terrace crosses the Moreton col at 390 ft. O.D. according to Arkell's diagram; but the gravels 'hanging' on this profile are shown as 30 ft. thick in one of the Paxford patches and 27 ft. at Bledington. There should, therefore, be a gravel-filled channel crossing the Moreton col at a level of about 360 ft. O.D., whereas I can see no sign, from the mapping of either Dr Tomlinson or the Geological Survey, that Pleistocene deposits of any sort cross the col lower than at about 415 ft. O.D. at least.

Though I disagree with the argument, I accept the view that the Hanborough terrace is pre-Moreton drift, a conclusion strongly reinforced by the record of an unworn early Acheulian hand axe (Arkell 1947*b*). The Hanborough terrace may yet prove to be equivalent to the Paxford gravels, though I have preferred to equate the latter with the Snitterfield and Lillington gravels. These certainly are not to be correlated with the Hanborough terrace, for they clearly have a cold fauna and Hanborough has a different and a warm one (Sandford 1924, 1926).

The placing of the terraces from Wolvercote onwards is based on considerations of height, erosion surfaces, fauna and implements. It is doubtless open to argument—as, for example, whether the Wolvercote terrace is directly equivalent to the Moreton drift or somewhat later.

(*g*) *Other British areas and the continent*

Geographical proximity calls for the succession of the Severn Valley to be included in table 6, but I can add nothing to Wills's classic work (1938, 1950). Other areas of great importance to the interpretation of the British Pleistocene—the lower Thames, East Anglia and Lincolnshire to mention but three—have been omitted from consideration. There are sufficient points of dispute and variety of interpretation between those areas, that it would add nothing to force central England into a so-called correlation.

It might therefore seem absurd to discuss the question of correlation with the continent; but a few broad points of principle seem to me to be important. In the Midlands, the glaciation that stands out is the Catuvelaunian (Ca) of Arkell (1943). It left behind the Great Chalky Boulder Clay of Leicestershire, Northamptonshire and east Warwickshire, eventually pushing forward as far as Moreton-in-the-Marsh, while simultaneously Wills's

Second Welsh Glacier jostled with it for position and left equally extensive evidence of its existence in the West Midlands and Severn Valley. There is, however, an earlier Berrocian (Be) glaciation, represented by the lower boulder clay of Northants, the Bubbenhall clay, Wills's First Welsh deposits, and the 'Northern Drift' of the south Midlands, which was just as extensive as its successor, but relics of it are fragmentary compared with those of Ca, partly because of the immensity of the interglacial period which separated the two glacial periods and partly for the very reason that the second glaciation was in a position to obliterate the effects of the first. The products of the Ca glaciation are so extensively preserved because no subsequent ice maximum reached nearly so far south—the Irish Sea (Co) and Welsh Re-advance (Cy) fell short by a hundred miles or so.

These facts are entitled to more than a local significance, for immediately they suggest that the Ca glaciation was the same as the Drenthian of Holland (the only one which leaves in that country major evidence of land ice), the Saale of Germany, and the second of the two larger Alpine glaciations, the Riss. All subsequent cold phases in the Midlands, represented south of Wolverhampton only by periglacial solifluxions and terrace gravels with cold fauna, then become stadia of the Weichsel or Würm. The first Midland glaciation (Be) becomes equivalent to the Elster and Mindel, and up to the present we can find no clear evidence that the less important Gunz cold period left any mark on central England.

This broad correlation would probably now find widespread acceptance—certainly it agrees with views expressed by Zeuner (1945), Wolstedt (1950) and Arkell (1951). Any attempt to place the Ca glaciation one stage further back and to equate it with the Elster poses the problem that nothing of importance remains in the Midlands to represent the Saale and Drenthian, apparently the greatest glaciation of the continent. Support for equating the Wolston Clays and Chalky Boulder Clay with the Saale, however, is given by the Baginton-Lillington gravels (which would then be early-Saale) and which include abundant *Elephas primigenius*. According to Zeuner (1945, p. 264) this is not recorded before Saale times. Similarly, Van der Vlerk (1953, pp. 41, 43) credits the first appearance of the mammoth to the Drenthian.

6. The broader implications of the present work

(*a*) *Glacial Lake Harrison*

It has been shown that the Wolston Series consists very largely of clay which is mainly stoneless or contains only rare pebbles, is sometimes laminated, and can only be explained as a sediment of still water. Its extent even within the area I have mapped in detail would require a lake several miles across. A fresh-water lake is assumed, for the alternative of a marine submergence is contrary to the complete lack of marine evidence anywhere in the Midlands and to the interpretation of the underlying Baginton-Lillington gravels as land stream deposits. Indeed, a submergence of 400 ft. as late as Saale (Riss) time would outrage all the conclusions of the many workers on the British Pleistocene.

It must be apparent, however, from what I have already written, that the Wolston Series of my mapping is only a small part of the original extent of these lake deposits. Going southwards we may still note, despite the great loss of evidence caused by the Avon's erosion, the laminated clays and stoneless clays of Snitterfield, Welcombe and perhaps Oversley Lodge (Tomlinson 1935, pp. 435–5) and the lake clays of the Moreton area (Tomlinson 1929, p. 184). Going northward, the evidence is much more extensively preserved. The laminated clays in Coventry have already been mentioned (p. 223). At Bedworth (Eastwood *et al.* 1923, p. 118) varved clays have been described and recognized as lake deposits, though no inference was drawn from the fact that they lie exactly on the present-day watershed between the Humber and Severn drainage. All over the eastern half of Sheet 169, in the neighbourhood of Hinckley, Ullesthorpe, Monks Kirby and Brinklow, there is a continuous cover of drift, known to extend very deep, and showing at the surface a division into two clay series separated by a persistent sand and gravel horizon. Though shown on the map under the general symbol of boulder clay, the descriptions in the memoir and even more so the manuscript notes on the original 'six-inch' field maps which I have examined in the offices of the Geological Survey, indicate that the lower clay is consistently stoneless or nearly so and the upper clay sometimes similar—though it may include also true till. Deeper evidence can only be provided by boreholes, but figure 5, which shows some of the more important ones, indicates the dominance of lake deposits.

Still farther north, in Sheets 155 (Atherstone) and 156 (Leicester), not only are lake clays abundantly developed in the Older Drift, but Fox-Strangways recognized this in many places by mapping them as brick-earths and showing them under a separate colour.

There thus can be built up a picture of a lake, belonging to the time of the Chalky Boulder Clay glaciation, extending from a few miles north of Leicester and Market Bosworth down at least to Moreton-in-the-Marsh, a length of 56 miles.

Before discussing this lake further, it is desirable to give to it a name. Fifty-five years ago, W. Jerome Harrison, a pioneer figure in Midland glaciology, wrote a paper (1898) in which he recognized the importance of the convergence of great glaciers from the north-west and north-east upon the central counties and postulated that they had ponded up a lake in Leicestershire. His type locality for the deposits was Hinckley and he proposed the name of *Lake Bosworth* (after Bosworth Field), though with no attempt to define its geographical limits. Curiously enough, Fox-Strangways, who described lake-deposited brickearths at Market Bosworth in 1900, and equally clear sediments of still-water origin near Leicester in 1903, seems to have been unaware of Harrison's suggestion. The only subsequent reference I can find is in the Coventry memoir (Eastwood *et al.* 1923, p. 118), where Eastwood, referring to laminated clays at Little Bayton brickworks near Bedworth, writes: 'The frequent transitions from clay to loam and sand, together with the bedded character of the drifts here, coupled with the occurrence of laminated clays, all point to deposition in water rather than to a moraine, and the Lake Bosworth of W. Jerome Harrison may have extended to the neighbourhood of Bedworth.'

It seems undesirable to use the name 'Bosworth' for the lake which contained the Wolston clays. Harrison clearly visualized a ponding against the north side of the watershed between the Avon and Trent systems, but the deposits of Coventry, Wolston, Snitterfield, Welcombe and Moreton are south of the watershed. The most far-reaching implication of the lake is its complete independence of the present river system and topography, and any place-name which refers to one side or other of the watershed could be misleading. I therefore propose the name of *Lake Harrison*. In doing so, I am putting a less well-known geologist in the distinguished company of Agassiz and Lapworth, but a prophet need not be without honour in his own country.

To give precision to Lake Harrison, we need to know as much as possible about two series of facts—the height or heights of its surface and the shape of its floor.

(*b*) *The height of Lake Harrison*

The surface of a lake is the highest level to which its own under-water deposits can reach. If, therefore, we leave out of consideration such formations as the Dunsmore gravel which might have been spread out on dry ground, or till which is largely independent of height, there remain such beds as the Wolston sand which quite probably was a deposit of shallow water and the stoneless clays and related beds of the Wolston Series which were certainly accumulated in the lake. Material laid down in the centre of the lake may never have reached to the top water level, while, in addition, such central deposits are likely to have been thicker than those on the margin and hence will have suffered more subsequent compaction. For both these reasons, the present height of such beds will fall short of lake level but, by similar reasoning, the marginal deposits are likely to be nearly coincident with the old water level. Where lake deposits are covered by boulder clay, some of the former may have been removed.

Applying these criteria to Moreton-in-the-Marsh, where the lake clays described by Dr Tomlinson (1929, p. 184) are thin and obviously marginal, the highest level I can assign to them is 404 ft. O.D. Near Dunchurch, the Upper Wolston clay can be seen at Thurlaston, just before it dies out under the overlapping Dunsmore gravel at about 370 ft. O.D. Still farther north, east of the Warwickshire coalfield, lake deposits are proved in a number of boreholes, of which the most significant are shown in figure 5. The maximum height of clays, silts or sands which can reasonably be ascribed to lake deposition, omitting all question of boulder clay, is 389 ft. at Lutterworth, 390 ft. at Sibson and 398 ft. at Hinckley. It seems justifiable to assume a level of just over 400 ft. for the lake, and I shall henceforth use the figure of 410 ft. without further argument. It is not yet possible to discuss what lower positions, if any, were standing levels at stages below the maximum. Furthermore, though the clays of Moreton and silts of Sibson are 45 miles apart, there is only a difference of 14 ft. in their level; between the former and the sands of the Hinkley Bond Street boring, there is only a difference of 6 ft. in 40 miles. Even these small figures could be lessened if an allowance were made for compaction, so it is justifiable to assume that there has been no tilting in a north-north-east–south-south-west direction since Chalky Boulder Clay times. In the direction at right angles there is not enough evidence to draw a safe conclusion. On the west side of the lake at Claverdon (Tomlinson 1935, p. 433), silts and laminated clays occur up to just over 400 ft., but as they overlie the moraine gravel which marks the westernmost extent of the eastern ice, they might be the result of a local ponding by this and the western ice on their retreats and be independent of the level of Lake Harrison.

A remarkable independent confirmation of this height close to 410 ft. has been furnished by Dury (1951). Working on geomorphological lines and in ignorance of my research farther north, he mapped for 35 miles from Ebrington Hill, round the Moreton gap and along the Jurassic escarpment of Edge Hill and Burton Dassett, a bench which he interpreted as the erosional feature at the edge of a lake. Its level is 410 ft., and Dury dated it to Chalky Boulder Clay times. Over a north-east–south-west distance of 27 miles it appears to remain horizontal. I suggested in the discussion to his paper that until the ground had been geologically mapped, it might be difficult to separate erosion benches from residual patches of lake deposits, but this criticism does not in any way weaken his case. The correspondence of his conclusions and mine is striking, though the methods of approach differ.

(c) *The floor of Lake Harrison*

The lake deposits which are so well developed in east Warwickshire and west Leicestershire are crossed by the main English watershed which is below the 400 ft. contour in places, i.e. lower than the level of Lake Harrison. Even more significant, however, is the fact that borings east of the Warwickshire coalfield have proved over 200 ft. of drift (cf. figure 5, No. 3). It is obvious that the present-day watershed lies across the site of a great pre-glacial hollow, and that the topography which assisted in the formation of Lake Harrison must have been radically different from that of to-day.

Figure 11, is an attempt to reconstruct the topography of the Midlands immediately before the period of the Second Welsh and Great Eastern glaciation. It is based solely on several thousands of points where the level of the bottom of the older drifts can be determined exactly or by estimation from maps. No account has been taken of present-day topography nor of low-level valley deposits which clearly belong to a later erosional cycle than the older drifts. To obtain information, I have used all the published maps and memoirs and the six-inch field maps of the Geological Survey, the well records of that organization, private papers, in particular those of Dr Tomlinson, and my own mapping and augering. Professor Wills has generously placed unpublished information in the Clent and Alcester districts at my disposal, and Mr D. L. F. Gilbert has done reconnaissance mapping of the blank area between the south edge of the Birmingham sheet and the area of Dr Tomlinson's 1929 paper. In some places, observations on the height of solid formations have been useful in giving minimum levels for the pre-glacial surface.

The map purports to show the base of the Older Drift. No doubt in some places it records the base of deposits of the first Midland glaciation, but these are so insignificantly preserved compared with the relics of the Second Welsh and Great Eastern episodes, that for all practical purposes it is a reconstruction of the country as it appeared when Lake Harrison was about to be impounded, or at least immediately prior to the deposition of the Baginton-Lillington gravels and their equivalents.

The great feature which stands out on this map is the existence of a major valley leading from the Soar at Leicester in a south-south-western direction across the main watershed into the Avon country and towards Bredon Hill. This valley is a natural feature whose continuity is now interrupted by the thick filling of drift which still remains north-east of Coventry—it is the strike vale of the Upper Keuper marl, bounded on the south-east by the various hard beds of the Jurassic from the White Lias upwards, and on the north-west by Charnwood Forest, the Warwickshire coalfield and the Arden Sandstone country.

The slope of this valley, at least from Warwick to Leicester, is clearly down towards Leicester. There are no Older Drift deposits below 240 ft. anywhere in the Warwick district, yet various boreholes in the great plug of drift east of the Warwickshire coalfield prove the base of the Pleistocene at 220* and 215 ft. O.D., problematically at 205 ft., and in three cases it was not reached at 215, 230 and 240 ft. O.D. Most of these bores are unlikely to be exactly in the trough of the old valley. These figures prepare the way for the reappearance of the base of the older drift in the sides of the Soar valley near Leicester around the 200 ft. contour.

The evidence of lack of tilting of the deposits and bench of Lake Harrison (in a south-south-west–north-north-east direction) means that this wide preglacial valley had the same slope then as it has now. It is extremely gentle—a matter of about 40 ft. in 25 miles. Nor does it steepen appreciably when traced to the south-west. In the neighbourhood of the Ridgeway and Church Lench, there are enough relics to fix the 350 and 300 ft. contours on the north-west side of the valley and show that the valley bottom was lower than 300 ft. It is not possible to find evidence for the 300 ft. contour on the other side of the valley, but the present-day 400 ft. contour on the solid of Bredon Hill helps to fix its probable position. The valley bottom might therefore have been as high as 290 ft. here, but even this only entails a drop of 50 ft. from Bredon to Warwick. Our modern British rivers, such as the Severn and Thames, have this order of gradient between the 25 and 75 ft. contours.

The probability is that this old valley, though it had the shape I have shown at the time of the Riss glaciation, is the beheaded relic of a much more ancient drainage system.

(*d*) *The recent origin of the Avon drainage*

One of the most striking conclusions which follows from what has been written above is that virtually the whole of the Warwickshire Avon river system is of comparatively recent origin. The catchment of the river now makes a great embayment in the north-south line of the main English watershed and has always been accepted as a classic case of river-capture on a large scale. Davis (1895) and Buckman (1899) pictured the Avon cutting back and intersecting rivers which hitherto had flowed from the south Pennines and north Wales into the Thames. Wills (1950, p. 101), elaborating the same theme, regarded the middle Severn as having once been a relatively small tributary of a large lower Severn-Warwickshire Avon river. All writers have assumed that the establishment of the Avon basin was an event of some geological antiquity, certainly pre-Pleistocene and antedating all stages of glaciation. Radically different views must now be held if my conclusions are sound. Accepting the pre-glacial valley beneath Lake Harrison as rising to the south-west, to a col between Bredon Hill and Church Lench, the following conclusions may be made:

(*a*) At the onset of the Catuvelaunian glaciation, the middle Severn was an important river which had, however, no Avon tributary except possibly the ancestor of a small length near Tewkesbury.

(*b*) At this time, the Worcestershire and Warwickshire Midlands drained to the Trent system.

* This is the Cloudesley Farm boring at 458858 (Richardson 1928, p. 42). The base of the drift would be at 239 ft. O.D. according to this record, but I think the surface height of the boring is over-assessed. No personal judgement of this kind enters into the other figures.

(*c*) The main watershed between the Trent and the Severn, coming southward from the Clent Hills, continued without change of direction through the Ridgeway, Church Lench, Bredon Hill and so to the main Cotswold scarp behind Cheltenham.

(*d*) The Jurassic escarpment along the line of Cleeve Common, Moreton, Brailes Hill, Edge Hill and Daventry was then, as now, the watershed of the Thames system, though separating it from country draining to the Trent.

(*e*) The whole of the Avon system upstream from Bredon was developed after the maximum of the Catuvelaunian glaciation.

(*f*) This drainage system was completed in its pattern, though not at its present level, by the period preceding the aggradation of terraces 3 and 4.

It seems advisable here to resist the temptation to theorize about the bearing of these ideas upon the question of still more ancient drainage lines, and to revert to Lake Harrison.

(*e*) *The impounding of Lake Harrison, and its generalized history*

As a glacier pushed forward from the north, it would reach a position where it blocked the ground between the Jurassic escarpment and Charnwood Forest, at which stage it would impound a lake in the ancient valley described above. It was such a lake which Harrison visualized and named Lake Bosworth; but the Lake Harrison which I picture had a water surface as high as 410 ft. O.D. and therefore came as far south as Moreton and the neighbourhood of the Ridgeway (figure 6). Clearly this lake could not have held water at this height if the col below 300 ft. between Bredon Hill and Church Lench remained open. As an alternative to maintaining that the pre-glacial valley extended another 50 miles or more to the south-west, until its valley bottom rose higher than 410 ft. —a postulate which cannot seriously be put forward—it is necessary to invoke the presence of the Second Welsh Glacier in the Severn and Worcestershire Stour valleys, forming a wall from the Clents to the Cotswold scarp. The simultaneous existence of ice dams at both ends of the ancient valley is essential if it is to hold water.

To retain water up to a level of 410 ft., however, certain other outlets must be blocked. Ice must have covered the low ground around Kibworth Harcourt (M.R. 6897), while on the other side of the valley pre-glacial cols at Snarestone (3508) and Caldecote (3596) cannot have functioned as overflows. As soon as ice is pictured in a position to prevent this, it becomes obvious that the Tame valley might also be blocked; indeed one can deduce that it must have been, since at Meer End (2474) a col exists on the pre-glacial surface, separating the head of the Tame valley from the proto-Avon, at a height of about 380 ft. O.D. and water could not stand at 410 ft. O.D. to the south-east of this unless it also stood at the same level in the Tame valley.

Since it has not been possible to demonstrate that no post-glacial tilting of Lake Harrison occurred in a direction from south-east to north-west, it could be argued that this last col might have been higher when the lake was in existence. To make it act as a water barrier independent of the Tame valley would entail a post-glacial subsidence relative to the east side of the lake of at least 30 ft. Not only does this amount seem unlikely, but its direction seems even more improbable. The great powers of down-cutting which the Avon subsequently developed might be correlated with some behaviour of the Severn—stimulated, for example, by an uplift of land in the west relative to the east—but it is difficult to believe that this erosional activity could coincide with relative subsidence to the west. For this reason, therefore, I believe that the col at Meer End did act as a connexion between the main Lake Harrison and a Tame valley branch. In figure 6 I have attempted a reconstruction of the lake at somewhere near its greatest possible extent, though the lines of the

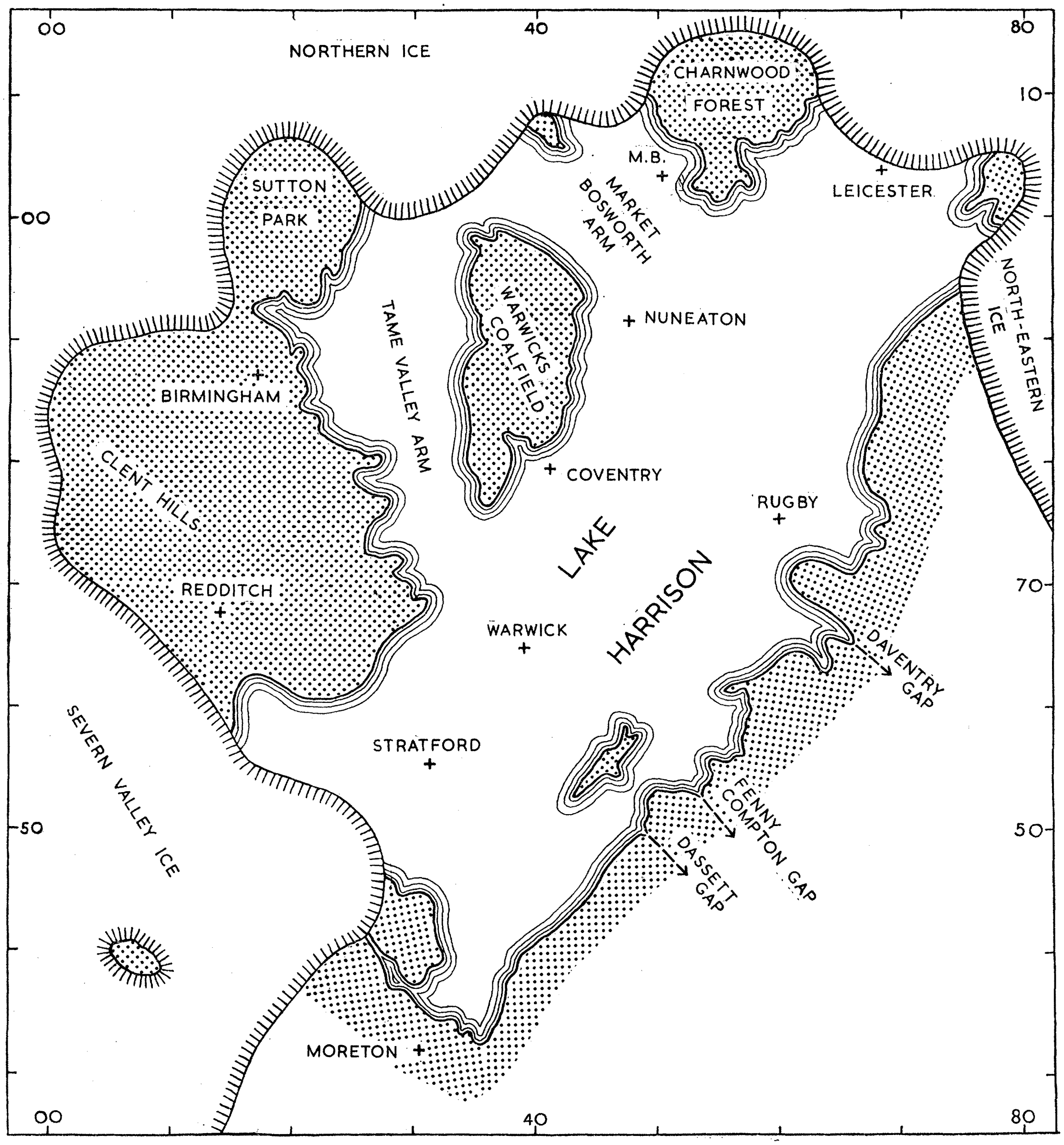


FIGURE 6. Possible appearance of Lake Harrison near to its maximum extent. (The map is marked in 10 km units of the national grid.)

various ice fronts must not be taken to be either precise, or strictly contemporaneous in the positions shown.*

The possible outflows of Lake Harrison are several, for there are at least three cols across the Jurassic scarp on the south-east side of the lake which have a level at least within a few

* The Tame Valley arm is based upon the probable position of the 410 ft. pre-glacial contour. Upon this surface in the ancestral Tame valley, thick gravels had been deposited before ice dammed the lake. The rise in the level of the land due to these would make the Tame Valley arm of Lake Harrison narrower than I have shown.

feet of 410 ft. O.D. In order from north to south they are the Daventry, Fenny Compton and Dassett gaps, marked on figures 6 and 7. The mapping of the Geological Survey in Sheet 185 may answer the question as to whether the first operated; and Dury (1951, p. 169) has suggested that the Fenny Compton gap may have let the waters escape into the Cherwell valley. Until these various areas have been geologically surveyed with the idea of Lake Harrison as a possible explanation of their deposits, it is not possible to select one of them as the controlling outflow of the lake. There is, of course, no intrinsic reason why only one should have operated.

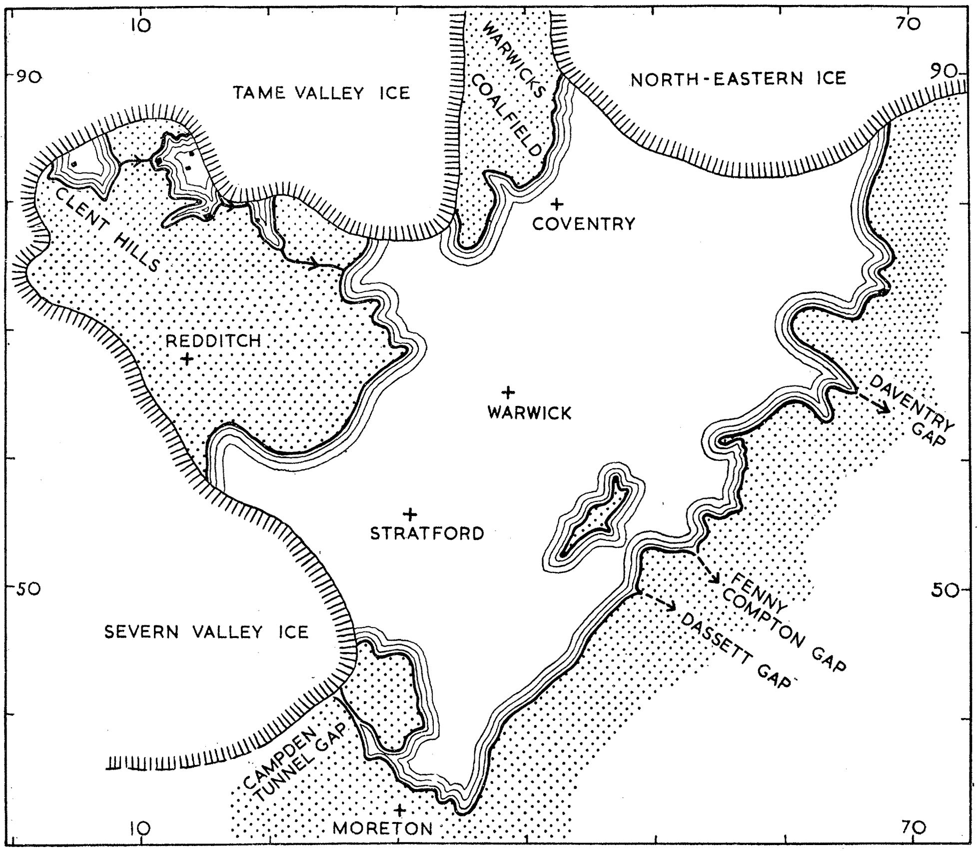


FIGURE 7. Possible appearance of Lake Harrison at an intermediate stage in the advance of ice over the lake site. (The map is marked in 10 km units of the national grid.)

There is a further possibility to be considered. It has been pointed out (p. 243) that the solid foundation to the Campden Tunnel Drift in the col between Dover's and Ebrington Hills has a level of somewhere between 400 and 414 ft. O.D. according to Gavey's section (1853, p. 29). Consideration must therefore be given to the possibility that it too could have functioned as an overflow, with water then getting away southward along the margin of the ice which pressed against Dover's Hill. The facts discussed on p. 243, which indicate that Stretton sand with Welsh erratics was being deposited before Lake Harrison was impounded, suggest that the Welsh ice was blocking the col with its own detritus before there was any lake to escape, and raising the level of the gap to such a point that subsequent overflow would be impossible.

The subdrift contours of the Moreton gap cannot be drawn with precision, but it seems impossible to make them sufficiently low for Lake Harrison to escape down the Evenlode.

At a very late stage, however, when eastern ice was depositing the Moreton drift and the Campden Tunnel gap was blocked with clays and gravels, there must have been a phase when ponding occurred between Ebrington and Brailes Hills at a slightly higher level, with the Moreton gap acting as overflow.

After Lake Harrison had been initiated, the northern glacier continued to advance up the old valley. On the north-west side of the latter lay the successive igneous outcrops of Mount Sorrell granite, Groby markfieldite, Enderby, Croft and Sapcote monzonites, ready to be plucked by the glacier and to contribute the distinctive boulders of Leicestershire rock which dropped from bergs into the lake clays. Fairly early on the ice must have reached as far south as Croft, for I have found erratics from here no more than 3 ft. above the onset of the lake deposits. The glacier which first blocked the valley was a northern one, carrying many Bunter pebbles. It cannot be described as either Welsh or Lake District, though I have found two boulders of dolerite in the lowest 4 ft. of Wolston clay at Ryton (M.R. 385736), which are more suggestive of one of these sources of origin than of any other. Gradually, however, the north-eastern glacier gained in power and displaced the northern ice westward, so that the ice-front which moved up the valley calved off bergs with an ever-increasing content of Cretaceous material (see pebble analysis figures, p. 225). Ultimately it was a glacier with a full Chalky Boulder Clay ground moraine which spread over the lake deposits to Claverdon in the west and Moreton in the south.

There is ample evidence that the history of Lake Harrison was complex. The advance of the ice over the Wolston clays was not uninterrupted, and there seem to have been at least three such advances separated by retreats. Evidence for the first oscillation is provided by the Wolston sand, whose distribution is shown in figure 8. It was laid down on an undulating surface of clay which had by no means grown up to lake level over the old valley near Leicester, nor south of Coventry, but which south of Charnwood Forest was nearly up to the water's surface. By this stage the ice must have advanced at least as far south as Croft, because of the boulders from there in the Lower Wolston clays, yet the later Wolston sand (and gravels of the same age around Hinckley), obviously water deposited, extend back to the Leicester area. This means a glacial retreat, and the very fact that clay gives place to sand and gravel is further evidence of much increased summer melting.

This first advance presumably halted some way north of the southern limit of the Wolston sand (figure 8). Yet an auger traverse on Radford Semele hill (M.R. 351643 and just south of the edge of figure 9) showed two layers of typical Chalky Boulder Clay interbedded with stoneless plastic clays (see figure 10). Unless one of these is a very large raft, which is unlikely, two more ice oscillations are called for, making three in all, though the second seems to have left no outwash gravel on its retreat.

An anomalous feature which is not easy to explain is that over the area which I have mapped in detail (figure 9) there is a strong development of Dunsmore gravels which are interpreted as outwash of the north-eastern glacier on its final retreat, but except in the Rugby neighbourhood there is no real development of till beneath the gravels; yet north, south and west of the Dunsmore area, as well as to the east, ground moraine is present. I can only suggest that late-stage melting was at a maximum in the Dunsmore area and that pre-existing till may have been eroded and redistributed.

Though the north-eastern ice grew in power relative to that from the west, its advance from the Charnwood Forest latitude to Moreton must almost certainly have been accompanied by similar movements of the western ice. If the Tame Valley glacier pushed far enough south, it would press against the north face of the Clent hills and could be expected

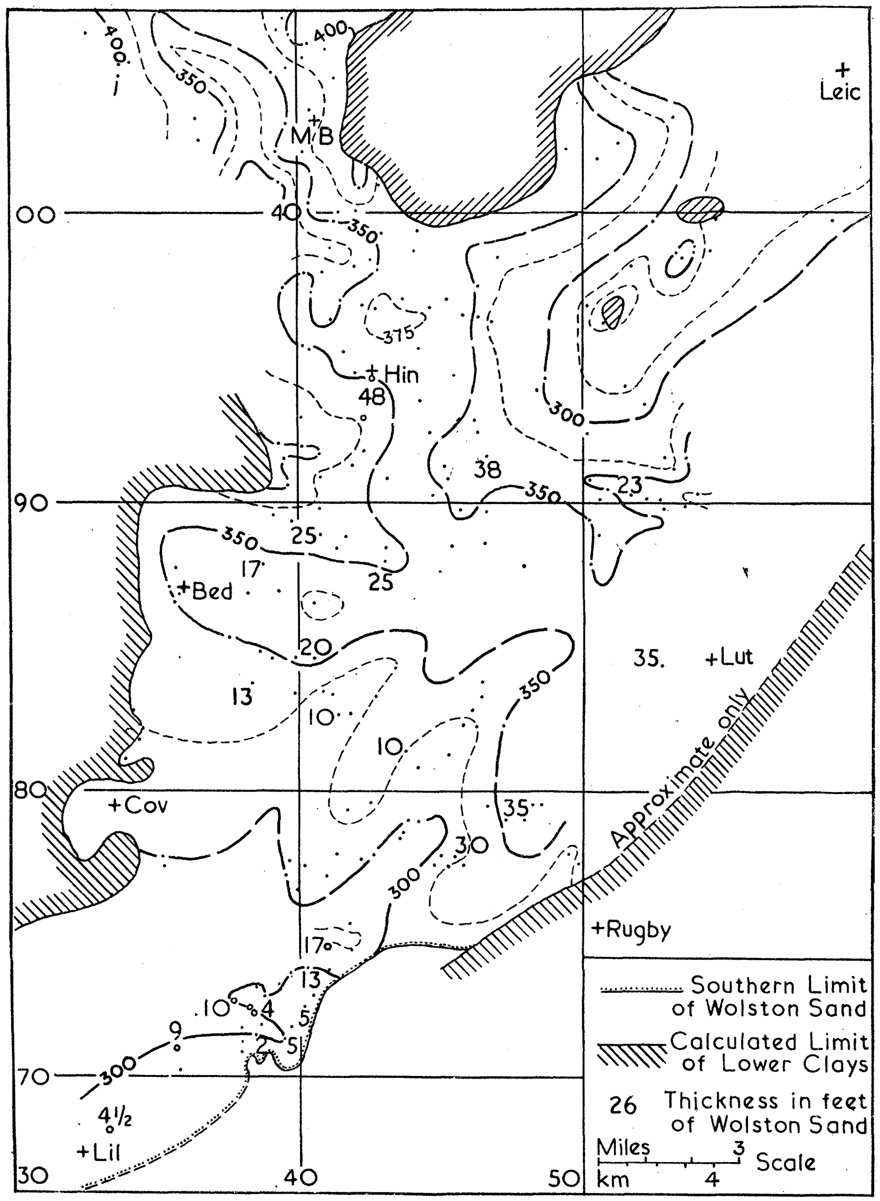
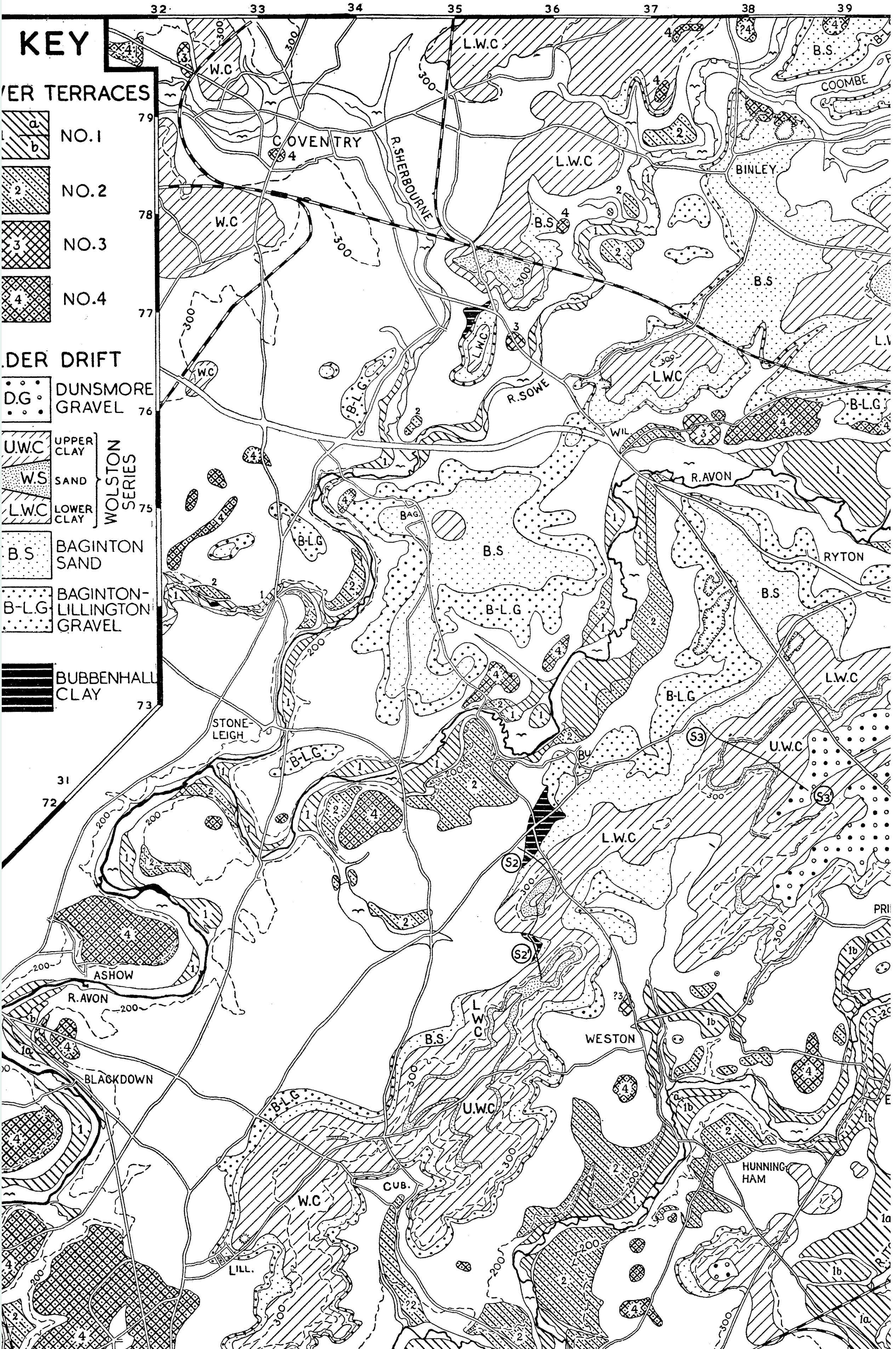
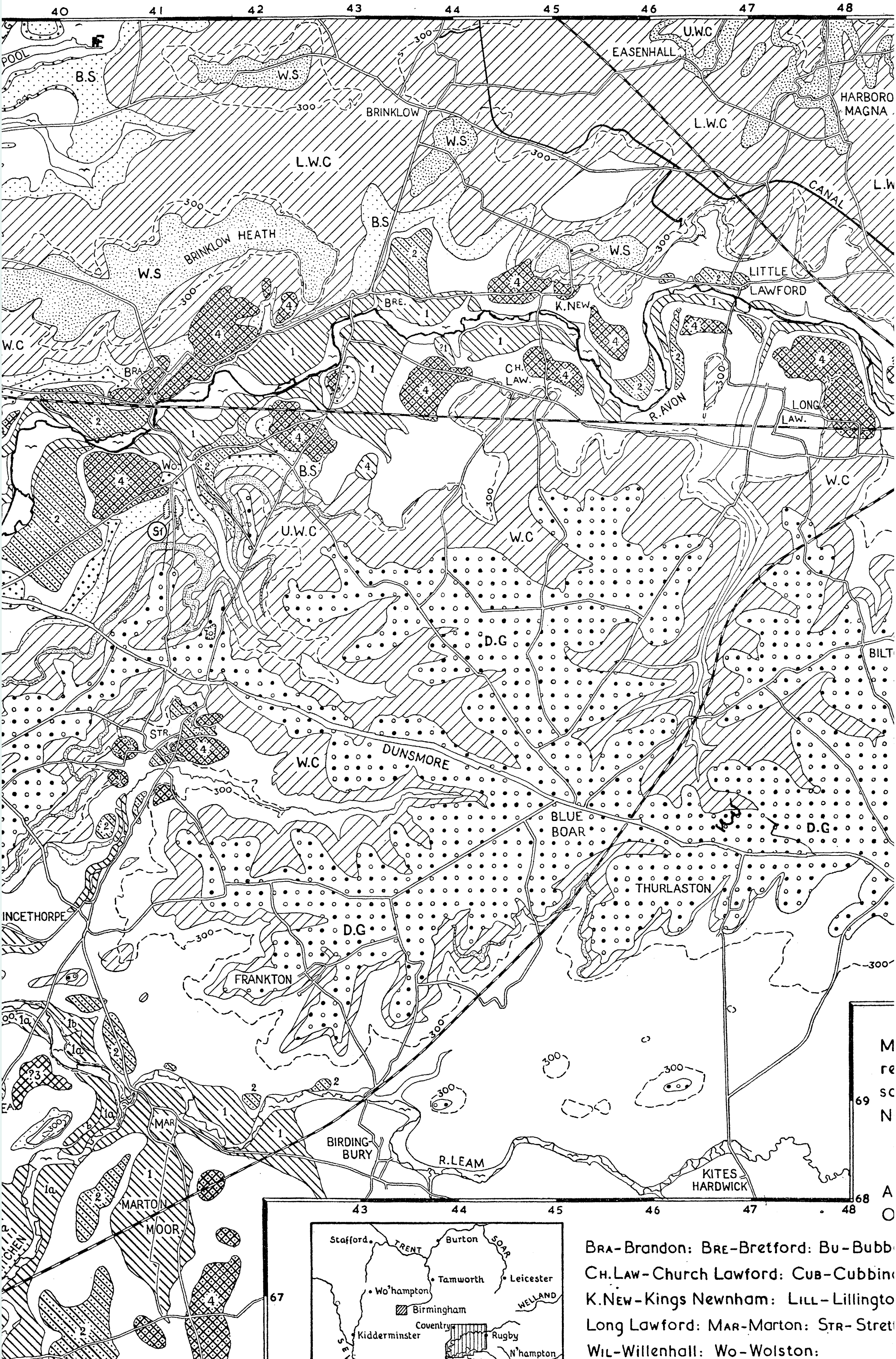


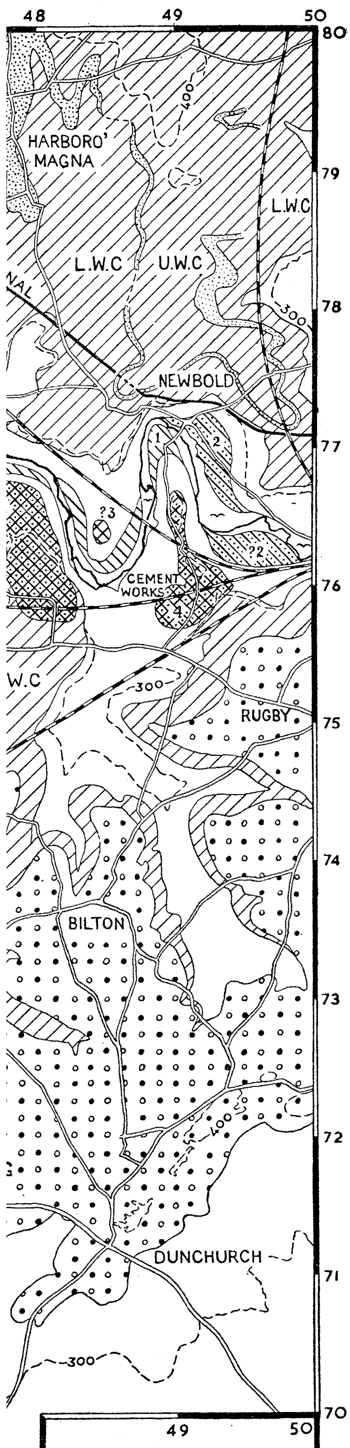
FIGURE 8. Contours (feet above present sea level) of the plane separating the Wolston sand from the underlying clays. Bed = Bedworth; Cov = Coventry; Hin = Hinckley; Leic = Leicester; Lil = Lillington; Lut = Lutterworth; M.B. = Market Bosworth.

to impound a series of marginal lakes, above the level of Lake Harrison and, as study of the subdrift contours of figure 11, indicates, draining into it by a series of eastward-flowing channels. Figure 7 is a tentative reconstruction of this situation, a phase in Lake Harrison's history intermediate between the initiation stage of figure 6 and the final obliteration by the advance of ice to Moreton.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES


KEY
VER TERRACES
a b NO.1
NO.2
NO.3
NO.4
DER DRIFT
D.G DUNSMORE GRAVEL
U.W.C UPPER CLAY
W.S SAND
L.W.C LOWER CLAY
WOLSTON SERIES
B.S BAGINTON SAND
B-L.G BAGINTON-LILLINGTON GRAVEL
BUBBENHALL CLAY
32
33
34
35
36
37
38
39
79
78
77
76
75
73
31
72
COVENTRY
R.SHERBOURNE
BINLEY
COOMBE
R.SOWE
WIL
R.AVON
BAG
RYTON
STONE-LEIGH
BU
ASHOW
R.AVON
BLACKDOWN
WESTON
HUNNING-HAM
CUB.
LILL.


40 41 42 43 44 45 46 47 48
POOL
B.S
W.S
U.W.C
EASENHALL
HARBOROUGH MAGNA
BRINKLOW
L.W.C
CANAL
BRINKLOW HEATH
LITTLE LAWFORD
BRE.
K.NEW
BRA
CH. LAW.
R. AVON
LONG LAW.
WO
ST
W.C
D.G
BILT
STR.
DUNSMORE
BLUE BOAR
THURLASTON
INCETHORPE
FRANKTON
MAR
BIRDING-BURY
R.LEAM
KITES HARDWICK
MARTON
MOOR
300
69
68
67
Stafford
TRENT
Burton
SOAR
Tamworth
Leicester
Wo'hampton
Birmingham
WELLAND
Coventry
Rugby
Kidderminster
N'hampton
BRA-Brandon: BRE-Bretford: BU-Bubb
CH.LAW-Church Lawford: CUB-Cubbin
K.NEW-Kings Newnham: LILL-Lillingto
Long Lawford: MAR-Marton: STR-Strett
WIL-Willenhall: WO-Wolston:



Marginal numbers refer to kilometre squares of the National Grid

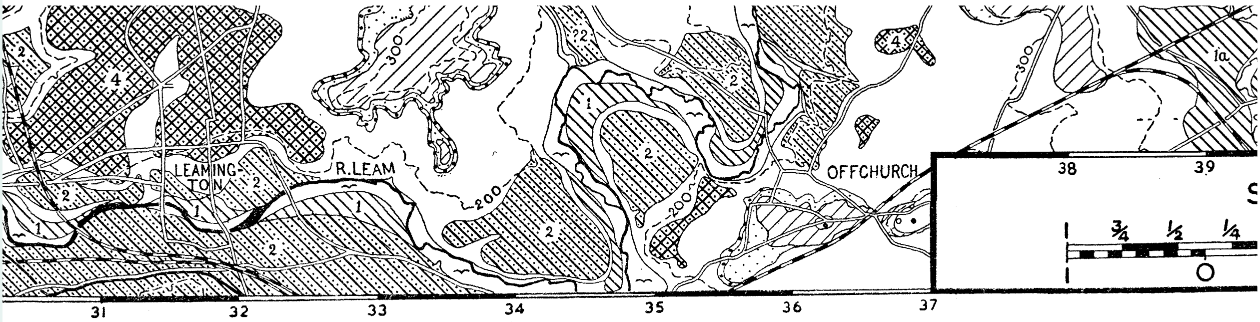
ABBREVIATIONS OF PLACE NAMES

Bu - Bubbenhall:

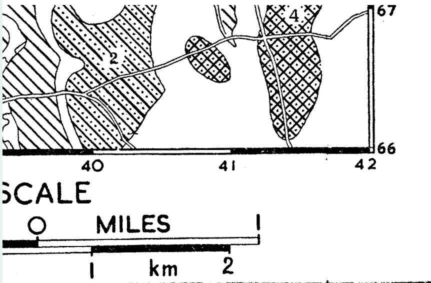
-Cubbington:

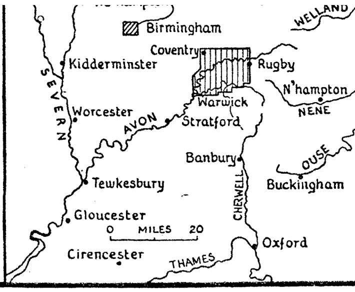
-Lillington: Long Law-

Str- Stretton-on-Dunsmore:



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES





K.New-Kings Newnham: Lill-Lillingto
Long Lawford: Mar-Marton: Str-Strett
Wil-Willenhall: Wo-Wolston:

THE SUPERFICIAL D
BETWEEN COV
LEAMINGTON AND

Figure 9

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

- Lillington: LONG LAW-
STR - Stretton-on-Dunsmore:

AL DEPOSITS
COVENTRY,
AND RUGBY

(*Facing p.* 254)

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

I have been cautious in showing only three such marginal lakes, though I believe that future work will show a chain all round the Clents. The three indicated would have levels, from west to east, of approximately 570, 510 and 460 ft. O.D. All are known to contain lake deposits. From the most westerly one, Birmingham University Geological Department has samples of laminated clays with leaf impressions collected by Dr F. Raw in Wasselgrove Dingle. The middle lake is well documented by stoneless plastic clays at California, Harborne, King's Norton and Walker's Heath (Eastwood 1925, pp. 113–117; Wills 1950, p. 118) and varved clay not previously recorded from the site of the Queen Elizabeth Hospital at Metchley. From the lowest lake, stoneless clays are known at Maypole (Eastwood 1925, p. 117). All these occurrences are indicated by black patches on figure 7. Intensive work with an auger is necessary to work out the full extent of this chain of lakes, but the general principle of their existence is established.

(*f*) *The development of the Avon and associated drainage changes*

When the Catuvelaunian ice commenced to dwindle away, there was no Warwickshire Avon river system, only a mass of new deposits from the Baginton-Lillington gravels to the Dunsmore gravels and Chalky Boulder Clay, filling the old Bredon-Soar valley to a more or less level plain. The edge of these deposits near Bredon Hill must have been in the nature of an ice-contact slope—a steep wall with 120 ft. or so of soft drift overlying Keuper marl. As soon as the recession of the Severn ice allowed, it became a target for rapid erosion, particularly since water from the melting north-eastern ice could now escape this way. Thus was started a primitive Avon which cut back its head with amazing rapidity. It is possible that some added vigour of the River Severn assisted the Avon's cutting back, but it may not be necessary to invoke any explanation besides the combination of an ice contact wall with deposits still only partly consolidated.

We may picture a pause in the shrinkage of the north-eastern ice lobe, with a halt stage somewhere north of Stratford-on-Avon. At this time the backward erosion of the Avon gave place to an aggradation and No. 5 terrace was deposited. Dr Tomlinson (1935, p. 453) had such an explanation for the restriction of Avon No. 5 terrace to the river's course below Stratford, though I think it is necessary to believe that the valley filled by No. 5 gravels extended back some miles north of that town. At Stratford, the base of these gravels could only be at about 250 ft. above Ordnance Datum, and as most certainly the deposits of Lake Harrison stood much higher than this, considerable erosion at Stratford is implied. Assuming that Lake Harrison were filled in its central part with sediments up to about 350 ft. O.D., it is necessary to extrapolate the long profile of the base of No. 5 back to beyond Warwick before it rises to this height. I would therefore suggest that the ice-front whose melt waters deposited the gravels of No. 5 lay north of Warwick. Over the 12 miles or so of valley between this point and Welford Hill, south of Stratford, later erosion appears to have removed No. 5 terrace entirely—unless the two patches shown as local drift at Bishop's Tachbrook and Ashorne (Tomlinson 1935, Pl. XXVII) are relics of it.

As the ice retreat redeveloped, so erosion again got under way. It has been shown that Avon No. 4 terrace can be traced at least up to Rugby, and along the tributaries of the Leam, Itchen, Sowe and Sherbourne. No. 3, though less often recognized, goes almost as far. It follows that by the time the aggradation of No. 3 gravels was about to commence

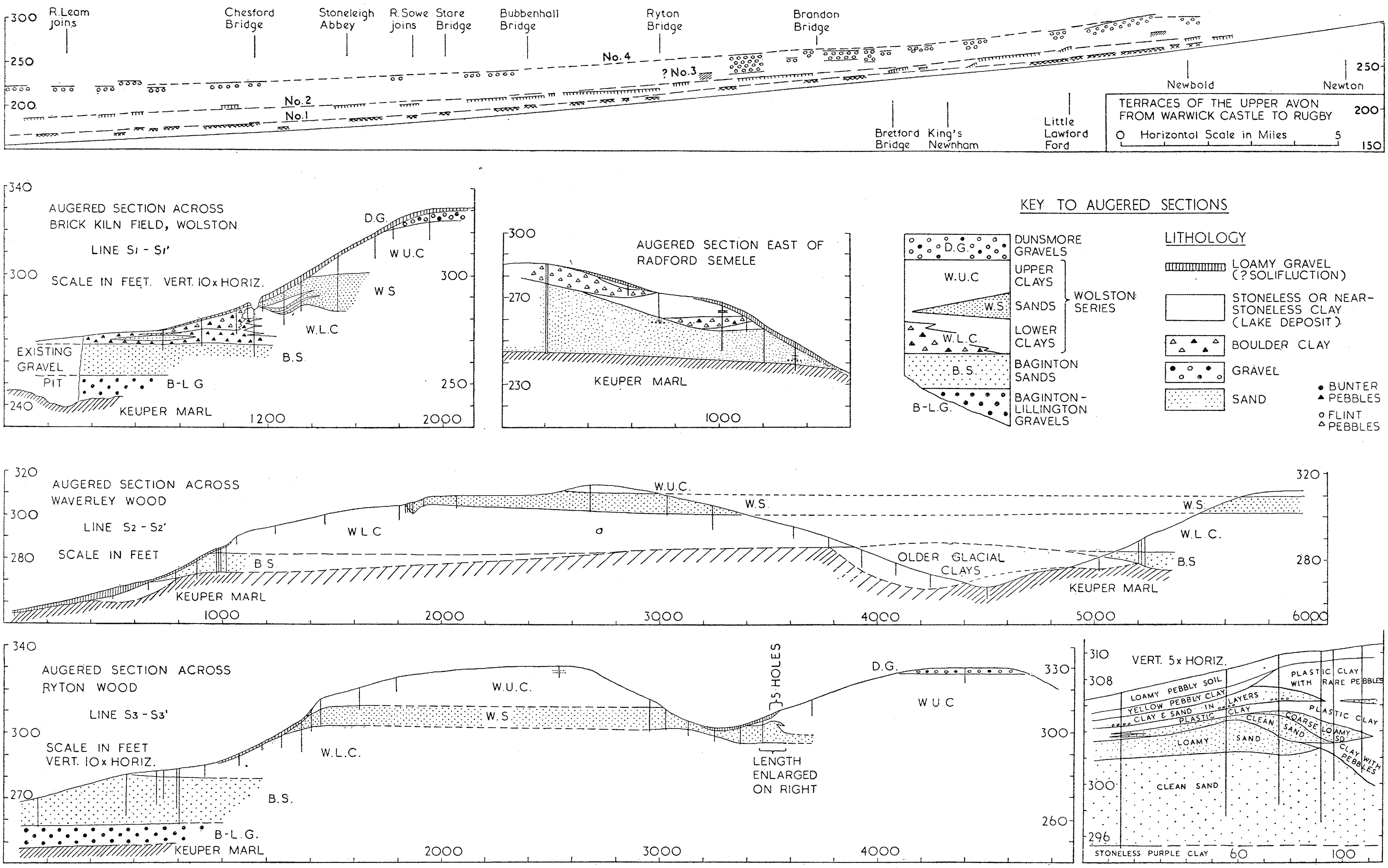

R.Leam joins
Chesford Bridge
Stoneleigh Abbey
R.Sowe joins
Stare Bridge
Bubbenhall Bridge
Ryton Bridge
Brandon Bridge
No.4
? No.3
No.2
No.1
Bretford Bridge
King's Newnham
Little Lawford Ford
Newbold
Newton
TERRACES OF THE UPPER AVON FROM WARWICK CASTLE TO RUGBY
0 Horizontal Scale in Miles 5
AUGERED SECTION ACROSS BRICK KILN FIELD, WOLSTON
LINE S1 - S1'
SCALE IN FEET. VERT. 10x HORIZ.
D.G.
W U.C
W S
W.L.C
B.S.
EXISTING GRAVEL PIT
B-L G
KEUPER MARL
AUGERED SECTION EAST OF RADFORD SEMELE
KEUPER MARL
KEY TO AUGERED SECTIONS
DUNSMORE GRAVELS
UPPER CLAYS
SANDS
LOWER CLAYS
WOLSTON SERIES
BAGINTON SANDS
BAGINTON-LILLINGTON GRAVELS
B-L.G.
LITHOLOGY
LOAMY GRAVEL (? SOLIFLUCTION)
STONELESS OR NEAR-STONELESS CLAY (LAKE DEPOSIT)
BOULDER CLAY
GRAVEL
SAND
BUNTER PEBBLES
FLINT PEBBLES
AUGERED SECTION ACROSS WAVERLEY WOOD
LINE S2 - S2'
SCALE IN FEET
W.U.C.
W.S.
W L C
W.L.C.
B S
OLDER GLACIAL CLAYS
KEUPER MARL
AUGERED SECTION ACROSS RYTON WOOD
LINE S3 - S3'
SCALE IN FEET VERT. 10x HORIZ.
B.S.
B-L.G.
5 HOLES
LENGTH ENLARGED ON RIGHT
VERT. 5x HORIZ.
LOAMY PEBBLY SOIL
YELLOW PEBBLY CLAY
CLAY & SAND IN LAYERS
PLASTIC CLAY
CLEAN SAND
COARSE SAND
LOAMY SD
LOAMY
SAND
PLASTIC CLAY WITH RARE PEBBLES
CLAY WITH PEBBLES
CLEAN SAND
STONELESS PURPLE CLAY

Figure 10

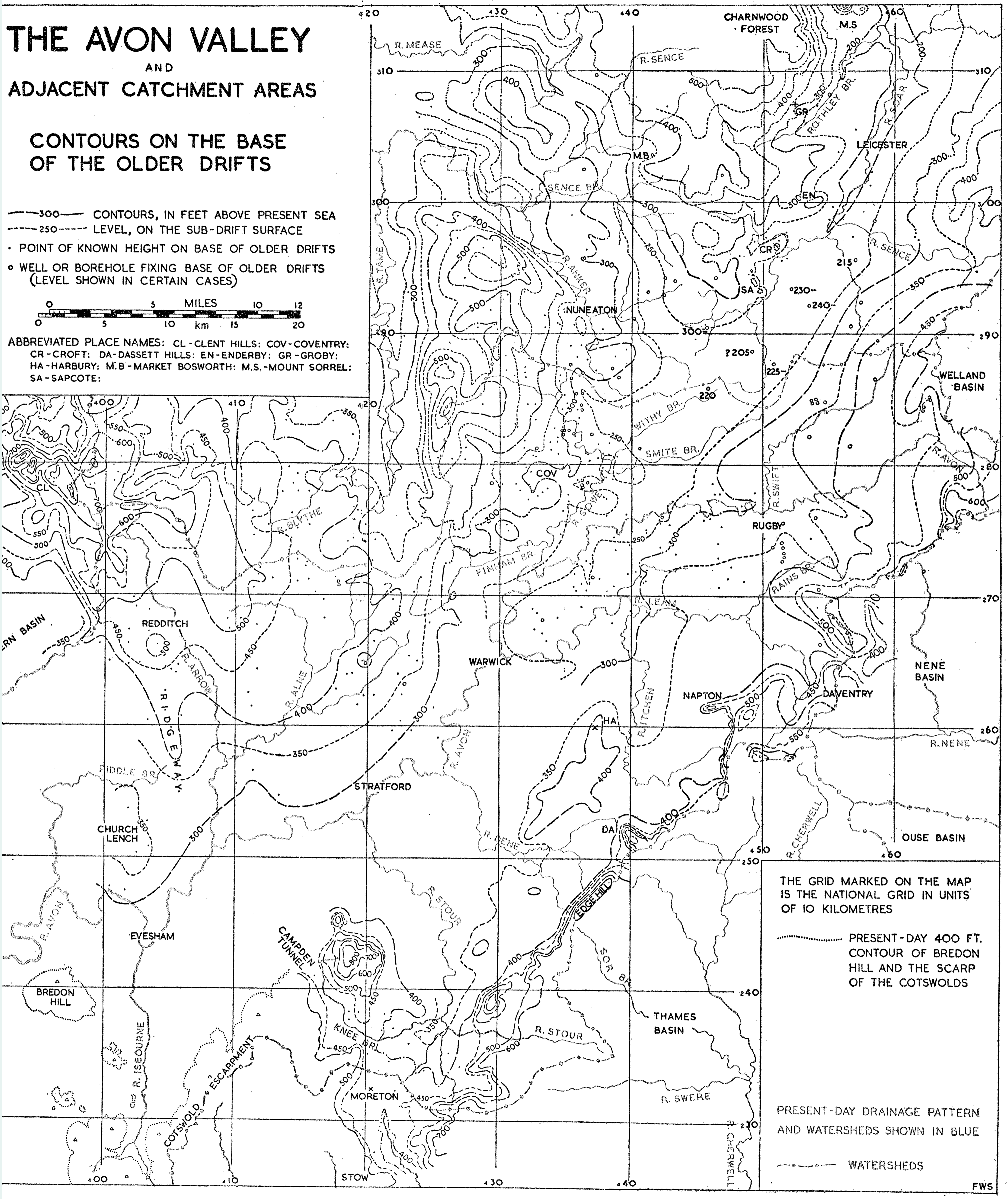

THE AVON VALLEY
AND
ADJACENT CATCHMENT AREAS
CONTOURS ON THE BASE OF THE OLDER DRIFTS
300 CONTOURS, IN FEET ABOVE PRESENT SEA
250 LEVEL, ON THE SUB-DRIFT SURFACE
· POINT OF KNOWN HEIGHT ON BASE OF OLDER DRIFTS
o WELL OR BOREHOLE FIXING BASE OF OLDER DRIFTS (LEVEL SHOWN IN CERTAIN CASES)
0 5 MILES 10 12
0 5 10 km 15 20
ABBREVIATED PLACE NAMES: CL-CLENT HILLS: COV-COVENTRY: CR-CROFT: DA-DASSETT HILLS: EN-ENDERBY: GR-GROBY: HA-HARBURY: M.B-MARKET BOSWORTH: M.S.-MOUNT SORREL: SA-SAPCOTE:
CHARNWOOD FOREST
M.S
LEICESTER
R. MEASE
R. SENCE
R. SOAR
ROTHLEY BR.
SENCE BR.
R. TAME
R. ANKER
NUNEATON
WITHY BR.
SMITE BR.
R. SWIFT
WELLAND BASIN
R. AVON
COV
R. BLYTHE
R. SOWE
FINHAM BR.
RUGBY
RAINS BR.
R. LEAM
REDDITCH
R. ARROW
R. ALNE
RIDGE WAY
WARWICK
NAPTON
DAVENTRY
NENE BASIN
R. ITCHEN
R. NENE
STRATFORD
CHURCH LENCH
R. CHERWELL
OUSE BASIN
THE GRID MARKED ON THE MAP IS THE NATIONAL GRID IN UNITS OF 10 KILOMETRES
EDGE HILL
R. STOUR
EVESHAM
CAMPDEN TUNNEL
PRESENT-DAY 400 FT. CONTOUR OF BREDON HILL AND THE SCARP OF THE COTSWOLDS
BREDON HILL
SOR BR.
THAMES BASIN
R. ISBOURNE
KNEE BR.
COTSWOLD ESCARPMENT
MORETON
R. SWERE
STOW
CHERWELL
PRESENT-DAY DRAINAGE PATTERN AND WATERSHEDS SHOWN IN BLUE
WATERSHEDS
FWS

FIGURE 11

(these being assumed to be older than the No. 4 gravels), the Avon system had determined the main lines of its present pattern. The whole river system, and the great loop in the British watershed, had developed between the Riss glacial and the Riss/Würm interglacial.

Such a violent alteration and such deep down-cutting was naturally accompanied by related changes both in tributaries and adjacent rivers, and a study of figure 11 with the present-day rivers and watersheds superimposed on the pre-glacial topography will show how striking some of these were. The Arrow system was stimulated by the Avon into great erosion, and now lies deeply incised into the older drifts—much more so than the Tame, for example. Doubtless some of the Tame's head waters were captured, but the growth of the Arrow and Alne was small compared with the Avon—for the obvious reason that the Avon was working largely on the great filling of soft drifts, whereas the Arrow and Alne had only the thin edge of these to cut through before reaching the Keuper marl stiffened by the Arden sandstone. This difference meant that the Tame, though slightly reduced, was not turned into a shadow of its former self like the Soar was. In consequence, the Tame system attacked the Soar, with the River Anker, Sence Brook and western River Sence cutting back, so that they now lie completely transverse to the old pre-glacial topography. The validity of this statement can be tested by following the tributary of the River Sence north of Sence Brook on the drift edition of Sheet 155 of the Geological Survey and noting how, between two lengths where it runs on Keuper marl, it crosses the thick filling of glacial drift which marks the old pre-glacial channel at Market Bosworth.

It would be possible to extend this analysis of drainage changes to a finer scale, to include such facts as the changes of direction made by the Itchen, Finham Brook and other streams. The purpose of this paper is, however, only to describe the detailed geology of one special area and to use the conclusions which arise from it to throw a general light on the Midlands. It would be out of place to pursue that wide inquiry to the stage of detail.

I am indebted to so many people for assistance, that to mention them all by name is impossible, and a short list must suffice. From Professor L. J. Wills, Dr M. E. Tomlinson and Mr D. L. F. Gilbert I have had a wealth of facts and much stimulating criticism. Dr A. Tindell Hopwood and Dr K. S. Sandford have given their time and experience in the examination of vertebrate remains, and under the general heading of the Geological Survey I can tender my thanks to the numerous officers who have assisted me in my examination of published and unpublished maps and borehole records. Mr W. Yardley, of the Wolston Sand and Gravel Company, and Messrs Baillie, Brind and Company have given me unrestricted access to all trial hole information. From the hundreds of farmers and landowners whose ground I have traversed, I have never had anything but cordiality and co-operation. Finally, in the arduous work of augering I have had a number of willing assistants, of whom I would specially like to mention the late Mr J. H. Edwards and Mr P. Hemsley.

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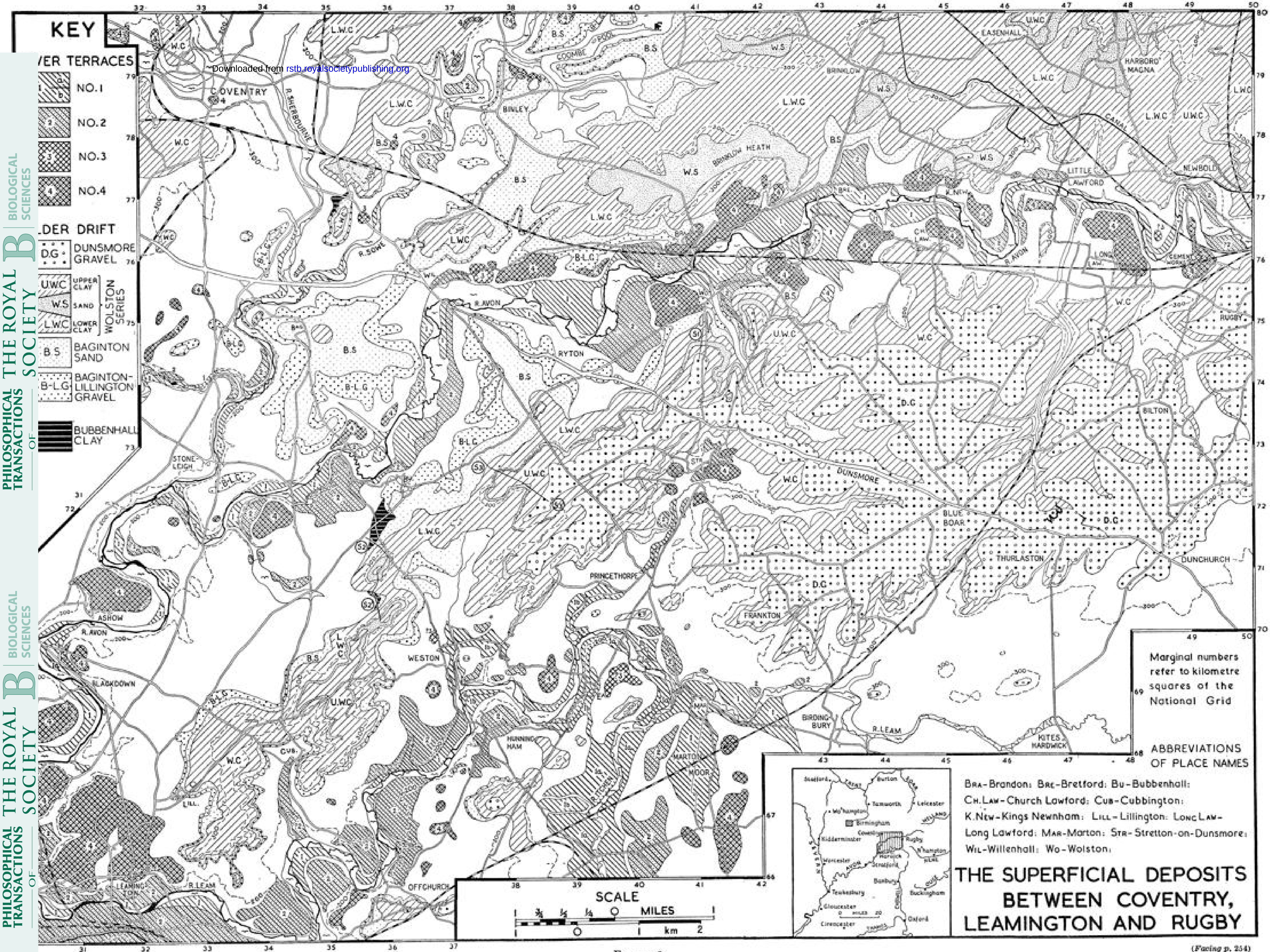

FIGURE 9

(Facing p. 254)

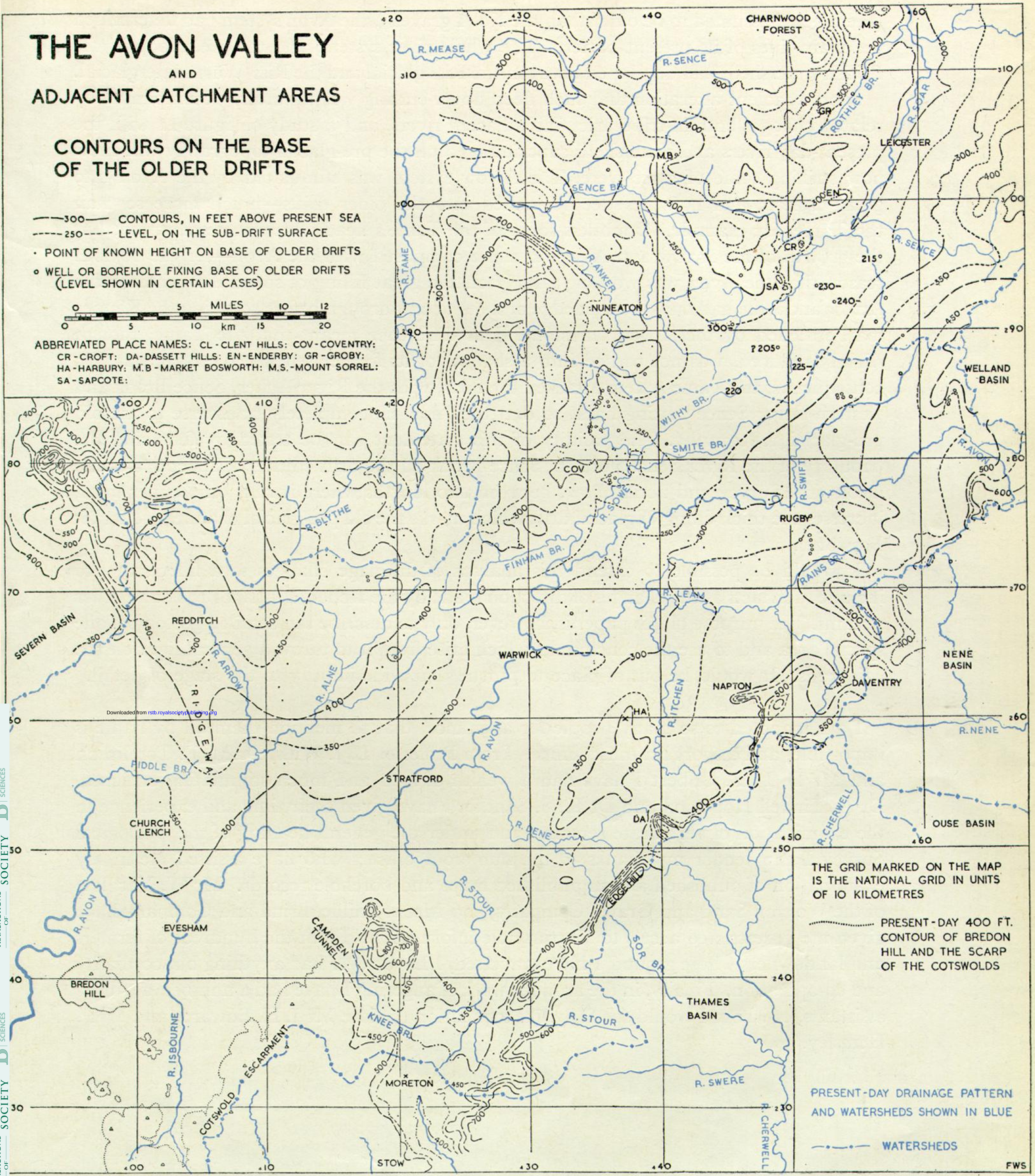
THE AVON VALLEY
AND
ADJACENT CATCHMENT AREAS
CONTOURS ON THE BASE
OF THE OLDER DRIFTS
300 CONTOURS, IN FEET ABOVE PRESENT SEA
250 LEVEL, ON THE SUB-DRIFT SURFACE
· POINT OF KNOWN HEIGHT ON BASE OF OLDER DRIFTS
o WELL OR BOREHOLE FIXING BASE OF OLDER DRIFTS
(LEVEL SHOWN IN CERTAIN CASES)
MILES
km
ABBREVIATED PLACE NAMES: CL - CLENT HILLS: COV - COVENTRY:
CR - CROFT: DA - DASSETT HILLS: EN - ENDERBY: GR - GROBY:
HA - HARBURY: M.B - MARKET BOSWORTH: M.S. - MOUNT SORREL:
SA - SAPCOTE:
CHARNWOOD
FOREST
R. MEASE
R. SENCE
ROTHLEY BR.
R. SOAR
LEICESTER
SENCE BR.
R. TAME
R. ANKER
NUNEATON
WITHY BR.
SMITE BR.
WELLAND
BASIN
R. AVON
COV
R. BLYTHE
R. SOWE
FINHAM BR.
RUGBY
R. SWIFT
RAINS BR.
R. LEAM
SEVERN BASIN
REDDITCH
R. ARROW
R. ALNE
WARWICK
RIDGEWAY
NAPTON
DAVENTRY
NENE
BASIN
R. NENE
R. ITCHEN
FIDDLE BR.
STRATFORD
R. AVON
CHURCH
LENCH
R. DENE
R. CHERWELL
OUSE BASIN
THE GRID MARKED ON THE MAP
IS THE NATIONAL GRID IN UNITS
OF 10 KILOMETRES
R. STOUR
EDGE HILL
EVESHAM
CAMPDEN
TUNNEL
PRESENT-DAY 400 FT.
CONTOUR OF BREDON
HILL AND THE SCARP
OF THE COTSWOLDS
SOR BR.
BREDON
HILL
R. ISBOURNE
KNEE BR.
R. STOUR
THAMES
BASIN
COTSWOLD
ESCARPMENT
MORETON
R. SWERE
PRESENT-DAY DRAINAGE PATTERN
AND WATERSHEDS SHOWN IN BLUE
WATERSHEDS
R. CHERWELL
STOW
FWS

FIGURE 11