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The Pleistocene Geology and Geomorphology of Three Gaps in the Midland Jurassic Escarpment

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THE PLEISTOCENE GEOLOGY AND GEOMORPHOLOGY OF THREE GAPS IN THE MIDLAND JURASSIC ESCARPMENT

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CONTENTS

Previous literature is reviewed and field and laboratory methods are discussed in relation to four areas.

The type area of the Itchen drainage basin reveals the composite nature of ice movement within one glacial period. Shallow facies deposits of glacial Lake Harrison have been located and a spillway into the Cherwell, associated with a lake bench at 410 ft. o.d., is considered to have been cut after most of the Older Drift had been deposited.

Morphological features and gravel deposits along the Cherwell are described and a tentative link established between the sequence on the Itchen and Avon and that published for the Lower Cherwell–Upper Thames.

In the Moreton gap, deposits are related to the history of Lake Harrison. Clays were laid down during the advance of the ice in an 'extra-morainic' lake, while a lake bench is related to a later 'inter-morainic' lake.

Possible gaps in the Daventry–Kilsby–Rugby area are obscured by thick drift but glacial spillways may formerly have existed.

The evidence suggests several possible overflows from Lake Harrison during the ice advance. The lake ceased to exist when the ice-front reached Moreton-in-the-Marsh but was re-established during the subsequent retreat. At least two levels of ponding and two points of overflow occurred at this time, before damming was suddenly ended and erosion of the present landscape commenced. The sequence of events in Lake Harrison is related to the rivers Cherwell, Evenlode, Stour and Itchen and correlated with those established for the Upper Thames, the Severn–Avon, and other areas.

I. INTRODUCTION

(i) *Aims, layout and approach*

> An eternity of actual causes would never produce ye Oxford Gravel, neither the Thames or Cherwell could ever have brought from their highest sources any other rocks than Oolite. Nor could any lake from centre of England have ever rushed in by ye Cherwell Valley, seeing it would have found a more ready descent by the valley of ye Severn.
>
> (W. Buckland. Private paper noted in North (1943))

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* At present with the Geological Survey of Uganda.

> 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 feet of 410 ft. O.D.... Dury (1951, p. 169) has suggested that the Fenny Compton Gap may have let the waters escape into the Cherwell Valley.
>
> (Shotton 1953, pp. 251–2)

The above quotations summarize the position in 1953 when the writer commenced work. Shotton, in the paper just cited, had greatly changed the concept of the role of the Warwickshire Avon in Midland Pleistocene history by producing evidence that up to the time of the Saale (Riss or Penultimate) Glaciation it did not exist but that along its future site ran a north-eastward flowing tributary of the River Trent. Ice from the north-east advancing up this valley allowed the impounding of a lake which, held up also by Welsh ice across the headwater col between Bredon Hill and the Cotswold Scarp, rose to a level a little above 400 ft. O.D. This is 'Lake Harrison' referred to repeatedly in the following pages. Only when the retreat of the ice sheets allowed the impounded water to escape at its southern end was erosion initiated which led to the cutting of the south-westward flowing River Avon. During the existence of Lake Harrison, escape of the ponded water could have been across low points in the Jurassic Cotswold scarp into the Thames system

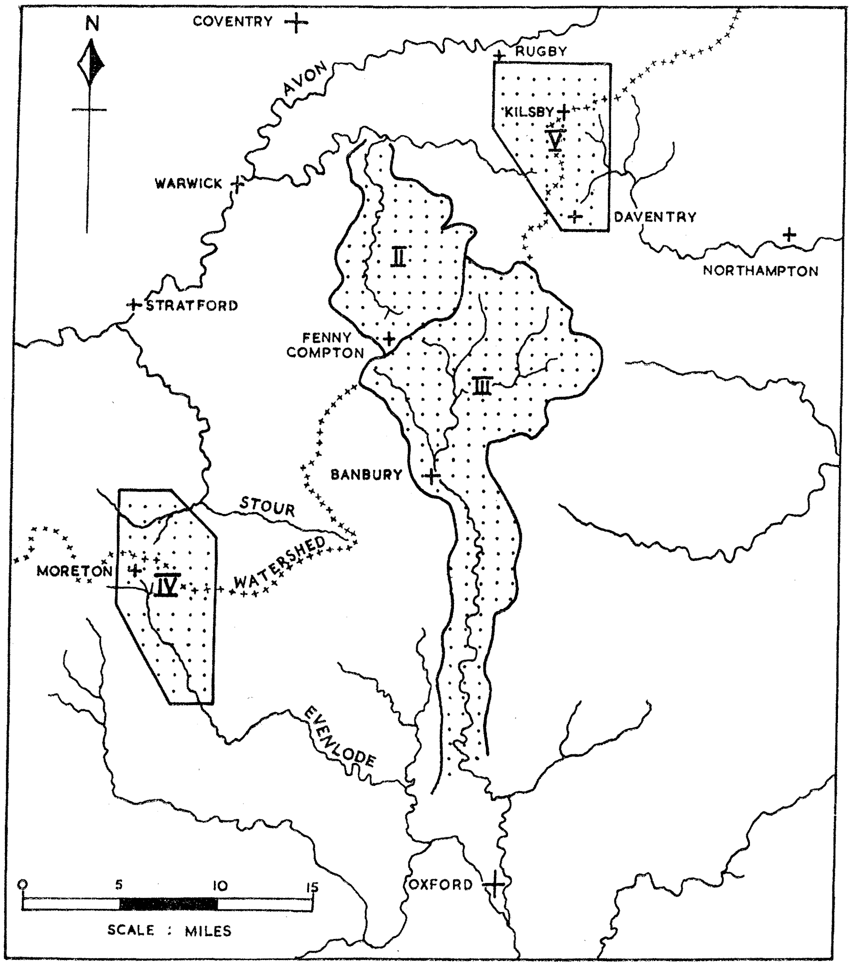

FIGURE 1. Regional setting. II, River Itchen basin; III, River Cherwell; IV, Moreton gap; V, Daventry–Kilsby–Rugby.

and Shotton suggested three such possible places (which did not include the Moreton gap, though the writer hopes to demonstrate later that this also functioned as an overflow). The main object of the present work was to investigate the possible overflows by a combination of geomorphological and geological mapping. From the evidence of Dury's 1951 paper, the Fenny Compton gap seemed the best point at which to start work. This area, separating the Itchen from the Cherwell, had been virtually unexplored since Buckland (1821, 1823) produced maps showing Triassic and flint debris to the north-west of the Jurassic escarpment connected with the Thames drainage by the valleys of the Cherwell and Evenlode.

Four areas have been studied (figure 1). In the River Itchen drainage basin (§ II) a type sequence of Pleistocene deposits was worked out and the complete mapping of these and of the morphology was attempted. This area, within the Avon basin, allowed the possibility of correlation with Shotton's sequence.

The Itchen mapping confirmed the existence of a Fenny Compton overflow and on the other side of this, analysis of landforms and deposits was carried out in the Cherwell Valley (§ III). Mapping was restricted to the 'valley trough' and continued southwards to overlap with the known sequence near Oxford (Sandford 1924, 1926).

The Moreton gap area (§ IV) had been mapped by earlier workers, but the vertical sequence was re-investigated and related to the mapped record.* The depositional history was then re-interpreted in the light of conditions in the Itchen Valley and Middle Avon.

In the Daventry–Kilsby–Rugby area (§ V) the Jurassic escarpment still retains thick patches of superficial deposits. Field mapping in selected areas was carried out to investigate the possible existence of sub-drift cols which might have acted as spillways.

(ii) *Literature on adjacent areas*

Severn–Avon valley

This area had a period of intense research on superficial deposits from about 1860 to 1900, which culminated in the papers of Harrison. His 1898 contribution on the 'Ancient glaciers of the Midland counties of England' contained mention of glacial Lake Bosworth (p. 94) which is the first reference to the extensive lacustrine deposits which have been later proved to have a common origin in Lake Harrison (Shotton 1953, p. 246).

It is interesting that two works published in 1894 had invoked the existence of glacial lakes in the Midlands. Carvill Lewis (1894, pp. 49–57) suggested that similar conditions of ice advance in Central England and North America had allowed a fringe of morainic lakes to be developed in each area. He even gave 400 ft. O.D. as the height of the English lake but was thinking in terms of the present-day topography rather than of that beneath the Older Drift.

James Geikie (1894, pp. 380–2) suggested that the Mer-de-Glace in the Midlands, which extended as far south as the Cotswold Hills, would give rise to conditions favouring glacial lakes on both its advance and its retreat.

All the regions covered in the early papers have been redescribed, but the works of Symonds, Brodie, Lucy, Lloyd, Wilson and Ingram are of value for their accurate descriptions of sections that have since been destroyed.

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* I am indebted to Dr M. E. Tomlinson for much helpful detail of exposures that have now deteriorated.

More recently the work of Tomlinson (1925, 1935), various papers by Wills, in particular (1948), and the detailed succession of events outlined in Shotton (1953), have built up a detailed history of the Severn–Avon system.

Lower Cherwell Valley

The Lower Cherwell and Upper Thames received many early treatments which have been summarized by Harmer (1907). His concern with the deposits was in support of the existence of a 'Lake Oxford' which established an overflow via the Goring gap and was supposed to be responsible for determining much of the present form of the River Thames.

Pocock (1908, p. 81) gave a detailed account of the deposits within the area covered by the Oxford Sheet of the Geological Survey and outlined the probable river development (p. 106) stressing the degree of incision of the dip slope rivers. This is well seen at Kirtlington where the present river is 100 ft. below the base of the Hanborough Stage gravels and has cut down through the Lower Cornbrash, Forest Marble and White Limestone.

Sandford (1924 and 1926) redescribed the gravels mapped by Pocock and from the abundant fauna and implements a detailed sequence was developed in which broad climatic types could be distinguished for the majority of stages. This succession has remained largely unaltered although Arkell (1947*a*, *b*) indicated the presence of two high terraces in the Evenlode valley at Combe and Freeland. These are included in the Plateau Drift of Sandford.

The Cherwell Valley appears to have been a critical boundary for the Chalky Boulder Clay ice sheet. Thus, Sandford (1926, p. 113) says 'there seems to be a regional partition of predominant Northern Drift to the west and of flint drift with some constituents of Northern Drift in it, to the east'. A similar division is stressed by Harmer (1907), Arkell (1947*a*) and Wills (1951). Within the valley some deposits remain, although it has largely 'been swept clear of gravel at all stages' (Sandford 1926, p. 133). The writer felt that mapping the morphological terrace flats, in conjunction with, but separate from the river gravel deposits, would provide additional information upon periods of erosion and down-cutting.

(iii) *The mapping: field and laboratory methods*

(*a*) *Field*

Work in the Itchen basin has been based upon the methods of augering described by Shotton (1953, p. 211). On four of the hill-tops mapped in detail, 114 holes were bored to an aggregate depth of 614 ft. Of these thirty-three were with a 4 in. bucket to an aggregate of 199 ft., twenty with a 3 in. bucket (147 ft.) and sixty-one holes with a 1 in. screw auger (268 ft.). The maximum depth reached was 22 ft. 6 in. The rather low average depth of the holes (5·4 ft.) is related to the limited nature of the drifts. The heights of the majority of holes were surveyed to ±0·5 ft. but in many cases bench-marks were missing and their site had to be estimated. The majority of holes were grouped in fourteen traverses of which nine are illustrated in this work (figures 4 and 5). This enabled the vertical sequence to be established accurately in an area of few exposures.

The mapping of areas between hillocks capped by Older Drift was based upon normal soil and ditch geology, but difficulties were encountered from solifluction and sludge. Frequently the screw auger was used as thin bands of contrasting deposits could not be traced in the soil. Beds of the lake sequence were normally controlled by undulations of the pre-lake floor, which invariably bore little resemblance to present topography.

The principles used in differentiation of drifts followed those of Zeuner (1944). Pebble counts were made to help correlate similar types of deposit on their lithological content.

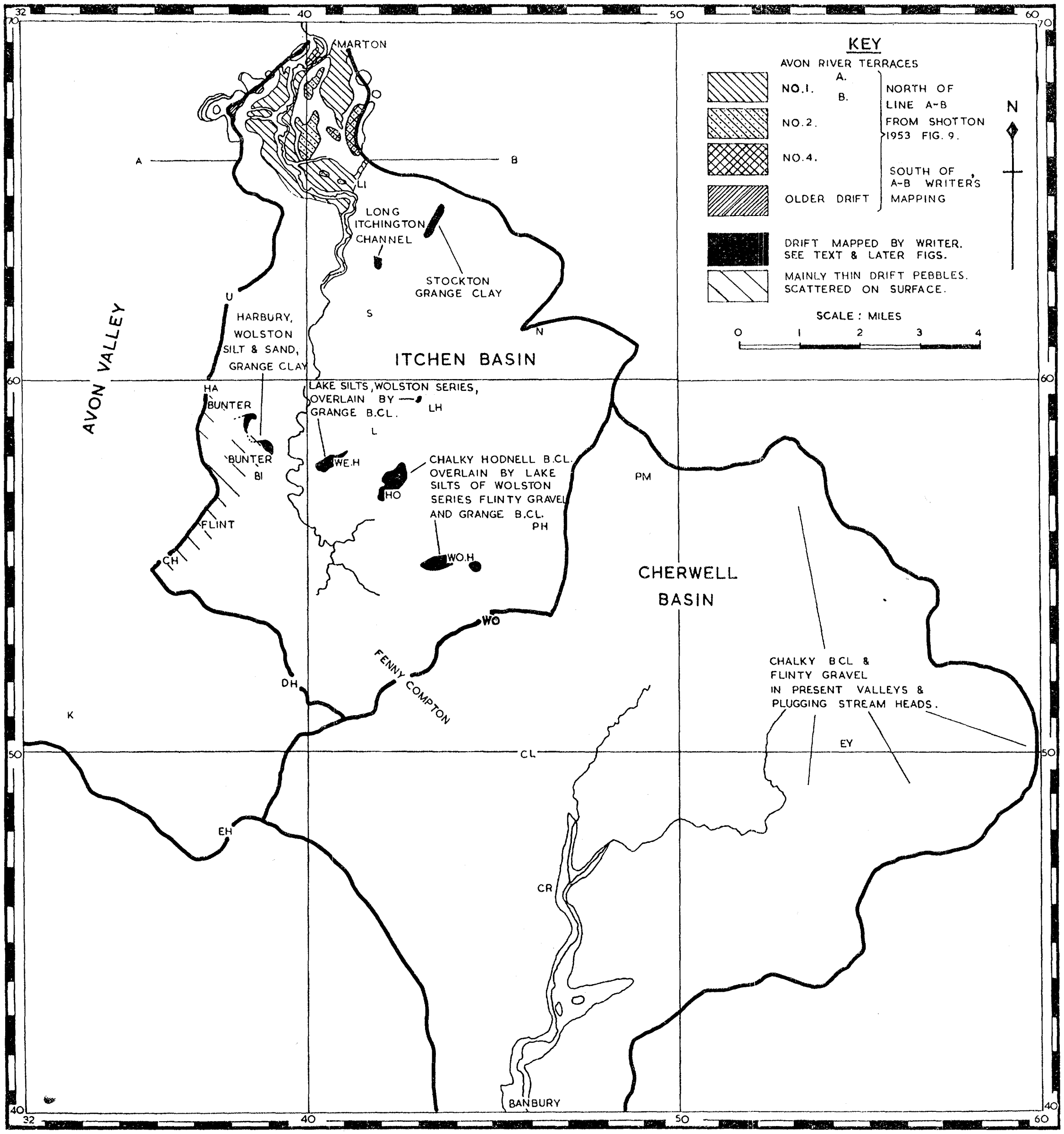

Figure 2. Drift geology. Abbreviated place-names: BI, Bishops Itchington; CH, Christmas Hill (south-west end); CL, Claydon; CR, Cropredy; DH, Dassett Hills; EH, Edge Hill; EY, Eydon; HA, Harbury; HO, Hodnell; K, Kineton; L. Ladbroke; LH, Ladbroke Hill; LI, Long Itchington; N, Napton; PH, Priors Hardwick; PM, Priors Marston; S, Southam; U, Ufton; WE.H, Weddington Hill; WO, Wormleighton; WO.H, Wormleighton Hill.

A hundred erratics were considered sufficient to give a typical sample but more were counted where possible. Diagnostic erratics were collected but emphasis was laid upon total constituents rather than single outstanding rock types.

(*b*) *Laboratory*

Dried and weighed samples were washed and all material removed in suspension was classed as silt or finer. The remainder was sieved and weighed in the following divisions:

coarse fraction—	pebbles, above 10 mm
	gravel, between 2 and 10 mm
sand—	coarse, 2·00–0·42 mm
	medium, 0·42–0·19 mm
	fine, less than 0·19 mm

The inaccuracy of the lower silt/fine sand boundary was realized but as only the coarse fraction was required for further analysis, nothing was to be gained by more accurate sub-division.

Few samples contained pebbles above 10 mm, but this was considered to represent selectivity of the bucket auger, since dug pits commonly revealed large pebbles, particularly in boulder clays.

The results can be summarized as follows:

(*a*) In correlation of separate hill-tops the washings merely support observed divisions.

(*b*) In differentiating lake deposits from boulder clays (tills) it was possible to discern a sharp boundary. Boulder clay gave a figure of about 20% for constituents above the silt grade while in silty lake clays the sieved portion lay between 0·5 and 5·0%. This proved useful since 'rafts' of boulder clay were frequently found within the lake silts. The percentages obtained are considered to be only of local application.

(*c*) The method proved useful in showing vertical changes within a sequence.

(*d*) Insufficient samples were dealt with to reveal ice movements. The local nature of the bulk of the boulder clay indicates the dangers of long-distance correlations based on lithology alone. Two types of 'local' material have been intermingled in a complicated manner within the small region of study.

(*e*) The washings have underlined the sharpness of changes in grade within the lake deposits but have not suggested a cause.

Pebble counting was usually carried out in the field but in some cases samples were brought back to the laboratory, washed through a 2·0 mm sieve and counts carried out on the 'total sample'. Results were identical with the 'face count' with two exceptions:

(1) In 'total samples' of gravel or solifluction an overweighting of small pieces of easily comminuted, boxy ironstone tended to mask the large volume of pebbles of flint, Bunter or oolite.

(2) In boulder clay, 'total' washings revealed a matrix of numerous angular limestone, chalk and other semi-resistant fragments with only a few harder flint, Bunter and other larger pebbles. These resistant and valuable indicators frequently made up the whole of a 'face' count.

(iv) *Geomorphology: field and map methods*

The preparation of a slope analysis map has been the principal field operation. Breaks of slope or 'Kanten' (Lucerna 1938, p. 101) separating flats and slopes, were plotted on to 6-in. base maps in the field. The definition of 'flat' used is that of Sparks (1949, p. 167), 'an area possessing a visibly lower degree of slope than its surroundings'. 'Flat' is, therefore, a purely relative term. Flats which appeared to have a similar and contemporary origin were grouped into stages. The term terrace is used only to refer to a 'geological terrace' or gravel deposit which may occur on, or underlie, several visual features.

The heights of the positive (convex) and negative (concave) breaks delimiting flats were obtained by making traverses along selected lines with a level and light staff.

A complete analysis of the Itchen–Cherwell area was attempted and features due to the geological formations were differentiated from those of the main erosion stages. Other flats remained which it was not possible to assign to either group. A local name was applied to each erosion stage to enable it to be fitted into the depositional sequence and to avoid arbitrary height designations. The value of this method became clear when tracing erosional stages across the feature-forming resistant bands of Lias and Oolite in the contra-dip Itchen and dip-slope Cherwell.

II. WEST OF THE FENNY COMPTON GAP: THE RIVER ITCHEN DRAINAGE BASIN

A. The physical background

Solid geology, relief and drainage

The eastern boundary of the Itchen basin is formed by the bold scarp facing north-west and west, which also earlier formed part of the eastern shore of Lake Harrison. It is due to the Middle Lias which consists of 60 to 70 ft. of buff-grey silts overlain by about 17 ft. of erosion-resistant ferruginous sands and ironstone.

To the north and west of this scarp occurs the broad vale of the Lower Lias, traversed by the Itchen and Dene and their numerous small tributaries. Within this area a number of rounded hillocks rise to a little over 400 ft. (Wormleighton Hill 431 ft., Hodnell 422 ft., Ladbroke 452 ft., Weddington Hill 400 ft.+ and Thorn Hill 440 ft., see figure 2). The Lower Lias consists essentially of dark-blue and steely-grey shales and clays with occasional limestone nodules and thin limestone bands, but towards the base down to within 30 ft. of the White Lias, the proportion of limestone increases to form what has been called the 'Hydraulic Limestone Group'. This is responsible for the north-east to south-west trending ridge of Christmas Hill (400 ft.+) which forms the western boundary of the Itchen vale and the watershed between this and the main Avon valley.

Still further to the west, the Rhaetic White Lias produces another strong north-west facing scarp, well seen at Ufton (378622)* overlooking the low ground of the Rhaetic Black Shales and Keuper Marl.

The simple, large-scale structure is of alternating weak and resistant strata tilted gently to the south-east but complicated in detail by the presence of superficial buckling and warping of the type described by Hollingworth, Taylor & Kellaway (1944). Cambering, gulling and dip-and-fault structures are all present to judge by the evidence of steep dips

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[*] Localities are indicated by National Grid references to the nearest tenth of a kilometre and can be found on maps of the Ordnance Survey 1 in. to 1 mile, Sheets 132, 144, 145 and 158.

and opened joints in old ironstone quarries though it is difficult to be certain on worked-over ground with an intricate network of small faults.

The region presents a physical aspect from which feature mapping results in an accurate determination of the geological skeleton, but on this basement there is also preserved a more fragmental record, in the shape of facets breaking smooth slopes and irregularities in the drainage pattern, which suggest processes and stages of landscape sculpture.

B. Superficial deposits

(i) *Introduction and literature*

Buckland (1821, 1823) mentions flints and rounded masses of hard white chalk 'promiscuously heaped together' with Bunter pebbles in the gravel capping most of the hillocks between Southam and Shipston but the area has been little studied since the Old Series maps of the Geological Survey were published (1855–70).

Dury (1951) mapped over a distance of 35 miles, a series of 'Back and Bench' forms cut into the wall of the Lower Lias vale at a height of 400 to 412 ft. O.D. and interpreted the feature as a lake bench. Shotton (1953), from a study of superficial deposits, gave the name Lake Harrison to a glacially dammed lake which existed on the site of the Avon valley during the Penultimate Glaciation.* The heights of lake clays and silts still remaining suggested a minimum of 410 ft. O.D. for the maximum height of the lake.

Dury had shown that his lake bench passed into the floor of the col crossing the Middle Jurassic scarp at Fenny Compton (435525) and Shotton had suggested this as one of the most probable overflow channels of Lake Harrison. Hence, in the writer's attempt to elaborate the history of this lake by a combination of geomorphological and geological techniques, the areas on each side of the hypothetical overflow called for first attention. Unless the area of Lower Lias now covered by the Itchen basin had everywhere stood above 410 ft. O.D. at the time of the impounding of Lake Harrison, it could be anticipated that deposits of the lake would have been laid down there and that relics of these would have survived the more recent erosion which has produced the Itchen drainage of the present day.

Accordingly the hill-tops were investigated in detail, with the following results.

(ii) *Wormleighton Hill* (436552)

This locality has provided a type section of the drifts. Their distribution on the hill as deduced from fifty-six holes in five augered sections (figure 4) is shown in figure 3. The sequence is:

6.	Upper Till	(Grange clay)
5.	Gravel	(Dunsmore gravel)
4.	Sands	(Wolston Series?)
3.	Silty clays	(Wolston Series)
2.	Lower till	(Hodnell clay)
1.	Lias clay	

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* The nomenclature of Zeuner (1944) is used throughout to refer to the major glaciations.

3. *Silty clays*

At the west end of the ridge, the succession commences with silts. Although nowhere exposed these have been proved in four auger holes and vary in thickness from 14 ft. to 1 ft. 6 in. The height range is from 381 to 399 ft. O.D. The silts are buff in colour, calcareous in reaction and, although virtually stoneless, contain pebbles of flint, Bunter, chalk and coal. The coarse fraction varied from 4·3 to 0·5%.

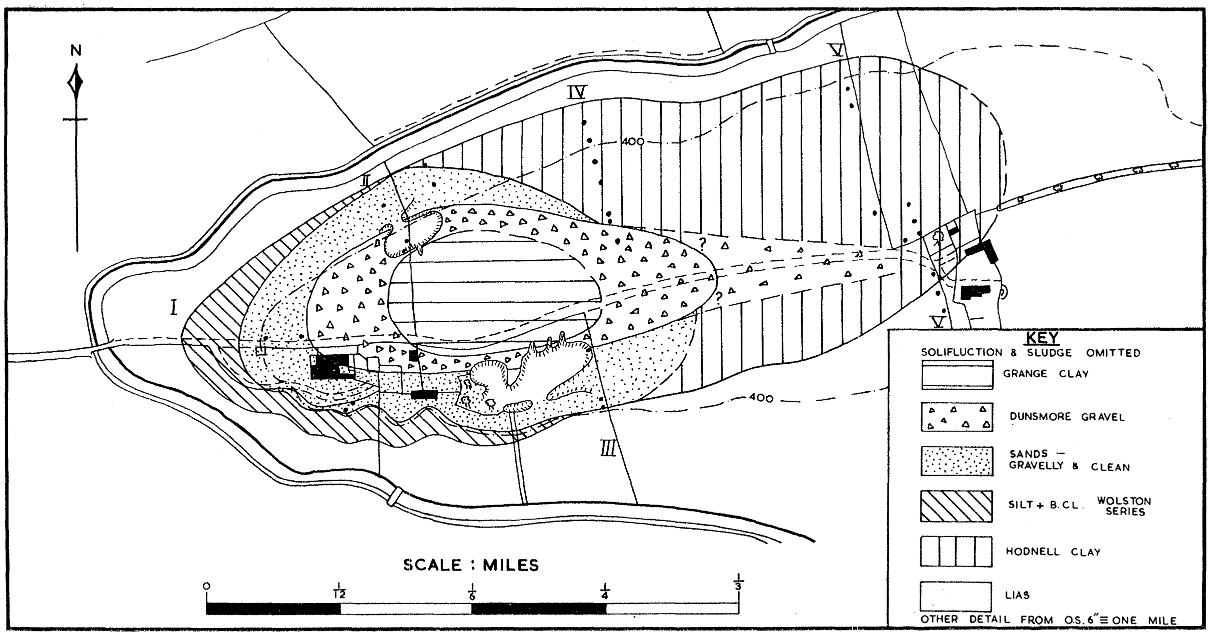

FIGURE 3. Wormleighton Hill drift deposits.

Lenses of stiff clay containing much chalk, some flint and occasional Bunter and carbonaceous matter, were met at different levels. The coarse fraction was 17·9% and 19·6%. This material suggested till. The silts are interpreted as still-water lake deposits into which boulder clay rafts were deposited by melting bergs. Some of the silts are probably laminated but in a shredded auger sample it is impossible to be certain.

4. *Sands*

The silts are overlain by a variable series of sands. The lower layers are medium-coarse and contain a high proportion of clay and some pebbly gravel (Bunter 54%, flint 23%, ironstone 14%, shale, sandstone, etc.) and vary in thickness from 3 to 5 ft. They are succeeded by clean buff sand 3 to 9 ft. thick with occasional bands of small pebbles. This is exposed in an old pit on the south of the hill and can be seen to pass into 4 ft. of transitional dirty, sandy-gravel with increasing pebble bands.

5. *Gravel*

The sands become dirtier and grade into coarse, ochreous flinty gravel which has a maximum thickness of about 10 ft., in the quarry to the north of the hill. The gravel showed 42% Bunter, 38·5% fresh flint and ironstone, sandstone, etc.

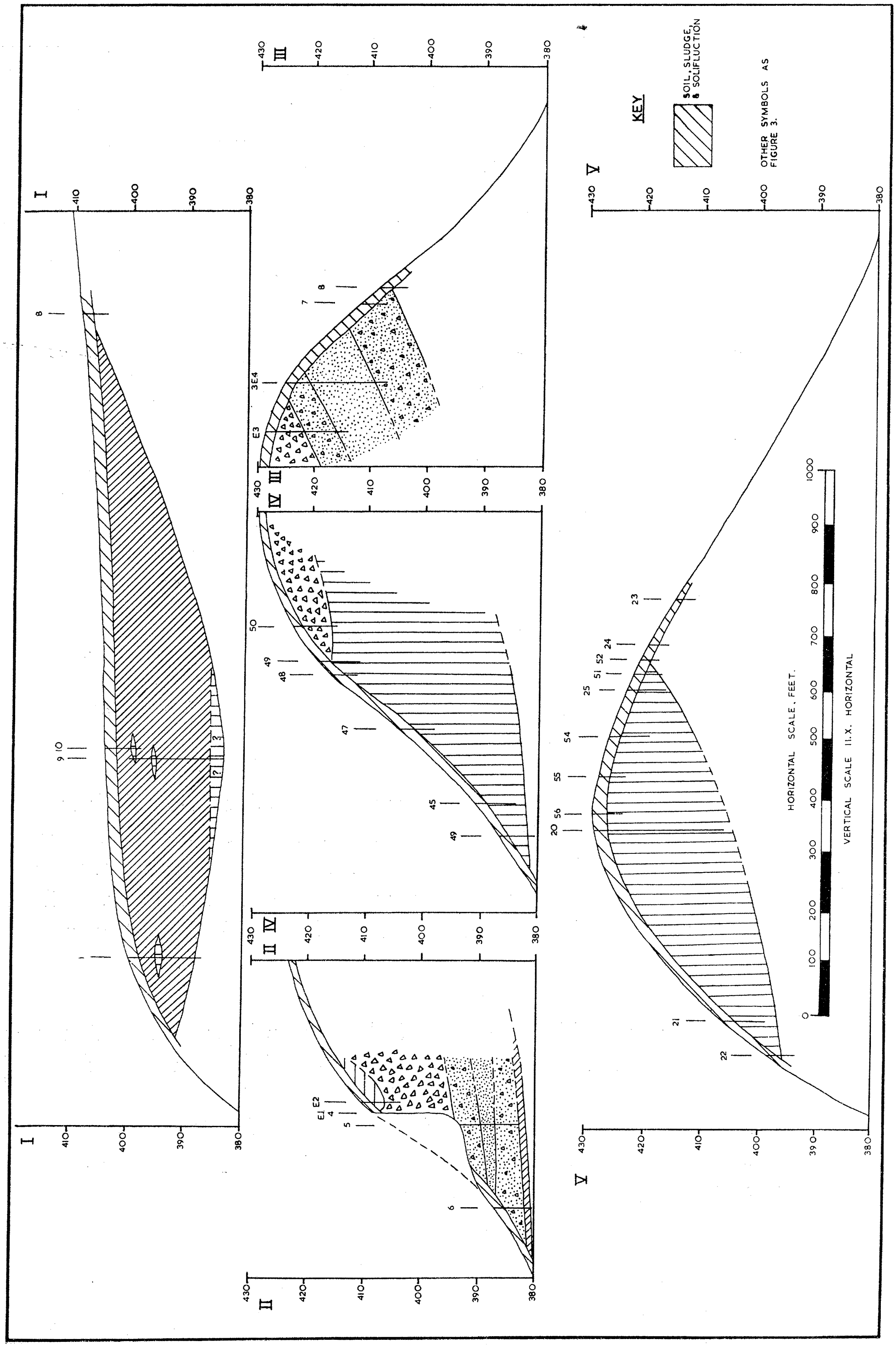

FIGURE 4. Wormleighton Hill, auger traverses.

6. *Upper till*

On top of the gravel and lying on a pocketed irregular surface, there is up to 3 ft. 6 in. of heavy, reddish brown boulder clay with pebbles mainly of Bunter and some flint.

2. *Lower till*

It was originally thought that the above succession (3 to 6) would be traced along the ridge to the east but on augering sections IV and V (figure 4) a predominantly clay sequence was located. Hole 20 was put down to 22 ft. 6 in., together with a pit to 5 ft., to try to decide whether the deposit was till or lake silt with many boulder clay rafts. Sixteen samples were washed and sieved but no change was discerned from top to bottom. The eastern end of the ridge consists of fragmental, chalky boulder clay containing 18·9 % of coarse matter (chalk 18·8 %, various grey limestones and shales 42·8 %, flint 6·6 %, Bunter 4·5 %, etc.)* The clay thins to the west to pass under the sands and gravels and possibly part of the silts.

The upper surface of the hill has been planed off and while the gravels and sands thin rapidly to the east, the large amount of sand present in pockets and in the sludged veneer, suggests that they were thicker at one time or that a former clay matrix has been washed away. The silts also thin rapidly eastwards and have not been located beyond a line joining the old pits. It seems impossible to get further information on the relationship of the silts to the lower till as the gravel cap precludes augering at the critical point. One obvious possibility is that they are equivalent in time and that one passes laterally into the other, an interpretation supported by the fact that the boulder clay rafts in the silts are identical in composition with the lower till. It was, however, considered improbable that material no coarser than silt would be deposited so close to the ice even if the lake were frozen over. Since at the adjacent hill of Hodnell (p. 266) silt has been proved to rest upon a similar till (called the Hodnell clay) the same space relationship has been invoked at Wormleighton and the lower till is correlated with the Hodnell clay. It seems that a minor advance and retreat took place before the deposition of the lake silts which were, however, laid down in the proximity of a chalky boulder clay ice sheet. The lowest sands of bed 4 indicate a change to ice from a different locality with Bunter material dominant and flint second although still significant. This lithology is maintained up to the deposition of the upper till which has been named the Grange clay from Wormleighton Grange which stands on the deposit.

Local names have been given to the two tills because of their local characters and their lack of correspondence to drifts described from surrounding districts. Two other deposits are identical with those described by Shotton (1953) and his terms are adopted to avoid duplication of nomenclature. The coarse gravels correspond in lithology, relation to other deposits and suggested mode of origin, to the Dunsmore gravels (1953, p. 226), while the lake silts, from their general nature, height above O.D. and areal distribution, would seem to have once been continuous with the Wolston Series (1953, p. 223).

The sands underlying the Dunsmore gravel have only been located at Wormleighton. The lower portion is probably of lacustrine origin as there are signs of even bedding and

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* The proportion of coarse matter is percentage by weight but the various types of rock present are stated as numbers of individual pebbles.

no sign of false bedding.* The upper gravelly sand may be the lower section of the Dunsmore gravel into which it grades imperceptibly. As the deposit is transitional no local name is given to it.

The variation in thickness of the silts may indicate a period of subaerial erosion, or of scour from stronger currents depositing the sand and gravel. It seems probable, however, that the thinning towards the north side of the ridge is connected with abstraction of the silts and with sludging under periglacial and present conditions. The pre-drift floor slopes to the north and the overlying sands and gravels show a similar inclination of about 1 in 14, and there is a great deal of seepage at the silt/Lias junction which may have resulted in the removal of soft permeable silt from the 'pre-glacial downslope' side of the hill (see figure 4, IV).

The changes in the sequence described seem to have been induced by ice advancing into a lake and contributing progressively coarser outwash material, culminating in an ice-front gravel capped by a till.

(iii) *Other areas*

(*a*) *Hodnell*

The vertical sequence at Hodnell (422570) is based on three sections drawn from twenty-four auger holes and some shallow exposures around the sides of an old clay pit. One section (no. VI) is illustrated in figure 5. The succession is:

4.	Dunsmore gravel	Coarse gravel	Maximum *ca.* 9 ft.
3.	Wolston Series	Stoneless silt,	*ca.* 3 to 4 ft.
		gravelly sand	*ca.* 4 ft.
2.	Hodnell clay	Boulder clay—chalky and highly calcareous	5 to *ca.* 20 ft.
1.	Lias clay		

2. *Hodnell clay*. The 'Hodnell' chalky boulder clay forms the bottom deposit of the drift sequence. Its thickness has only been determined from a series of shallow holes and the clay may drape a former hill rather than cover a gentle slope to the south-east. The clay is grey-brown and calcareous near the Lias junction becoming less stiff and redder in colour away from it. A pit revealed pebbles of flint, Bunter and a rolled *Gryphaea*, but chalk was predominant with one striated pebble (2 in. × $2\frac{1}{2}$ in. × 2 in.). The Hodnell clay thickens north-eastwards along the ridge, which has been planed off to give an extensive flat at *ca.* 420 ft. O.D., and till becomes the height equivalent of the gravel and silt. Correlation with the similarly situated boulder clay at Wormleighton has been assisted by heavy mineral analysis† (table 1).

3. *Wolston Series*. A regular layer of red-brown, dirty, gravelly sand overlies the till and yields figures of 50%, 71% and 75% for its coarse content. It passes up into a stoneless, orange-buff silt which is exposed in the sides of a pit where no vestige of bedding or lamination was discovered. This is pink with grey or purplish-green mottling and irregular

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* Pickering (1957) studied numerous exposures of similar glacial lake deposits and stressed the rapid variation of lithology between silt and sand.

† The writer is indebted to Dr J. D. Solomon for carrying out the analyses and for permission to publish them.

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pockets of fine sand and boulder clay rafts occur within it. The gravelly sand has been included with the overlying silts as lake deposits of the Wolston Series, for both behave as a layer, and the gravel grades up into the silt.

4. *Dunsmore gravel.* The deposit capping the south-west end of the hill is a dirty, flinty, coarse gravel (pebbles up to 5 in.) containing 44 % flint, 37 % Bunter, various sandstones, a block of local limestone, and some Leicestershire igneous rocks. This make-up compares closely with the 38·5 % flint, 42 % Bunter for the Dunsmore gravel at Wormleighton and 49 % flint, 29 % Bunter for that of the Middle Avon (Shotton 1953, p. 225).

TABLE 1. HEAVY MINERAL ANALYSES

	minerals (percentages)								
locality	garnet	horn-blende	epidote	tourma-line	stauro-lite	kyanite	zircon	rutile	ilmenite
chalky boulder clay Hodnell (Hodnell clay)	21	6	8	8	4	1	14	4	33
chalky boulder clay Wormleighton Hill (Hodnell clay)	15	7	6	5	3	1	18	4	41
chalky boulder clay Stretton-on-Fosse (Moreton Drift)	17	6	4	4	3	1	27	5	35

(*b*) *Weddington Hill*

The Weddington (405577) sequence is based on the evidence from twenty-five auger holes in three traverses, of which nos. IX and X are illustrated in figure 5. The Hodnell clay and Dunsmore gravel are absent but other deposits are as encountered elsewhere:

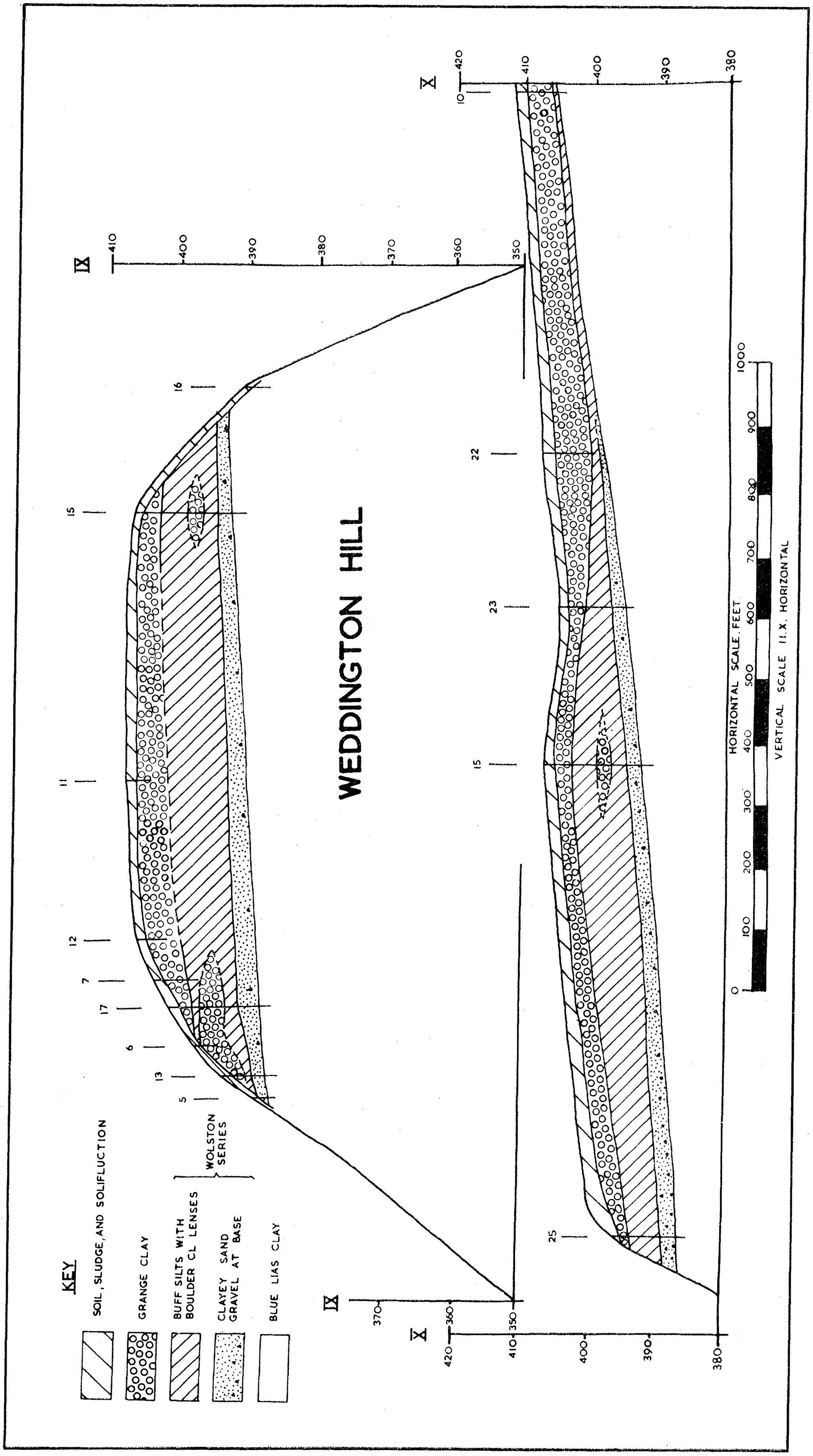
1. *Wolston Series.* Moist, red-brown, gravelly sand maintaining a 2-ft. thickness rests on the Lias and grades up into typical pebble-free, buff silts of the still-water series. These vary in thickness from 1 to 8 ft. and contain lenses of red-brown to grey boulder clay with pebbles of Bunter, local limestone, ironstone, sandstone and pieces of coal, but no flint or chalk.

2. *Grange clay.* The silts are capped by a heterogeneous, fragmental, reddish and often sandy, pebbly clay, between 4 and 6 ft. thick, which forms an almost impenetrable layer over the flat top of the hill at *ca.* 408 ft. O.D. Pebbles include Bunter, sandstone, limestone and occasional flint. In the absence of an exposure it is difficult to decide whether this is a true boulder clay or the result of solifluction. The flat nature of the hill-top and the need to find a source if solifluction is invoked, leads the writer to include the deposit as a boulder clay, which, from its relations and nature, is another example of the Grange clay.

(*c*) *Ladbroke Hill*

At Ladbroke (430595) the superficial deposits are limited in extent. Nine auger holes on two lines of section have been bored, although only no. XIII, figure 5, is illustrated. The drift is located in a channel in the Lias as a height of between 425 and 442 ft. O.D., near the hill-top.

1. *Wolston Series.* Some 9 in. to 2 ft. of stoneless silts form the lowest deposit and are succeeded by 2 to 3 ft. of fine-grained silty sands. The silts are thin but grade up into the sands, which are stoneless with an even, clayey bedding.


KEY
SOIL, SLUDGE, AND SOLIFLUCTION
GRANGE CLAY
BUFF SILTS WITH BOULDER CL LENSES
CLAYEY SAND GRAVEL AT BASE
WOLSTON SERIES
BLUE LIAS CLAY
WEDDINGTON HILL
IX
X
410
400
390
380
370
360
350
420
5
13
6
17
7
12
11
15
16
25
23
22
10
HORIZONTAL SCALE FEET
0
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VERTICAL SCALE 11.X HORIZONTAL

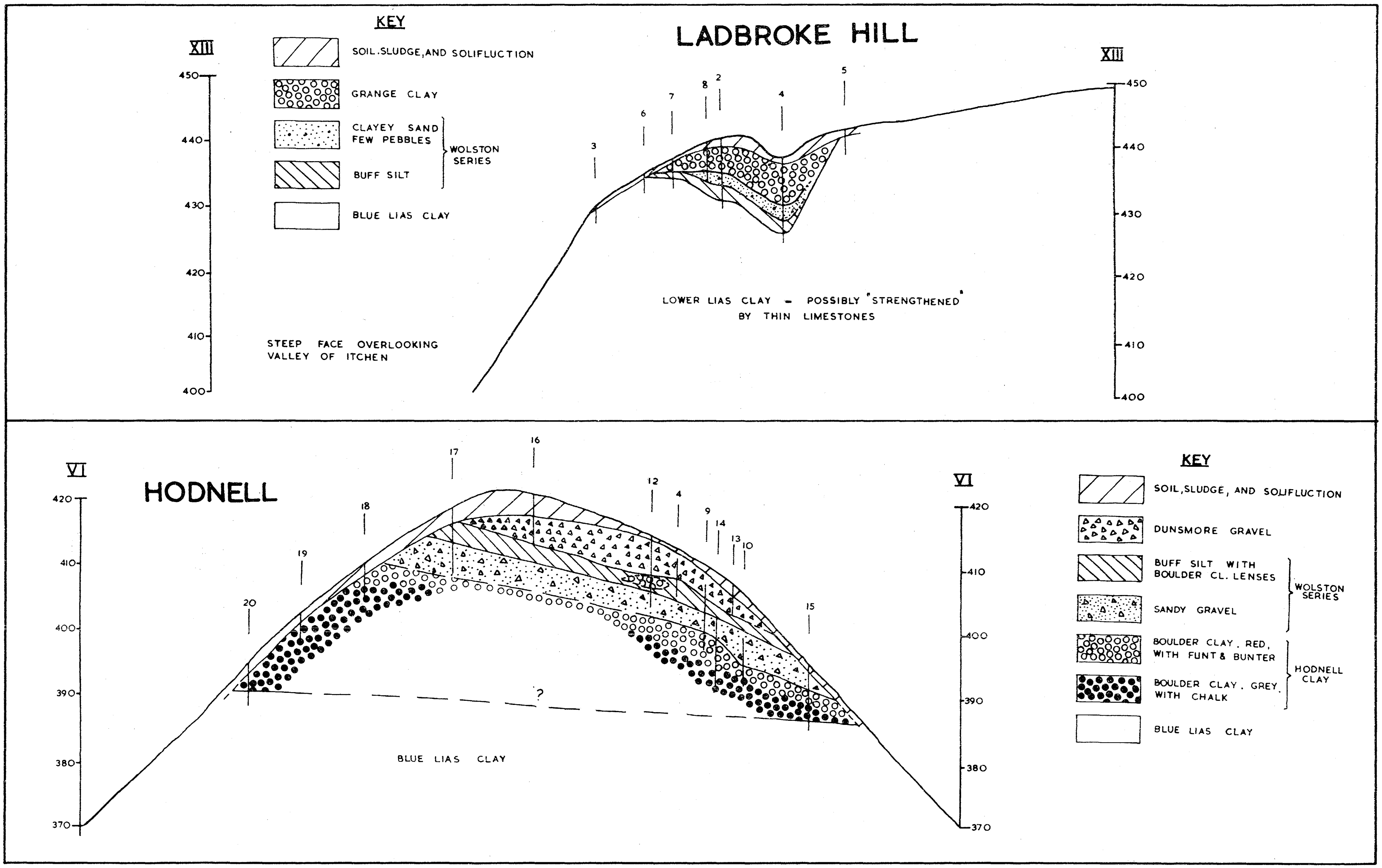

FIGURE 5. Auger traverses.

2. *Grange clay*. The lake deposits are capped by a heterogeneous, gravelly clay with a maximum thickness of 6 ft. The clay is considered to be till rather than solifluction as the hill-top (452 ft.) exposes blue Lias clay while the channel capping is a reddish, sandy clay of Triassic aspect. It contains 56% Bunter, 8% sandstones and 35% local limestone. No flint was found.

It remains to consider whether the greater height of the silts (up to 435 ft. with sands to 436 ft. O.D.), nearly 35 ft. above those located elsewhere, prevents them from being included in Lake Harrison. Their situation in a channel would facilitate damming to a higher level, but the lack of local material in the silts and sands suggests a large body of water. The presence of a boulder clay identical with the Grange clay and the similarity of the silts and sands to those at lower levels, led the writer to include them as part of the Wolston Series although not necessarily the time equivalent of the lower occurrences.

Professor Shotton has located silts up to 431 ft. in the 'Tame Valley Arm' of Lake Harrison (175716),* while Pickering (1957) describes three sets of deposits in the South Birmingham area, marking successive stages of ponding. The lowest 'still-water series' reaches a height of 431 ft. O.D. at Birmingham University (045835).

These occurrences and that at Ladbroke may only indicate high level ponding in 'local' lakes, but the writer feels that the coincidence in height is so great that they must all be interpreted as remnants of a widespread ponding to a minimum of 435 ft. O.D.

(*d*) *Harbury*.

In the Harbury Cement Works Old Quarry (391583), steep faces of interbedded limestones and shales are capped by 20 ft. of drift deposits.

The divisions seen are:

3. *Grange clay*	A fragmental, unbedded, grey-brown boulder clay with red and purple streaks, containing large and small angular and subangular pebbles	10 to 15 ft.
2. *Wolston Series*	(*c*) *Clean sand*: Pebble-free, pinkish buff; horizontal bedding with clayey partings	2 to 2·75 ft.
	(*b*) *Silty Sand*: Fine-grained, pebble-free, pinkish buff, horizontally bedded with 1 in. hard bands cemented by calcite	1·25 to 3 ft.
	(*a*) *Silt*: Fine-grained, sometimes thinly laminated; horizontally bedded; pebble-free; some cemented bands; buff to pink, becoming grey with depth	4·5 to 5 ft.
1. *Lias*	Limestone and shale	50 ft.

The silts have only been seen in auger samples since they are obscured at outcrop by slumping. They rest on the solid at heights from 372·0 to 376·5 ft. O.D. The Grange clay does not appear as a typical till near the junction with the sands, but from 2 ft. above it has a normal heterogeneous aspect. The pebbles were mainly Bunter and local limestones and no flint was recorded although it occurs on the surface of the hill which forms an extensive flat between 400 and 410 ft. O.D.

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* Personal communication of unpublished mapping.

The working quarry at Harbury had superficial deposits capping the north-west face (384589) at two points. The more westerly exposure gave in 1955 the following section through the Wolston Series.

	thickness (ft.)	depth (ft.)	height O.D. (ft.)
			380
9. Soil	2		
		2	378
8. False-bedded orange to pink-brown sands. Clean and pebble-free	9		
		11	369
7. Buff, silty clay	0·5		
		11·5	368·5
6. False-bedded, clean, medium, pink sand; pebble-free	3		
		14·5	365·5
5. Plastic, buff silt; occasionally grading into irregular patches of sand	1·75		
		16·25	363·75
4. Pink-grey, false-bedded silt; very moist and plastic; some lighter, fine sandy partings	1·5		
		17·75	362·25
3. Very moist blue-grey silt, showing yellow laminations near base	1		
		18·75	361·25
2. Irregular junction with occasional pebbly and sandy pockets. 'Old land surface'	0·5		
		19·25	360·75
1. Lias shale; slightly brown and weathered for first few inches; becoming steely-grey with limestones	40+		

The sandy and weathered nature of bed 2 and the top of bed 1 suggests that the transgression by the lake at this height was rapid and that it buried a land surface of Lias. This is of interest when considered in relation to the Hodnell clay which forms the bottom of the Pleistocene sequence less than 3 miles away, and underlines the fact that this latter deposit represents a local 'ice lobe' advance and retreat.

The Harbury deposits suggest that the Hydraulic Limestones formed, in some places, a feature in the pre-lake landscape which was cuesta-form. The sub-drift surface rises from about 330 ft. O.D. at Hunningham (382665) (Shotton 1953) to 357 to 361 ft. in the New Quarry and 377 ft. in the Old Quarry at Harbury, while the Wolston Series thickens rapidly to the north from 9 ft. in the Old Quarry to 17 ft. in the New. To the south-east the pre-lake floor stood between 380 and 400 ft., occasionally rising to 440 ft. O.D. These figures depend on a reconstruction of the shape of the old lake floor from the levels of the isolated hill-top deposits which have survived the deep erosion of the recent drainage (figure 7). An 'Itchen embayment' running southwards was also a feature of the pre-lake topography, as the limestones swing north under Harbury village (375600) where there is only thin drift with a base at 390 ft.

The basal deposit in the New Quarry is a grey-blue silt formed of re-deposited Lias material. The colour is presumably the result of ponding in an area of steep slopes which gave deep sheltered water in which the usual Triassic-derived silt did not form at first. The deposit soon acquires a more normal aspect, becoming a hybrid after 1 ft. and passing up into pink-buff silts and clean sands. Samples from the bottom 2 ft. of the silt have yielded pollen, though the preservation is poor.

(*e*) *Remaining areas.*

The Older Drift has been mapped on eight separate hill-tops. There are no good exposures south and west of the cement works and no augering has been carried out on Christmas Hill Ridge or on the other hillocks in the area. The present drainage has cut deeply into the Lias and Trias and the fierceness of this erosion is shown up by the isolated remnants of what must once have been an extensive and continuous sheet of deposits (figures 2 and 7). The Newer Drift of the river terraces (below) is always divided from the Older Drift, whence it derived much of its material, by a substantial 'solid' step.

(iv) *Terrace deposits and alluvium: Newer Drift*

Bunter and flint pebbles can be picked up practically anywhere in the region of study, but no true terrace deposit has been located upstream south of Long Itchington (415652) where the River Itchen runs off the Hydraulic and White Limestones on to Trias. Down from this point, Avon Terraces 1, 2 and 4 have been mapped, to join on to those recognized by Shotton (1953) below Marton Bridge. Thus a direct correlation has been effected and although no fauna has been recovered, similar climate is assumed to that established downstream.

No. 1 terrace forms extensive gravel-covered flats bordering the alluvium with an extensive development, 5 to 15 ft. above the flood plain, at Long Itchington village. No. 2, similarly developed at a slightly higher level, ceases to be a continuous feature when traced upstream and becomes a series of small knolls 15 to 18 ft. above the flood plain.

The deposits of no. 4 are exposed in an overgrown pit north of Sand Pit Farm (414673), where augering proved sand and gravel between 43 and 59 ft. above alluvium.

(v) *Solifluction and sludge*

On unconsolidated drift there is generally about 5 ft. of heterogeneous veneer and it is difficult to know to what extent this should be considered the result of sludging or solifluction. The broad term 'Head' as defined by Dines (1940) could be used as it does not necessarily imply cold conditions. Inclusions within the Dunsmore gravel at Wormleighton and in pebbly clay overlying the limestones at Long Itchington show a tumultuous relationship which suggests contemporary solifluction festooning (cryoturbation), but this is not easily dissociated in time from later cold periods, as, for example, that of the end deposits of Avon no. 4 terrace or of Avon no. 2 (Shotton 1953).

(vi) *Summary*

The general succession of depositional events in the Itchen valley appears to have been as follows:

1. Advance and retreat of an ice lobe depositing the Hodnell clay. This deposit is not considered to be the equivalent of Shotton's Bubbenhall clay as it is not weathered and contrasts completely in lithology, and because similar chalky till rafts occur in the overlying silts.

2. The main advance of combined north-west and east ice that had been preceded by the Hodnell clay ice lobe gave rise to the formation of Lake Harrison as postulated by Shotton. The lake increased in depth until its waters flooded the pre-lake landscape of the Itchen valley which seems to have stood between 380 and 400 ft. over much of the south of the area. Advance of the ice and increase in depth of the lake were in a series of stages, but the Harbury evidence suggests that quite sudden increases in water level took place, leaving no time for erosion of the existing surface or for deposition of coarse marginal deposits. Local gravelly-sand, Liassic silt or pink to red Triassic silt may form the basal lake deposit which rests either upon a surface of slightly weathered Lias or of Hodnell clay. Rafts of till occur within the silts.

3. The level of the water surface rose to a maximum of at least 435 ft. The contrast in height of the sub-drift floor north-west and south-east of the outcrop of the Hydraulic Limestones suggests that they formed a cuesta-like feature in the pre-lake topography. The deposits south-east of this escarpment were laid down in a shallow, possibly late stage of ponding, on topography having a shelf-like relationship to the main sub-drift valley to the north-west. On the shelf a thinning of the still-water deposits is observed together with a lithological change. Horizontally bedded sands occur more frequently on the shelf although clays and silts remain characteristic of the lake deposits.

4. The limestone cuesta was responsible for cutting out the Baginton-Lillington gravels and Baginton sands which occur beneath the Wolston Series in the deeper part of Lake Harrison (Shotton 1953) but which have not been recognized south-east of the escarpment. This raises the problem of correlation between deposits of the valley and the shelf. The Baginton-Lillington gravels and Baginton sands seem to be the time equivalent of erosion and possibly of the Hodnell clay. However, it is more likely that by the time this clay lobe had invaded the Upper Itchen the main ice had completed the blocking of the lower Proto-Soar. The shelf-lake could not be established until the water level was well over 380 ft. O.D. and probably by this time much of the Lower Wolston Series had been deposited. The still-water deposits of the shelf are considered as equivalent to part or the whole of the Upper Wolston clay. However, ponding may have been so rapid that the Itchen deposits form a condensed sequence which is the time equivalent of the thick Wolston Series of the trough.

5. Gradual advance of the ice sheet across the whole area and across the deposits of its own lake sealing them in places or churning them into the Grange boulder clay.

6. With retreat of the ice, rapid erosion was initiated, cutting the courses of the present streams and depositing newer drift. An attempt to decipher the manner and time of this erosion forms the next part of this work.

C. MORPHOLOGICAL FEATURES

(i) *Introduction*

Geomorphological theory has for long been divided into two main schools, one represented by W. M. Davis and his supporters and the other by the theories of Penck (1953) with elaboration by Bryan (1940), Meyerhoff (1940), and Wood (1942). The degree to which they are mutually exclusive has been matter for much debate, but the writer feels that elements of the processes of both schools can be found in the area studied.

The relations of river to rock in the area are interesting as there is a superimposed drainage pattern and 'the lie of the hills and valleys appears to be totally independent of the distribution of the clays and limestones' (Wilson 1870).

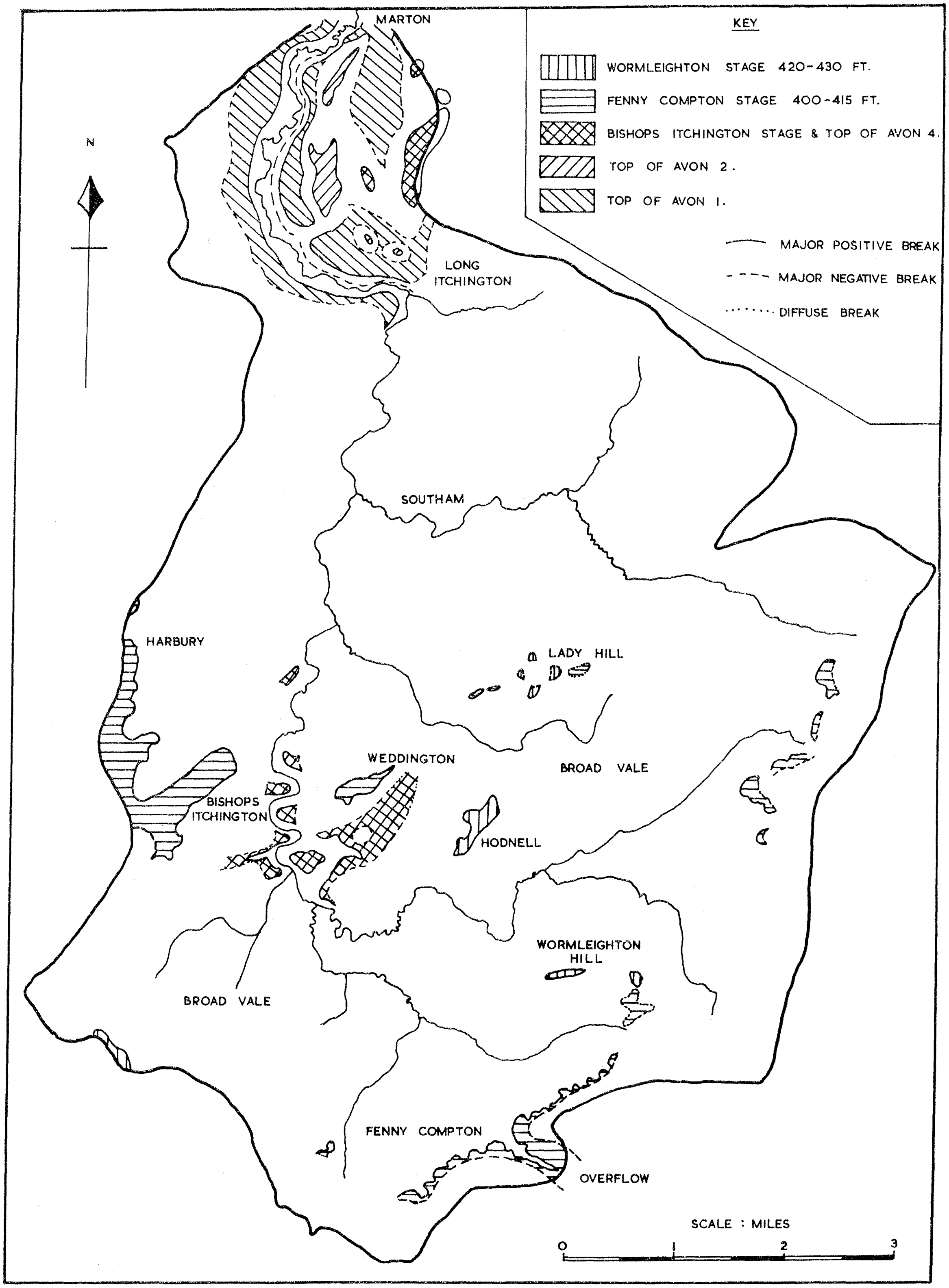

Figure 6. Morphological features of the River Itchen basin.

(ii) *Wormleighton stage*

The flats that have been grouped into stages are shown in figure 6. The highest stage has been named from the first occurrence observed, at Wormleighton Hill. The flats vary from 430 to 415 ft. O.D. and have been located on several isolated hills and ridges north-west of the Middle Lias scarp. No flat of this stage has been found cutting into the sharp rise from the vale to the Middle Lias and no vestige of the stage has been found below 415 ft. O.D.

The stage truncates drift at Wormleighton, Hodnell and Ladbroke Hill and Lower Lias clays and limestones on Christmas Hill Ridge and at Ladbroke Hill. The drifts include the Grange clay, Dunsmore gravel and Hodnell clay, but while the Wolston Series may also be affected, no example has been found where it occurs at the flat surface. There is a sharp contrast between these gentle hill-top features and the surrounding steep slopes (figure 7). The mode of formation of the Wormleighton Stage is obscure, but as it is closely related in height and occurrence to the Fenny Compton Stage it probably had a similar origin.

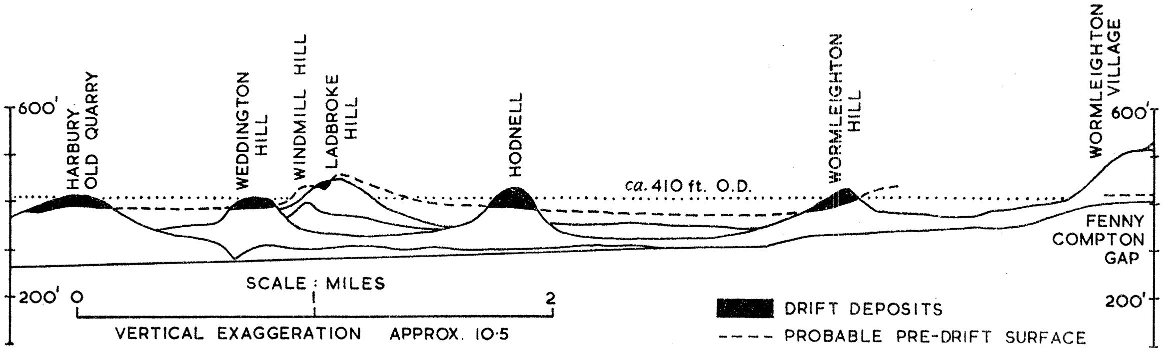

FIGURE 7. Projected cross-sections—Lower Lias vale.

(iii) *Fenny Compton Stage*

To the north-west of the Middle Lias cuesta this is the equivalent of the 400 ft. lake bench of Dury (1951, p. 167) who described the feature as 'flattened spur-tops and narrow ledges, up to a quarter of a mile wide'. Augering by the writer failed to establish any hard band associated with the feature. Indeed, from the continuous nature and height of the bench for about 30 miles from north-east to south-west the writer agrees with Dury that the feature is quite independent of lithology.

The author can take no credit for recognizing the feature, but it was mapped in, with others, in the field on the scale of 6 in. to 1 mile for the sake of completeness and to avoid differences in recognition in such a subjective study as geomorphology. Some of the benches mapped by Dury have not been located and some have been included within the Wormleighton Stage. The positive break of the feature was always close to 400 ft. O.D. and the negative seldom above 412 ft. O.D. The feature has been traced through the Fenny Compton gap and evidence from north and south of the col supports Dury's suggestion that the gap acted as a spillway. As the negative break denotes most accurately the height of the lake, 410 ft. is taken to indicate the approximate water level although solifluction may have obscured the exact height.

In addition to its occurrence as a 'back and bench' feature, the stage has been located on drift-capped hillocks in the vale. North of Piper's Hill (377574), Christmas Hill descends to about 415 ft. O.D. and bifurcates to continue for almost a mile as flat-topped spurs at a height of 410 to 400 ft. O.D. with drift at the surface. It seems impossible that the flat is merely the result of horizontal deposition of boulder clay and therefore it is included as Fenny Compton Stage, eroded by a lake in which the crest of Christmas Hill was an island. Further 'off-shore' fragments of the bench are preserved at Windmill Hill, Ladbroke (424592), cut in Lias and at Weddington Hill (407578) on Grange clay.

It remains to discuss: (*a*) the relation of the Fenny Compton Stage to the Wormleighton Stage and (*b*) the relation between both these features and the Lake Harrison deposits.

(*a*) The Fenny Compton Stage has limits of 400 to 412 ft. O.D. and although the positive break may have been lower before trimming by erosion, the lowest point of the Fenny Compton gap is 402 ft. O.D. The presence of still-water deposits up to 435 ft. O.D. shows that Lake Harrison formerly 'held water' to a much greater height than indicated by the Fenny Compton bench and spillway, which must either have been dammed by ice or have formed a wind gap at a higher level. Several spillways may have operated in turn to discharge the Lake Harrison water and their level, and that of the lake, would fall rapidly under the fierce erosive action. With falling water level, hills of Lias and drift would be exposed and subjected to wave and ice-floe action.

The lake would give rise to rapid undercutting and slumping as in present-day Lias cliffs, and a wide bench would be formed which would remove any higher benches. With the end of lacustrine conditions the base level of erosion would revert to the stream and the bench of the last, Fenny Compton, stage would remain as a pronounced feature passing into and through the gap. Even accelerated movement under solifluction would be unlikely to obliterate the signs of wave action. Thus, there is an explanation of the Wormleighton and Fenny Compton features with the former as surviving remnants of a higher earlier stage of the lake which, with falling surface level, cut the latter.

(*b*) Shotton (1953, p. 247) commented upon the correspondence between his mapping of lake silts up to about 410 ft. O.D. and Dury's lake bench at 410 ft. O.D., both associated with the Chalky Boulder Clay. However, on the present evidence, if the cut-feature and still-water deposits belong to the same lake, the following difficulties have to be faced:

(i) The spillway from Lake Harrison must have eroded from 435 to 410 ft. O.D. during the advance of the ice responsible for the Grange clay, or a change in the conditions of damming caused a lowering of the lake surface despite the general ice advance.

(ii) The Grange clay must have been laid down as a level and uniform sheet which mirrored the benches upon which it rested.

(iii) As the boulder clay above the Wolston Series continues as far south as Moreton-in-the-Marsh, the ice must have travelled 20 miles to the south-west without destroying or obscuring the bench.

(iv) The Wormleighton and Fenny Compton flats truncate drift ranging from the Hodnell to the Grange clay.

The sharpness and drift-free nature of the Fenny Compton flats shows that they belong to a phase which is later than the overriding of the earlier lacustrine deposits by the

Grange clay ice sheet and the benching is to be associated with the retreat of this ice. The evidence from the Wolston and Dunsmore deposits is of an ice advance culminating in coarse outwash gravel and bottom moraine (Shotton 1953, p. 253) but conditions still favoured ponding during the initial retreat stages. In East Warwickshire a shelf again existed in the lake which became progressively shallower and where successively lower stages of benching and erosion were dominant. It is possible that still-water deposits were also laid down at this time but they would be instantly eroded when further retreat initiated the present drainage pattern in the hollows of the undulating lake floor. Only the interfluves now retain Older Drift, and they seldom rise above the 410 ft. level of the final Fenny Compton Stage, while the Wolston silts owe their preservation to a protective cap of Grange clay.

The evidence for both an advance and a retreat stage of ponding is more clear in the Moreton area, but it was first suggested by the Itchen mapping and therefore the evidence of each region finds confirmation and support in the other.

(iv) *Stages of the River Itchen*

There is a pronounced series of levels between 330 and 300 ft. O.D. which grades into the valley floors of many of the Itchen tributaries. These plunge into the main stream almost as 'hanging valleys' and valley-in-valley relationship is well seen near Bishops Itchington. The upper feature has been named the Bishops Itchington Stage. Further downstream the first flats below the Older Drifts form the top of the no. 4 terrace gravel already described, with a positive break at about 54 ft. above the river, rising to 59 ft. on the hill-top. When plotted on a profile this can be seen to be the downstream equivalent of the Bishops Itchington Stage.

Following the ice retreat, melt-water commenced excavating the vale behind the Hydraulic and White Limestone barrier and the valleys were maintained by the decreasing ground water supply as the hill-top drift 'reservoirs' were eroded. Slope retreat was rapid across the clays and only isolated patches of drift now remain, usually on hills strengthened by limestones.

In the Lower Itchen, many of the problems, including that of the numerous dry through valleys, can probably be related to superposition upon a series of permeable, resistant limestones within impermeable and easily sculptured clays and shales. The angularity of the course may be the result of the river differentially eroding along joint planes and the general course of the Itchen seems to be associated with a large-scale fault. This line may have been followed by a 'pre-lake' Itchen as the angle it makes across the limestones and with the main Avon valley suggests a former tributary of the Proto-Soar. The problem of the large spread of no. 1 terrace at Marton Moor remains (Shotton 1953).

The limestones have functioned as a barrier, and knick-points, probably initiated by separate eustatic movements, have had their migration slowed down and their associated erosion flats and terrace deposits curtailed upstream by a geological formation. The Itchen has continued downcutting and maintained its superimposed course across the limestones. The river has probably cut down below no. 1 terrace level well into its headwaters, but slope retreat has been delayed in the limestone area. Wash slopes have developed following rapid retreat of clay faces but steep, gravity slopes remain on the limestones.

(v) *Summary*

The erosion history can only be elucidated for a limited number of the features mapped. Some of these indicate the presence of a glacial lake and spillway which has resulted in a useful 'time-line' etched into the wall of the Lower Lias vale. The present relationship of the landscape to the distribution of the resistant and superficial strata reflects superimposition but present-day processes show an increasing adjustment to structure.

D. CHRONOLOGY

The accompanying table 2 is an attempt to combine the depositional and erosional sequences. The drainage basin and the dominant process of erosion are shown to

TABLE 2. PLEISTOCENE EVOLUTION: RIVER ITCHEN

glacial periods	deposits and associated events		conditions	morphological features and events	
post glacial and last glacial	sludge	alluvium Avon no. 1	river		flood plain top of no. 1 terrace downcutting
	solifluction	Avon no. 2			top of no. 2 terrace downcutting
last inter-glacial		Avon no. 4: gravel *ca.* 16 ft.	river	Bishop's Itchington Stage	and top of no. 4 terrace downcutting *ca.* 100 ft.
penultimate glacial	solifluction	end of ponding fierce outwash and erosion	river		erosion by melt-water present drainage pattern established
					sudden end of conditions favouring damming
		lacustrine conditions again established: no remaining deposits located	glacial lake	Fenny Compton Stage	lake bench at 410 ft. O.D. spillway into Cherwell at Fenny Compton
					lake level falling
				Wormleighton Stage	lake at 420 to 430 ft. O.D.
		ice retreat commences			retreat of ice: conditions again favour damming
		Grange clay	ice sheet		ice present throughout Itchen basin
		Dunsmore gravel			
		Wolston Series Hodnell clay	glacial lake	Lake Harrison	lake rises at least to 435 ft. O.D.
		ice advance			advance of ice
penultimate interglacial		erosion to pre-drift (pre-P.Gl.) floor of gently undulating nature	river		rivers flowing through gently undulating landscape: cuesta form in Itchen valley

have changed as deposition and erosion by ice sheets has been replaced by fluvial action.

The dating of the deposits follows that of Shotton (1953, p. 238). The advance of the combined chalky boulder clay and north-west ice sheets and their associated deposits is of Penultimate Glacial (Riss, Saale, Drenthian, Catuvellaunian, Gipping) age. This dating has been further supported by recent work on peaty silts at Nechells, Birmingham (Duigan 1956), a deposit earlier than this glaciation and yielding a pollen sequence similar to part of that characteristic of the Great Interglacial at Hoxne (West 1956). The last stage of the Older Drift was followed by excavation of the present drainage pattern and deposition of the Newer Drift.

The climatic sequence is picked up again at no. 4 terrace level on the Avon which has been correlated by direct mapping with the Itchen. No. 3 Avon terrace, which has yielded *Hippopotamus*, is thought by Shotton (1953) and Tomlinson (1925) to grade up into the lower part of no. 4 which has produced *Unio littoralis* and *Corbicula*. Both terraces suggest warmer climate. The top of no. 4 has suffered cryoturbation and at one pit has yielded the Siberian form of *Elephas primigenius* and heralds the cold conditions that had become fully established by the time erosion had reached the level of no. 2 terrace. This has yielded *Elephas primigenius*, *Tichorhinus antiquitatus* and *Rangifer tarandus* (Shotton 1953, p. 233). The no. 2 level of the Avon grades into the main terrace of the Severn which Wills (1938) shows to be the downstream equivalent of the Irish Sea glaciation.

Thus, a warm period of aggradation with *Corbicula* and *Hippopotamus* is separated by erosion from the deposits of the Penultimate Glaciation and those of the Last Glaciation (Würm, Weichsel, Tubantian, Cornovian and Cymrian). This includes various re-advances following the maximum Irish Sea advance and their time equivalent in river gravels with cold fauna.

III. EAST OF THE FENNY COMPTON GAP: THE RIVER CHERWELL

> ...ice-water streams,...accumulated in small lakes between the northward slope of the cuesta and the southward slope of the ice, and ran over the lowest depressions in the cuesta crest...it will not seem unreasonable to regard the Cotswold ice-water streams as competent to produce a significant modification of the pre-existent valleys.
>
> W. M. Davis (1910, p. 151).

(i) *Introduction and Literature*

It is sufficient to treat the area as a simple south-east dipping structure of Jurassic rocks ranging from Lias to Oxford clay. The Middle Lias is an important feature-former and the Great Oolite, with the Cornbrash, acts as a large block of resistant strata. The Cherwell and Evenlode come within the scope of the classic geomorphological papers of W. M. Davis (1895, 1900, 1910) in which the theory was developed of consequent, dip-slope streams originating upon a formerly more extensive cover of resistant strata. Their underfit nature was accounted for by removal of headwaters through capture by subsequent streams excavating rapidly along the strike of the weaker beds which were, in this case the Keuper and Lower Lias clays. Buckman (1899) and Lake (1934) made theoretical reconstructions of former drainage patterns which linked the Cherwell, Evenlode, Windrush, etc., into a mesh which reached as far as North Wales. A more limited reconstruction was suggested by Linton (1951).

It appears that the wind gap accounted for in the capture theory may have been much modified by ice and water since the time of beheading, and if loss of headwaters took place it must have been considerably before the Penultimate Glaciation. Dury (1954) related the underfit state to a recent regional climatic change reducing the run-off.

Literature on the superficial deposits is limited and most references date from the nineteenth century. As early as 1821 and 1823, Buckland speculated on the origins of gravels, which his map shows extending down the Evenlode and Cherwell, and invoked a diluvial explanation for the movements involved. Green (1864) mentions thick boulder clay draping the north-east part of the area and Woodward (1897) records chalky boulder clay and flinty gravels plugging the stream heads between Catesby (525595) and Helmdon (587426). Although the Evenlode has received attention since this date, the upper Cherwell has been neglected.

(ii) *Morphological features*

(*a*) *Upland Stages*

Away from the main valleys, the area is an undulating upland which descends to the south and east from over 700 ft. at Edge Hill, to below 400 ft. near Rousham and terminates at about 330 to 350 ft. above the Oxford clay vale near Begbroke and Bletchington. As the feature has a diversified surface and has been dissected by stream erosion, it is in no sense one flat, neither does it form the dip slope of any one formation although the Marlstone is coincident with it in the north-west where the land rises to Edge Hill. The positive break above the trough made by the Cherwell can be accurately mapped although its height may have been a little obscured as the cap rock can be seen to ‘drape the spurs’. The term Upland Stages is used as it seems that more than one period contributed to its formation.

(*b*) *Stages connected with River Cherwell* (*figures* 1, III *and* 2)

Within the valley the heights of the positive and negative breaks bounding flats are plotted on the long profile, figure 8. Some flats can be shown to have a close association with hard bands, but this does not of itself account for flat formation but rather for its preservation. The river must have been in part responsible for the stripping but the hard bands would in turn act as a local base level.

(*c*) *The long profile* (*figure* 8)

An extensive series of flats occurs near Claydon (457601) from 405 to 410 ft. O.D. to about 370 ft. O.D., rising gently towards the col. Their height and disposition invites correlation with the Fenny Compton Stage, and augering failed to locate any hard band. There is a sharp contrast between the open, upper level and the present steep-sided valleys occupied by insignificant streams. The evidence supports Dury’s suggestion of the gap as a spillway with a large volume of water from the Fenny Compton Stage lake giving rise to the broad upper valley. The feature is probably composite with an early, high course to the west of Claydon and a lower, later diversion to the east. It becomes less extensive southwards but can be traced to Clattercote (466487) where it is seen as isolated knolls.

For the next 10 miles (13 miles south)* there is scarcely a flat within the trough more than 35 ft. above the flood plain but there is a pronounced series from 10 to 25 ft. above the river from 3 to 15 miles south of the gap. This will be termed the Begbroke Stage. Near Banbury (9 miles south) the trough edge commences to descend from 400 ft. (100 ft. above the river) and at 13 to 16 miles south is only 40 to 50 ft. above the flood plain. This corresponds to the dip of the Middle Lias ironstone but the bed does not again become a feature-former although it persists another 6 miles to Rousham. This absence of benches controlled by lithology may be the result of faulting plus rapid thinning. The manner in which the Middle Lias marlstone has been stripped to a point 40 ft. above the river but only slightly below that level suggests that the flats are due to corrasion controlled by a long-standing base level. Upstream, flats on the softer, blue and sandy clays have not been preserved. An exception is the preservation of flats and gravels from 12 to 25 ft. above the flood plain north of Kings Sutton at 497367, in an old meander cut-off. The marlstone may have preserved evidence of a former river level at some points, but elsewhere it has concentrated later erosion by 'canalizing' the river within a trough.

In the next 4 miles (16 to 20 miles) flats occur from 35 to 50 ft. above the flood plain which do not correlate with hard bands although some with a basis of shelly limestone occur at 80 to 90 ft. A large low level flat with pebbly sandy soil occurs south-west of Somerton (487285) within a loop of the Cherwell. The positive break is at 12 ft. and the diffuse negative break at 30 to 35 ft. above the flood plain.

The stretch from Upper Heyford (498260) to Nethercott (480208) (20 to 24 miles) is a repetition of the trough with again an absence of flats. The positive break of the Upland Stage descends from 130 to 160 ft. to form a 100 ft. high wall of the Cherwell Gorge where the valley crosses the Great Oolite and Cornbrash. The gorge is narrower and deeper than that through the Middle Lias and the only extensive flat is at Rousham (476237) from 25 to 55 ft. above the flood plain. No thickness of gravel was located although patches of sandy, pebbly soil occur towards the river. The feature suggests a large meander loop. The flat slopes from north-west to south-east, and its higher portion is just below the marlstone outcrop and cut in clay. It seems that instead of becoming incised, the river found it easier to erode downstream and migrated to the south-east off the resistant strata, leaving a large gently sloping flat.

The 4½ miles from Nethercott to Hampton Gay (485165) (28 miles south) marks the end of the writer's detailed mapping. It is the area of overlap with the work of Pocock (1908), Sandford (1924, 1926), Richardson, Arkell & Dines (1946) and Arkell (1947*a*), and the area in which the Oolite limestones and Cornbrash are at river level. The Cherwell traverses the outcrop as a series of incised loops within a deep gorge whose southern limit is the point at which the river runs from the limestone on to the clay vale. The flats of the Upland Stage here include some very extensive features developed upon Hanborough terrace gravels and Oxford clay. In the valley, flats are represented only as tops of spurs of incised meanders as at Tackley (487200 and 477193) (Arkell 1947*a*, p. 212).

The tops of the terraces mapped by Pocock, Sandford and Arkell are plotted on the long profile, figure 8, to show their relationship to the erosion stages. The range of height of the flood plain has been plotted for comparison purposes and reflects the rock resistance,

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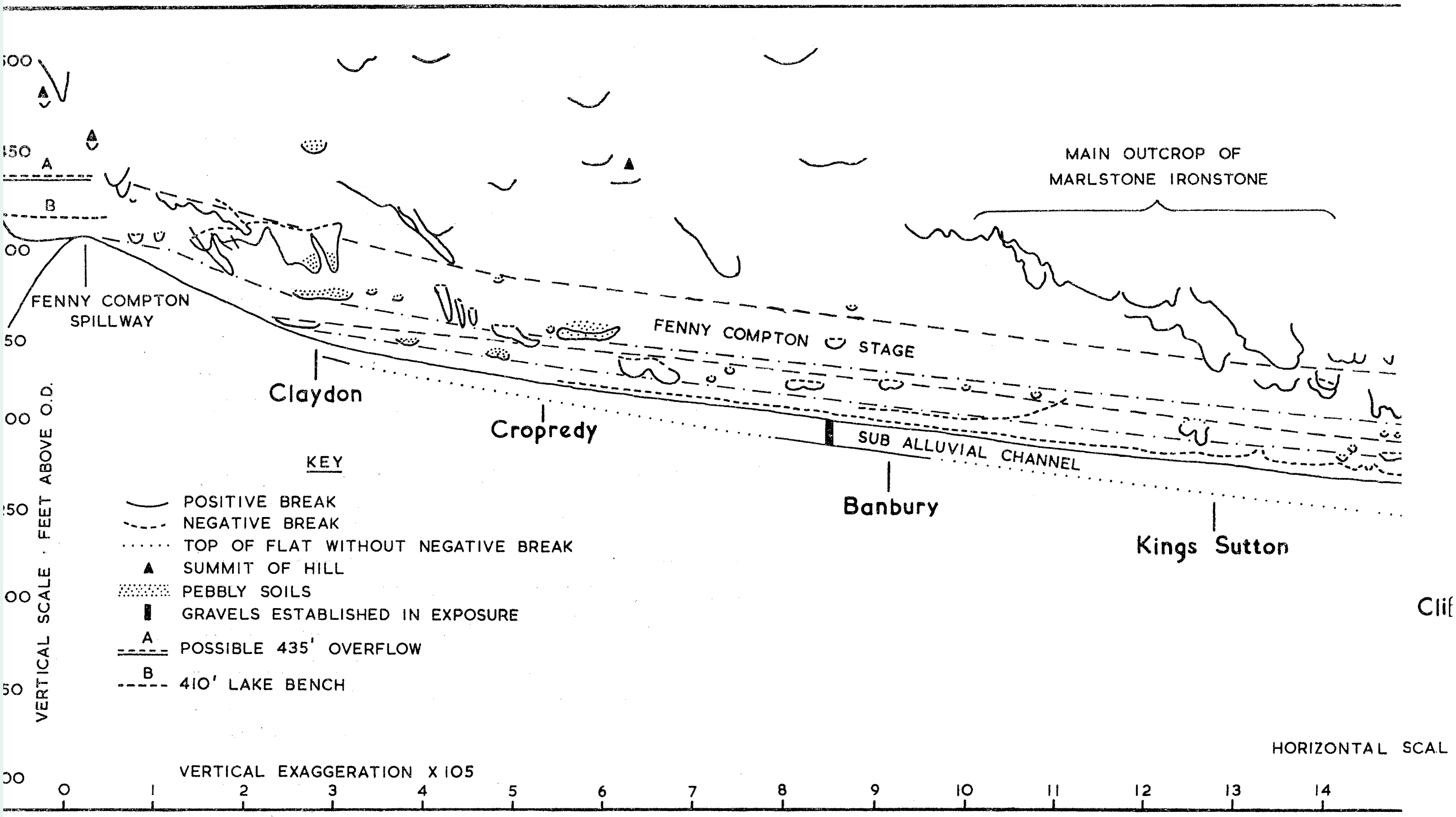
* References are to miles along the centre of the flood plain south of the Fenny Compton gap.

becoming small in the gorge sections. Extensive flattening at the Begbroke Stage has resulted in the removal from the valley of most of the higher stages which only remain in protected situations on the lee side of hillocks as at the Wolvercote plateau where an extensive flat of the Fenny Compton–Wolvercote terrace stage exists to the south of an Oxford clay knoll.

South of Thrupp (483159) the flood plain becomes extensive and the river loses its incised form, meandering in a wide vale. The Oxford clay acts, and has acted in the past, as a base level for the Cherwell, and over-deepening is seen in the steepening of the flood-plain and terraces as they pass on to the clay. The up-dip limit of the clay outcrop has migrated southwards over 4½ miles since Hanborough terrace times, which is important when considered in relation to the 'strike' stream of the upper Thames.



The base level of the clay vale is itself controlled by the Goring gap and so must reflect the erosion regime of the whole lower Thames, but would respond to changes more rapidly than the harder rocks upstream where increased resistance results in cramping of stages. There would be a considerable time lag between the initiation of a lower Thames erosion stage and its arrival in the Oxford area following a migration of 100 miles.

(*d*) *Summary*

It is difficult to join the various flats into a profile owing to gorge-like sections where evidence is absent. However, stages are present at similar heights upstream and downstream from the gorges. The following conclusions are drawn from the profile:

1. The top of the Hanborough terrace is associated upstream with the Upland Stages. At this period the Oxford clay was at river level, 4½ miles farther up-dip than at present.

2. The Fenny Compton Stage is complex. A smooth curve can be drawn joining most of the positive breaks, but it is more difficult to join the negative breaks although assistance is available from spur terminations. For 5 miles downstream from the col the feature is contemporary with and grades into the Fenny Compton Stage of Lake Harrison. The tracing of this level downstream is difficult, but a line approximately parallel to the river is suggested, approaching gradually upstream towards the flood plain. It appears to link with the top of the Wolvercote terrace.

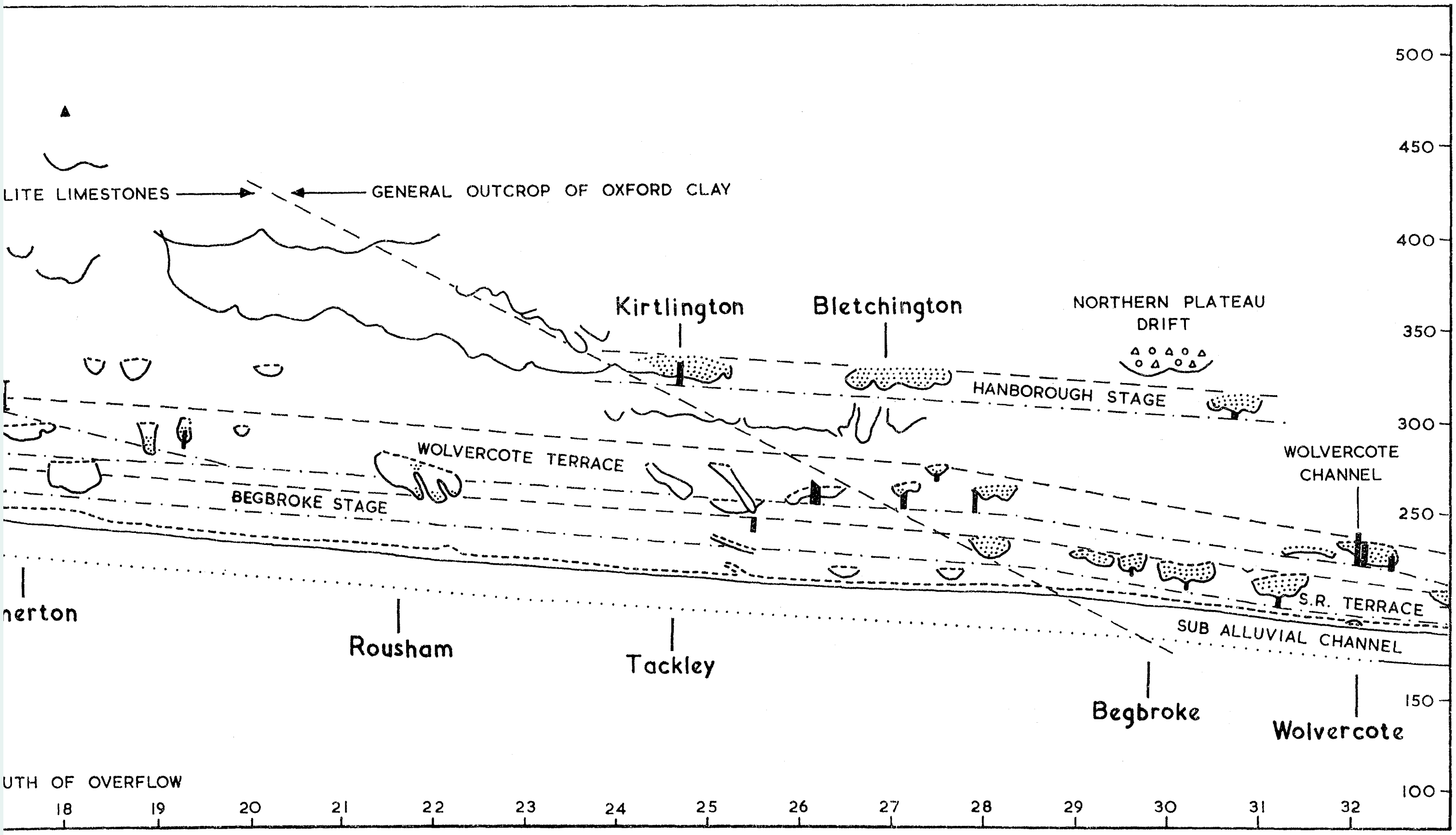


FIGURE 8. Long profile of the River Cherwell.

3. This tentative correlation is strengthened by the fact that a lower set of flats occurs consistently in the sections between the gorges. It has been termed the Begbroke Stage, as extensive flats occur near Begbroke (480135). It grades into the top of the Summertown–Radley terrace and remains sub-parallel to the flood plain.

4. The parallelism of stages above and below the Fenny Compton level suggests that the lake overflow water must have entered the Oxford district at approximately Wolvercote terrace height. The Oxford area is both complex and critical as the meeting place of climatic and eustatic influences.

(iii) *Superficial deposits*

(*a*) *High level deposits*

1. *Northern Drift.* This occurs sporadically on the upland in the south of the area as the Plateau Drift of Sandford (1924, 1926). It is generally 'only a few feet thick: a very heavy tenacious, ferruginous clay with boulders and pebbles. It is entirely disordered' (Sandford 1924). Where seen by the writer at Cumnor Hurst (476043) and poorly exposed at Bladon Heath and Begbroke Wood (465134) it had the appearance of a till and the presence of flint and absence of chalk suggested decalcification. The flint was patinated and shattered and frequently white and amorphous throughout. The former more extensive existence of Northern Drift is proved by the materials involved in the solifluction found capping later terraces.

2. *Chalky Boulder Clay.* The ice, at its maximum, terminated near the Cherwell and thick boulder clay can be traced north-west of Brackley (586370) and then west towards the Cherwell catchment, plugging the eastern headstreams, before swinging southwards as the Avon Valley–Moreton lobe.

(*b*) *Solifluction deposits*

(i) *At higher levels.* The accompanying table, 3*A*, shows pebble counts from solifluction deposits capping terrace gravels at Somerton (490294, probably Wolvercote terrace), Gibraltar Quarry (478187, joints in the limestone and capping Wolvercote terrace), Kirtlington (496199, Hanborough terrace) and at Wolvercote (500104 on Wolvercote terrace and 498106, near Wolvercote Channel).

The deposit is almost entirely non-calcareous and composed of rocks foreign to the area with the exception of ironstone.*

In joint fillings at Gibraltar this numbered:

(*a*) 1026 fragments between $\frac{1}{4}$ and 1 in. out of a total of 1326.

(*b*) 519 fragments of *ca.* $\frac{1}{3}$ to $\frac{3}{4}$ in. out of a total of 659.

The ease with which the ironstone became broken into numerous sub-angular pieces overshadowed counts of more resistant and larger pebbles. As the ironstone percentage varied from 21 to 79, a further table (3*B*) was constructed without ironstone and with Bunter, sandstone and flint shown as a percentage of the remainder. There was a remarkable similarity between the four sites, with 57 to 67 % flint, 22 to 32 % Bunter and 5 to 9 % sandstone. Most of the pebbles were worn and the flints were frequently shattered, with a deep patina and many white and amorphous throughout.

The make-up is similar to that of the Northern Drift, evidence of whose former more widespread distribution is found on flats and within joints, where the gentle slope or protected situation has preserved a solifluction remnant. Some decalcification of oolitic terrace deposits has also occurred and white, soft and rotten pebbles can be found just beneath the solifluction. The joint fillings at Gibraltar show a pebbly clay lining to the cavity, enclosing a sandy gravel core, and both have identical constituents (counts 5 and 6) although sorted into grades. At Gibraltar the Wolvercote gravel backs against the

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* Low percentages of Jurassic material were recorded in only three samples, all from Gibraltar Quarry. Two were from joint fillings in the oolite and even here the angular limestone element was at its maximum only 2·75 % of the total. The third occurrence was near the transition to oolitic terrace gravel and was only 0·32 %.

oolite and a sludge of oolitic coombe rock has been festooned and intercalated with the ferruginous terrace capping. It seems that both solifluction and decalcification have taken place although the former is responsible for the thick capping of the oolitic gravels.

(ii) *At lower levels.* The Begbroke Stage and the Summertown–Radley terrace lacks the thick solifluction deposits of higher levels although festooning occurs in nearly all exposures (Sandford 1924; Arkell 1947*a*, p. 258). Decalcification by solution has also been more active on this terrace and at Begbroke the writer observed small (2 to 3 in.) incipient solution pipes of ferruginous material. The bedding of the terrace gravel could sometimes be traced through the pipe (Richardson *et al.* 1946, p. 120).

TABLE 3. SOLIFLUCTION MATERIAL: RIVER CHERWELL

A. Percentage pebble counts

locality / rock type		Somerton	Kirtlington			Gibraltar				Wolvercote	
		1	2	3	4	5	6	7	8	9	10
Bunter	foreign	17·3	15·4	19·0	12·4	6·8	6·0	20·0	3·60	19·0	25·5
sandstone and grit		7·0	2·5	4·5	7·0	1·8	0·5	8·4	—	6·0	1·4
chert		3·85	—	—	1·1	—	0·15	—	—	—	5·0
flint		48·0	27·0	55·0	55·4	13·6	12·0	42·0	4·25	40·0	40·0
ironstone		22·5	54·5	21·5	24·5	77·0	79·0	29·0	92·0	33·0	27·0
jurassic limestone		—	—	—	—	0·5	2·75	—	0·32	—	—
others		1·2	0·5	—	—	—	—	—	—	2·0	0·7

B. Selected pebble counts, neglecting ironstone

	1	2	3	4	5	6	7	8	9	10
Bunter	22·3	33·0	24·3	16·2	30·0	28·0	29·0	44·0	28·3	36·0
sandstone and grit	9·1	5·5	5·7	9·3	8·0	2·2	11·8	5·5	9·0	2·0
flint	62·0	58·0	70·0	74·0	60·0	56·0	60·0	52·0	59·5	56·0

(*c*) *Terrace deposits and alluvium*

Between Fenny Compton and Tackley (485195), a distance of 25 river miles, the valley is remarkably free from terrace deposits. The first appreciable example is near Somerton ($17\frac{1}{4}$ miles). It caps a knoll, rising from a flat 40 to 41 ft. above the flood plain, to a summit 72 ft. above the flood-plain. In an overgrown pit the following sequence was established:

		thickness (ft.	in.)	height (ft.) O.D.	above flood plain
				324	72
hill-top	4. sandy ferruginous soil: many flint and Bunter pebbles not seen	*ca.* 6	4		
trench	3. Solifluction: ferruginous sandy and gravelly clay: many flint and Bunter pebbles	2	8	315	63
	2. Sharp junction: sub-rounded oolitic gravel with numerous foreign pebbles	4	0	311	59
auger hole	2. cont: gravel with flint, Bunter and oolite. Becoming moist and clayey	3	0	308	56
	1. impermeable Liassic clay	1	1	307	55

The lower deposit (2) is a terrace gravel similar to those well documented farther downstream. Gravels also occur, without exposure, on spurs cut by the railway 1½ miles south of Somerton, from 45 to 55 ft. above the flood-plain.

On the spur of the Tackley meander loop (472188) the pit recorded by Arkell (1947*a*) is now overgrown. Just downstream, terrace deposits thickening towards the river occur in the Gibraltar Quarry. A typical sequence follows.

	thickness (ft. in.)	depth (ft. in.)	height (ft.)	
			O.D.	above flood-plain
			265	51
4. soil and sub-soil	1 6			
		1 6	263·5	49·5
3. solifluction	5 6			
		7 0	258	44
2. water-worn mixed oolite and ironstone gravel with foreign pebbles	2 2			
		9 2	256	42
1. massive oolitic limestone				

Downstream the terraces have been mapped by Pocock (1908), Sandford (1924, 1926), Arkell (1947*a*), Dines (in Richardson *et al.* 1946), and their climatic sequence outlined from the evidence of flora, fauna and artifacts. The writer has little to add but the terraces are included in figure 8.

At Wolvercote a large spread of terrace gravel occurs to the south-east of a curved ridge of Oxford clay which rises to 60 to 65 ft. above the present flood plain. In a tentative survey of the flat, which has a negative break at about 50 ft. and a positive break at 35 ft. above the flood-plain, the writer chanced upon a temporary exposure (500104):

	thickness (ft. in.)	depth (ft. in.)	height (ft.)	
			O.D.	F.P.
5. tarmac	3		235	45
		3		
4. made and disturbed ground passing into loamy clay with pebbles of flint and Bunter: solifluction (table 3*A*, count 9)	3 6			
		3 9	231·25	41·25
3. Clayey gravel with oolite, flint and Bunter (table 4*A*, count 6)	1 0			
		4 9	230·25	40·25
2. bedded orange sand with irony gravel layers plus Bunter and ironstone: clay layers: one grey silt lens with shells (table 4*A*, counts 7 and 8)	2 0			
		6 9	228·25	38·25
1. very coarse (up to 3 in.) gravel of Bunter, flint and oolite (table 4*A*, count 9): very moist (Oxford clay near)	1 0+			
		7 9	227·25	37·25

The sequence is similar to those quoted by Sandford (1924, 1926) from the Wolvercote terrace and to temporary exposures seen by the writer nearby (502106). The shell marl yielded the following specimens which are compared with those recovered by Dr Sandford and identified by Kennard & Woodward (1924, p. 173), from the Wolvercote Channel.*

Of eleven terrace and sixteen channel species, seven are common to both localities. The lithology of the two areas, which are only 400 yards apart is, however, very different and the preservation of the channel shells was in marked contrast to those from the terrace.† Presumably this is due to a difference in the permeability of the containing sediments and is no measure of relative age. It will be argued that there may be only a short period between the two deposits. The shells are not diagnostic of climatic conditions as they are tolerant species and are all found in the district at the present day, and have also been recovered from the Summertown–Radley terrace. Ostracods have not been recorded before from the area.

	Wolvercote terrace	Wolvercote channel
Mollusca		
Bithynia tentaculata (Linné)	—	3
Valvata piscinalis (Muller)	4	6
Lymnaea palustris (Muller)	3	2
Lymnaea pereger (Muller)	6	—
Ancylastrum fluviatile (Muller)	19	2
Pupilla muscorum (Linné)	3	4
Vallonia excentrica (Sterki)	—	3
Vallonia costata (Muller)	—	2
Helicella virgata (Da Costa)	—	1
Hygromia hispida (Linné)	common	common
Cepaea nemoralis (Linné)	—	1
Sphaerium corneum (Muller)	2	2
Pisidium amnicum (Muller)	2	3
Pisidium casertanum (Alder)	—	1
Pisidium nitidum (Jenyns)	—	1
Pisidium subtruncatum (Malm)	—	2
Pisidium henslowanum (Sheppard)	—	1
Pisidium sp.	62	—
Succinea pfeifferi (Rossmassler)	7	—
Planorbis planorbis (Linné)	1	—
Ostracoda		
Herpetocypris reptans (Baird)	5	—
Eucypris zenkeri (Chyzer)	2	—
Eucypris crassa (O.F.M.)	1	—
Mammalia		
Vole incisor, *indet.*	1	—

As the Upper Cherwell deposits have yielded, so far, no flora, fauna or implements, an investigation of pebble content was carried out to facilitate correlation, and to trace a possible influx of material from the Lake Harrison spillway. Counts were carried out upon Wolvercote terrace gravel at Somerton (three samples at various levels), Gibraltar (two samples) and Wolvercote (four samples at various levels). Table 4, counts 1 to 9. The following tentative conclusions are drawn:

1. In counts 1 to 9 foreign pebbles make up approximately 50 % of the total at Somerton (17¼ miles from gap), 10 to 20 % at Gibraltar (26¼ miles) and 15 to 25 % at Wolvercote

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* The writer is indebted to the late Mr A. G. Davis for identification of the molluscs and to Dr J. P. Harding for that of the ostracods.

† The writer is indebted to Dr Sandford for discussing the area and for the information that the channel shells were so fragile that they required preservation *in situ* before movement was possible. The writer sieved the terrace shells in the normal manner.

(32 miles). The Gibraltar samples come from near the edge of the terrace where local material would possibly be more abundant while counts 5 and 7 were from finer grained lenses from which larger pebbles of flint and Bunter may be absent owing to weakness of current. The foreign materials were, much battered flints (some amorphous), sandstone and Bunter, and they seem, from the few sites available, to decrease downstream.

2. Counts 10 to 14 are from the sub-alluvial channel at Banbury, the Hanborough terrace at Kirtlington and the Summertown–Radley terrace at Begbroke. Although few in number, their foreign content is considerably lower than the Wolvercote level gravels.

TABLE 4: CHERWELL TERRACES

A. Percentage pebble counts

		Wolvercote terrace									other terraces				
locality		Somerton			Gibraltar		Wolvercote				Banbury		Kirtlington		Beg brok
rock type		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Bunter	foreign	7·0	7·6	13·6	6·0	3·4	11·6	4·5	5·3	10·7	1·7	1·8	1·9	—	2·
sandstone and grit		5·0	12·2	3·5	—	—	3·85	—	1·8	2·0	3·4	—	1·0	—	0·
flint		39·0	35·0	35·0	14·0	7·2	10·4	10·6	19·7	9·1	6·0	2·7	10·6	—	4·
ironstone		20·0	19·8	22·0	27·0	37·0	9·0	9·0	8·0	29·0	85·5	92·0	29·5	37·0	26·
Jurassic limestone	local	26·0	18·4	21·0	53·0	42·4	57·0	61·0	53·0	37·5	—	—	51·0	55·0	64·
weathered limestone		3·0	6·1	5·3	—	—	—	—	—	—	—	—	—	—	—
Jurassic shells		—	—	—	—	9·7	7·1	15·0	10·7	9·4	—	—	4·9	7·7	1·
siltstones		—	—	—	—	—	—	—	—	1·3	—	2·25	—	0·4	—
others		—	0·75	—	—	—	1·3	—	1·8	1·0	3·4	1·35	0·5	—	—

B. Foreign and local pebbles (excluding ironstone)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
foreign	51·0	54·8	52·1	20·0	10·6	25·9	15·1	26·8	21·8	11·1	4·5	13·5	0·0	8·
local	29·0	24·5	26·3	53·0	52·1	64·1	76·0	63·7	36·9	ironstone	ironstone	55·9	62·7	65·

3. The greater abundance of foreign pebbles in the Wolvercote terrace and its correlatives compared with higher and lower terraces, and also the apparent tendency for an increase upstream can be related to two possible causes:

(*a*) Direct outwash from Chalky Boulder Clay ice with its predominance of fresh flint;

(*b*) Solifluction and downslope movement from the Northern Drift.

The evidence is insufficient to prove either, but both explanations require a period of glaciation or of intensive freeze-thaw conditions. The first entails a direct correlation with the penultimate glaciation to which Lake Harrison is attributed. The second explanation suggests the same period, since between it and the time of the Northern Drift intervenes an episode of extensive erosion interrupted by the deposition of the Hanborough terrace with its fauna suggesting a warm climate and so an interglacial period.

An interesting sub-alluvial channel was located at Grimsbury (458418) near Banbury.* It attains a depth of 14 to 15 ft. and its width corresponds to that of the present flood plain. The basal deposit of the channel is a sandy gravel, varying from 3 to 7 ft. in thickness and containing flint, sandstone and Bunter material in an abundance of ironstone fragments (table 4, count 10). This is overlain by a channel of ferruginous gravelly clay of re-sorted

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* The writer is indebted to Mr H. A. Nelson, Banbury Water Engineer, for access to material gathered in investigating a new reservoir site.

Lias with a few pebbles of flint, Bunter and much ironstone (count 11). The channel was traced a mile to the south into Banbury where the same sequence was seen at 454408 and 462405 and to the north at 457247. Tiddeman (1910) recorded similar deposits at the station (463405). The channel is thus established over a distance of 2 miles beneath the flood-plain. No other deposits have been seen near Banbury, but Dury (1953, 1954) records channels on the Cherwell and the Eydon Brook, almost 8 miles north of Banbury and Sandford (1924, 1926) mentions deep channels in the Oxford district. Augering is required in the intervening areas but it is probable that the feature exists along the full length of the Cherwell.

(*d*) *Summary*

1. Deposition of the Northern Drift over the whole area. Antepenultimate Glacial. Now only remnants of Upland Stages.

2. Following a period of erosion, deposition of the Hanborough terrace. Penultimate Interglacial.

3. Following another long period of erosion the Chalky Boulder Clay ice entered the north and east of the area. Penultimate Glaciation.

(*a*) Deposition of till to east of valley.

(*b*) Outwash into eastern headstreams.

(*c*) Outwash and/or solifluction combined with local material in Wolvercote terrace gravel.

(*d*) Solifluction of the Northern Drift on to all lower terraces and flats.

4. After further erosion, deposition of the Summertown–Radley terrace gravel. From Sandford's evidence, this took place in two stages separated by a slight unconformity. The lower gravel yields a cold (Penultimate Glacial?) fauna and the upper a warm fauna (Last Interglacial?).

5. After yet another erosion period sand and gravel was deposited in a sub-alluvial channel. Mammoth suggests cold conditions (Last Glaciation?). Cryoturbation of top of Summertown–Radley terrace.

6. Deposition of alluvium.

(iv) *Chronology*

Table 5 shows erosional and depositional evidence for the Cherwell valley and for the Avon and Oxford areas. It is suggested, both from the profile and climatic evidence that the Fenny Compton Stage enters the Oxford district within the approximate height limits of the Wolvercote terrace and not at any of the other major terrace levels. The fact that outwash is followed by overflow accounts for the limited preservation of the Wolvercote terrace and the level is suggested as being complex.

The dating of the Hanborough terrace as early Penultimate Interglacial seems in accordance with its position, fauna, probable climate and the record of one Early Acheul or Late Abbeville (Chellean) implement from Long Hanborough (Arkell 1947*c*). The continuation of the Summertown–Radley profile parallel to the present flood-plain and the link of the Wolvercote terrace with Lake Harrison allows correlation of the *Hippopotamus* and *Corbicula* deposits of both Avon and Cherwell as Last Interglacial in age (*see* King 1955, p. 204).

It will be noted that the Wolvercote channel has been omitted from table 5, but in figure 12 it is placed tentatively at the end of the Penultimate Interglacial and immediately before the deposits of the Wolvercote terrace. This is a substantial reorientation from the views of Sandford (1924, 1932) who in his earlier paper dated the channel deposits between the Wolvercote and Summertown–Radley terraces, and in his later work placed them after the Summertown–Radley terrace, but in each case considered that there was good stratigraphical evidence for the Wolvercote terrace being earlier than the channel. It will be appreciated, of course, that no variation in the age-relationship of the channel affects the correlation of the Chalky Boulder Clay (Moreton drift) with the Wolvercote terrace, as accepted by Sandford (1932, p. 8).

Table 5. Pleistocene evolution: River Cherwell

		Cherwell		
	Itchen and Avon	morphological features	depositional features	Oxford (Sandford, Pocock, Arkell, etc)
Last Glaciation	solifluction no. 2 terrace (cold) solifluction		solifluction sub-alluvial channel and gravel at Banbury erosion	solifluction flood-plain terrace gravel (cold)
Last Interglacial	no. 4 terrace (+ no. 3) *Hippo*. and *Corbicula*	Begbroke stage	Summertown–Radley gravel	top. Summertown–Radley gravel warm. *Hippo*. and *Corbicula* base. Summertown-Radley gravel (cold)
Penultimate Glaciation	solifluction outwash retreat lake ice maximum Lake Harrison deposits Baginton-Lillington gravel	overflow. Fenny Compton stage outwash overflow?	Wolvercote terrace gravel	Wolvercote terrace gravel
Penultimate Interglacial	erosion	erosion 50 ft. + Hanborough stage erosion	Hanborough terrace gravel	Hanborough terrace gravel
Antepenultimate glaciation	Bubbenhall clay	early Upland stages	Northern Drift	Northern (plateau) Drift

When Sandford placed the Wolvercote channel after the terrace of the same name, he did so partly on archaeological grounds, but even more so because he recorded under the western side of the channel deposits, a small thickness of horizontal gravels which he regarded as terrace deposits. This observation he still regards (*in litt.*) as conclusively defining the relationship of the two sets of deposits.

It would be inappropriate for me to discuss the implements, which Dr Sandford tells me are under re-study at Oxford and clearly will have to be compared with the Hoxne succession. Although my placing of the Wolvercote channel in figure 12 puts it at the end of the Hoxnian Interglacial as Sandford also did (1932, p. 10), he need not necessarily maintain that correlation now that the Hoxne succession has been re-interpreted (West 1955; West & McBurney 1955; West 1956).

It is because of the height and areal relationships of the channel to the terraces of Wolvercote and Summertown–Radley that I have suggested a third possibility of age, which might be considered as an alternative to either of Sandford's views. The channel has only been located at the Wolvercote pit (498105), where it is essentially cut into Oxford clay. Its base is 37 ft. and its top 55 ft. above flood-plain level. On its eastern side, it rests on Oxford clay which, when last seen, has risen to within $3\frac{1}{2}$ ft. of the surface. Within a very short distance, Oxford clay must outcrop, apart from any solifluction deposits, and this separates the channel from the main spread of the Wolvercote terrace whose top surface is a few feet lower than the top of the channel deposits and which ends against this Oxford clay ridge with a diffuse negative break of slope.

The simplest interpretation of these space relationships would make the channel earlier, though not necessarily much earlier, than the terrace. The opposite interpretation involves a complex history of deposition and re-excavation for the terrace, which is not to be ruled out merely because it is less simple. The later view of Sandford (1932), which placed the Wolvercote channel later also than the Summertown–Radley terrace, with the bottom of the latter's deposits at about river level and the top 15 to 20, or rarely 25 ft. above this, involves a much more complex history of erosion and deposition—for example, about 25 ft. of deposits must once have existed above the present top of the Summertown–Radley terrace in order to produce land high enough to allow the channel to hold water for its still-water silts.

Obviously, in the interpretation of the chronology, great importance attaches to the 3 ft. or so of level-bedded gravels which Sandford (1924) recorded beneath the western bank of the channel and which he interpreted as Wolvercote terrace. These gravels can hardly belong to the main terrace spread of Wolvercote, which is a Cherwell terrace ending westward against a low ridge of Oxford clay. It is on the other side of this ridge that the channel is seen, and it is under the west bank of the latter that the level gravels were recorded. It is possible, therefore, to interpret these as a deposition phase earlier than the Wolvercote terrace, and to have the channel cut into them before the main terrace spread of the Cherwell was laid down during the overflow of Lake Harrison from the Fenny Compton gap. It is this explanation which has been adopted in figure 12 in the belief that it can be considered as an alternative to either of the other interpretations advanced by Sandford.

IV. THE MORETON GAP

> ...there might have been a ponding of waters and a deposition of clay around the margin of the lake, which appears to have stood at about 400 ft.
>
> Dr M. E. Tomlinson (1929, p. 184).

(i) *Introduction*

The Pleistocene deposits at the head of the Stour valley south of Shipston and in the Upper Evenlode rest entirely upon Lower Lias. A striking morphological feature is the contrast between the deeply incised Stour headstreams, which are often 150 ft. below the drift-capped spurs, and the broad valleys of the more gently flowing Evenlode headstreams (figure 10).

The area is well covered by the drift mapping and description of Miss Tomlinson (1929) and Dines (1928 and in Richardson *et al.* 1929). The sequence established by Miss Tomlinson has been confirmed by the writer's observations and the lake-clay that she recognized has been located in several more areas and its height determined by levelling.

(ii) *Pleistocene deposits*

(*a*) *Drift exposed in the Stretton-on-Fosse pit* (218382)

Moreton drift	5. Grey, Liassic chalky till	5 to 7 ft.
	4. Chocolate-coloured lake-clay with some Bunter pebbles	1 to 3 ft.
Paxford (Ditchford) gravel	3. Oolitic limestone gravel. Little matrix, poorly bedded	0 to 8 ft.
Stretton sands (Campden Tunnel drift)	2. False-bedded, quartzose, clean pinkish sand with thin pebble strings. Pebbles almost entirely Bunter	20 to 30 ft.
Lower Lias	1. Impermeable blue-grey clay	

This important exposure lies on the Stour side of the watershed.

The junction of the Stretton sands with the Lias was determined by augering to be at about 382 ft. O.D. but was difficult to fix accurately owing to water causing collapse. A pebbly band in the Stretton sands, 8 to 11 ft. below the top of the pit, gave material for a pebble count (no. 1 in table 6) which showed the overwhelming Triassic nature of the deposit (84% Bunter). The 0·75% of small flints were very worn and patinated. Miss Tomlinson suggested that the Stretton sands were outwash from a front of western ice near Campden Tunnel.

The Paxford gravels are here typically sub-rounded, oolitic gravels with ironstone (counts 4 and 5, table 6). However, the bottom few feet contain a variable percentage of foreign matter. Counts 2 and 3 are from two shallow channels in the south-west face of the pit, containing clayey and false-bedded gravel resting at about 409 ft. O.D. on Stretton sands. The clay is resorted Lias, and the Bunter pebbles forming the bulk of the foreign material seem to be derived from the underlying Stretton sands. The gravel soon loses its foreign and clayey aspect and passes into crudely bedded local oolitic material (count 4).

The Paxford gravels clearly had a local origin, probably from freeze and thaw breaking up the oolite to a scree which sludged down the hill-sides and became sub-rounded. The bedding suggests that the deposit was water-laid and contaminated by the material it passed over.

The chocolate lake-clay (no. 4) occurs resting upon the Paxford gravel with an uneven junction and forming a regular bed from 2 to 3 ft. thick of stiff plastic clay. The transition is via greenish-grey coarse calcareous sand. Frequently both the clay and gravel are calcreted and stringers of sand are sometimes included in the gravel. The chocolate to red Triassic aspect, often with bluish-green mottling, contrasts with the creamy Paxford gravel below and the Liassic chalky boulder clay above. Pebbles occur occasionally, usually in bands (counts 6 and 7).

The term 'lake-clay' is given to this deposit because of its behaviour as a consistent bed and its similarity in height and lithology to deposits in the surrounding area and further north. The writer assigns it to the lake deposits described by Miss Tomlinson (1929). Shotton (1953) has suggested that they were associated with the Lake Harrison ponding and the writer has no hesitation in supporting this correlation. The lake in this area received clay rather than silt or sand grade material and it seems that only thin deposits were laid down. The lake at this time was dominated by northern and western ice, and the chalky boulder clay ice sheet had not yet reached the region.

Table 6. Pebble counts: Stretton-on-Fosse

formation / rock type		Stretton sand	Paxford gravel				lake clay		Chalky Boulder Clay	
		1	2	3	4	5	6	7	8	9
Bunter	foreign	84·4	11·4	32·3	—	—	51·5	45·5	4·8	27·2
quartzite		0·4	—	0·4	—	—	0·8	0·7	1·2	—
sandstone and grit		4·5	0·6	3·5	—	—	5·5	9·5	—	0·7
siltstone		—	—	—	0·6	—	4·2	5·9	4·8	2·9
flint		0·75	—	0·4	—	—	2·6	5·1	19·2	33·0
chalk		—	—	—	—	—	—	—	27·8	5·9
chert		—	—	0·4	—	—	1·3	2·2	—	2·2
others		5·25	—	0·4	—	—	4·2	2·2	—	—
limestone (grey)		—	—	—	—	—	—	0·7	—	2·2
ironstone		4·85	25·5	35·0	11·0	11·0	30·0	28·0	8·5	4·4
oolitic limestone		—	57·0	25·0	86·0	88·0	—	—	19·2	20·5
rolled Jurassic fossils		—	4·0	2·7	2·2	1·0	—	—	1·2	0·7
calcareous concretions		—	—	—	—	—	—	—	13·3	—

Typical Chalky Boulder Clay (no. 5), exposed in the north-west corner of the pit overlies the lake-clay (pebble counts 8 and 9), and shows that eastern ice finally spread over the site of the lake. Count 8 is a 'total washing' and 9 a 'face count' which accounts for the high percentage of flint and Bunter in 9 and the high chalk count in 8. However, both show a great increase of flint and incoming of chalk compared with 6 and 7. There is thus a similar influx of eastern erratics to that described by Shotton (1953, p. 225). The heavy mineral analyses (table 1, p. 267) emphasize the similarity between this clay and the Hodnell clay at Wormleighton and Hodnell. Figure 9 illustrates the interesting faulting which can be seen in the pit. The Paxford gravels and lake clays at the east end are downthrown in a trough within the Stretton sand, trending east to west and visible also at the other end of the pit. Within the main trough are a number of smaller dislocations. The downthrow of the trough is about 9 ft.

This depressed block preserves nothing higher than the lake-clays (up to 410 ft. o.d.) but in the north-west corner of the pit, lake clays are again seen and here they are covered by chalky boulder clay with the junction at 408·5 ft. o.d. There must therefore be a second downthrown block with a throw of 10 to 12 ft., north of the one shown in figure 9. Apparently these faults die out downwards for augering did not indicate that the underlying Lias was affected.*

The mechanics of the faulting are obscure but the date can be closely placed. The boulder clay is involved in the faulting, which must therefore postdate the advance of the ice to the Moreton area. The Stretton ridge is bevelled off at 415 ft. o.d. and it will be

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* Since this paper was written, the pit has been deepened over part of its area, to reveal the Lias basement. The left-hand fault of figure 9 is traceable as a scarp 2 or 3 ft. high, but the displacement is in the opposite sense to that of the sands and gravels.

demonstrated later that this planation was produced during the end stage of Lake Harrison following the retreat of the ice, but the bevelling truncates the faulting. The dislocations of the Stretton pit appear therefore to have been formed as the ice load was taken off.

It remains to note that if allowance is made for the amount of downthrow observed, the lake deposits probably existed at Stretton at heights of from 415 to 419 ft. O.D. All the deposits have suffered solifluction and a heterogeneous deposit showing cryoturbation occurs over most of the pit.

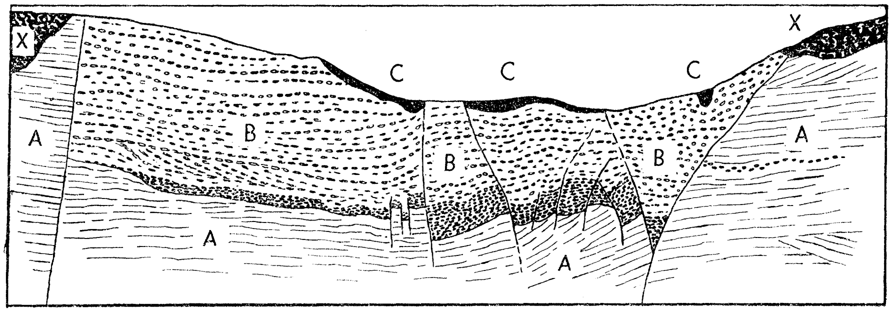

FIGURE 9. Face of Stretton-on-Fosse gravel pit. (Drawn from photographs). Section about 40 ft. long. A, Stretton sand; B, Paxford gravel; C, Lake clay; X, made ground.

(*b*) *Drift in other localities*

(i) *Rolphe's Pit, Great Wolford* (242340) (Tomlinson 1929; Dines in Richardson *et al.* 1929, pp. 127, 129). The following sequence and levels were established:

		thickness (ft.	in.)	depth (ft.	in.)	height O.D. (ft.)
						412·7
upper pit:	6. pebbly, brown soil and sub-soil	1	6			
				1	6	411·2
	5. boulder clay	2	1			
				3	7	409·1
	4. mixed oolitic and flinty outwash gravel (not well exposed)	13	0			
				16	7	396·1
	3. chocolate coloured lake-clay	1	8			
				18	3	394·5
	2. clean, medium-fine, buff, pebble-free sand, becoming silty at times: seen to	3	0			
				21	3	391·5
						394·3
lower pit:	soil and soliflucted lake-clay in patches near surface	1	4			
				1	4	393
	2. (cont.) clean, reddish-buff pebble-free sand	3	10			
				5	2	389·2
	1. oolitic, Paxford gravel: seen to bottom of pit	8	6			
				13	8	380·7

(ii) *Pepperwell's Farm Pits*, Little Wolford (264344 and 266343) are now overgrown, but counts from the lower and upper workings emphasize the difference in lithology noted by Dr Tomlinson (1929, p. 161) with predominantly western drift overlain by eastern material.

The lower pit contained 64 % Bunter, 10 % ironstone and 16 % flint (which may include some solifluction contamination from the upper pit) while the upper pit showed only 36 % Bunter with 52 % flint.

(iii) *Other localities proving the presence of the lake-clay series*. The writer located lake-clay at the following points:

At Ditchford-on-Fosse (217371) the sequence illustrated by Tomlinson (1929, p. 169) and Dines (Richardson *et al.* 1929, p. 129) is now only poorly exposed on typical Paxford (Ditchford) gravels with some overlying solifluction. The top of the clay is at approximately 390 ft. O.D.

At Paxford (Tomlinson 1929, p. 169, Dines in Richardson *et al.* 1929, p. 129) similar clay is 1 ft. 6 in. thick and lies on the oolitic gravels in their type site (188380) at about 415 ft. O.D.

On the road to Great Wolford just north of Barton-on-the-Heath (257328), augering revealed 1 ft. of purple chocolate clay, at 391·5 ft. O.D., resting upon 2 ft. 10 in. of medium-fine, red-brown quartz sand, resting on Lias.

Further north, across the deep valley of the Stanford Brook (256334), the lake-clay was seen in a pipe trench with Lias outcropping below. The junction was at 365 ft. O.D. and the clay was again overlain by coarse flint and Bunter gravel.

A purple chocolate clay occurs in a ditch near Lower Woodhills (235344) just below 400 ft. O.D. The steep hill to the west is covered by flint and Bunter gravel and above 425 ft. many large fresh flints occur weighing up to 10 lb.

An old pit at *ca.* 425 ft. O.D. south of Lemington Coppice (235339) shows flint and Bunter gravel while to the south-east and below a spring issues above a band of red clay about 2 ft. thick at 410 ft. O.D. overlying at least 6 ft. of reddish sand with occasional pebbles.

The undoubted lake-clay has been seen at eight localities at the following heights: 415 to 419, 394 to 396, 390, 415, 392 to 393, 365, 395 and 410 ft. O.D. There is some height variation but the fact that the deposit is in every case overlain by Moreton drift emphasizes that we are dealing with the same deposit which, although only thin, maintains a remarkable continuity. Its distribution indicates that the lake transgressed upon quite a diverse surface, depositing its muds on Lias, Paxford gravel and possibly Stretton sand, but the clay invariably lies between the western plus local deposits and the eastern Moreton drift. The lake would seem to have stood at least at 415 ft. O.D. before it was overrun by the ice.*

(*c*) *Outwash gravels*

Gravels here regarded as outwash deposits formed during the retreat of the eastern ice occur at the pits at Daylesford (244255); south of Adlestrop (238263); Gravels Barn (246328); Wolford Heath (236326) and north of Moreton (206332). They all show coarse to fine sandy and dirty flint and Bunter gravel. Miss Tomlinson records mixed gravels near Oddington (230262) and Buckman (1903) describes flint and Bunter gravels east of Moreton (215323), while Hull (1857) and Callaway (1905) record similar gravels from this upper Evenlode region. The area is shown mainly as boulder clay by the Geological Survey, but it seems likely that no true boulder clay exists south of the present watershed

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* A similar chocolate clay described by Miss Tomlinson from Daylesford (244255) may indicate local ponding, but as it is overlain and underlain by flinty gravel, it must be later than the main lake-clay. It is the only known occurrence of lake-clay from south of the present watershed and so it is separated both in time and space from the Lake Harrison deposits.

and that, as Miss Tomlinson suggests, the Moreton drift deposits of this area are an outwash train (1929, p. 187). The gravel may occasionally be capped by a clayey solifluction deposit. The nature and pebble content of all the exposures resemble the Dunsmore gravel of Shotton (1953, p. 225). For example,

Daylesford	1	Bunter	22%	flint	53%	others	25%
	2	Bunter	22%	flint	59%	others	19%
Dunsmore		Bunter	29%	flint	49%	others	22%

Their identical mode of origin seems beyond doubt.

(*d*) *Boulder clay*

Further evidence for the existence of only outwash south of the watershed is seen in the fact that proceeding northwards, heavy pebbly clays are first met in the watershed region. In addition to the large flints already mentioned from west of Lower Woodhills, Gavey (1853) recorded in the railway cutting near Aston Magna (202349) an unsorted deposit with fresh angular flints up to 1 or 2 cwt. and large marlstone blocks.

(*e*) *Sub-drift surface*

Cross sections of the col region show a sub-drift valley trending south-west to north-east through Great Wolford. Although the pre-drift watershed may have been further south than at present, it does not seem to have been more than a mile in that direction, near Moreton-in-the-Marsh. Thick drift deposits have obscured the pre-drift topography and determined the line of the present watershed, but a former hill in the Lias landscape is exposed at Dunsden Coppice (229348).

(*f*) *The age of the Stretton sands*

The early western drifts (the Campden Tunnel drift) had been considerably eroded by the valleys containing the Paxford gravels before the ponding that heralded the chalky boulder clay advance. This raises the problem of the date of the Stretton sands. The writer thinks that in view of their similar height relations the Moreton and Campden Tunnel drifts represent two cold phases of the same major glacial period separated by a short period of erosion with deposition of the Paxford gravels.

(iii) *Morphological features*

The mapping has been concerned with two major features—the benching by the waters of Lake Harrison and the position of the Moreton moraine.

(*a*) *The Lake bench*

The bench located by Dury and already described (§ II) was traced southwards by him and proved to exist at a similar height round the Shipston embayment (Dury 1951 *b*, Fig. 1). As at Fenny Compton, the writer re-mapped these features. Extensive flats occur between 400 and 415 to 418 ft. O.D. and definite evidence of age is found as the feature is cut not only in the Lias on the east side of Ebrington Hill (Dury 1951 *b*, Fig. 1) but from the writer's mapping, across a series of spurs and hillocks capped by Older Drift. The main examples are:

Todenham, 235360 (Stretton sands); east of lower Woodhills, 236345 and near Aston Magna 202346 (Moreton drift); Ditchford, 217372 (Paxford gravels and lake clay), and Stretton where the planation post-dates and truncates all deposits from Stretton sand to Chalky Boulder Clay.

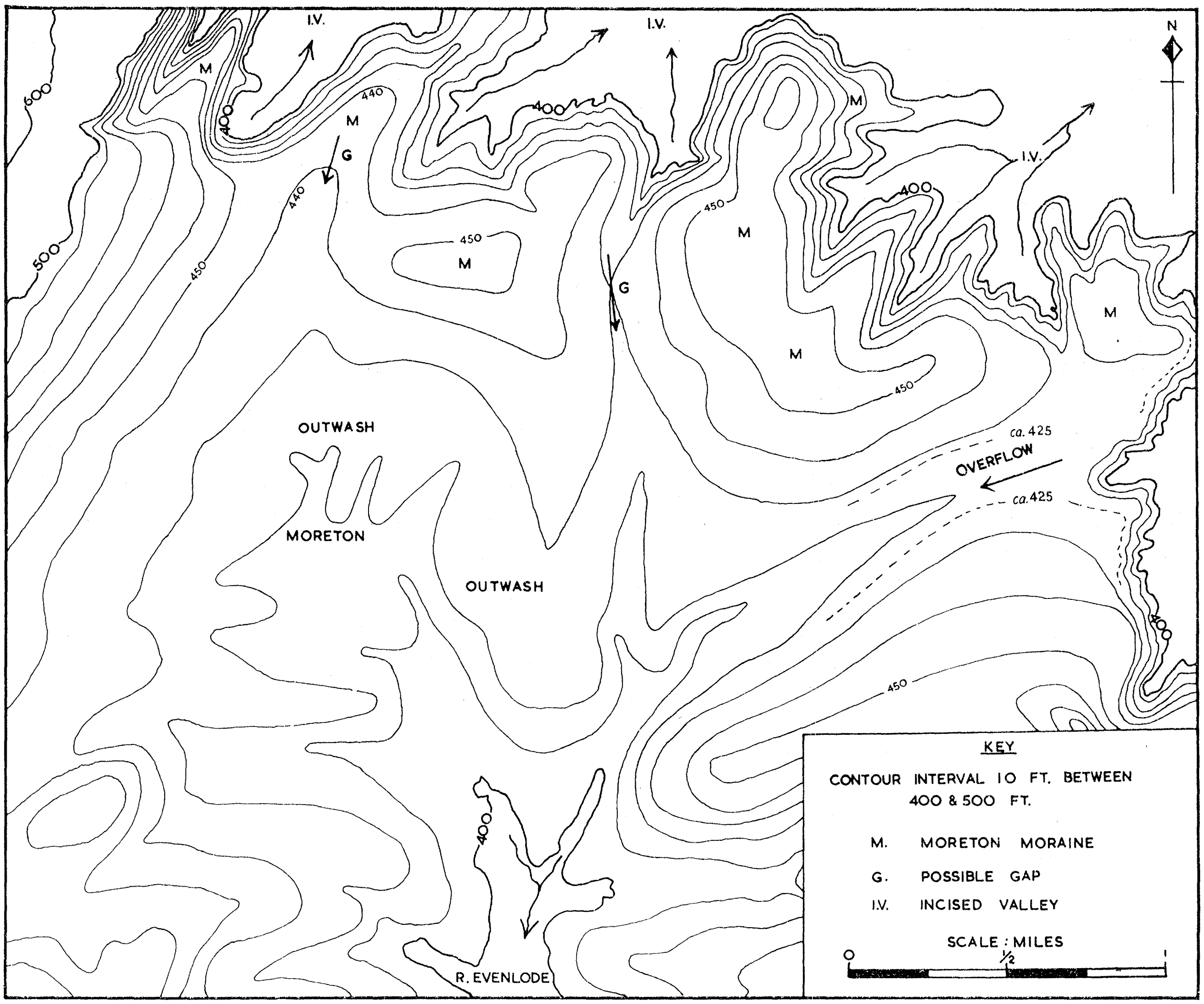

FIGURE 10. Moreton gap—morphology.

The similarity of form and height of the feature from Moreton to Fenny Compton prove the flats to be identical with those cut by the 410 ft. lake which overflowed at that place. The features are all well below the lowest col across the watershed at Moreton. The fact that the lake-clay has been benched dates the 410 ft. lake as a feature of ice retreat separated from the Wolston Series of Lake Harrison by the Chalky Boulder Clay which is also benched.

(*b*) *The Moreton moraine*

Mapping revealed a substantial ridge across the Moreton gap, followed by the present watershed. Figure 10 illustrates, by contours at an interval of 10 ft., the broad details of the feature. The surface of the ridge is, in general, over 450 ft. but three gaps are indicated. Of these, the western is only just below 450 ft. and the central one is at 430 ft. The more eastern gap is the widest and has a flat bottom between 425 and 430 ft. O.D. on the watershed. It is in many senses a dry valley as, although slightly marshy, it contains no present-day stream.

The main ridge coincides with the clayey soils already referred to and is also the area of large flint and other blocks. It seems to mark the southern limit of true moraine of the Moreton drift. From this and its morphological form, the feature is suggested as a terminal moraine of the Chalky Boulder Clay ice sheet. Water from any lake established during the retreat of the ice must have escaped initially into the Evenlode across the moraine. It may have done so at first via one or all of the three gaps but the eastern one became established as the major outlet at 425 to 430 ft. O.D., only to be deserted after the lake level had fallen.

(iv) *Summary*

(*a*) Deposition of Stretton sands of Campden Tunnel drift. Glacial.

(*b*) Short cold period. Valleys cut into Stretton sands and Lias. Deposition of Paxford gravel.

(*c*) Transgression of Lake Harrison on to an undulating landscape. Deposition of lake-clays. The height of the clays and the estimated height of the sub-drift col, suggest a lake level, just prior to obliteration by ice, of about 415 ft. O.D. At this stage the lake must have overflowed into the Evenlode.

(*d*) Ice present as far south as the Moreton moraine. Outwash into the Evenlode.

(*e*) Retreat of the ice. Establishment of ponding again behind the moraine. Overflow across the moraine into the Evenlode. The lake may have stood as high as 450 ft. O.D. at first but soon cut down to give a wide overflow channel which was deserted when the lake surface was at about 430 ft. O.D.

(*f*) Establishment of a larger lake which had a final water level of 410 ft. O.D. and which truncated the earlier deposits. Overflow via Fenny Compton into Cherwell.

(*g*) End of ponding and establishment of present drainage system.

(*h*) Newer drift of valleys and some solifluction.

V. POSSIBLE GAPS IN THE DAVENTRY–KILSBY–RUGBY AREA

(figure 1, IV)

Mention must be made of the numerous papers written by Beeby Thompson (1897, 1898) between 1880 and 1930, many of which are still in manuscript form.* Shotton (1953, p. 252) indicated the Daventry gap (565650) as a possible overflow from Lake Harrison and Thompson's manuscripts suggest that Kilsby Tunnel (577698) is the site of another drift-plugged col. It is impossible to say what are the sub-drift relationships in the Daventry gap, but the Chalky Boulder Clay surface is little below 500 ft. O.D. and the drift must be very thick if an overflow once existed.

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* 'Northamptonshire Room', Borough Library, Northampton.

However, the thickness is not exceptional, as at Kilsby, boulder clay rises to over 500 ft. but on cutting the tunnel in 1836 (Thompson, Manuscript 5822), a sand bed was found to rest on Lias at 424 ft. O.D. and to extend from 600 to 1850 ft. from the south entrance. It must lie in a narrow channel as it was not located by test bores. The general sequence of the area is:

2*b*. Chalky Boulder Clay } sometimes interbedded and sometimes only one deposit present:
2*a*. coarse, dirty, flinty gravel } variable thickness
1. clean, medium to fine and often false-bedded sands: some pebbles: becoming silty with clay bands near base

The best section is in a pit at Low Morton (531744) where the following is exposed:

	thickness (ft.)	height O.D. (ft.)
		360
2. coarse, dirty gravel (having the appearance of Dunsmore gravel) with flint dominant, much Bunter and some ironstone	8 to 10	
		350 to 352
1. false-bedded, clean, pinkish quartz sand with pebbles of ironstone, flint, Bunter and rolled gryphea frequent in the upper layers: towards the bottom of the pit, consistent beds up to 2 ft. thick of horizontally bedded, laminated silty clay and smaller 1 to 2 in. silty bands interbedded with fine sand: the silts fade out at about 335 ft. O.D.	about 40	
seen to		310

Temporary exposures have proved running sands well below 305 ft. O.D. Occasional gravel washouts disturb the false-bedded sands and at one point a block of clay was recovered which showed signs of rolling. The lower silty layers indicate a still-water deposit and the upper false-bedded sands may be deltaic as they pass into still-water silts without visible break, while the washouts and rolled clay suggest the influence of the adjacent steep Lias slope. The series is tentatively correlated as a stage of Lake Harrison with overlying Dunsmore outwash gravel.

The same sequence can be made out in old pits at 546734; 542736; 539739; 538737; 537739; 535740; 533744 and 531744. A doubtful record of a boring at 542736 mentions 145 ft. of drift below the pit (Wilson 1870). A deep, sand-filled, valley undoubtedly occurs running south-east to north-west with drift banked on the south side against a Lias face so steep that Wilson (1875) postulated a fault.

At various points south-east of Kilsby* the same dual sequence can be recognized and the sands on both sides of the watershed may prove to be of similar age as both are overlain by Chalky Boulder Clay or coarse gravel. The existence of a south-east to north-west sub-drift valley, below and at variance with the present drainage, may indicate a pre-lake tributary of the Proto-Soar with headstreams near Kilsby, giving rise to a low col which became an early overflow but was later plugged by drift.

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* The writer is indebted to the Director of the Geological Survey for permission to look at drift distributions on unpublished 1 in. to 1 mile Sheet 185.

VI. SUMMARY, CONCLUSIONS AND CORRELATIONS

> . . . both before and after the glacial invasion of the Midlands, wide areas in the low grounds would be converted into broad glacial lakes.
>
> James Geikie, (1894, p. 381).

(i) Pleistocene evolution of the country west of the Midland Jurassic escarpment

The whole problem is related to the advance and retreat of the combined Chalky Boulder Clay and north-western ice during the Penultimate Glaciation.

Two major stages of ponding were separated by the maximum extension of the Chalky Boulder Clay ice sheet which passed completely over the deposits of the earlier lake to leave a moraine near Moreton-in-the-Marsh. It seems desirable to name the two stages, and the writer has adopted Carvill Lewis's definition (1894, p. 43) which divides the lakes of the ice 'Fringe' into an Extra-Morainic and an Inter-Morainic Series.

Extra-Morainic Lake Harrison

This earlier lake was bounded to the west by the Severn valley ice and to the north-east by the oscillating but ever advancing moraine and outwash of the Chalky Boulder Clay ice sheet. The lake increased gradually in height and in it were laid down the varvedc lays, silts and sands of the Wolston Series, their thickness and lithology depending upon their position in the lake. The maximum observed height of these sediments and hence the minimum value for the highest extension of the lake was 435 ft. O.D. The size of the lake gradually diminished until ice obliterated it completely and deposited the Moreton Moraine. Any one of three possible overflows may have operated during this Extra-Morainic period (figure 11 *A*).

(*a*) *Kilsby and Daventry*

If an overflow (or overflows) existed here, it operated at an early stage. A gap at 420 to 430 ft. O.D. is a possibility, but the ice soon overwhelmed it, depositing thick plugs of sand, gravel and boulder clay which effectively prevented any later overflow.

(*b*) *Fenny Compton*

Still-water deposits up to 435 ft. O.D. occur just north of the area and as the lake held water at this height the gap must either have been higher than at present, in which case it could have operated as a spillway at this stage, or have been plugged by ice.

(*c*) *Moreton-in-the-Marsh*

The Moreton col may have operated throughout the existence of the Extra-Morainic Lake or only after one or both of the other gaps had ceased to exist. Unless ice-blocked, it must have stood over 435 ft. O.D. during the early evolution of the lake. As soon as ice closed the Fenny Compton gap, water escaped into the Evenlode via Moreton (figure 11 *B*). Erosion in the gap continued as the lake grew smaller, and just prior to its obliteration, the water level stood at about 415 ft. O.D.

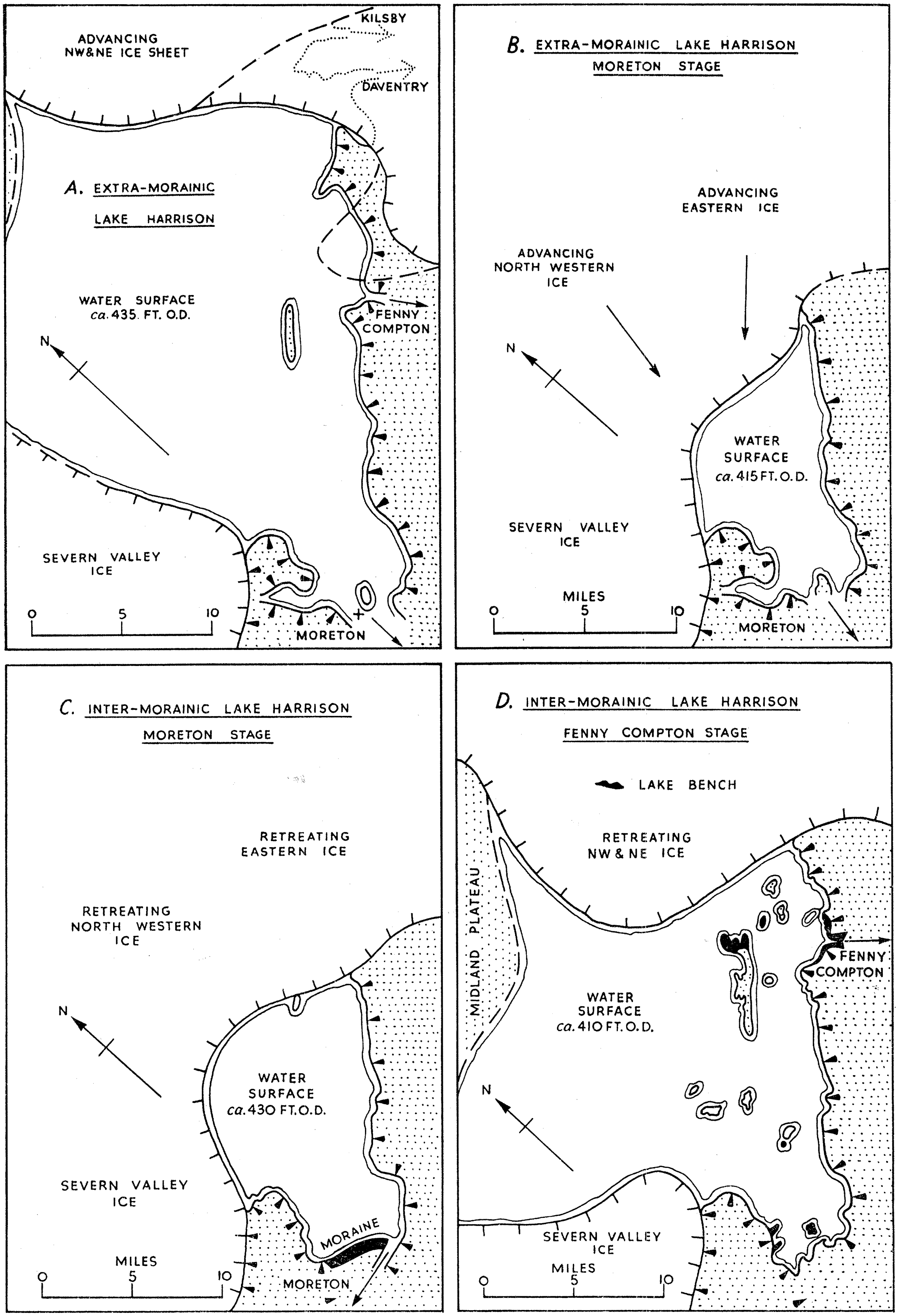

FIGURE 11. Stages of Lake Harrison.

The Moreton Moraine

This is probably a terminal moraine and the ice certainly paused at this point before retreating, depositing ill-sorted morainic material up to a height of 450 ft. O.D. and coarse outwash in the Upper Evenlode similar to the Dunsmore gravel.

Inter-Morainic Lake Harrison

As soon as retreat commenced, ponding was re-established in an ever-expanding lake. The water surface was at rather a greater height than during the last Extra-Morainic stage owing to the moraine blocking and raising the level of the Moreton Col. No lacustrine deposits have been found but there is morphological evidence. Two sub-stages are recognizable:

(*a*) *Moreton Stage*

With the re-establishment of a lake behind the Moreton Moraine, the waters found an escape route, or routes, across the morainic barrier and the overspill may have been as high as 450 ft. O.D. Finally, an eastern spillway became dominant but erosion did not proceed sufficiently far to bottom the drift and attain again the level of Extra-Morainic overflow before the outlet was abandoned leaving a flat valley bottom at 425 to 430 ft. O.D. traversing the debased moraine (figure 11*C*, 430 ft. lake).

(*b*) *Fenny Compton*

This gap must have been lower than 425 ft. O.D. by the time it was unblocked, enabling it to capture the overflow in competition with Moreton. The load-free waters carried out intensive erosion in the Cherwell headwaters and contributed to the landscape features as far south as Oxford. A wide overflow and pronounced lake bench was formed by a 410 ft. lake (Figure 11*D*) before the ponding was brought suddenly to an end, by the removal of the Severn Valley–Welsh ice block, leaving the morphological evidence sharply preserved.

(ii) CORRELATIONS

The table, figure 12, outlines the main correlations established and suggested.

(*a*) *Lower Severn–Avon*

The link with the Avon system has been by direct mapping and the writer has nothing to add to the sequences established by Shotton (1953) and Miss Tomlinson (1925). In correlating these with Wills's sequence of the Severn valley (1938), I have suggested that the Bushley Green terrace is later, rather than earlier than the Second Welsh Glaciation. This is also the view of Shotton at the present time. Wills, although placing it before this glaciation, correlated it also on grounds of height with Avon no. 5 terrace which is incised into the deposits of Lake Harrison. It is this second view which I have taken. If it is correct, it follows that the earlier Woolridge terrace might be the outwash of the Second Welsh Glacier rather than of the First, though it may be premature to make this change of view.

Glaciations Zeuner, Alps, N. Germany, Britain	Severn	Avon Leamington–Rugby	Itchen	Cherwell	Evenlode and Oxford	Moreton and River Stour
Post glacial	alluvium	alluvium	alluvium	alluvium	alluvium	alluvium
Last, Würm, Weichsel, Cymrian and Cornovian, glaciation	erosion	erosion	erosion		erosion	erosion
	Welsh readvance and Worcester terrace	No. 1 terrace	No. 1 terrace	alluvial pebbly clay	solifluction cold gravel of flood plain terrace	
	erosion	erosion	erosion	slight erosion		
	main Irish Sea glaciation	No. 2 terrace	No. 2 terrace	solifluction: buried channel gravel		No. 2 terrace
	erosion	erosion	erosion	erosion	erosion	erosion
Last, Riss-Würm, Eemian, Ipswichian, interglacial	Kidderminster terrace	top of No. 4 terrace	terraces 3 and 4 and Bishop's Itchington Stage	Begbroke Stage flats S.R. terrace gravel	solifluction	terraces Nos. 3 and 4
		erosion and solifluction			upper gravels of Summertown–Radley terrace	
		base of No. 4 terrace No. 3 terrace				
	great erosion	great erosion	great erosion	erosion	slight erosion	erosion
Penultimate, Riss, Saale, Catuvellaunian, Gipping, glaciation	Bushley Green terrace	outwash No. 5 terrace?	outwash No. 5?		base of Summertown–Radley terrace	No. 5 terrace
	second Welsh glaciation	inter-morainic Lake Harrison	inter-morainic Lake Harrison 410 ft. Fenny Compton Stage →	overflow from 410 ft. Lake Fenny Compton Stage	overflow from 430 ft. lake: erosion ←	ponding behind moraine: inter-morainic Lake Harrison, 430 ft.
		Dunsmore gravel and Chalky Boulder Clay	Dunsmore gravel and Chalky Boulder Clay →	outwash and solifluction in Wolvercote terrace	Wolvercote terrace outwash ←	Chalky Boulder Clay Moreton drift and moraine
		extra-morainic Lake Harrison Wolston Series	extra-morainic Lake Harrison 435 ft. Wolston Series →	overflow? erosion	overflow from 415 ft. lake: erosion ←	chocolate clay of extra-morainic Lake Harrison, 415 ft.
		Baginton sand Baginton–Lillington gravel	Hodnell clay		solifluction (warp) silts Wolvercote Channel	Paxford gravel erosion Campden Tunnel drift Stretton sands
Penultimate, 'Great', Mindel–Riss, Holstein, Hoxnian, interglacial	great erosion	great erosion	undulating sub-drift floor	river grading to Wolvercote Channel level	sands and peat lower gravel Wolvercote Channel	
			great erosion	great erosion river grading to Hanborough terrace erosion	great erosion	erosion
					Hanborough terrace	
					erosion	
Antepenultimate, Mindel, Elster, Berrocian, Lowestoft, glaciation	first Welsh glaciation	Bubbenhall clay		Northern Drift (now largely removed)	Freeland and Coombe terraces Northern Drift	Northern Drift (plateau)

Figure 12. Correlation table.

(*b*) *The upper Thames*

The attempt to span the gap between the Oxford district and the Midlands via the Cherwell has not been entirely successful owing to scarcity of evidence where the river traverses the Jurassic uplands. The link between the Chalky Boulder Clay ice and the Wolvercote terrace, suggested by Tomlinson (1929) and Sandford (1932) from evidence in the Evenlode, has been confirmed in the Cherwell. The complexity of erosion and deposition at the Wolvercote level is stressed and accounted for by the combination of direct outwash and lake overspill, at two stages and from at least two points in the headwaters. The dating of the complex Wolvercote terrace level as of Penultimate Glacial age has suggested a re-interpretation of the position of the Wolvercote Channel in the lower Cherwell sequence.

(*c*) *Other areas*

The writer hesitates to pursue correlations further afield, but there is a remarkable similarity of both morphology and geology between the sequence suggested here for the Midlands and that suggested for East Anglia in recent papers by West 1955, West & Donner 1956, and Baden Powell 1948*a*, *b*. Correlation to accord with this is adopted in figure 12.

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REFERENCES

Arkell, W. J. 1947*a* *The geology of Oxford.* Oxford: Clarendon Press.

Arkell, W. J. 1947*b* The geology of the Evenlode Gorge, Oxfordshire. *Proc. Geol. Assoc. Lond.* **58**, 87–114.

Arkell, W. J. 1947*c* A palaeolith from the Hanborough Terrace. *Oxoniensia*, **10**, 1.

Baden-Powell, D. F. W. 1948*a* Long distance correlation of boulder clays. *Nature, Lond.* **161**, 4086, 287.

Baden-Powell, D. F. W. 1948*b* The chalky boulder clays of Norfolk and Suffolk. *Geol. Mag.* **85**, 279–96.

Bryan, K. 1940 The retreat of slopes. *Ann. Assoc. Amer. Geog.* **30**, 254.

Buckland, W. 1821 Considerations on the evidence of a recent deluge, etc. *Trans. Geol. Soc.* **5**, 506.

Buckland, W. 1823 *Reliquae diluvianae.* London: John Murray.

Buckman, S. S. 1899 The development of rivers and particularly the genesis of the Severn. *Nat. Sci.* **14**, 273.

Buckman, S. S., Reade, T. M. & Callaway, C. 1903. Gravel at Moreton in Marsh. *Proc. Cotteswold Nat. Fld Cl.* **14**, 111.

Callaway, C. 1905 The occurrence of glacial clay on the Cotteswold plateau. *Geol. Mag.* II, 491, 216.

Davis, W. M. 1895 The development of certain English rivers. *Geogr. J.* **5**, 127–46.

Davis, W. M. 1900 The drainage of cuestas. *Proc. Geol. Assoc. Lond.* **16**, 75–93.

Davis, W. M. 1910 The valleys of the Cotswold Hills. *Proc. Geol. Assoc. Lond.* **21**, 150–2.

Dines, H. G. 1928 On the glaciation of the North Cotteswold area. *Summ. Prog. Geol. Surv. London for 1927.* II, 66–77.

Dines, H. G. *et al.* 1940 The mapping of head deposits. *Geol. Mag.* **77**, 198–226.

Duigan, S. L. 1956 Interglacial plant remains from the Wolvercote Channel, Oxford and pollen analysis of the Nechells Interglacial Deposits, Birmingham. *Quart. J. Geol. Soc. Lond.* **112**, 363–72, 373–91.

Dury, G. H. 1951. A 400 ft. bench in south-eastern Warwickshire. *Proc. Geol. Assoc. Lond.* **62**, 167.

Dury, G. H. 1953 A note on the Upper Cherwell. *J. Northants. Nat. Hist. Soc.* **32**, 193.

Dury, G. H. 1954 Contribution to a general theory of meandering valleys. *Amer. J. Sci.* **252**, 193.

Gavey, G. E. 1853 On the railway cuttings at the Mickleton Tunnel and at Ashton Magna, Gloucestershire. *Quart. J. Geol. Soc. Lond.* **9**, 29–37.

Geikie, J. 1894 *The great ice age.* 3rd ed. London: Stanford.

Green, A. H. 1864 Geology of the country round Banbury. *Geol. Surv. Memoir*, Sheet 45, 51.

Harmer, F. W. 1907 On the origin of certain canyon-like valleys associated with lake-like areas of depression. *Quart. J. Geol. Soc. Lond.* **63**, 470.

Harrison, W. J. 1898 The ancient glaciers of the Midland Counties of England. *Proc. Geol. Assoc. Lond.* **15**, 400–8.

Hollingworth, S. E., Taylor, J. H. & Kellaway, G. A. 1944. Large-scale superficial structures in the Northamptonshire ironstone field. *Quart. J. Geol. Soc. Lond.* **100**, 1–44.

Hull, E. 1857 Geology of the country around Cheltenham. *Mem. Geol. Surv.* Sheet 44.

Kennard, A. S. & Woodward, B. B. 1924. The Pleistocene non-marine Mollusca of the river gravels of the Oxford District. *Quart. J. Geol. Soc. Lond.* **80**, 170–5.

King, W. B. R. 1955 The Pleistocene epoch in England. *Quart. J. Geol. Soc. Lond.* **111**, 187–208.

Lake, P. 1934 The rivers of Wales and their connection with the Thames. *Sci. Progr.* **29**, 25.

Lewis, H. C. 1894 *Glacial geology of Great Britain and Ireland.* London: Longmans.

Linton, D. L. 1951 Midland drainage: some considerations bearing on its origin. *Advanc. Sci.* **7**, 449–56.

Lucerna, R. 1938 Kantographie. *C.R. Congr. Int. Geog.* **2**, Pt. I, 101–3.

Meyerhoff, H. A. 1940 The migration of erosion surfaces. *Ann. Assoc. Amer. Geogr.* **30**, 247–54.

North, F. J. 1943 Centenary of the glacial theory. *Proc. Geol. Assoc. Lond.* **54**, 1.

Penck, W. 1953 English translation of *Die Morphogeologische Analyse* Pub. 1924. *The Morphological analysis of land forms. A contribution to physical geology.* Czech, H. & K. C. Boswell. London: Macmillan.

Pickering, R. 1957 The Pleistocene geology of the South Birmingham area. *Quart. J. Geol. Soc. Lond.* **113**, 223.

Pocock, T. I. 1908 The geology of the country around Oxford. *Mem. Geol. Surv.*

Richardson, L. *et al.* 1929 The country around Moreton in Marsh. *Mem. Geol. Surv.* Sheet 217.

Richardson, L., Arkell, W. J. & Dines, H. G. 1946. Geology of the country around Witney. *Mem. Geol. Surv.*

Sandford, K. S. 1924 The river gravels of the Oxford District. *Quart. J. Geol. Soc. Lond.* **80**, 113.

Sandford, K. S. 1926 'Pleistocene deposits' in 'The geology of the country around Oxford'. Pringle, J. 1926. *Mem. Geol. Surv.*

Sandford, K. S. 1932 Some recent contributions to the Pleistocene succession in England. *Geol. Mag.* **69**, 1–18.

Shotton, F. W. 1953 Pleistocene deposits of the area between Coventry, Rugby and Leamington and their bearing on the topographic development of the Midlands. *Phil. Trans.* B, **237**, 209–60.

Sparks, B. W. 1949 The denudation chronology of the dip slope of the South Downs. *Proc. Geol. Assoc. Lond.* **60**, 165–215.

Thompson, B. 1897 Pre-glacial valleys in Northamptonshire. *J. Northants. Nat. Hist. Soc.* **9**, 47–51

Thompson, B. 1898 Excursion to Hillmorton and Rugby. *Proc. Geol. Assoc. Lond.* **15**, 428.

Tiddeman, R. H. 1910 The water supply of Oxfordshire. *Mem. Geol. Surv.*

Tomlinson, M. E. 1925 River terraces of the Lower Valley of the Warwickshire Avon. *Quart. J. Geol. Soc. Lond.* **81**, 137.

Tomlinson, M. E. 1929 The drifts of the Stour-Evenlode watershed and their extension into the valleys of the Warwickshire Stour and Upper Evenlode. *Proc. Bgham Nat. Hist. Soc.* **15**, 157.

Tomlinson, M. E. 1935 The superficial deposits of the country north of Stratford-on-Avon. *Quart. J. Geol. Soc. Lond.* **91**, 423.

West, R. G. 1955 The glaciations and interglacials of East Anglia. *Quaternaria, Rome,* II, 45.

West, R. G. 1956 The Quaternary deposits at Hoxne, Suffolk. *Phil. Trans.* B, **239**, 265–356.

West, R. G. & Donner, J. J. 1956 The glaciations of East Anglia and the East Midlands. *Quart. J. Geol. Soc. Lond.* **112**, 69–91.

West, R. G. & McBurney, C. M. B. 1955 The quaternary deposits at Hoxne, Suffolk, and their Archaeology. *Proc. Prehist. Soc.* **20**, Part 2.

Wills, L. J. 1938 The Pleistocene development of the Severn from Bridgnorth to the sea. *Quart. J. Geol. Soc. Lond.* **94**, 161.

Wills, L. J. 1948 *The palaeogeography of the Midlands.* Liverpool: University Press.

Wills, L. J. 1951 A palaeogeographical atlas. London and Glasgow: Blackie.

Wilson, J. M. 1870 On the surface deposits in the neighbourhood of Rugby. *Quart. J. Geol. Soc. Lond.* **26**, 192–202.

Wilson, J. M. 1875 On the probable existence of a considerable fault in the Lias near Rugby. *Quart. J. Geol. Soc. Lond.* **31**, 355.

Wood, A. 1942 The development of hillside slopes. *Proc. Geol. Assoc. Lond.* **53**, 128–40.

Woodward, H. B. 1897 The geology of the London extension of the Manchester, etc. Railway. Part II. Rugby to Quainton Road, near Aylesbury. *Geol. Mag.* (n.s.) **4**, 97.

Zeuner, F. E. 1944 *The Pleistocene period. Its climate, chronology and faunal succession.* London: Ray Society.