THE SECOND AND THIRD TERRACES OF THE RIVER NENE

by

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Summary

The distribution, composition and stratigraphy of the River Nene's Second and Third Terrace gravels are studied, following the author's earlier study of the River Nene's floodplain and First Terrace gravel sequence. The three terrace sequences are seen to be substantially similar and imply similar palaeoclimatic conditions at the time of emplacement. No absolute dates are available for the older terraces, but the circumstantial evidence for deposition within cold (periglacial) sub-stages of the Devensian is strong and the author suggests an outline chronology for the Nene valley using terrace type-areas as names for the major stadials. A map of a sample reach of the author's reconstruction of the former extent of the older terrace gravels is included; this clearly indicates that the regular form of the meandering valley has evolved during the Devensian and that the large wavelength meanders have become better defined with each successive cold sub-stage.

Introduction

The River Nene (text-fig. 1) is of medium size compared with other English rivers, being roughly half as long as the River Thames. The Nene has a channel length of some 167 km (104 miles), a mean annual discharge of 8.6 cumecs at Orton Longueville, the lowest gauging station on the river, and a catchment area of 2370 km^2 (915 miles^2). In each respect it is somewhat smaller than its neighbour, the Great Ouse, which once joined the Nene at Upwell in the Fens; the two waters originally flowed together for the last 10 km to a common outfall at Wisbech. The Great Ouse changed its course in the thirteenth century, making a separate outfall at King's Lynn, to which it has kept ever since. Since that time, the mouths of both rivers have advanced seaward, towards the centre of the Wash, as they have become choked with silt and sand. In this way, the rivers may eventually be re-united and receive as tributaries the lesser rivers which also drain to the Wash: the Witham, Glen and Welland. It will be apparent from discussion later in this paper that the Fenland rivers have been joined together in the remote past, as headstreams of a more extensive river system than exists in the region today.

As yet, little is known of the denudation chronology of these rivers. Worssam & Taylor (1969) discussed the four terraces of the River Cam at Cambridge and suggested a chronology for them. Straw (1958) ascribed the Martin and Southrey Terraces of the River Witham in Lincolnshire to the last (Devensian) cold stage. Horton *et al.* (1974) gave a Devensian date

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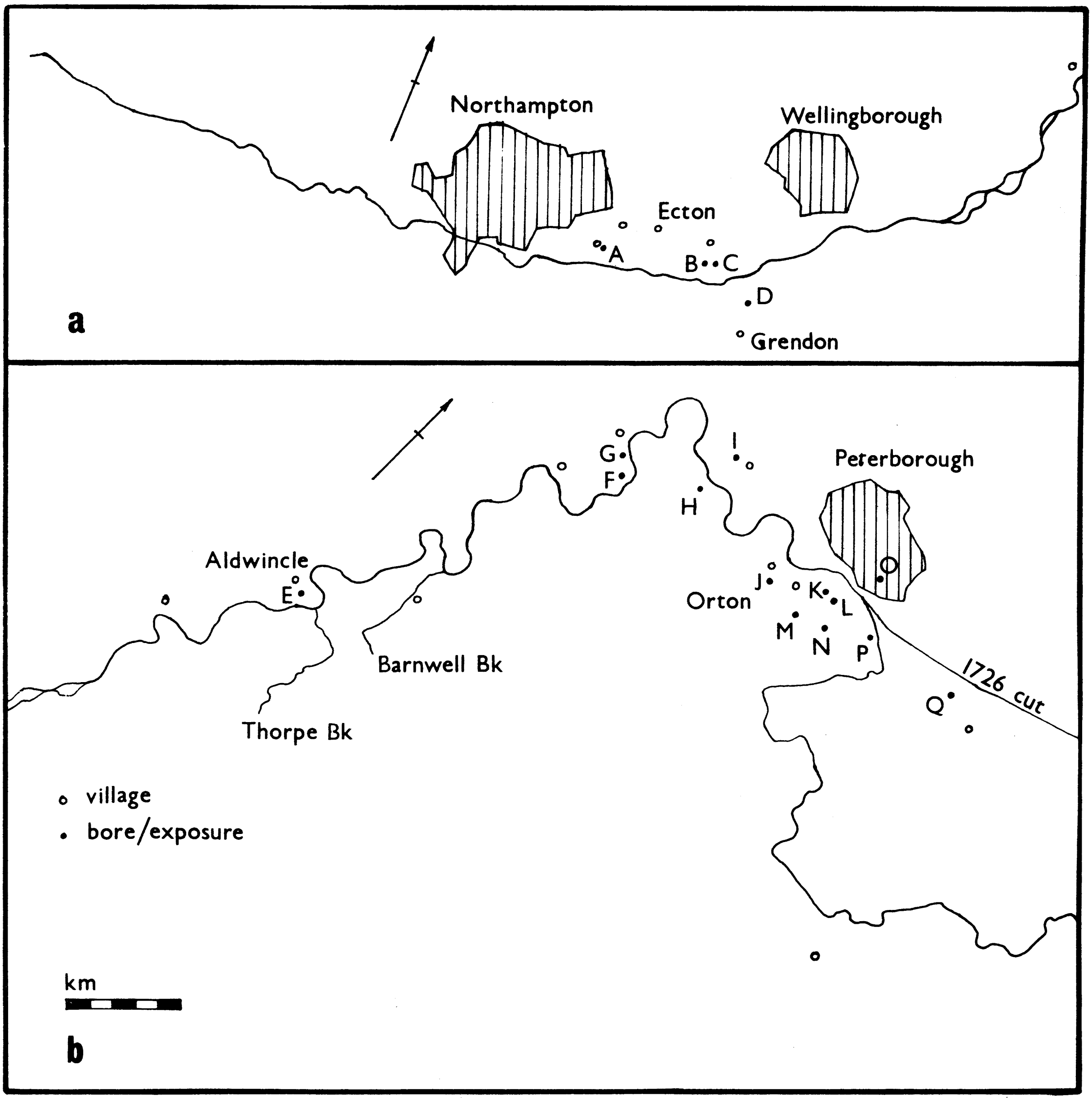
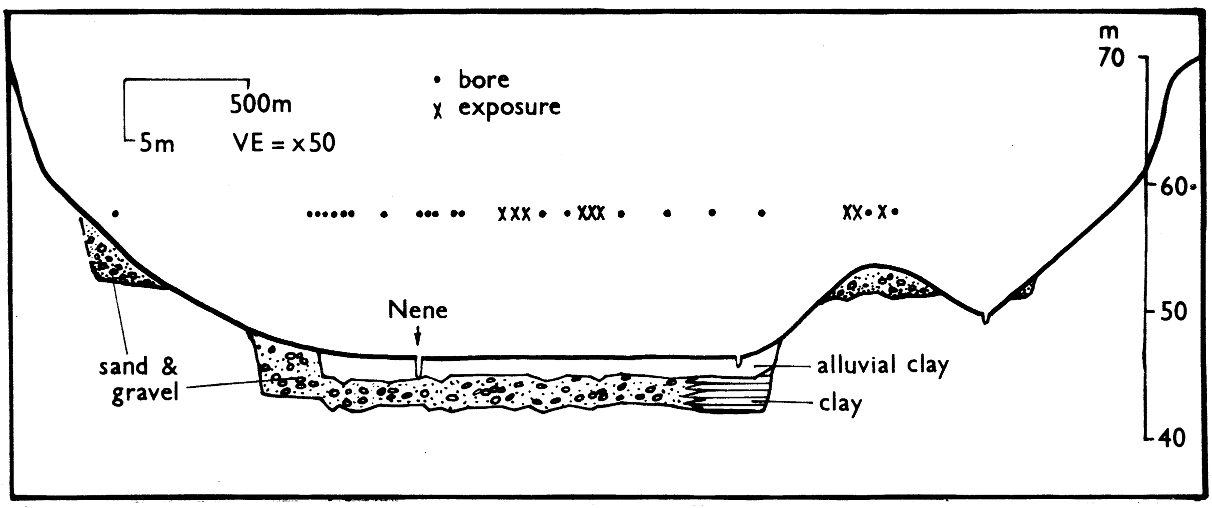


Text-fig. 1: The location of major terrace sites in the Nene valley;
a, source to Woodford; b, Woodford to March and Whittlesey.
All lettered sites are named in Table 3 except the following:
I = Ailsworth, J = Orton Waterville, M = Orton Longueville, N = Woodston



Text-fig. 2: A section across the Nene valley from Earls Barton (left) to Grendon (right).

to the First and Second Terraces of the Great Ouse, based on a single radiocarbon date for an ambiguous deposit at Earith. Taylor (1963) stated that the Nene's three terraces are 'post-glacial' (i.e. post-Wolstonian). The regional chronology is precariously tenuous, and there has been no really systematic exploration of any of the terraces mentioned: the Welland terraces do not appear to have been studied at all. Thus, the establishment of a reliable chronology for the terraces of at least one of the Fenland rivers would be regarded as a major advance.

The author's earlier paper (Castleden 1976) investigated the nature of the Nene's floodplain and First Terrace gravel deposit. It was shown that the basal gravels of that sequence were laid down from 28,000 BP onwards, and the uppermost layers were being deposited as late as 9,000 BP. The texture, stratigraphy and organic remains were used as evidence of the palaeoenvironment at the time of deposition.

This paper investigates the gravels of the Second and Third Terraces of the Nene valley. The study of the floodplain gravels revealed a subjacent pediment (i.e. a planed surface produced by lateral corrasion) instead of the expected deep fluvial channel. This discovery led to renewed discussion of the origin of valley meanders. Evidence of still earlier river behaviour may give scope for extending that discussion and possibly resolving some of the problems.

The Distribution of the Second and Third Terraces

The terraces are distinguished from one another by altitude (text-fig. 5, p. 43). Taylor (1963) defined the surface heights of the three terraces in relation to the floodplain; the First Terrace surface rising to as much as 3 m, the Second to between 5 and 9 m and the Third to between 10 and 17 m above the floodplain. It is on the basis of this convention that the Nene's terraces have been mapped by the Geological Survey. Identification in this way is not without problems. Some terrace sequences are complete, some are dissected and some have been removed altogether, so that the present altitude of the land surface may be misleading. When the interiors of the terrace remnants are known more fully, however, the altitudes of their respective bedrock floors may prove to be a surer means of identification.

The First Terrace is really an undissected extension of the floodplain gravel sequence and, as such, is always contiguous with the floodplain gravel which forms an uninterrupted lining to the valley bottom. The Second Terrace gravels rest on a valley-side bench whose floor is often only 1 m above the top of the First Terrace gravels. The Third Terrace gravels also rest on a valley-side bench. For most of the valley, the Third Terrace is situated no more than halfway up the valley side, but east of Alwalton (TL 130960) the valley walls become gradually lower and the Third Terrace fragments extend across the interfluves. On the Fenland edge itself, the gravels of the Third and Second Terraces merge with similar deposits that have debouched from the Welland and Great Ouse valleys, to form a spread of undifferentiated material known as Fen Gravel.

The floodplain gravel deposit is found along the entire length of the Nene valley to within 5 km of the river's sources. The Second Terrace, which is older and has not only its surface but its floor above the present valley bottom, has undergone considerable dissection and fragmentation. The deposit has been cleared entirely from the uppermost parts of the catchment area, and the first remnant of the Second Terrace is not encountered until Weston Favell (SP 792612). The Third Terrace, assumed from its height to be the oldest, has undergone even more dissection and is not encountered until Aldwincle (TL 003810). Downstream from these two sites, the Second and Third Terrace remnants occur intermittently as far as Peterborough, where the Nene leaves its valley to cross the Fens.

Low-angle benches cut into the Jurassic rocks outcropping on the valley sides at heights corresponding to the levels of the Second or Third Terrace bases are interpreted as terrace remnants which have been stripped of their deposits, as shown in Table 1.

Table 1

Stripped Benches in the Nene Valley

Site	Grid Reference	Terrace
Ratling Irons	TL 030830	3
White Lodge	TL 043856	3
Stoke Doyle	TL 022866	3
Oundle Lodge	TL 025875	3
Oundle	TL 043880	3
Glapthorn	TL 035898	3
Walcot Lodge	TL 045935	3
Westwood Farm	TL 168996	3
Clifford Hill	SP 810606	2
Islip	SP 989797	2
Cotterstock	TL 044912	2
Elton Park	TL 085925	2

Although these stripped benches offer no stratigraphical evidence of past river behaviour, they do indicate the former extent of the terrace gravels and so help to delineate the former margins of the floodplain.

The Composition and Stratigraphy of the Third Terrace Gravels

Realistically, the stratigraphy of the Third Terrace gravels can only be assessed from exposures, where structures such as bedding, imbrication and cryoturbation are clearly visible. Although bore-logs give useful information on sediment depth, lithology and particle size, they do not normally reveal structural features. Unfortunately, exposures in these deposits are rare. The writer was, however, able to visit an extensive exposure (100 m long) at Woodston in 1974, although this has since deteriorated.

The Woodston-Orton Longueville site (TL 178954) is 2 km south-south-east of the modern river. That is not to say that the river has changed its course: there are Third Terrace deposits 2 km to the north of the Nene as well, at the Westwood Works in Peterborough (TF 180000). The Woodston deposit occupies an interfluvial (i.e. skyline) site, with its surface 13 m above the modern floodplain, which stands at 4 m OD. The deposit consists of fine sand, coarse sand and fine and medium gravel. The largest particles are sub-rounded cobbles 10 cm in diameter, but these are rare. A sample of about 8 kg was dry-sieved and the distribution of sediment sizes was as follows:

0-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	> 5.0 mm
37%	10%	11%	8%	6%	28%

This analysis shows a positively skewed distribution, with the fine sand particles predominating. Although the figures appear to show a bimodal distribution, it must be emphasised that the > 5.0 mm category includes a larger range of sediment sizes, so that 0-1.0 mm can be regarded as the mode.

The larger particles (> 4 mm in diameter) were subjected to a Powers' Roundness Analysis. This revealed that 24.5% of the stones were sub-angular, and a further 27.5% were sub-rounded.

Although these were the largest two categories, there were significant fractions of the sample in the very angular and well-rounded classes. This tends to suggest that both frost-shattering (producing angularity) and water-rolling (producing roundness) have contributed to the morphology of the deposit.

The gravel includes some local material derived from the bedrock outcrops in the Nene's catchment area and some erratic material that was presumably winnowed from the glacial drifts. The local Jurassic material includes shelly limestone, oolitic limestone, ironstone and sandstone. The erratic material includes pebbles of Bunter quartzite, gritstone, flint, chalk and pink gneissose granite.

Samples from four different sites were divided into their various lithologies and the fractions weighed. The proportions are shown, in Table 2, by percentage weight of each sample. In samples 1 to 3 the largest fraction (37-54%) is flint. Flint is important in sample 4, accounting for 29% of the sample's weight, but ranks second to limestone. The ratio of erratic to local material is 2:1 in samples 1 to 3, but 1:2 in sample 4. The results in Table 2 show sample 4 as unusual by comparison with both Third and Second Terrace samples; the amount of quartzite is unusually low and the amount of limestone unusually high, but the oddity of sample 4 is probably not significant since all floodplains, both past and present, offer a variety of sedimentary micro-environments.

Table 2

Lithological Analysis of Terrace Gravel Samples (weight %)

	1	2	3	4	5	6	7	8	9
Quartz	-	-	-	-	1.4	-	-	-	-
Felspar	-	-	-	-	-	0.4	-	-	-
Quartzite	13.4	6.8	30.0	3.3	25.7	9.2	8.9	7.5	22.5
Chalk	2.2	3.0	2.5	1.8	-	15.0	8.5	2.5	5.2
Flint	53.3	53.5	37.0	28.9	31.5	26.8	35.0	55.0	50.0
Limestone	15.0	22.0	9.0	57.8	31.4	37.6	41.8	20.0	13.0
Ironstone	13.3	13.2	20.0	5.8	2.9	9.8	5.8	12.5	7.5
Sandstone	2.8	1.5	1.5	2.4	7.1	1.2	-	2.5	1.8
Erratic	68.9	63.3	69.5	34.0	58.6	51.4	52.4	65.0	77.7
Local	31.1	36.7	30.5	66.0	41.4	48.6	47.6	35.0	22.2

Sample	Terrace	Site	Grid Reference
1	3	Aldwincle	TL 004821
2	3	Barnwell	TL 046851
3	3	Oundle	TL 045878
4	3	Orton	TL 178955
5	2	Billing	SP 808621
6	2	Grendon	SP 880618
7	2	Grendon	SP 878617
8	2	Aldwincle	TL 009815
9	2	Oundle	TL 049872

The greatest recorded thickness of Third Terrace gravels is 3 m and occurs near the centre of the Woodston-Orton Longueville remnant, at My Lady's Lodge Farm (TL 159955) and again just to the north (TL 160960). Alwalton (TL 138960) has 1.5 m, Orton Waterville and north Peterborough (TF 200010) both have up to 1.8 m. Cow Pastures Farm at Woodston (TL 181958) has 2.3 m of gravel (Horton *et al.*, 1974). The differences in thickness are explained by irregularities in the rock floor on which the gravel rests and by differential dissection of the surface layers of gravel.

The gravel at My Lady's Lodge Farm is well sorted with seams of sand and clay, but the other sites mentioned show poor sorting. This poor sorting may indicate that the entire deposit results from solifluxion. This seems unlikely, though, because so many of the particles are rounded or sub-rounded and even the unbedded gravels are interrupted by thin lenses of sand, which must have been waterlaid. An alternative interpretation is that virtually the entire sequence was waterlaid but later disturbed by frost. The repeated freezing of ground water in a gravel deposit may cause some or most of the particles to be levered into an erect position, thus disrupting the original bedding. This view is borne out by the section seen at Woodston (text-fig. 3a). In the centre of the section the original bedding survives; to the right it is disturbed by simple involutions; to the left it is disturbed by complex or amorphous involutions which almost completely obscure the original stratification.

In some places the disturbance is so severe that the base of the deposit is contorted, with the gravel folded down into pockets in underlying Oxford or Lias Clay, as at Woodston. Otherwise, the gravel rests on a nearly horizontal erosion surface.

The Composition and Stratigraphy of the Second Terrace Gravels

Exposures in the Second Terrace deposits are more numerous. The author was able to utilise temporary exposures at Grendon, Aldwincle, Fotheringhay and Ailsworth, as well as reports of exposures and bore-logs in Horton *et al.*, (1974). A sample of about 8 kg of the gravel from Grendon (SP 878617) was tested for sediment size by dry sieving. The results are similar to those from the Third Terrace:

0-1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	> 5.0 mm
44%	9%	9%	7%	7%	24%

The Grendon sample was also tested for roundness. As in the Third Terrace sample, there were large sub-angular and sub-rounded fractions (29% and 27.5% respectively). There was also a significantly large angular fraction, (24% as compared with only 8.5% in the Third Terrace sample). The roundness distribution for Grendon is displaced towards angularity implying that, at the Grendon site at least, extreme cold has played a major part in determining the sediment's texture. Significantly, many of the pebbles, irrespective of lithology, have been shattered *in situ* to produce very angular fragments with sharp edges. Nevertheless, enough of the particles are sub-rounded, rounded or well-rounded (34%) to suggest that the deposit as a whole was probably waterlaid.

The Second Terrace contains both erratic and local material. The local material includes shelly and oolitic limestone, siderite ironstone and sandstone. The erratic material includes Bunter quartzites, white quartz, flint, chalk and feldspar. Samples taken from Grendon, Aldwincle and Oundle were divided into lithological fractions and the results are shown in Table 2. In samples 6 and 7, from Grendon, limestone is the largest fraction (38% and 42%) while flint is the second largest (27% and 35%). In samples 8 and 9, from Aldwincle and Oundle, flint is the largest constituent (55% and 50%). In sample 5, from Little Billing, the two rock types are represented in roughly equal proportions, with 31%. The erratic content ranges from 51% to 78% and exceeds the local material in each sample.

The thickness of the Second Terrace deposit varies, largely owing to differential dissection. Table 3 shows the thickness of selected Second Terrace deposits, as reported in the literature

(Taylor, 1963; Horton *et al.*, 1974) or seen by the writer in temporary exposures. They are listed in order, with 1 as the furthest upstream.

Table 3

Thickness of Second Terrace Gravel

No.	Letter on text-fig. 1	Site	Grid Reference	Thickness (m)
1	A	Billing	SP 808621	5.0
2	B	Earls Barton	SP 850626	5.5
3	C	Earls Barton	SP 857627	3.1
4	D	Grendon	SP 878617	2.0
5	E	Aldwincle	TL 009815	5.0
6	F	Fotheringhay	TL 079947	2.0
7	G	Nassington	TL 072957	6.1
8	H	Water Newton	TL 115971	4.6
9	L	Woodston	TL 184974	4.6
10	K	Woodston	TL 180974	7.6
11	K	Woodston	TL 181975	6.4
12	O	Peterborough	TL 197990	2.7
13	P	Stanground	TL 210971	6.0

The stratigraphy of the Second Terrace deposit is also varied, as the sample sections in text-fig. 3 show. For convenience, five lithostratigraphical units may be distinguished:

(1) Sand, fine and medium gravel, coarsely bedded with occasional lenses or seams of clean sand. Often there are involutions towards the top of the sequence or amorphous involutions throughout: e.g. Ailsworth.

(2) Densely compacted masses of fine and medium gravel with little sand matrix: e.g. Nassington.

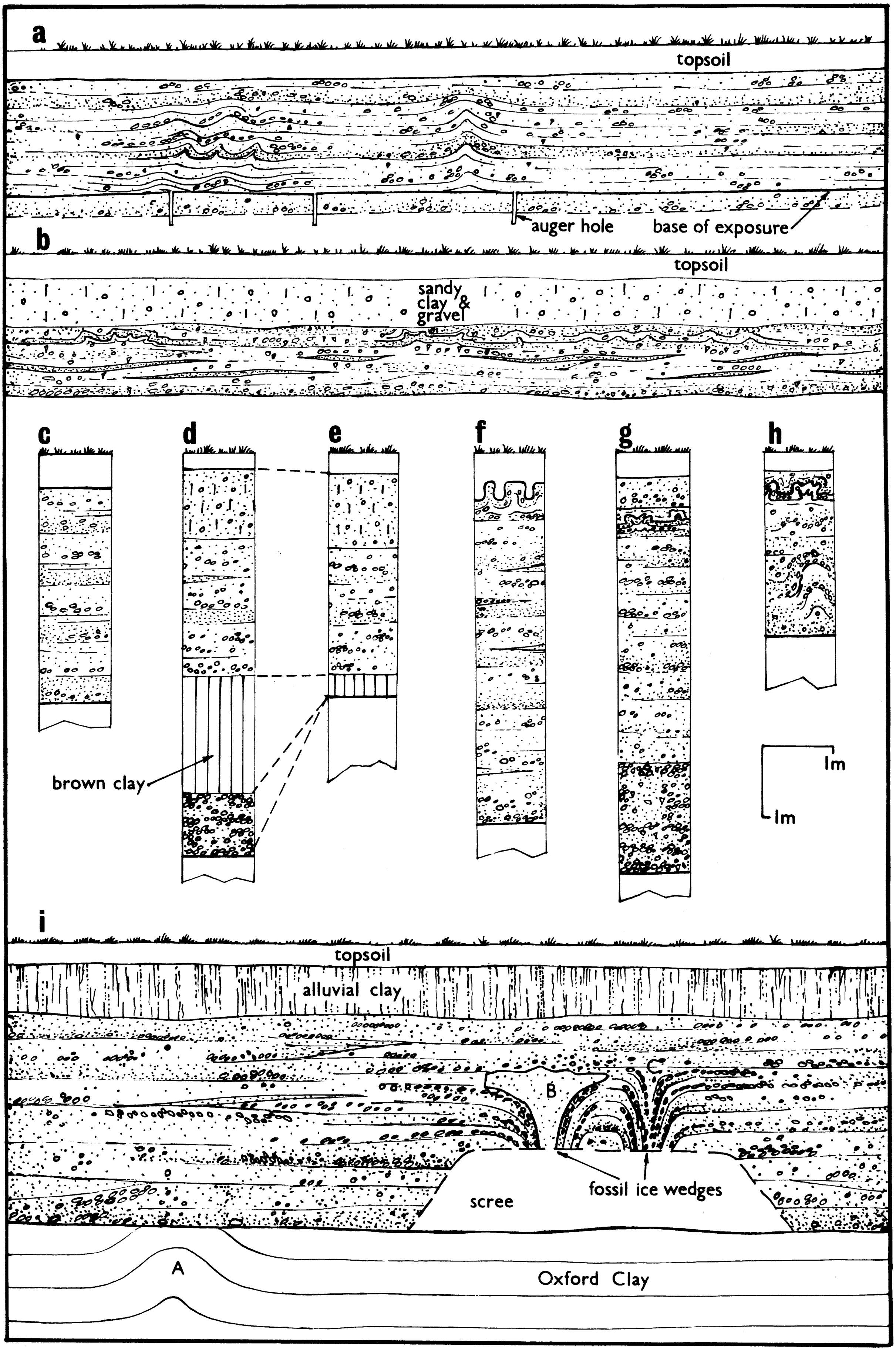
(3) as (2), but with a clay matrix: e.g. Little Billing.

(4) as (1), but with a clay inclusion separating two phases of sand and gravel deposition: e.g. Earls Barton, Woodston.

(5) as (1), but with consolidation of layers up to 0.3 m thick: e.g. Fotheringhay.

Despite the fact that the Second Terrace gravels are often severely disturbed by involutions, it seems likely that they were originally waterlaid and horizontally bedded. It is possible that local variants such as the clay-rich deposits at Billing and Earls Barton may have been formed by material flushed into the main valley by minor tributaries. The Billing terrace remnant is on the downstream side of the outlet of the Billing Brook valley; the Earls Barton terrace occupies a similar situation downstream from the Sywell Brook's outlet. Both these sites could have been supplied by clay from the interfluves. This interpretation is supported by a feature developed in the floodplain gravel sequence, and shown on text-fig. 3. Immediately below the outlet of the Grendon Brook, the floodplain gravel is entirely replaced by clay on the southern edge of the floodplain.

The morphology and stratigraphy of the terrace gravels have far-reaching implications in any consideration of past river processes. But before those implications are discussed,



Text-fig. 3: Sample sections through terrace deposits.
a = Woodston (TL 175954), b = Grendon (SP 880619),
c = My Lady's Lodge (TL 159955), d = Earls Barton (SP 850626),
e = Earls Barton (SP 857627), f = Aldwincle (TL 009815),
g = Nassington (TL 072957), h = Ailsworth (TL 113987),
i = Whittlesey (TL 250977).

there are two controversial groups of features which must be re-examined: the Third Terrace fragments in the Barnwell valley and the isolated inliers of March Gravel in the Fens.

The Third Terrace Sequence in the Barnwell Valley

The Barnwell valley has three small remnants of Third Terrace gravel between Wigsthorpe and Barnwell St. Andrew (TL 046830-046851). It is not unusual for tributary valleys to have terraces: the River Ise has both First and Second Terraces. The Barnwell Brook is, on the other hand, a very minor tributary. The presence of the gravel may be explained in four different ways, as follows:

(1) The gravel is autogenic, i.e. it was produced within the confines of the Barnwell Brook's present catchment area. The difficulty with this interpretation is that the lithology of the Barnwell terraces is so similar to that of the terraces in the main valley that it seems unlikely that they developed independently in a catchment area of only 12 km^2.

(2) The gravel originated in the Nene valley and was washed into the Barnwell valley from its outlet end, i.e. from Oundle. This type of plugging would be possible for a short distance at the outlet of a tributary valley, if the main river was aggrading. Nevertheless, the highest terrace remnant is 4 km up the Barnwell valley, which seems too far for the sediment to be transported up a tributary valley.

(3) The gravel was deposited allogenically, by a distributary of the Nene passing over the sites of Thorpe Waterville, Wigsthorpe and Barnwell, following the general alignment of the dismantled Northampton-Peterborough railway. The Nene of Third Terrace times would, as will be argued below, have been a braided river flowing over a relatively wide belt of gravel occupying a shallow valley. A distributary valley at this site is a real possibility. The terrace gravels, like the braids of the Nene itself, would have surrounded the higher ground of Wigsthorpe Hill. This is the interpretation followed in text-fig. 6a. There are, however, two features which suggest that another explanation needs to be considered. The first is the summit altitudes of the Barnwell terrace surfaces (text-fig. 5) which shows a higher culmination than terraces in the main valley. This may argue for an independent river regime in the Barnwell valley. The second feature is the orientation of the Barnwell valley in relation to Thorpe Brook, which forms the basis of the fourth hypothesis.

(4) Leleux (1970) drew attention to the right-angle bend in the Barnwell Brook at Wigsthorpe (TL 043820), interpreting it as evidence of river capture. She argued that the Barnwell Brook originally flowed southwards, basing her view on an examination of the 'terrace gravel' in cuttings along the disused railway. The imbrication of the pebbles was said to show that the river had flowed southwards. The samples were, however, taken from shallow depth (10-15 cm) and there is a strong possibility that they had been disturbed. One site selected for fabric analysis was actually on a low embankment (TL 046849). Although Leleux's version of the capture can be seriously questioned, the lower Barnwell Brook is nevertheless aligned with the upper reach of Thorpe Brook, which turns suddenly from that alignment about 1.5 km to the south-south-west of the Barnwell elbow. It seems likely that Thorpe Brook and Barnwell Brook were originally one stream, and that the lower Thorpe Brook has lengthened headward to capture the upper Thorpe Brook. The Barnwell Brook, starved of headwater and groundwater, is now fed by one of its former right bank tributaries as its main feeder. Whether the combined catchment areas of the two streams would have supplied enough debris to build the terrace deposits between Wigsthorpe and Barnwell is open to debate; the enlarged catchment area would still have been only 40 km^2.

The issue must remain open. The fourth hypothesis explains the peculiar drainage pattern in the Thrapston-Oundle area and is acceptable on that count. Even so, it is not possible to say when the disruption of the Thorpe-Barnwell stream might have occurred. If it occurred before Third Terrace times, it would still allow acceptance of the third hypothesis. Indeed, the opening up of the interfluve east of Thorpe Waterville by the lower Thorpe Brook would have made access to the Barnwell valley easier for the Nene, so the capture may well be Ipswichian in date. The Third Terrace remnant at TL 040816 must postdate the capture: it lies athwart the original course of the Thorpe-Barnwell stream and would have been dissected if it had predated capture.

The Fen Gravel and March Gravel

Fen Gravel is the term applied to the gravel deposits lining the fenland edge, between the exits of the major valleys and rising above the level of the fen alluvium. The composition of the Fen Gravel is similar to that of the Nene's terrace gravels, with erratics indicating a post-Wolstonian date. Horton *et al.* (1974) suggested that it may be older than the terrace deposits. Whilst this may be true, there is no reason to believe that the gravel is anything but contemporary with the Second or Third Terraces. The Fen Gravel was in fact probably formed by the coalescence of the terrace gravels of the rivers Welland, Nene, Great Ouse and Cam. As such, it seems likely that the deposits were formerly more extensive and have been reduced in area by dissection.

In the following section, the evidence for a Devensian date for the terraces will be discussed. Although it has been argued that there were phases when sea level was similar to that of the present day, the Devensian cold stage is generally held to have been dominated by low sea levels, down to about -100 m OD (e.g. Goudie 1977). It follows that the Nene of First, Second or Third Terrace times would have been a mere tributary to a river three or four times longer than the present Nene, with a North Sea outlet possibly as far out as the Devil's Hole (56° 30'N, 0° 30'E). The Fens and the Wash would have been the meeting-ground for the Witham, Glen, Welland, Nene and Great Ouse, and would presumably have been covered by a wide sheet of terrace gravel crossed by dozens of braided channels. Tidal currents have since dispersed the river gravels laid down on the North Sea bed, so the ancient course of the 'proto-Nene' seaward of the Wash is now unrecognisable.

The gravels were largely cleared from the Fens by rivers in the early Flandrian, when sea level was still relatively low. The 'islands' of gravel scattered across the Fens may be interpreted as dissected remnants of the formerly continuous gravel spread. The isolated remnants are designated March Gravel, after the type-locality, but the gravel of which they are made appears to be identical with the Fen Gravel and the Nene terrace gravel.

The March Gravel exposure at Whittlesey (TL 250977, Q on text-fig. 1, i on text-fig. 3) shows a level-bedded deposit of sand and gravel 3 m thick, resting on a horizontal surface eroded across Oxford Clay at about 2 m OD. The gravel is overlaid by 1 m of alluvial clay and topsoil. The altitude of the gravel bed suggests a correlation with the Second Terrace and it is incorporated as such in the reconstructed profile on text-fig. 5. Sand lenses and occasional pebble imbrication prove that this is a waterlaid deposit. There are no involutions in this exposure, but there are two fossil ice-wedges. Frost-wedge C was evidently opened piecemeal by several phases of wedge formation separated by phases of thawing when stones could fall into and line the wedge. Frost-wedge B contains a sand cast, suggesting that it was formed in one phase, the sand filling the cavity only on final melting.

It has been assumed for a long time that the March Gravel was formed as offshore bars. Baden-Powell (1934) drew attention to the presence of 'marine' shells in support of this view, but admitted that freshwater shells also occur. This may indicate that the evidence has been misread or that the depositional environment was a tidal estuary or, more likely, a delta. Baden-Powell interpreted the remains of timber found in the gravel at March as driftwood, incorporated by chance into the offshore bars. It is simpler to interpret wood remains as indicators of terrestrial origin. The 'offshore bar' is even more eccentric in view of the bones which have been found in the March Gravel. *Rhinoceros*, *Bos*, *Equus caballus* and *Elephas* are all represented. Since these are all terrestrial animals, a fluvial, estuarine or deltaic interpretation makes more sense.

Baden-Powell deduced from the fauna that the climate at the time of deposition was cold-temperate, though not arctic. There is, on the other hand, strong stratigraphical evidence for very cold conditions at the time of deposition. The fossil ice wedges mentioned above show that intense cold accompanied the deposition of layers 1.5 m above the base. Text-fig. 3i also shows a periglacial bulge (at A) developed in the Oxford Clay underlying the basal layers of the gravel. Significantly, the crest of the bulge has been trimmed off by the gravels as they were transported across the site. The presence of the decapitated bulge confirms that intense cold accompanied the deposition of the basal layers of the March Gravel.

The March Gravel is thus interpreted as a cold stage or stadial deposit, just like the Second Terrace gravel with which it was probably once continuous.

The Date and Mode of Origin of the Terraces

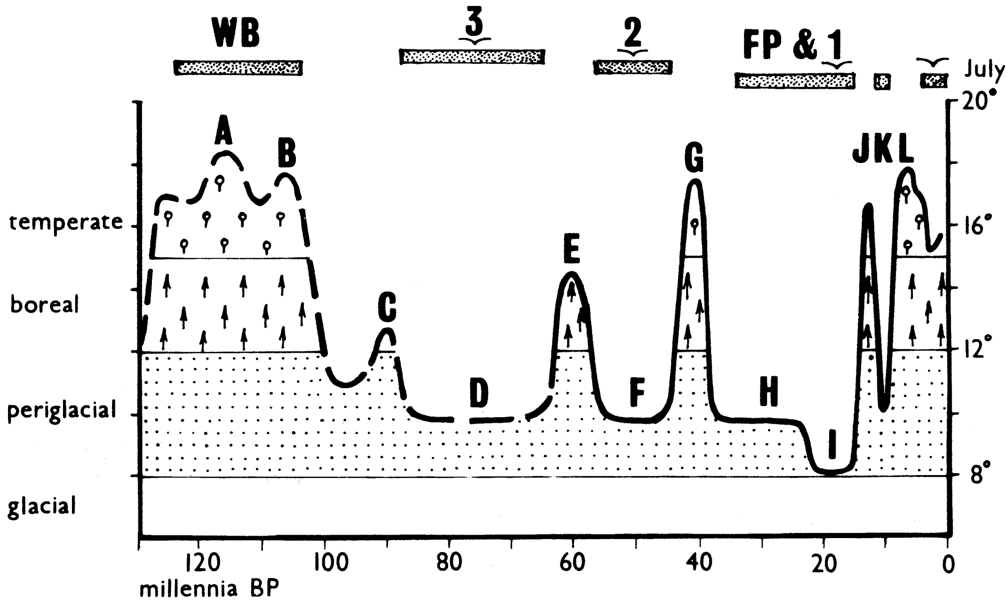
The lithological and stratigraphical similarities between the gravels of the older terraces and those of the First Terrace and floodplain imply formation under similar circumstances. In an earlier paper (Castleden, 1976), the climatic conditions and river behaviour indicated by the floodplain gravels were discussed at length. It was argued that the floodplain gravels were transported and deposited under a periglacial climatic regime, with mean January temperatures as low as -20° C and a short summer thaw lasting perhaps three months. The precipitation stored as snow and ice during the winter was released during the summer to create high flood discharges capable of transporting a very coarse load. The palaeo-climatic indicators for the Second and Third Terraces are coarse sediment, frost wedges, involutions and an eroded bulge.

The braided channels which deposited the floodplain gravel evidently migrated laterally to erode a planar or sub-planar surface. Text-fig. 2 (p.32) shows a typically scalloped pediment flooring the floodplain at Earls Barton. It also shows three Second Terrace remnants with floors which, prior to dissection, would have formed a very similar sub-planar surface 9 m higher than the floodplain pediment. Similar pediment forms are evident at other sites, such as the Third Terrace exposure at Woodston (text-fig. 3a) and the March Gravel at Whittlesey (text-fig. 3i). The recurring pediment form under each of the Nene's terraces gives further confirmation that a similar process or group of interacting processes was responsible for the formation of each of the terrace sequences.

The date of the floodplain and First Terrace sequence is well established by four radiocarbon dates. The earliest date for the basal layers is 28,225 ± 330 BP at Ecton and the sequence culminates at 8,920 ± 160 BP in the surface of the First Terrace at Thrapston (Castleden 1976). Text-fig. 4 shows prevailing July temperatures in central England during the last 130,000 years. This composite graph was drawn from several sources including Coope *et al.* (1971), Lamb (1971), Kenneth & Huddleston (1972), Bowen (1977), Goudie (1977) and West (1977). The floodplain and First Terrace deposit, shown as 'FP & 1', relates mainly to a periglacial sub-stage described in detail by Coope *et al.* (1971) and Morgan (1969) from organic material recovered at Ecton. This cold sub-stage might be called the Ecton stadial. At present, the interstadials have widely accepted names, but of all the British stadials, only the Loch Lomond stadial (11,000-10,000 BP, Mitchell & West, 1976) has been named after a type-locality.

The Second and Third Terraces pre-date the Ecton stadial. They post-date the Wolstonian glaciation which supplied some of the erratic content of the gravel, but that still leaves a long period (i.e. the Ipswichian interglacial and the early and middle Devensian) when they could have been formed. The Woodston Beds (TL 180960) have been identified as Ipswichian estuarine deposits, on the basis of an infinite radiocarbon date, an interglacial flora and a high frequency of fine particles (Horton *et al.*, 1974). The Woodston Beds are overlaid by Third Terrace gravel.

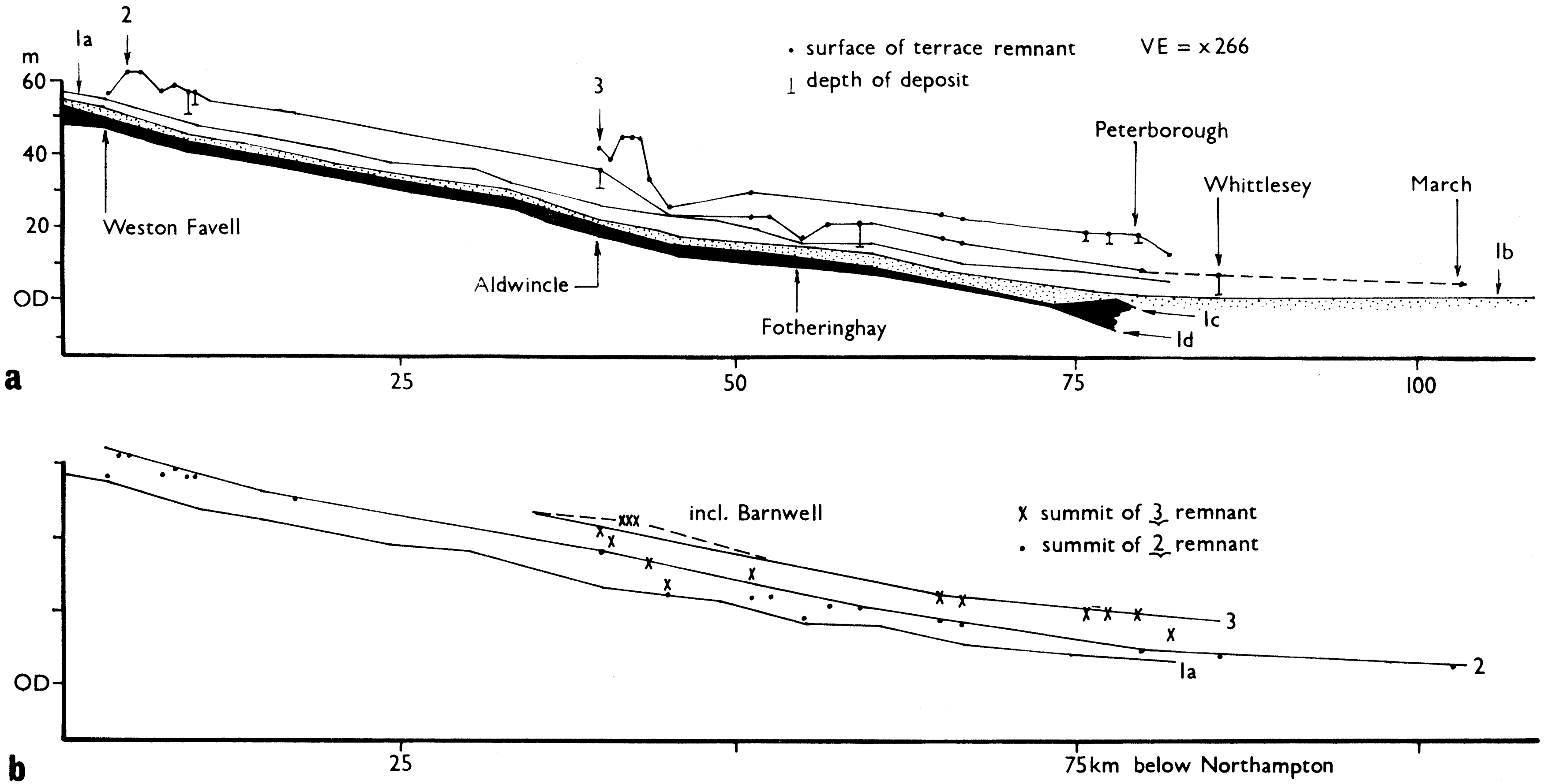
Using the outer limits imposed by the floodplain gravels and the Woodston Beds, together with the knowledge that the terraces are cold-stage deposits, we are left with two obvious 'time windows': the stadials of the early and middle Devensian. The Third Terrace, as shown on text-fig. 4, appears to have been emplaced between 87,000 and 65,000 BP, before the Chelford interstadial. The Second Terrace was emplaced between 57,000 and 45,000 BP, between the Chelford and Upton Warren interstadials.



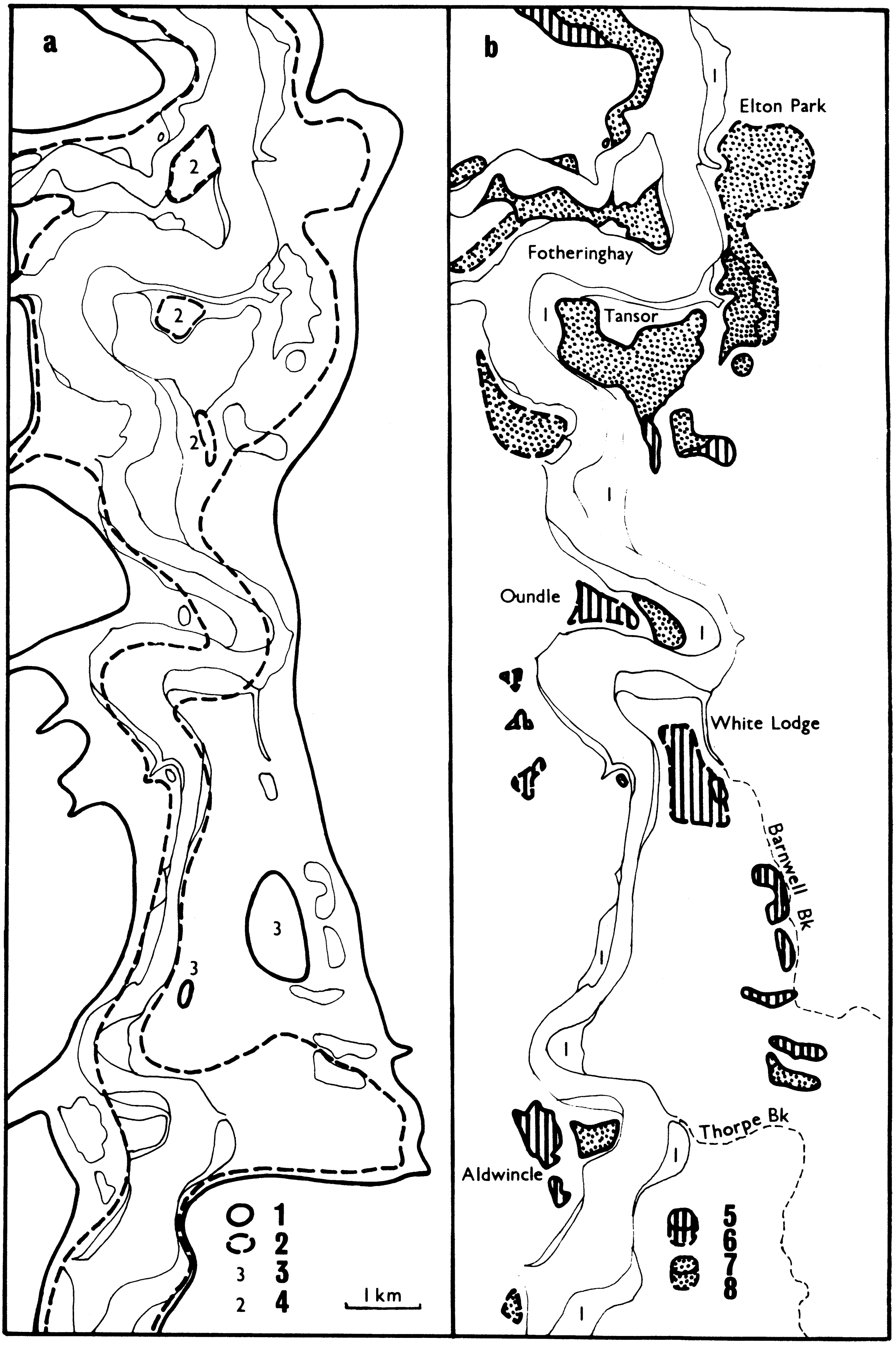
Text-fig. 4: Prevailing summer temperatures in central England during the Ipswichian, Devensian and Flandrian stages.
WB = Woodston Beds, 3 = Third Terrace, 2 = Second Terrace,
FP & I = Floodplain and First Terrace, ⌣ = Alluvium,
A & B = maxima of Ipswichian interglacial, C = Amersfoort interstadial,
D = Longueville stadial, E = Chelford interstadial, F = Woodston stadial,
G = Upton Warren interstadial, H = Ecton stadial, I = Devensian ice maximum,
J = Windermere interstadial, K = Loch Lomond stadial, L = maximum of Flandrian (present) interglacial; dashed line = not yet proved for central England.

There are, as yet, no radiocarbon dates for either of the older terraces. In view of this, some corroboration was sought for the dates offered above. The Reserve Collection at Peterborough Museum contains many flint artefacts taken from the Second Terrace at Woodston, most of them from pits at Woodston Hill (TL 180975) and found by Edwardian collectors. Of the 77 identified by the writer, 12 were early Acheulian or older, 21 were middle or late Acheulian, 24 were Levalloisian and 20 were Mousterian: none were later than Mousterian. The flints cannot have been incorporated into the deposit until the latest cultural level, i.e. the middle Devensian Mousterian, so they are compatible with the date 57,000-45,000 BP argued above.

The mode of origin of the terraces is assumed to be similar to that of the floodplain and First Terrace sequence. The cold sub-stage phases of lateral abrasion or valley-bottom widening were separated by interludes of vertical incision, so that the pediment forms associated with successive stadials were developed at progressively lower levels. The Second Terrace pediment is 10-17 m lower than the Third Terrace pediment, whilst the First Terrace and floodplain pediment is 8-10 m lower than the Second Terrace pediment.



Text-fig. 5: Long profiles of the Nene's terraces.
1a = First Terrace surface, 1b = Surface of alluvium, 1c = Base of alluvium,
1d = Base of floodplain gravel, 2 = Second Terrace surface, 3 = Third Terrace surface.
5a shows present state of terraces; 5b shows reconstructed culmination levels.



Text-fig. 6: The Second and Third Terraces between Aldwincle and Elton.
1 = Floodplain edge in Third Terrace times, 2 = Floodplain edge in Second Terrace times, 3 = Inliers in Third Terrace floodplain, 4 = Inliers in Second Terrace floodplain, 5 = Third Terrace deposit, 6 = Third Terrace bench, 7 = Second Terrace deposit, 8 = Second Terrace bench. 6a shows the reconstructed floodplain; 6b shows the valley today.

The Long Profiles of the River Terraces

Text-fig. 5a shows the long profiles of the terrace surfaces. The Second and Third Terraces are discontinuous; the summits of the terrace fragments are shown by dots. The lines joining those points show the lowest possible culmination levels of the terraces when they were intact. The reverse slopes must indicate dissected reaches. The second set of profiles, text-fig. 5b, shows tentative reconstructions of the original surface levels. The Second Terrace emerges as sub-parallel to the First Terrace surface.

The Third Terrace surface is open to two interpretations. The Barnwell remnants may be left aside as a tributary series with a gradient independent of that displayed by the gravel spread in the main valley. In that case, the lower, continuous line may be taken. If, on the other hand, the Barnwell valley is treated as the route of an early Nene distributary, the change in gradient could be explained by the substantial inlier of Wigsthorpe Hill; this could have caused a strictly local ponding of Third Terrace gravel, creating a gentler gradient above and a steeper gradient below the obstruction.

Table 4 shows the original surface heights of the terraces, ignoring the Barnwell valley.

Table 4

Reconstructed Altitudes of Terraces

Terrace	Surface height above 1st Terrace surface	Mean	Surface height above River Nene	Mean
3	15-12 m	14 m	20-17 m	17 m
2	9- 3 m	6 m	12- 6 m	9 m
1	0 m	0 m	1- 4 m	3 m

Reconstructions and their Implications for Valley Meander Formation

A tentative reconstruction of the limits of the Nene's floodplain gravel during Second and Third Terrace times is possible, given the interpretation of evidence from field and map which has been discussed so far. Text-fig. 6 shows the results of this reasoning for a short sample reach of the Nene valley between Aldwincle and Elton; text-fig. 6b shows the present distribution of terrace remnants and stripped benches whilst text-fig. 6a shows the probable former extent of the gravels, allowing for the form of the valley sides between the remnants and benches.

The reconstruction favours the third hypothesis; i.e. it assumes that the braided Nene surrounded Wigsthorpe Hill, making the Barnwell valley a distributary valley. As argued above, the reconstruction might alternatively have shown the lower Barnwell Brook and upper Thorpe Brook as occupying a separate valley. It is noteworthy, though, that the Second Terrace gravels also surrounded solid inliers at Tansor and Fotheringhay. This suggests that a pattern of distributaries surrounding occasional remnants of solid rock or even older gravel (e.g. at Tansor) may have been a normal feature of the Nene's Devensian river gravels.

A conspicuous feature of the reconstruction is the difference in width between the floodplain in Third Terrace times and that in Second Terrace times. There has been a progressive reduction in mean width from 3 km (Third Terrace) to 1.5 km (Second Terrace) to 0.5 km (First Terrace). It is possible that the terraces represent progressively shorter phases of lateral planation, but the climatic graph (text-fig. 6) gives no reason to suppose a shortening time scale. It is more likely that a relationship exists between floodplain width and valley depth; as the valley deepens, the floodplain width decreases. The rate of pedimentation would inevitably decelerate as the valley depth increased, since an increasing volume of rock would have to be eroded for each unit of width by which the valley bottom was widened.

The reconstruction also reveals stages in the evolution of valley meanders. The edges of the floodplain in Third Terrace times were irregularly sinuous, but by Second Terrace times the edges of the floodplain were meandering systematically, at least in some reaches. By First Terrace times the floodplain had developed a fully meandering course, with a degree of ingrowth evident at Aldwincle and Oundle.

Valley meanders have therefore evolved during the course of the Devensian cold stage. Successive stadials produced conditions favouring the development of large wavelength meanders in the river's braids. With the increasing depth of the valley and the progressive narrowing of the floodplain, the large wavelength meanders were increasingly imprinted on the valley walls.

Conclusion

Certain broad similarities between the Third and Second Terraces emerge. Their long profiles are sub-parallel, their sediment-size distributions are similar and they both rest on sub-planar erosional floors. The maximum recorded thickness of the Second Terrace (7.6 m) is twice that of the Third Terrace; this is probably due to the greater age of the Third Terrace and its greater vulnerability to erosion owing to its greater altitude.

The terrace sediments are broadly similar to those of the First Terrace and floodplain, except that no peat layers or peat erratics which are common in the floodplain, have so far been discovered in the older deposits. Nevertheless, there is sufficient evidence to conclude that similar river processes and climatic conditions prevailed during the transport and deposition of the three terrace sequences.

The Barnwell valley terrace remnants may be interpreted in two ways. They may have been formed as an integral part of the Nene's floodplain in Third Terrace times, laid down by a major distributary of the Nene flowing round Wigsthorpe Hill. Alternatively, Barnwell Brook may have been continuous with Thorpe Brook in those times, giving the valley floor at Barnwell a larger catchment area to supply it with sediment.

The March Gravel 'islands' in the Fens may also be interpreted as integral with the Nene's floodplain deposits, though in this case with the Second Terrace gravels.

It is evident that pedimentation was associated with the mobilisation of the basal gravels of all three terrace sequences. Pedimentation was characteristic of each major cold sub-stage of the Devensian. It is suggested that the important site at Ecton should give its name to the major stadial between the Upton Warren and Windermere interstadials, thus avoiding the highly ambiguous term 'Late-Devensian'. The type-area for the Second Terrace at Woodston might be used to name the earlier stadial between the Chelford and Upton Warren interstadials, whilst the Third Terrace site straddling the Woodston-Orton Longueville parish boundary could be used to name the earliest stadial. This would give a nearly complete nomenclature for the Devensian as follows:

Devensian sub-stage	Date (years BP)
Longueville Stadial	87,000 - 65,000
Chelford Interstadial	65,000 - 57,000
Woodston Stadial	57,000 - 45,000
Upton Warren Interstadial	45,000 - 39,000
Ecton Stadial	39,000 - 14,000
Windermere Interstadial	14,000 - 11,000
Loch Lomond Stadial	11,000 - 10,000

The river processes of the major stadials (Longueville, Woodston and Ecton) were associated with the formation of two major landscape features; the pediments beneath the river gravels and the large wavelength meanders moulding the valley sides. Lateral corrasion, producing pedimentation, characterised each cold sub-stage and each phase of lateral corrasion in turn brought with it a further stage in the ingrowth of the valley meanders.

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