THE FLOODPLAIN GRAVELS OF THE RIVER NENE

by

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Summary

The composition, morphology, stratigraphy and date of the gravel bed flooring the Nene valley provide evidence of ancient river behaviour very different from that of the present River Nene. The existence of a deep, large river channel buried beneath the floodplain deposits has been assumed by previous writers, but this assumption is challenged in the light of subsurface evidence. The same evidence is used in a discussion of the origins of the River Nene's valley meanders, which casts doubt on the current explanations of meandering valleys generally.

Introduction

The River Nene rises on the northern slopes of Arbury Hill (SP 541588) near Badby, Northamptonshire, some 116 km in a straight line from its outfall in the Wash. On its course to the sea, the river occupies a shallow valley which is about 25 m deep in the middle reach and cut into the Jurassic oolites, sandstones and clays which underlie the East Midland Plateau. The length of the valley is 145 km and it is floored with a meandering train of floodplain deposits on average 500 m wide, but reaching 1100 m at Earls Barton (SP 865625), Oundle (TL 035875) and Fotheringhay (TL 055928). As shown in text-fig. 1, the floodplain does not broaden systematically downstream from Northampton to Peterborough, but is narrowest (90 m) at Thrapston (SP 992788) and Wansford (TL 075992). At both localities the gravels continue laterally into First Terrace deposits. At Pilton (TL 028844) there are no flanking terraces and the entire gravel deposit is restricted to a width of 150 m. Below Peterborough (TL 190980), the Nene valley loses its identity in the Fens bordering the Wash.

Professor Dury (1954, 1958, 1964, 1965) has made extensive use of the River Nene and other Midland rivers, in the development of his theories of underfit rivers and meandering valleys. He has used the River Nene in particular, with the Great Ouse, to estimate former high discharges (river volumes) from modern ones and from the difference in amplitude between the river meanders and valley meanders (1958, 1965). The ancient high discharges, which he calculated mathematically, are a factor of 150 greater than the modern 'bankfull discharge', i.e. the maximum flow accommodated by the river channel. Embarrassed by the enormous volumes of water involved, Dury suggests lower factors on common-sense grounds. Either way, the presence of a deep, large river channel is assumed, contained within the River Nene's valley meanders, parallel to them, filled with sediment and buried beneath the present river deposits. It is this assumption which this paper seeks to test.

Sources of subsurface data

It was considered impractical to attempt hand-augering through the gravel which comprises the lower half of the Nene's river deposits. The data were gathered from a variety of sources: well-bores, geological site investigation reports and direct measurement of temporary exposures. Plate 1, fig. A, shows a typical temporary exposure in a gravel pit at Weston Favell (SP 794602), where 1 m of brown alluvial clay overlies 2.5 m of buff, level-bedded sand and gravel. These river deposits are underlain by a grey clay which is probably

Mercian Geol. Vol. 6. No. 1, 1976.
pp. 33-47, 3 text-figs. Plate 1.

a Wolstonian proglacial lake deposit. The grey clay forms the floor of the pit, just out of view at the foot of the photograph.

In all, about 200 bore-logs or equivalent data were collected, giving an admittedly coarse network over the area as a whole, since most are located in the Northampton-Thrapston reach. The published data came from Woodward and Thompson (1909), Woodland (1942), Gibbons (1969), Anon (1970), Horton (1970), Thomas (1970), Cadman (1972) and Lewis (1973).

The sub-gravel surface

(a) The Middle Nene Valley

Between Northampton and Thrapston, a 30 km reach in the Nene's middle course, the base of the river gravels fluctuates about a mean depth of 4.4 m below the floodplain surface. The model depth is 4.1 - 4.4 m, 34% of the profiles falling into that group. In this reach, the lowest level below floodplain surface is attained at Northampton. 13 bore-logs there show a river gravel base lower than 5.3 m, a depth not reached again until Thrapston. In 1896, Thomson found an exceptionally thick deposit with its base 13.4 m below the floodplain surface at Northampton Gas Works (SP 750600). East of Northampton, the gravel base declines irregularly from about 4 m at Earls Barton to about 4.5 m at Thrapston.

The great depths encountered at Northampton may be explained in two ways:

(1) The substrate at Northampton is laminated silt and clay deposited in a Wolstonian proglacial lake (Horton 1970). It may be that these younger, Pleistocene sediments were eroded more readily than the older Lias Clay, which succeeds them downstream.

(2) Similar great depths may occur downstream but, if this is so, widely spaced sample points have accidentally missed them.

The second hypothesis leads us back to the possible existence of a buried channel; the deep profiles at Northampton could be interpreted as a chance encounter with a deep fluvial channel which continues down the valley to Thrapston and beyond. To test this possibility, two complete and two partial cross-sections of the floodplain deposits were assembled, using the same vertical exaggeration (× 5) as the sections drawn by Dury *et al.* to support his theory on valley development.

Some of Dury's cross sections (1964, pp.3 and 9) notably those across the R. Itchen (Warwickshire), Kirdford Brook (Sussex) and Mineral Point Branch (Wisconsin), illustrate the alluvial drowning of a large channel. On the other hand, many of his sections show an alluvial skin covering an essentially flat floor: e.g. R. Evenlode (Oxfordshire), Black Earth Creek, Yellowstone River and Governor Dodge dam-sites (all in Wisconsin) (Dury 1964, pp. 3, 16 and 25). It could be argued that this second group ought to be treated as a distinct category, and that it is to this second category that the middle Nene valley appears to belong rather than to the first.

The two complete sections (nos. 1 and 2 on text-fig.1) show that, even at Northampton, the river deposits are of fairly constant thickness and rest on a sub-planar surface with only minor fluctuations. The gravel base at Earls Barton is remarkably flat. They are both in fairly straight reaches of the valley, however, and one might expect to find pools of a buried channel in more curving reaches. Dury states that the bed-form is "asymmetrical at valley-bends, deepest at the outside of curves, and shallower and more symmetrical near the point of inflection between one bend and the next" (1954a, p.85). The Woodford section (no.4) has asymmetrical valley walls, yet there is clearly no deep channel at the foot of the steeper slope.

The Thrapston section (no.5) reveals a buried channel under the modern river channel and might at first sight appear to vindicate the Dury view. It is, nevertheless, at a shallow depth and occupies only a fraction of the floodplain.

The flatness of the sub-alluvial surface noted here for the Nene valley was already apparent in some valleys investigated by Dury, e.g. those of the Rivers Leach and Evenlode in Oxfordshire, yet Dury (1958) drew attention to relatively small incisions in that surface. Some buried channels were joined to the surface valley walls by a more or less unbroken slope. The thesis that these buried channels are functionally related to the valley walls and valley meanders is reasonable, but in many cases a sub-planar surface is interposed between the buried channel and the valley walls. Clearly, it is the process responsible for eroding the sub-planar surface contiguous with the valley sides which is responsible for the form of the valley meanders.

The valleys which Dury studied closely tend to be rather small, the floodplain deposits averaging about 100 m in width. Inferences drawn from relatively small valleys should perhaps not be extended indiscriminately to larger valleys like that of the River Nene, whose floodplain deposits are up to 1 km wide. The catchment areas upstream from the sites studied by Drury are also significantly small. The mean of nine examples given (Dury 1954b, p. 213) is only 52 km^2 (20 $miles^2$), compared with 570 km^2), (220 $miles^2$) at Northampton South Bridge. Therefore the sites studied by Dury may be considered a whole order of magnitude smaller than the middle Nene valley.

In addition, Dury (1964 pp. 1 - 2) deliberately selected for field exploration in England river deposits which are fine-grained. The Nene floodplain has a layer of fine sediments resting on a coarse-grained layer, and both should be regarded as part of the valley's floodplain deposits. At localities where gravels underlie fine sediments, as in the Rib and Lea valleys of Hertfordshire, Dury (1964 pp. 4 - 5, 40 - 42) is concerned with the upper surface of the gravel, not with the relationship between the basal gravels and the shape of the valleys.

The finer, more recent upper deposits may legitimately be studied for evidence of recent reductions of discharge, but the underlying coarse sediments will have had a more direct role in the erosion of the valley floor and the form of the valley sides.

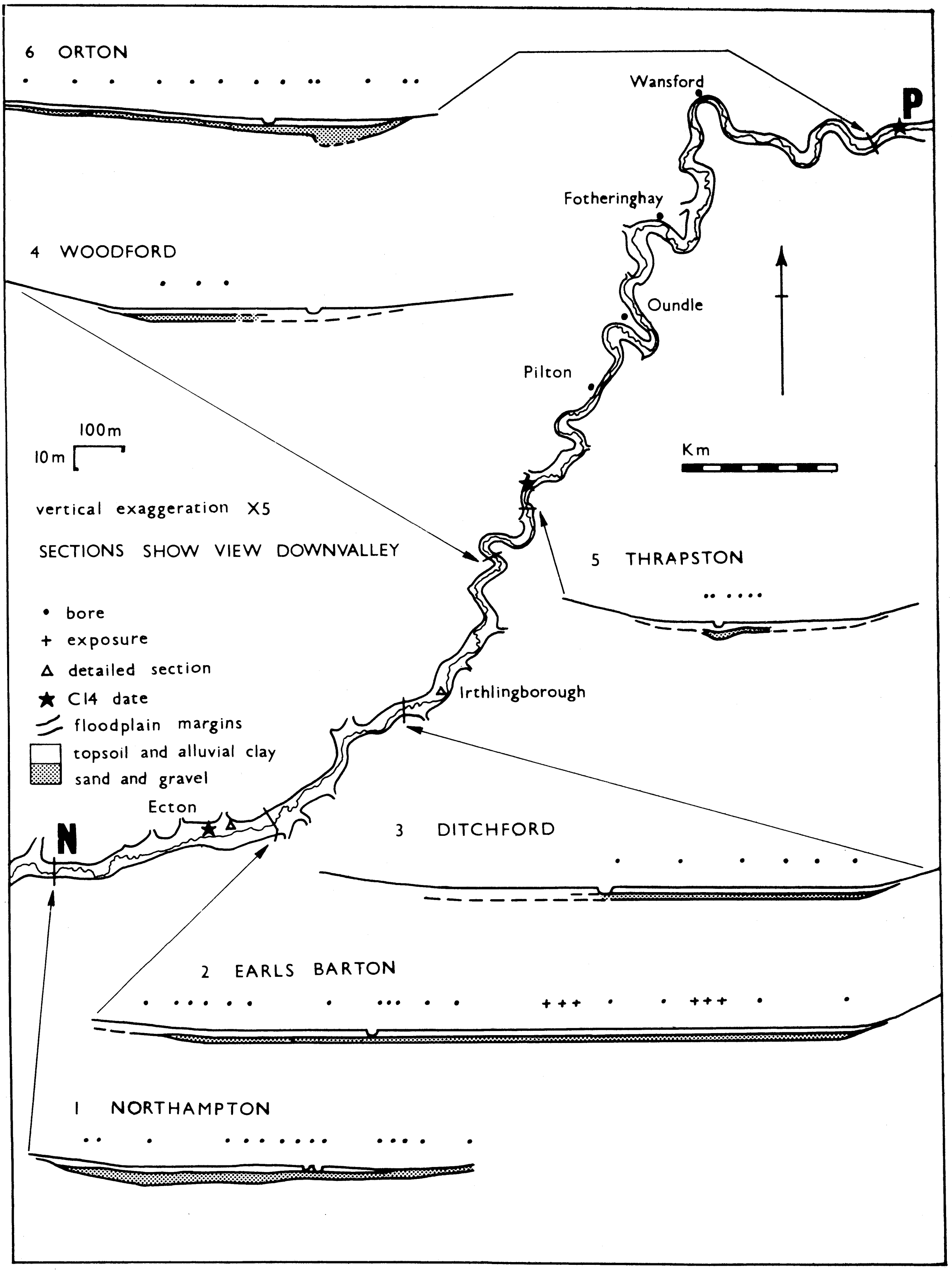
The buried channels belonging to the Rivers Nene and Great Ouse are theoretically ten times wider than the channels of the modern rivers. Their dimensions were inferred from the relative sizes of the modern river meanders and the ancient valley meanders, the latter being larger by a factor of ten, according to Dury. Dury was mistaken in assuming that large valley meanders necessarily contain a large channel, and it would appear that he neglected to collect the subsurface data necessary to demonstrate it.

(b) The Lower Nene Valley

The unexpected absence of a large buried channel in the middle reaches of the Nene valley leads us to speculate about its existence downstream. Does the sub-planar floor extend to the edge of the Fens, or is it replaced by a buried channel? A section through the river deposits was constructed from thirteen bore-logs at Orton Longueville (no. 6 on text-fig. 1). The Orton site is on a valley bend and the sloping, asymmetrical base of the gravels reflects this.

The lowest point of the gravel base at Orton is incised to at least 10.6 m below the floodplain surface, or - 6.6 m O.D. Although this does not exceed the greatest thickness recorded at Northampton, it is either at the toe of a slope of about 25° or partway down a slope of that steepness. The strong implication is that there is a deep Devensian buried channel at Orton, but that the incision does not penetrate upstream as far as the middle Nene valley.

It is possible that the higher gravels on the northern valley side at Orton have the same date of origin as the Woodston gravel immediately downstream on the opposite valley side. In this event, they may be Ipswichian in date (Horton 1974) and should not be regarded as



Text-fig. 1. Map and sections of Nene floodplain deposits between Northampton and Peterborough.

floodplain gravels, which were emplaced later, but lack of detailed information has made it impossible to separate them on the section.

The Composition of the Floodplain Gravels

The 'gravels' are composed of silts, sands and gravels with occasional boulders over 20 cm across. Samples of the medium gravel (0.5 - 5.0 cm) which make up the bulk of the deposit were collected, and the individual stones identified as shown in table 1. The figures represent percentage of total weight of samples.

Table 1 Composition of Floodplain Gravels

Local Material		Erratic Material	
Limestone	8.0	Quartzite	27.5
Sandstone	9.5	Flint	32.5
Ironstone	21.0	Chalk	1.5
Total	38.5%	Total	61.5%

The quartzite is not found in the solid strata of the catchment area and was introduced with the Lower Boulder Clay by the Anglian ice sheet. The flint and chalk fragments were introduced with the Upper (Chalky) Boulder Clay by the Wolstonian ice sheet. Erratic material, other than quartzite, flint and chalk, is also occasionally seen in the gravel. A piece of hornblende gneiss, for example, was found in the gravel at Ringstead (SP 978749): this may have originated in the Malverns, 130 m to the west of its present location, and was probably introduced into the River Nene's catchment area by the Anglian ice sheet. 61.5% of the gravel is re-worked Anglian and Wolstonian glacial debris. The local material has been derived from the solid rocks of the valley sides and interfluves. The 'limestone' in table 1 includes shelly and oolitic limestones, and Jurassic fossils such as belemnites and the bivalve, *Gryphaea.*

The Age and Stratigraphy of the Floodplain Gravels

Although the First Terrace and the floodplain are differentiated topographically by a step of about 2 m, the gravels beneath their surfaces are continuous and similar in age and character. The fossil evidence is consistent with a mid-Devensian emplacement; bones of *Elephas primigenius*, *Bison priscus*, *Ovibos moschatus*, *Coelodonta antiquitata* and *Rangifier tarandus* indicate tundra conditions of the Upper Pleistocene. For example, at Clifford Hill (SP 803603) many bones were found near the base of the First Terrace gravels, in a boulder layer 30 cm thick and 4.3 m below modern ground level. The bones represent remains of horse, mammoth, musk ox, woolly rhinoceros, bison and reindeer (Anon 1971).

Similar remains were found at Ecton (SP 826617), as well as bands of dark organic clay, in the lower layers of the floodplain gravels (Morgan 1969). The gravels are about 4 m thick and are overlaid by 0.8 m of alluvial clay. The organic material occurs in the lowest 1.5 m of the gravel bed and consists of thin bands of peaty clay, on average 15 cm thick, and extending up to several metres laterally. They are underlaid by 0.8 m of gravel.

The organic material yielded remains of beetles, flies, aquatic mosses, sedges, rushes, pondweed, dwarf birch and willow and many marsh and meadow flowers, a tundra assemblage. Festooning and a fossil ice wedge in the same horizon imply very low mean annual temperatures (- 6 °C or lower). The radiocarbon date for the material was 28,225 ± 330 B.P. Bones found in the same pit were given a provisional date of 37,000 - 42,000 B.P. by Professor Shotton (Brown 1967), who believed that this was an interstadial deposit corresponding to Upton Warren, an interpretation superseded by the radiocarbon date.

The Ecton deposit has been defaced by gravel working, but a similar deposit can be seen at Weston Favell (SP 794602), near the top of the floodplain gravels. Plate 1, fig. A, shows two layers of dark peaty material composed mainly of compacted root fragments (B). The layers are 10 - 30 cm thick, overlaid by 0.3 m of sand and gravel, and underlaid by a further 2 m of horizontal sand and gravel. The organic layers are gently folded; in the same horizon just to the left of the section shown on the plate there are stronger superficial folds. These folds, or involutions, were probably induced during a period of intense cold following the deposition of the organic layers. The dark tone of the gravel in the lower half of the section (C) is not due to organic material, but to the very high proportion of ironstone fragments in that horizon.

Wood fragments from the organic layers at Weston Favell tended to disintegrate when extracted for identification. Fragments from a similar organic layer at Irthlingborough (SP 947686) were identified as belonging to conifers, pine and possibly larch. Although the evidence is tenuous, this could indicate a temporary climatic amelioration during the deposition of the upper layers of gravel, possibly during Pollen Zone II (table 2).

Table 2 Chronology of the Devensian and Flandrian Stages

Stage	Pollen Zone	Phase	Began: Years B. P.	Archaeology (C)
Flandrian	VIII	Sub-Atlantic	2500 (C)	Iron Age-Historic
	VIIb	Sub-Boreal	5000 (C)	Bronze Age
	VIIa	Atlantic	7300 (C)	Neolithic
	VI	Late Boreal	8500 (EK)	
	V	Early Boreal	9600 (C)	Mesolithic
	IV	Pre-Boreal	10300 (C)	
Late Devensian	III	Younger Dryas	10800 (C)	
	II	Allerod	12000 (C)	
	Ie	Older Dryas		
	Ib	Bölling		
	Ia	Oldest Dryas	14800 (EK)	
			26000 (S)	Upper Palaeolithic
Middle Devensian		Upton Warren Interstadial	40000 (O)	
			50000 (S)	
Early Devensian		Chelford Interstadial	60000 (O)	
			70000 (S)	Middle Palaeolithic

Sources:
C = Cornwall 1970
EK = Embleton and King 1968
S = Shotton 1973
O = Coope *et al.* 1971

A second radiocarbon date obtained from organic clays at Thrapston (SP 989804) reinforces the Ecton date for the basal gravels. Here the organic layer was 5-10 cm thick and overlaid by 4.6 m of sand and gravel: it was superficially folded and fragmented. Underneath, at least 10 cm of gravel were seen before water level prevented further examination of the stratigraphy. The organic clay, dated 25,780 ± 870 B.P., yielded an insect fauna indicating a cold climate similar to that detected at Ecton (Coope *et al*, Coope 1975). Insect faunas from these and other Midland river deposits can be used as an index of climatic fluctuations during the Devensian. Text-fig. 3 shows that the lowest layers of gravel were emplaced in the cold continental phase following the Upton Warren interstadial but preceding the glacial maximum. The gravels were level-bedded and water-laid. The gentle superficial folds, or involutions, seen at A on Plate 1, fig. B, were induced by frost, possibly during the intense cold of the glacial maximum or during Zone III.

The middle Nene valley was, therefore, eroded to the base of the floodplain gravels by, or during, the middle Devensian. The gravels were then built up to the level of the First Terrace surface, which in places rises 3 m above the floodplain surface. This means a possible maximum accumulation of 13 m of gravel at Northampton, though this was evidently not typical. The mean present-day thickness of 2.5 m implies a late Devensian mean thickness of about 5 m. That the River Nene was ever sufficiently powerful to scour to the full depth of the gravels seems unlikely, so we may provisionally regard the sequence as an aggraded one.

Shotton (in Mitchell *et al.* 1973, p.19) has dated the River Nene's Second Terrace as middle Devensian. Information given leaves no doubt whatever that both the fauna and the dated sample were extracted from a gravel pit near the centre of the floodplain, and that the date of 28,000 B.P. refers to the lower layers of the floodplain gravels, not to a Second Terrace deposit (Morgan 1969).

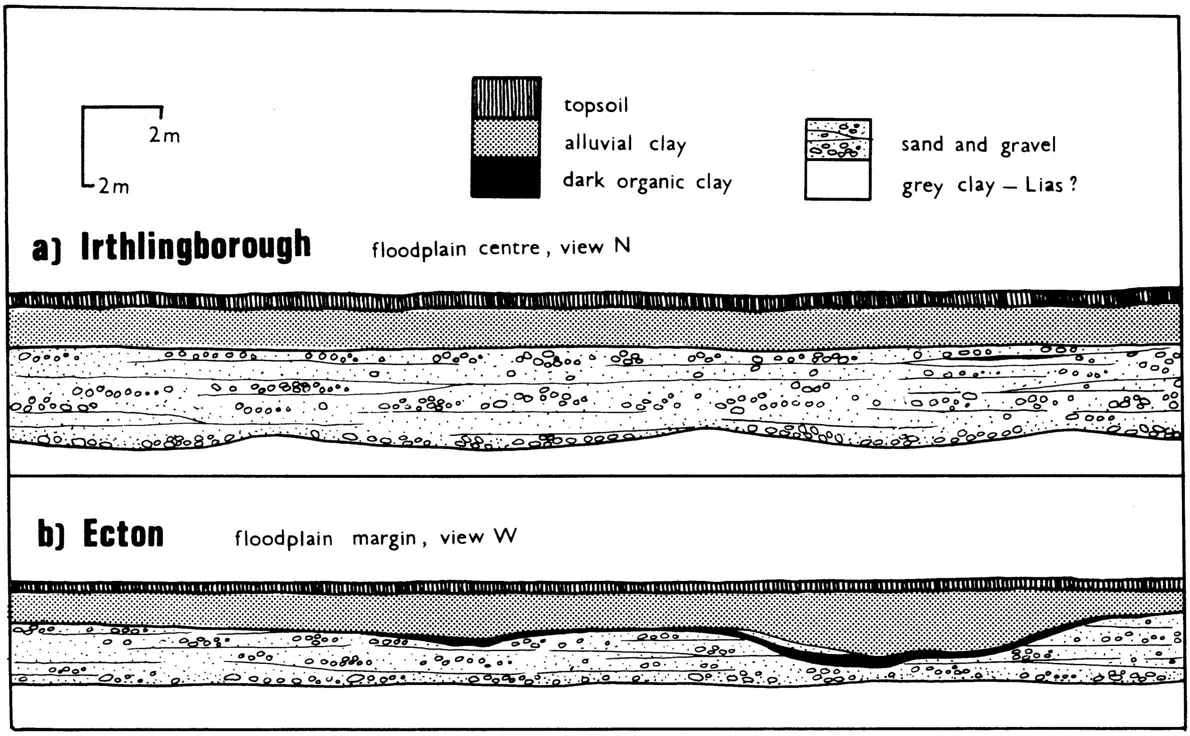
The lack of vertical erosion in the neighbouring valley of the Great Ouse during the Devensian has been commented upon already by Horton (1970, p. 28), as requiring explanation; "special circumstances" must be responsible for the inhibition of a Devensian nick-point's movement upstream beyond the edge of the Fens. The breadth and shallowness of the middle Nene's gravel beds seem to indicate a lack of downcutting in the Nene valley too. The width: depth ratio at First Terrace level is 100:1. Estimates of low Devensian sea levels are of the order of -110 m O.D. With falls of this magnitude, we would expect to see evidence of downcutting. Three alternative explanations of this apparent anomaly are worthy of consideration.

(1) The Hunstanton ice front, blocking the mouth of the Wash for part of the Devensian, may have created a locally high base level. Straw (1970) thinks that the surface of 'Lake Fenland' reached +30 m O. D. In this event, downcutting in valleys debouching into the Fens would have stopped and the accumulation of gravels would have begun.

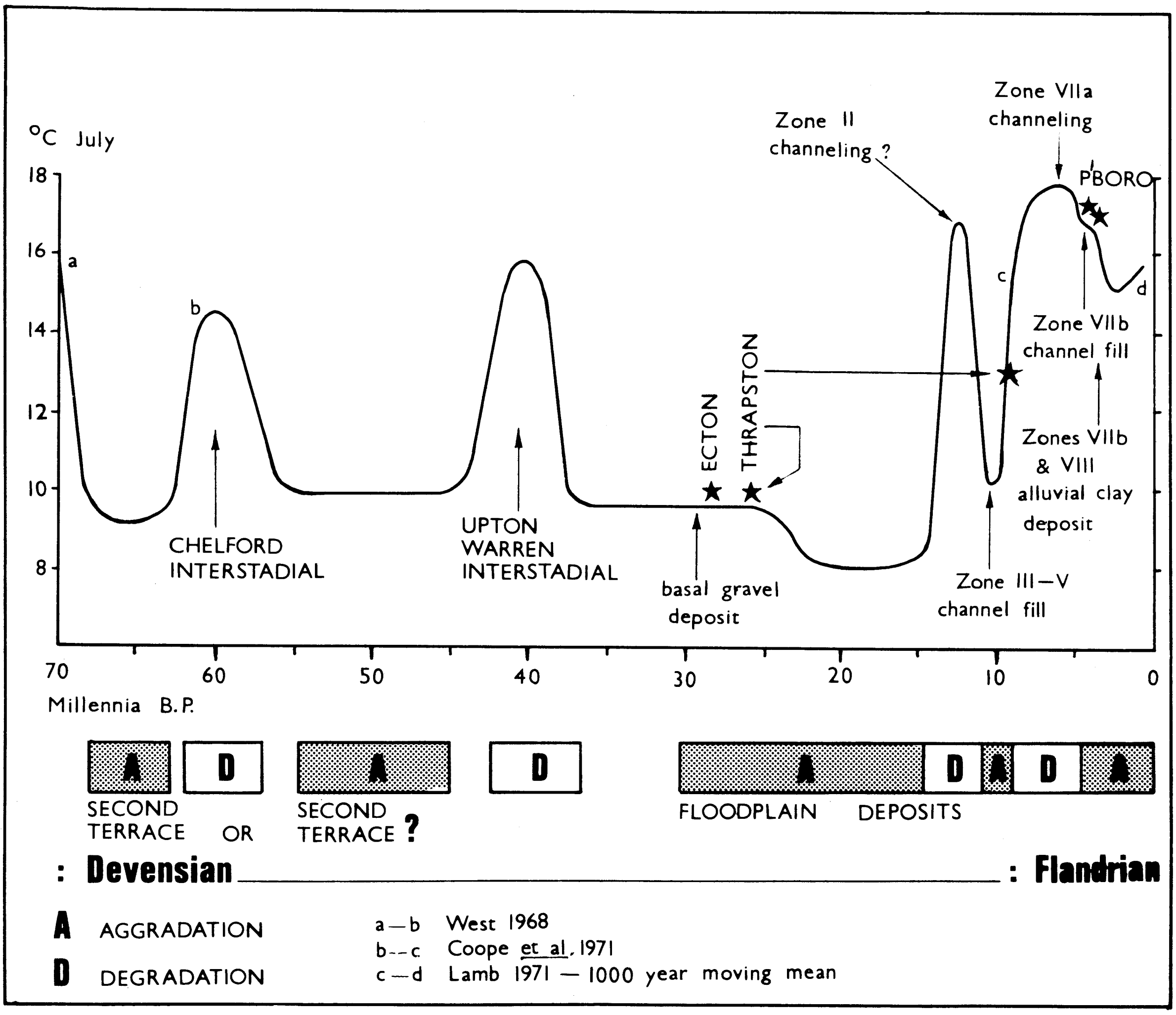
(2) Vertical erosion associated with low sea levels may have characterised only the early Devensian (-90 m O. D.) and late Devensian (-110 m O. D.). Sea level is thought to have been higher in the middle Devensian (Om. O. D.), when vertical erosion would have been inhibited and aggradation would have occurred. Durrance (1969) detects this sequence of events at the mouth of the River Exe (South Devon), and it would appear that the River Nene's floodplain gravels could also have been deposited at a time when sea level was at approximately its present position. The incision at Orton could be interpreted as vertical erosion dating from the early Devensian. The passage upstream of the early Devensian nickpoint stopped, either when the ice-front dammed the Fenland outlet, or later when sea level rose in the middle Devensian.

(3) Aggradation may be characteristic of the upper and middle Nene valley during glacial episodes. Periglacial conditions in the Devensian cold phases would have supplied large volumes of solifluxion deposits and frost-shattered debris to the inland valley, and could have led to aggradation quite independently of base level changes, which may have affected only the lowest reach. Glacial and periglacial aggradation is clearly characteristic of inland situations in other valleys. Goudie and Hart (1975) relate not only the floodplain gravels of the upper Thames to cold conditions, but most of its terrace gravels as well.

In other words "special circumstances" - other than the Ice Age itself - need not be postulated.



Text-fig.2. Detailed sections.



Text-fig. 3. Climate and floodplain processes.

The Middle Devensian Palaeo-environment

The plant remains, fossils, composition and stratigraphy of the gravels enable us to reconstruct with some accuracy the environment at the time of deposition. The insect faunas from Ecton and Thrapston provide evidence of the seasonal temperature regime of the Nene valley at this time (Coope *et al.* 1971). With mean July temperatures of 10 °C. and mean January temperatures of - 20 °C. (compared with + 20° and +4° respectively today), conditions were similar to those prevailing now in arctic Canada. We should look, therefore, to the rivers of the modern arctic zone for indications of river behaviour in the Nene valley 28,000 years ago.

Dury (1965) considers the possibility that a periglacial regime might yield the necessary occasional large volumes of water required to erode large channels, but the Alaskan rivers chosen to test this possibility exhibit rather uniform regimes. Dury's mean monthly run-off figures for these rivers are expressed as cusecs per square mile of catchment area. In table 3, Dury's figures are converted to percentages of the annual run-off total for each river. For comparison, the Nene's modern mean run-off is shown in the same way, calculated from Hydrological Survey monthly run-off figures given in inches.

Table 3. Run-off regimes of selected rivers (% of total annual volume)

River	J	F	M	A	M	J	J	A	S	O	N	D	Year
Fish Creek	8	6	5	6	10	9	7	7	8	14	12	8	100
Tanana	3	3	3	3	10	14	21	20	12	5	3	3	100
Kruzgamepa	2	2	2	1	14	32	16	10	12	4	3	2	100
Nene	18	17	15	8	5	3	3	2	2	4	11	12	100

Fish Creek appears not to be typical. True periglacial rivers flow almost exclusively in summer (Tricart 1969, p.141). The River Piassina on Taimyr Peninsula disposes of 83% of its annual discharge, or run-off, in the three summer months, June, July and August; only 23% of Fish Creek's discharge flows at that time. Dury's other examples are rather better. The River Tanana disposes of 55% of its annual discharge in the three summer months; the Kruzgamepa disposes of 58% in the same period. In the River Mecham on Cornwallis Island, Northwest Territories of Canada, the summer snowmelt contributes 90% of total annual run-off (McCann *et al.* 1972).

The contrast with the modern, humid-temperate regime of the River Nene is obvious. The mean high summer discharge (June, July and August) amounts to only 8% of the annual total. May-October accounts for only 19%, whilst November-April accounts for 81%. In a reconstruction of conditions in the Nene valley at the time of floodplain gravel emplacement, the modern run-off seasons are reversed, with 80 - 90% of the annual discharge total concentrated into three or four summer months.

The gravel itself represents the periglacial river's load. The coarseness of the sediment together with the poor cover of tundra vegetation suggest a river flowing over an uncohesive surface. On this surface, the river would have been likely to braid, and it is possible that braiding was responsible for the form of the sub-planar surface underlying the gravels. Braiding is characteristic of both periglacial and arid regions. Since streams in the two zones share both load characteristics and habit, it would not be surprising if their erosional effect on bedrock were similar. Johnson (1932) attributes the formation of pediments (low-angle erosion surfaces) in arid lands to planation by constantly shifting stream channels; it would seem likely that streams behaving similarly in periglacial landscapes would also produce pediments.

Periglacial valleys in south-east Iceland exhibit valley floor forms which are clearly pediments. The sediments of the Hoffellssandur only partially cover the pediment surface, which rises gently on each side until its abrupt junction with the valley walls (Hjulström 1954, p.182). The sediments still bear the braided drainage pattern which was probably responsible for the lateral corrasion of the pediment surface.

Whilst the relief of the Nene valley is much more subdued, a similar sub-planar floor is evident. The question remains whether planation was achieved by braiding. Text-fig. 2a shows a temporary exposure at Irthlingborough (SP 946690); this was unusual in that excavation had continued about a metre through the gravel-Lias boundary and revealed the form of the boundary very clearly. Although the boundary is often evident in pits as the level at which quarrying ceases, the detail of the surface is normally defaced. The section shows three out of a sequence of six shallow scallops, whose shape suggests erosion by a channel occupying several successive positions or by several channels shifting laterally occasionally. All the evidence supports the view that the gravels rest on a pediment, a well-defined low-angle surface planed by a periglacial braided river.

At the same time, not all low-angle slopes in the Nene basin are necessarily pediments. The lower slopes of Arbury Hill have already been mentioned as the location of the main source of the River Nene. They are also specifically cited by Dury (1972) as an example of a pediment, but they lack the distinctive sharp break of slope between low-angle pediment and high-angle free face which is normally regarded as the definitive characteristic.

The Origin of Valley Meanders

In the absence of a deep buried channel, it is considered that the processes which planed the valley floor were also responsible for the formation of the valley sides. The wavelength of the River Nene's meanders is, on average, about 100 m. The wavelength of the valley meanders is, on average, about 2500 m. The valley meanders can therefore be regarded as 25 times larger than the river meanders, not 10 times larger as Dury suggests. Two possible explanations for the large wavelength of valley meanders are worth considering; greater discharge or coarser load in the Devensian.

(1) Dury has favoured higher precipitation totals and intensities in the Pleistocene as factors causing high river volumes (e.g. 1954a, b). If high discharges in the Devensian are to be postulated, periglacial hydrology would seem an obvious cause of high river volumes in the summer months, as we have already seen. Dury was unconvinced of this, partly because of the atypical regimes of the Alaskan rivers which he chose as modern analogues. The summer run-off of the modern River Nene (June, July and August) amounts to 8% of the annual total; in the Devensian, this may have been over 80%. Winter run-off (December, January and February) now amounts to 47%. The periglacial regime involved not only a change of run-off seasons, but a significant difference in intensity. We do not know what the precipitation totals or the actual river volumes of the Nene basin were in the Devensian but, even if precipitation were no greater than at present, summer run-off (June, July and August) would have been almost twice the present winter run-off (December, January and February).

(2) Hack (1965) has shown that valleys formed post-glacially can also have large wavelength valley meanders. Since large-scale climatic change cannot be held responsible in these cases, some other factor must be operating. Hack suggests, for the Potato and Cranberry Rivers of Michigan, U.S.A., a relationship between wavelength, bed and bank material and load. Where the bed and bank material is very coarse, mostly boulders, the river channel tends to be fixed, contained and more competent to carry its load. In these reaches, the river wavelength tends to be large. Where the material is finer, sand and medium gravel in the case of the Michigan rivers, the channel is ill-defined and energy is used up in shifting. In these reaches, river wavelength tends to be small. The situation is significantly different from that of the Nene, whose deposits range from

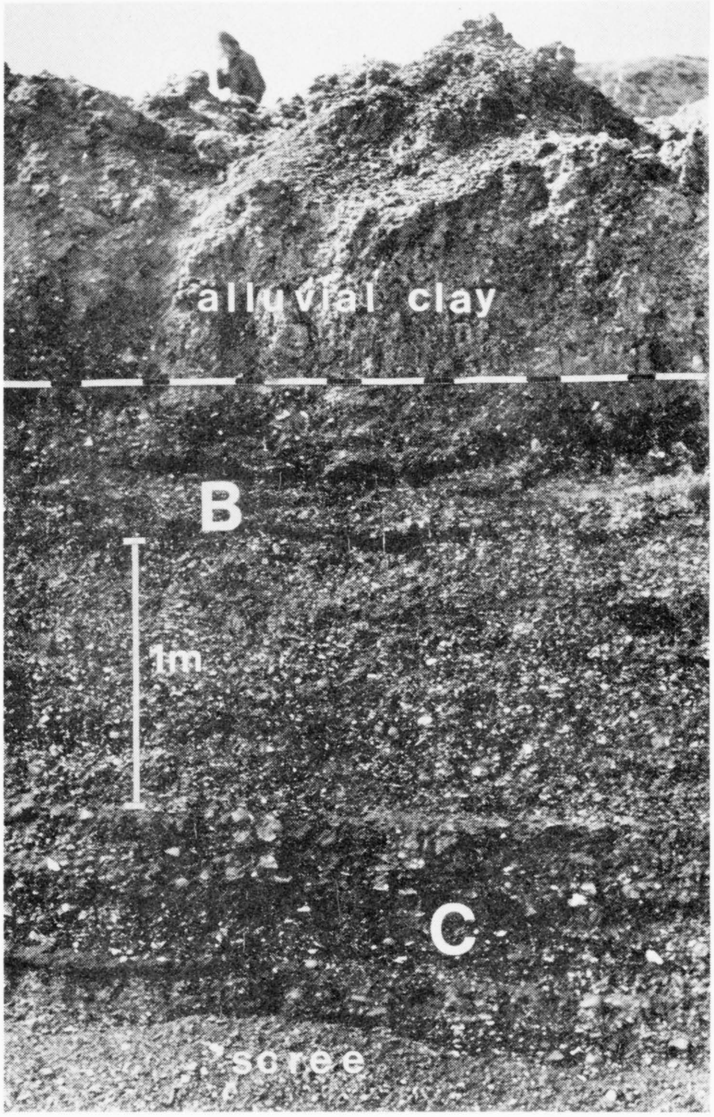
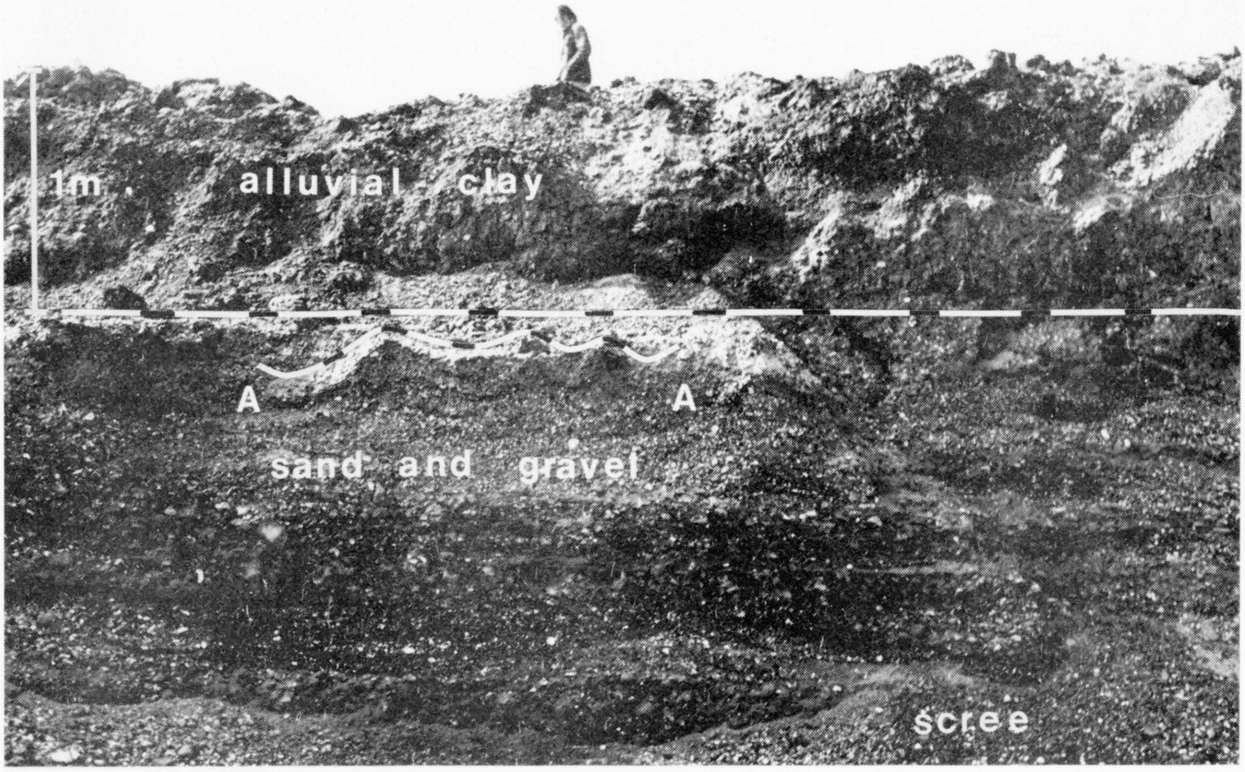


Fig. A (left) The floodplain deposits of the River Nene. A temporary exposure at Weston Favell (SP 794602).

Fig. B (below) As Fig. A, but a few metres to the left (south) to show peat layers.



coarse gravel down to clay, and the present 'clay river' seems to be more static than the former 'gravel river'. Nevertheless, Hack's work does suggest a possible relationship between sediment size and wavelength which may have application to the River Nene.

Vacher (1909) drew attention to the coarse sediments underlying modern river deposits of the River Cher at Montluçon in central France, and put forward the idea that these ancient boulder deposits were responsible for eroding the Cher's incised meanders.

The erosion of the River Nene's valley floor and the development of the valley meanders (which are ingrown rather than incised) have been associated with a coarse load, the gravels of the three terraces and the floodplain. Some exceptionally large boulders occur in the floodplain gravels. One large boulder of Northampton sand 1×0·8×0·35 m was found at the base of the gravels in Ecton pit. Associated with these coarse deposits are the large wavelength valley meanders. The River Nene's modern load is predominantly very fine and the present floodplain surface deposits are correspondingly fine-grained. It would appear that the reduction of sediment size and increased cohesion of bed and bank material have combined to give a reduction of meander wavelength, as well as a change in habit from braided to meandering. In other words, valley meander wavelength relates to the sand and gravel deposits, river meander wavelength to the alluvial clay deposits. Wavelength is proportional to sediment size.

This relationship is clearly seen along the course of the Smoky Hill River in central Kansas (Schumm, in Chorley 1969, pp. 209-210). Two reservoirs trap most of the coarse bedload, and below the reservoirs two tributaries introduce large volumes of silt and clay, so the load of the river changes from coarse to fine. Although discharge increases downstream, meander wavelength decreases. Interestingly, sinuosity increases and so the gradient is reduced. The Smoky Hill River seems to exhibit, in two successive reaches at one time, the two successive phases of meander development in the Nene valley.

Continuing the hypothesis that wavelength is proportional to sediment size, possible reasons for this relationship can now be considered. When the River Nene's banks were less cohesive and the river was dispersed among several braided channels with shifting banks, a smaller surplus of energy was available for turning; hence the large curves requiring only gradual changes of direction. Alternatively - or additionally - the coarse load may have necessitated higher velocities and therefore steeper stream gradients. The large wavelength meandering valley represents a shortening of the river's journey by 20%, as compared with the modern river channel, and the gradient was accordingly steeper.

As yet there is insufficient evidence to conclude whether it was higher discharge or coarser load which was responsible for forming valley meanders. Either, or both, may have contributed. What still remains inexplicable is the fact that the edges of the floodplain deposits are parallel. Whilst individual Devensian braids might have developed large wavelength meanders for either of the reasons discussed, there seems to be no reason why the edges of the Nene floodplain deposits should have developed systematic meanders. Plainly, existing explanations are inadequate to account for all the features of this particular valley, and the origin of the valley meanders in particular remains problematic.

The Erosion of the Floodplain Gravels

The middle Devensian floodplain deposits were partially re-excavated down to the present floodplain level; in places, along the valley side, the original surface survives as the fragmentary First Terrace.

This erosion phase is difficult to date. Comparison with other valleys suggests that some erosion may have taken place in the late Devensian. Durrance (1969) gives evidence of erosion at that time in mid-Devensian gravels deposited at the mouth of the River Exe, erosion relating to a low sea level at -110 m O.D. On the other hand, the upper and middle reaches of the Nene valley have an inland situation which may not have responded to sea level change in the same way. The Lea valley at Nazeing has an inland situation more comparable with that of the upper and middle Nene valley. Devensian gravels there were channeled three times, in Zones I, III and VI (Dury 1964, pp.40-47). Dury also notes that post-glacial Fenland deposits cover channels eroded in Zone IV, or earlier, and Zone VII.

Post-glacial deposits at Apethorpe, Northamptonshire, in the tributary valley of the Willow Brook (TL 028950) date from Zone III onwards, so the floor on which they rest must have been eroded in Zone III or earlier (Sparks and Lambert 1961). A post-glacial date for erosion in the main valley seems likely, although the available evidence is admittedly slight. The surface layers of the First Terrace gravels at Thrapston (SP 995802) contain some organic material (a peat erratic), which has yielded a radiocarbon date of 8920 ± 160 B. P. (Bell 1969). This means that the accumulation of gravels at First Terrace level was still continuing in about 7000 B. C., which is Zone V or Early Boreal (see table 2), and certainly post-glacial. The erosion down to floodplain level must have occurred later, perhaps in Zones VI or VII. That would appear to be the chronology at Thrapston, but we cannot assume that it was the same throughout the valley.

Dury (1964 p.46) attributes the partial re-excavation of some valley floor deposits to the Atlantic Phase (Zone VIIa) and cites Atlantic or late Neolithic channeling in the Fens. Several localities in the Nene valley have channels apparently out in Zone VIIa, filled or at least lined with Zone VIIb deposits, and overlaid by alluvial clay of Zones VIIb and VIII.

Temporary exposures at Ecton in 1974 (see text-fig. 2b) revealed two ancient stream channels cut into the gravel surface. The lowest point, or thalweg, of the larger channel was eroded to within 30 cm of the base of the floodplain gravel; re-excavation was almost complete at this point. The larger channel was 9 m across and 1·2 m deep. For comparison, the modern river channel, about 100 m to the south, would occupy the full width of text-fig. 2. Both of the ancient channels were lined with a dark grey clay layer containing many small sub-fossil twigs and roots, blackened and in some cases charred by fire. An oval worked flint from this layer was identified as a Neolithic scraper. Successive exposures revealed the larger channel at several points up to 60 m to the west (SP 840617). 300 m further to the south-west a similar buried channel was uncovered in 1971. At the same interface, evidence of forest clearance, charcoal and sherds of late Neolithic and Bronze Age pottery were found and dated approximately 4000 B. P. Some of the sherds were recovered from the organic channel fill itself, showing that the channel was eroded before 4000 B. P., i.e. probably in the Atlantic Phase.

Pollen analysis at the Ecton site shows that, at the time of the late Neolithic riverside settlement, low-growing plants predominated on the Nene floodplain. Three-quarters of the pollen belonged to grasses, bracken and meadow flowers such as daisies and dandelions, whilst tree species (hazel, oak and pine) were poorly represented. Significantly, very little of the pollen came from aquatic species such as sedges. The resultant picture of the Nene floodplain during at least part of Zone VIIb is that of a well-drained, more or less treeless, open grassland (Moore and Williams 1975).

Wood fragments from the eastern end of the Ecton pit (SP 842617) were removed from the organic channel deposit for identification. In spite of the rarity of hazel in the pollen spectrum, the wood fragments were hazel; there were also many hazel nuts in the deposit.

No radiocarbon dates are available for the alluvial clay sequence in the middle and upper Nene valley, but there are dates for the base of the alluvial clay from the floodplain at Peterborough (TL 182983 and 181984). Wood fragments at a depth of 6 m below the surface at the first site yielded a date of 4460 ± 105 B. P. Wood from the same depth at the second site gave a date of 3475 ± 100 B. P. (Horton 1972). These differing dates suggest that deposition of alluvium began at different times in different parts of the floodplain; in this case there is an apparent time-lag of a thousand years. Nevertheless, both dates are firmly in Zone VIIb (Sub-Boreal) and conform well with the late Neolithic and Bronze Age remains found at the clay base. The dates refer to horizons within 20 cm of the alluvial clay base, which we can assume was eroded in Zone VIIa (Atlantic).

The small dimensions of the River Nene's Atlantic Phase channels suggest either that the river carried a smaller volume of water than at present or that the river was split into many channels. Two channels uncovered at Ringstead (SP 975751) in the same horizon as a Bronze Age burial urn, dated about 3500 B.P., were similar in size to the Ecton channels. Although the Atlantic Phase was a period of substantially higher rainfall - 10-15% higher according to Lamb *et al* (in Sawyer 1969, pp. 174-217) - it is possible that the river's response to rainfall was reduced significantly by the forest which probably covered much of the catchment area. The pollen analysis at Ecton shows that before the late Neolithic occupation there was significantly less pollen from low-growing plant species, and that oak was far more important. In that case, the floodplain itself may have been wooded during Zone VIIa. With forest covering its catchment area, the River Nene may have required only a relatively small channel section.

At the same time, we know that the floodplain then lacked its present thick cloak of alluvial clay, and the gravel surface might well have continued to support a braided drainage pattern. If this is so, the exposed channels may represent only a part of the total channel cross section area. Unfortunately, exposures normally extend across only a fraction of the floodplain, so our knowledge of the Atlantic Phase drainage system of the Nene valley remains fragmentary.

Conclusion

In the middle Nene valley, no large buried fluvial channel has been detected either directly beneath the alluvial clay or the floodplain gravels. Towards Peterborough, a buried channel can be discerned, apparently graded to a low Devensian sea level, but upstream the gravels rest on a sub-planar surface which was produced by lateral corrosion under periglacial conditions. Its low gradient and its abrupt abuttal upon the steeper valley sides lead us to interpret it as a pediment.

The middle Devensian River Nene was braided and carried a coarse and excessive load, leading to aggradation to the level of the First Terrace surface. By analogy, it is possible, as suggested on text-fig. 3, that cold phases in the early Devensian also promoted aggradation to form the morphologically similar Second Terrace, whilst warmer phases were associated with vertical erosion.

Post-glacial or Flandrian changes to the Nene floodplain include partial re-excavation in Zone VIIa, deposition of fine sediment instead of coarse in Zones VIIb and VIII, the River Nene's adoption of a meandering habit in a large, single channel instead of braiding in several small channels, and reduction of meander wavelength.

The valley meanders evidently relate to a period, or periods, of large wavelength river flow. The reason for the large wavelength may be seasonally higher discharges resulting from summer snowmelts in the Devensian cold phases. Alternatively, it may be a response to a coarser load at those times. What still remains without any explanation is why the flat-floored meander-trough beneath the floodplain gravels itself developed large wavelength meanders along its edges. Whatever mechanism is responsible, the admittedly attractive scheme of relationships put forward by Dury is clearly inadequate.

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