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THE QUATERNARY TERRACES OF THE RIVER THAMES

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RÉSUMÉ

La Tamise dans le Bassin de Londres fut une conséquence de la régression d'une mer du début du Quaternaire. La suite des terrasses qui se développèrent ensuite a été la conséquence de changements de climat et de modifications du niveau de base. Une calotte glaciaire a atteint la bordure nord de la vallée, probablement à deux occasions. Dans la partie aval du bassin, l'abaissement eustatique du niveau de la mer et l'affaissement tectonique du bassin de la mer du Nord ont créé un ensemble complexe de terrasses, tant dans le plan vertical que dans le plan horizontal. La chronologie précise des terrasses fait encore l'objet des discussions.

INTRODUCTION

The River Thames is the southernmost of the major rivers of Britain draining into the North Sea. Its basin lies athwart the southern limits of glaciation and the river's course has twice been diverted by ice. Three southeasterly flowing streams, the Churn, Colne and Windrush form its headwaters on the dip slope of the Cotswold Hills. They are collected by a northeasterly flowing strike reach of the Thames along the outcrop of the Oxford Clay. Before turning southeast down dip, upstream of Oxford, the Thames is joined by the Evenlode and Cherwell from the north. Both formerly carried glacial meltwater into the Thames system from an ice sheet occupying the Midlands of England. Below Oxford the Thames is joined by the Thame from the Vale of Aylesbury, this also formerly carried glacial meltwater. Between Wallingford and Pangbourne the river cuts through the Chalk outcrop in the Goring gap a relatively narrow defile in which terrace remnants are few. At Reading where it flows on Eocene clays and sands it is joined by the Kennet which drains the western portion of the London synclinal basin. Between Reading and the sea the Thames follows an irregular but generally easterly course oblique to the northeasterly trend of the structural axis. In the London basin the Thames receives three principal north bank tributaries, the Colne, Lea and Roding; all formerly discharged glacial meltwater. From the south its

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major tributaries, the Wey, Mole and Medway drain the northern flank of the Wealden anticlinorium.

ORIGINS

The Thames probably originated on an emergent sea floor at the close of Cretaceous times when western Britain was uplifted. The downfold of the London Basin, into which it drained, was subsequently invaded by Palaeogene deposits, the western limits of which have not been defined at all clearly but by Neogene times it is probable that the Thames had lost its original headwaters following the development of a subsequent river along the outcrop of the Jurassic clays, west of the Cotswold escarpment.

Early in the Quaternary the London Basin was invaded by a Calabrian sea which left its mark in the form of fossiliferous marine deposits at a number of localities. Wooldridge and Linton claimed to be able to identify the shoreline of this marine transgression at a height of approximately 200 m cut into the bounding chalk dipslopes, but this has been disputed. It is, however, certain that the course of the Thames in the London Basin was re-established when the Calabrian sea regressed and that the Quaternary terraces of the Thames should be sought below heights of approximately 180 m above sea level.

During the Quaternary ice has invaded the valley of the Thames at least once and probably twice, reversing drainage which formerly flowed southwards across the Chilterns, into the Thames, and turning it northwards into the Ouse system. North of London the immediately post-Calabrian course of the river north-eastwards towards Colchester was shifted southwards by ice probably in two stages to its present course through London. At the same time glacial meltwater and outwash debris were fed into the upper Thames down the valleys of the Evenlode, Cherwell and Thame.

The southern watershed of the Thames in the Weald is markedly asymmetrical and the rivers draining directly to the English Chanel, such as the Arun and the Ouse, are actively engaged in the piracy of the headwaters of the Wey, Mole and Medway.

TERRACES

It is evident that the development of the terraces of the Thames has been determined by two principal factors, changing climate and changing base level conditions. As well as invasion of the northern margins of the valley by ice leading periodically to a greatly augmented discharge and increased load of glacial outwash debris, run-off and load were also significantly altered in the extra-glacial parts of the valley by an alternation of peri-glacial and interglacial climatic conditions. In the lower reaches of the river system eustatic lowerings of base level during cold phases were accompanied by incision and alternated with periods of aggradation during warmer periods. At the same time there appears to have been a tectonic lowering of base level in the lower Thames, consequent upon continued subsidence of the North Sea basin. The operation of these factors has led to the creation of a complex pattern of terraces in both the vertical and horizontal planes.

It is proposed to outline the terrace sequence in descending vertical sequence, first in the middle Thames where the terrace record is best presented, then in the lower Thames where the terraces may to some degree be dated and finally those in the geographically isolated upper Thames.

Middle Thames

Between the Rivers Colne and Lea, in north London, much of the London Clay outcrop forms a dissected plateau of roughly triangular plan. The main ridge runs at a height of approximately 122 m and appears to have outliers to the south at Totteridge and Hampstead. Northwards, beyond the Vale of St. Albans, a similar platform is developed on the Chiltern dipslope of the Chalk. Nearly everywhere the plateau surface is underlain by a thin sheet of pebbly gravel. Most of its constituents are flint pebbles derived from the Eocene. In addition there is an admixture of small white quartz pebbles probably derived from the outcrops of the Lower Greensand north of the Chiltern Hills. In a broad belt approximately 5 miles wide extending from south to north across the plateau there are in the gravels small pieces of chert which must have been derived from the outcrop of the Hythe Beds of the Lower Greensand in the Weald, south of London, as no such chert occurs in the northern outcrop of the Lower Greensand. The quartzose flint gravels are probably marine in origin, but the belts of chert debris marks the course of a river established on the emergent sea floor. The implication of the evidence is that this south to north flowing stream was a south bank tributary of a proto-Thames itself flowing from southwest to northeast approximately 32 km north of its present course through London. Further east similar chert bearing quartzose gravels on the hilltops north of the Thames in Essex may mark the course of another south bank tributary of the proto-Thames.

TABLE 1. — *Heights of Thames terraces above valley bottom* (after P. EVANS, 1971)

Terrace	Height in metres above valley bottom				Corresponding sea-level (O.D.)
	R	M	W	K	
Lower Floodplain	–	–	–	4	3 to 4
Upper Floodplain	2	2	2	6	7 to 8
Lower Taplow	10	8	8	13	17 to 18
Upper Taplow	18	13	12	16	17 to 18
Lynch Hill	27	22	21	22	23
Boyn Hill	32	34	34	37	32
Black Park	42	44	44	46	29
Kingston Leaf	–	–	–	53	27
Lower Winter Hill	45	50	56	? 58	55
Upper Winter Hill	53	57	60	? 62	
Rassler	61	64	67	? 68	62
Harefield	70	73	75	? 70	
Westland Green	(140)			(120)	103

R = Reading; M = Marlow; W = Windsor; K = Kingston. Heights, necessarily approximate, are taken from Hare (1948), Sealy and Sealy (1956), Zeuner (1959), Thomas (1962) and Hey (1966). The Westland Green course is too far from the present valley to permit close comparison of heights.

Confirmation of this very early northeasterly flowing Thames is provided by the gravels of the Westland Green phase (Hey, 1966), Table 1. These lie at lower levels than the Pebble Gravel, and are therefore deemed to be younger. They contain a much higher proportion of pebbles of quartz, quartzite, sandstone and Carboniferous chert. They have been traced discontinuously from the Goring Gap northeastwards along the southern margin of the Chilterns to Bishop's Stortford. The terrace falls from 146 m above Henley to 104 m at Bishop's Stortford where it passes beneath glacial drift. It is possible that the exotic material in the Westland Green gravels was carried into the upper Thames Basin by ice, alternatively it might be the remains of a much older deposit carried into the upper Thames when there were still river connections with Wales.

In 1938, S. W. Wooldridge identified a high level terrace of the Thames, now known to be lower and therefore probably younger than the Westland Green phase. It parallels the northeasterly trend of the Westland Green Thames but at Croxley Green in the Colne valley it is joined by a gravel train from the Vale of St. Albans sloping towards it from the northeast. From this Wooldridge deduced that by the time of the development of the Higher Gravel Train the Thames had already been diverted from its original northeasterly course. At a slightly lower elevation are the Harefield, Rassler and Winter Hill terraces, the latter subdivided into an upper and a lower leaf. The gravels associated with these terraces are for the most part rounded, angular and sub-angular flints with much Triassic quartzite, arkose and veined quartz. They do not entirely follow the present course of the Thames but between Goring and Henley pass through the Caversham trench, a now abandoned valley occupied by the Thames until at least the end of Winter Hill Terrace times. The gradient of the Harefield terrace is 1 m per mile, that of the upper Winter Hill terrace is approximately half that and on the lower Winter Hill terrace the gradient is barely perceptible. All these terraces appear to be heading for the broad linear depression through north London between the Hampstead and Highgate hills to the south and the Mill Hill ridge to the north.

The change in course of the Thames between the Westland Green phase and the Higher Gravel Train may well have been the consequence of the first incursion of ice into the Thames valley. In the Chiltern Hills a high level drift deposit, exposed in recent years at Mardley Heath, may be its ground moraine.

The second valley of the Thames is blocked by a mass of glacial drift resting on a surface at a height of 200 ft above sea level, substantially lower in elevation than the Chiltern drift. From the terminus of the younger drift there extends back westwards to the Colne valley a train of outwash gravels which appear to be confluent with the lower leaf of the Winter Hill terrace of the Thames suggesting that the second course of the Thames was abandoned at the time of the lower Winter Hill terrace when it was plugged by a second ice sheet. The anomalously low gradient of the lower Winter Hill terrace is consistent with a contemporary barrier of ice. The continuation of the second valley of the Thames beneath the cover of glacial drift in central Essex is evident in the configuration of the subdrift surface in which a substantial buried valley with tributaries entering from the north and the south heads towards the Blackwater estuary.

In the middle Thames there have been identified, as is shown in Table 1 and on Figure 1, at least six terraces. These have not all been traced through the built up area of London where the threefold division into Boyn Hill, Taplow and

Floodplain terraces mapped in the first two decades of this century is in urgent need of revision.

Lower Thames

The Boyn Hill terrace through central London is highly dissected. Its deposits have been the subject of intensive study downstream of London at Swanscombe, south of the estuary. A bench at 23 metres above sea level cut in marine Eocene deposits is covered to a depth of 11 metres by gravels, sand and loams. The thickness of the terrace deposits suggests that aggradation consequent upon a rising base level followed a period of lateral erosion. Analysis of the contained mollusca suggests that the deposits were laid down during temperate sub-stages of the Hoxnian inter-glacial. The uppermost gravel is of a solifluction origin indicating a return to cold conditions. A fragmentary human skull was discovered in 1935 in current bedded sands in association with a rick lower Palaeolithic handaxe industry (Acheulian).

On the north side of the lower Thames at Hornchurch deposits of gravels at 34 m are presumed also to be those of the Boyn Hill terrace of the Thames terrace. They rest on the tip of a lobe of glacial till extending down into the Thames valley through the broad col from the main expanse of the chalky boulder clay drift in Essex. This clearly indicates that the Boyn Hill terrace postdates the glaciation in which the chalky boulder clay ice of southern Essex was deposited.

The solifluction deposit overlying the Boyn Hill terrace gravels falls below present-day sea level and is therefore to be associated with a time of glacial low sea level subsequent to the Hoxne interglacial and prior to the aggradation of the coarse gravels in the Lynch Hill and Taplow terraces.

The Lynch Hill terrace is probably represented in central London by the upper part of what is mapped as the Taplow terrace. Fossiliferous beds in terrace gravels at a height of 26 m near Euston Station have yielded a cold fauna. The separation of the Upper and Lower Taplow terraces is evident upstream of London but within the built up area of London excavation for roads and buildings has substantially modified the shape of the surface. Unfortunately the many temporary exposures in the Taplow deposits have not been investigated. It is probable that the Lynch Hill and Taplow terraces are of Wolstonian age.

The Upper Flood Plain terrace deposits have been investigated in Trafalgar Square. Alluviation took place to a height of 15 m and the contained flora and fauna indicates an interglacial climate of Ipswichian (last interglacial) age. Thick deposits of brick earth related to this terrace at Ilford and Aveley in the lower Thames have yielded fossiliferous evidence of a similar climate and age.

During the Devensian (Weichselian) glaciation periods of low sea-level led to incision of the lower Thames creating deep channels later filled by aggradation deposits as sea-level rose during the Flandrian. Zeuner (1959) identified a number of benches cut during low sea-levels and these together with the terraces and limits of aggradation are shown in Table 2 adapted from P. Evans (1971).

It is difficult to distinguish discrete terrace surfaces over long distances and much more stratigraphical work on the low terraces is required before a detailed reconstruction of the recent history of the lower Thames can be made.

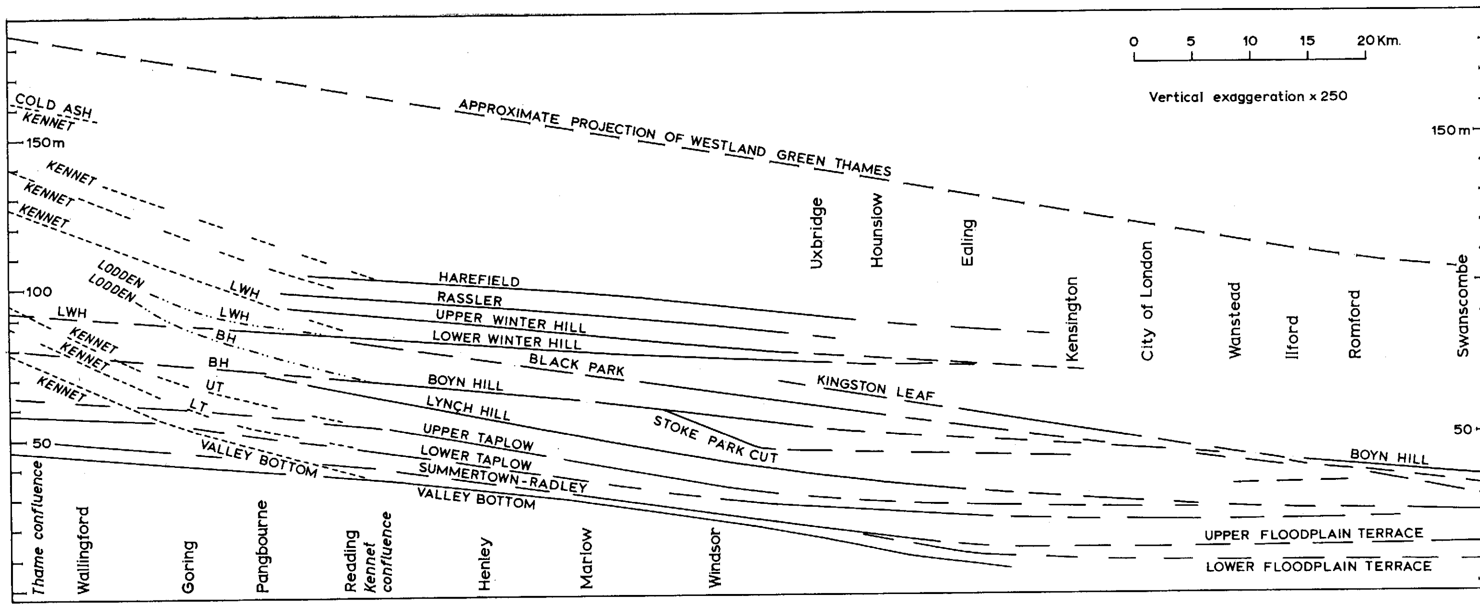

FIG. 1. — *Diagram illustrating the longitudinal profiles of the Thames terraces (P. Evans, 1971). Vertical exaggeration (×250).*

TABLE 2. — *Tentative suggestions for sequence of terraces and channels in the lower Thames during the past 100 t.y.*

	Zeuner's benches	Approximate height of sea-level (m)	
Tilbury aggradation	R	+ 2	
Third Buried Channel	R	− 30 ?	
Ponders End aggradation		− 10	
Ponders End Channel	Q	− 70 ?	Devensian
Lower Floodplain Terrace		+ 3	
First Buried Channel	P	− 100 ?	
Upper Floodplain Terrace		+ 7 to 8	Ipswichian

Upper Thames

The basin of the upper Thames is separated from that of the middle and lower Thames by the narrow defile of the Goring gap where the river cuts through the chalk of the Chiltern Hills. No direct links between the terraces of the middle Thames and those of the Oxford district have been established by field mapping.

A single occurrence of quartzose gravel at Watermans Lodge, 198 m, has the same exotic stone suite as the Westland Green gravels south of the Chilterns but is flint-free. This deposit may be a further remnant of the Westland Green Thames, with a gradient over a distance of 31 miles of approximately 0.75 m per mile.

Other remnants of plateau drift north of Oxford occur at somewhat lower levels and have a smaller proportion of quartz in their makeup, together with small fractions of metamorphic and basic igneous rocks which are absent from the Westland Green gravels. The former are probably the earliest true glacial deposits in the upper Thames basin and of a similar age to the Chiltern drift which likewise appears to postdate the Westland Green stage of the Thames. The sequence of gravel terraces in upper Thames is shown on Table 3 and in Figure 2.

The Coombe and Freeland terraces contain striated erratics re-worked from the plateau drift and are probably outwash terraces of an early glacial stage, perhaps the Anglian. They may be correlated with the Harefield and Rossler terraces of the middle Thames.

The next highest terrace is the Handborough Terrace, 31 m above the valley floor. Its gravels are mostly pebbles of local Jurassic rocks and it has a warm fauna with *Elephas antiquus*. It has been correlated with the Boyn Hill terrace of the middle and lower Thames.

The Wolvercote Terrace 17 m above river level contains a suite of erratics (Bunter pebbles and flints) which are probably glacial outwash from the Wolstonian ice sheet of the Midlands Chalky Boulder Clay. There are few terrace remnants in the Cherwell valley but detailed mapping by Bishop (1958) suggests that glacial lake Harrisson, formed ahead of the advancing ice, spilled through the Fenny Compton gap into the upper Thames system at this stage. Deposits filling a channel cut in the Wolvercote Terrace gravels have been correlated with both the Hoxnian

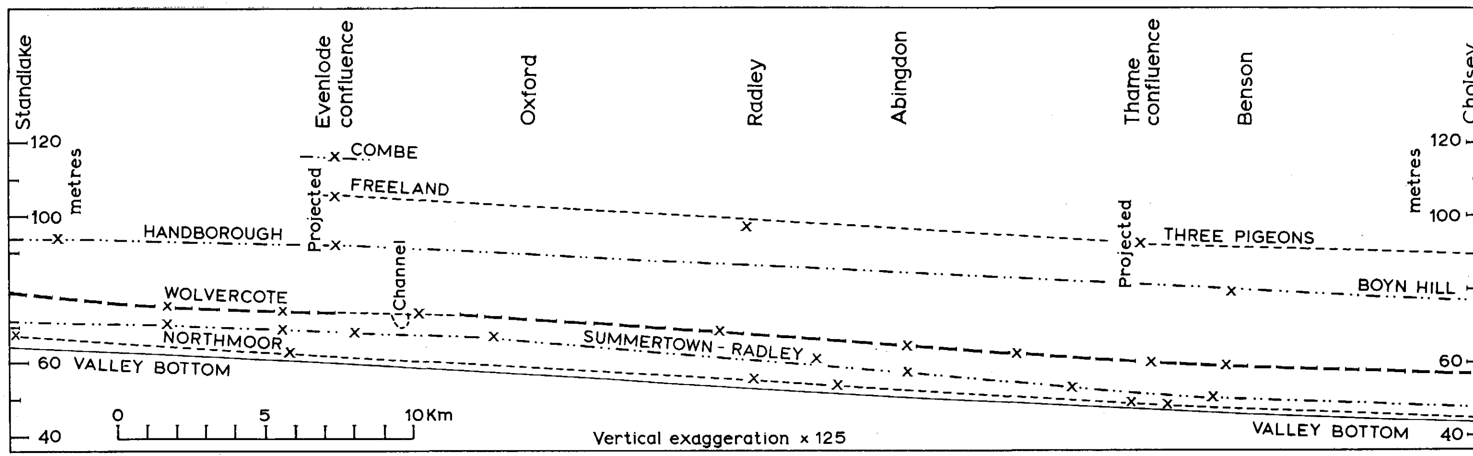

FIG. 2. — *Sketch of the Thames terraces near Oxford (P. Evans, 1971). Vertical exaggeration (×125).*

TABLE 3. — *Sequence of gravel terraces and other deposits in the Oxford area* (P. EVANS, 1971)

Terraces, etc.	Approx. height above valley floor (m)
THAMES (mainly Sandford, 1924)	
Northmoor Terrace	2 (top)
Buried channels	− 5 (bottom)
Summertown-Radley Terrace	
upper part	7 (top)
lower part	5 (top)
Wolvercote Channel	
upper (peat)	17 (top)
lower (sand and gravel)	12 (bottom)
Wolvercote Terrace	17 (top)
Windmill Hill (Nuneham Park) gravels	45 (top)
(Westland Green gravels)	(130)
THAME (Arkell, 1944)	
Floodplain Terrace	3 (top)
Chalgrove Terrace	8 (top)
Haseley gravels	(15 (top)
Tiddington gravels	30 (top)
Three Pigeons Terrace	46 (top)
EVENLODE (Arkell, 1947)	
Handborough Terrace (projected to confluence)	31 (top)
Freeland Terrace (projected to comfluence)	46 (top)
Combe Terrace (projected to confluence)	52 (top)

and Ipswichian interglacials and it is still not certain which interpretation is correct. It possibly correlates with one of the Taplow terraces of the middle Thames.

The Summertown-Radley Terrace 9 m above the valley floor at Oxford is only 3 to 4 m above at the entrance to the Goring Gap. The lower deposits near Oxford were deposited in cold conditions as indicated by the contained flora and fauna and are probably Wolstonian in age. The upper part above a minor break contains a temperate fauna with *Hippopotamus* and is attributed to the Ipswichian (Eemian) interglacial. The correlation downstream is with the Upper Floor Plain terrace.

The Northmoor Terrace 2 m above the flood plain corresponds to the Lower Flood Plain Terrace in London. It conceals a buried channel of presumed Devesian (Weichselian) age containing gravels with a cold fauna and flora.

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DISCUSSION

J. I. S. ZONNEVELD. — *You mentioned an idea concerning land ice covering South England up to the Channel. Who put forward this idea? What are the evidences?*

E. H. BROWN. — This idea was most recently propounded by Mr. G. A. Kellaway in a paper published in 1971 (Glaciation and the Stones of Stonehenge, *Nature*, 233, p. 30-35). The evidence is in the form of the distribution of what are suggested to be glacial erratics.

Ch. POMEROL. — *In connection with the hypothesis of a "Channel glacier" are there boulders of a northern origin on the British shore of the Channel?*

E. H. BROWN. — There are a number of erratics on the British shore of the channel, notably the Porthleven erratic in Cornwall, and there are erratic stones in the coastal shingle. Whether these are evidence of transport by land ice, ice flows, or other transporting agents is still a matter of opinion.

P. MACAR. — *There seems to be for the whole Quaternary some kind of alternation between glacial and interglacial terraces. Is it really the case?*

E. H. BROWN. — In the lower Thames there appears to be convincing evidence that at least two of the terraces are of interglacial age. The fauna of the Boyne Hill Terrace certainly suggests this, as described in M. K. Kirnie, 1971, *Interglacial Deposits in Burnfield pit to Swanscombe and their Moluscan Fauna,* Journal Geological Society 127, 69-93. And for the Ipswichian interglacial as described in R. G. West, Camilla A. Lambert and B. W. Sparks 1964, *Interglacial Deposits at Ilford, Essex,* Royal Society Phil. Trans. series B 247, 185-212.