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Pleistocene History of the Vale of St Albans

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PLEISTOCENE HISTORY OF THE VALE OF ST ALBANS

By P. L. GIBBARD
Subdepartment of Quaternary Research,
Botany School, Downing Street,
Cambridge, CB2 3EA

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[Pullouts 1–4]

CONTENTS

The stratigraphy of the Pleistocene sequence in the area of the Vale of St Albans has been investigated and the results used to link the sequences in East Anglia and the Middle Thames region. Lithological units have been characterized using various methods and thirteen formal lithostratigraphical units are proposed.

The bulk of the deposits are included in the Anglian glacial stage during which two major ice advances occurred. Both advances dammed the eastward-flowing river in the Vale causing, respectively, a minor and a more extensive proglacial lake. The river was finally diverted and after the ice retreat a westward-flowing river occupied the Vale.

Organic remains fill kettle holes resting on the glacial deposits. A new site at London Colney shows a late Anglian to Hoxnian Ho 1 pollen sequence. Wolstonian soliflucted gravels overlie the hollow fills. It is probable, since pre-Ipswichian and Ipswichian deposits occur near the present river level, that the modern river valleys were initiated during this stage. Overlying the Ipswichian deposits in river valleys and on interfluves is brown silt, containing a substantial loess component. This is considered to represent early Devensian river aggradation. A period of down-cutting then occurred, before the accumulation of valley gravels which contain organic horizons radiocarbon-dated to the Late Devensian.

The sequence is extended north to Stevenage and Hitchin and east into Essex. The Middle Thames Terrace sequence is equated with the Vale using relative heights and lithology, showing that the Thames flowed through the Vale until late Anglian times, when it was diverted southwards and took up a course close to that which it follows today.

1. Introduction

The Vale of St Albans area forms an extremely important link between the relatively well established stratigraphy of East Anglia and the poorly known sequence in the Middle Thames region, hitherto undated. Earlier workers have in part shown that the Vale of St Albans may have been occupied by the Thames, and that the river was diverted to its present course by an ice advance, but there has never been a systematic study of the stratigraphy of the deposits taking the area as a whole. As a result there has been little agreement on the age

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and relation of the glacial deposits, a lack of information on the mechanism and timing of the Thames' diversion from the Vale, and confusion over the age and origins of the modern river system.

The data described here provide evidence for the evolution of the Vale of St Albans and insight into the palaeogeography of the area, especially during the Anglian (glacial) stage. As will be shown, the history of the River Thames, revealed by deposits both in and adjacent to the Vale, can be put on a firm stratigraphical basis, with the events leading to its diversion being clarified.

(*a*) *Topography and geological background*

The study area is shown in figure 1. The Vale of St Albans consists of a wide (6.5–7.5 km), gently undulating plain dissected by many river valleys. The eastern half is drained by the River Lea and its tributaries, the Mimram, Rib and Beane, and the west by the Colne and its tributaries, the Mimmshall Brook and the Ver.

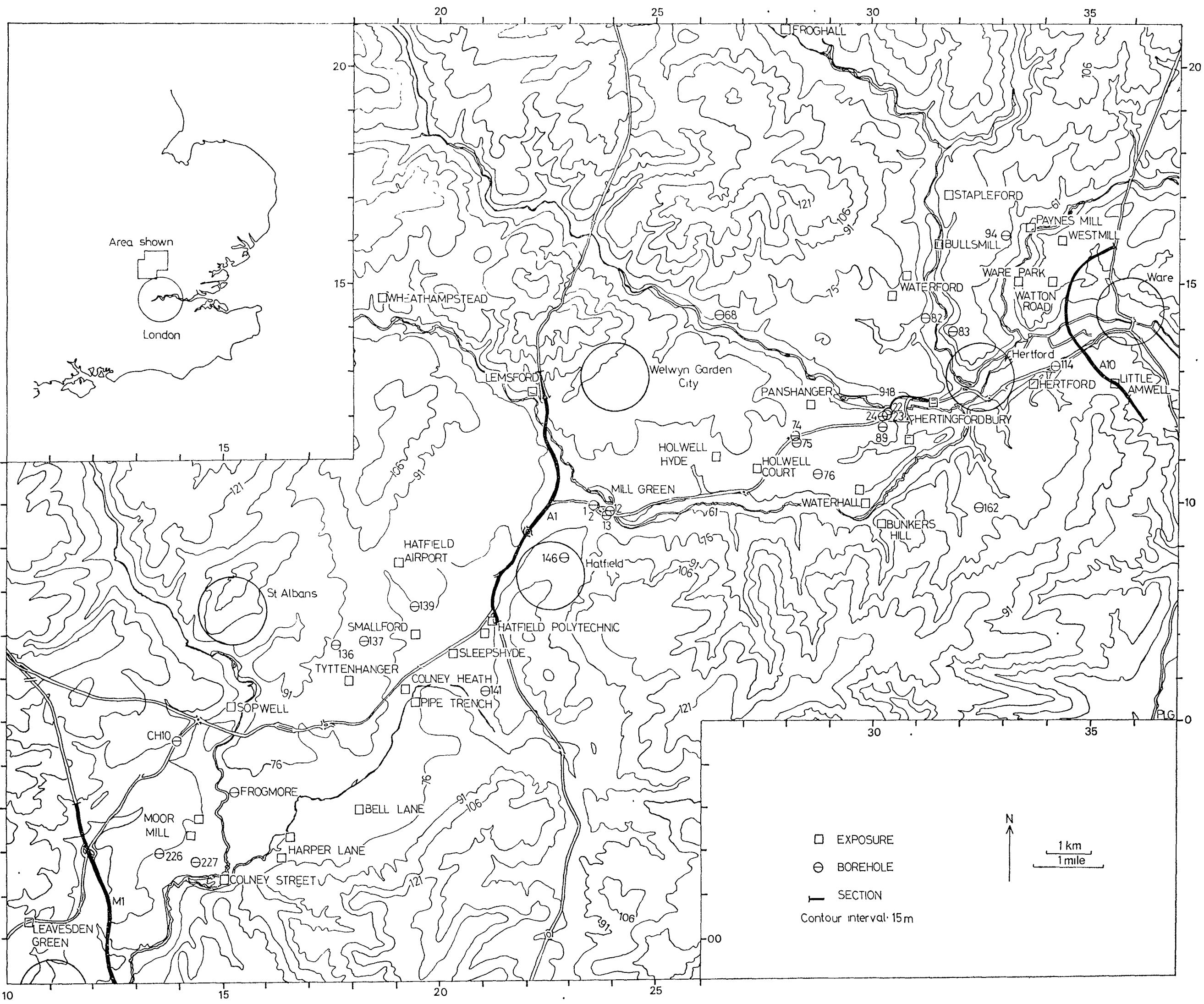


FIGURE 1. Location and topographical map, showing the area studied and the localities of exposures, boreholes and sections mentioned in the text.

The geological map (figure 2) shows that the Vale is underlain by a wide spread of 'glacial' gravel and associated Chalky Till (boulder clay). The gravels extend up some of the Chiltern valleys, e.g. the Lea. The 'glacial' deposits are dissected by modern river valleys containing narrow tracts of gravel, sand, silts and organic deposits. To the north are the Chalk hills of the Chilterns reaching over 125 m O.D. at Childwick Green (north of St Albans). They are dissected both by a complex system of dry valleys and by larger, often deeply incised, consequent valleys. The Chalk hills are covered by a varying thickness of Clay-with-flints, which descend with the dip slope to 120 m O.D. (Loveday 1962). South of the Vale are lower more dissected hills of the Tertiary escarpment. They have a ridge-like form near Radlett, and reach 102 m O.D. at Hatfield Heath. Few streams enter the Vale from these hills. The Tertiary formation here consists of the Reading Beds and overlying London Clay. A wide spread of early Pleistocene Pebble Gravels occurs on the Tertiary hills (Sherlock & Pocock 1924).

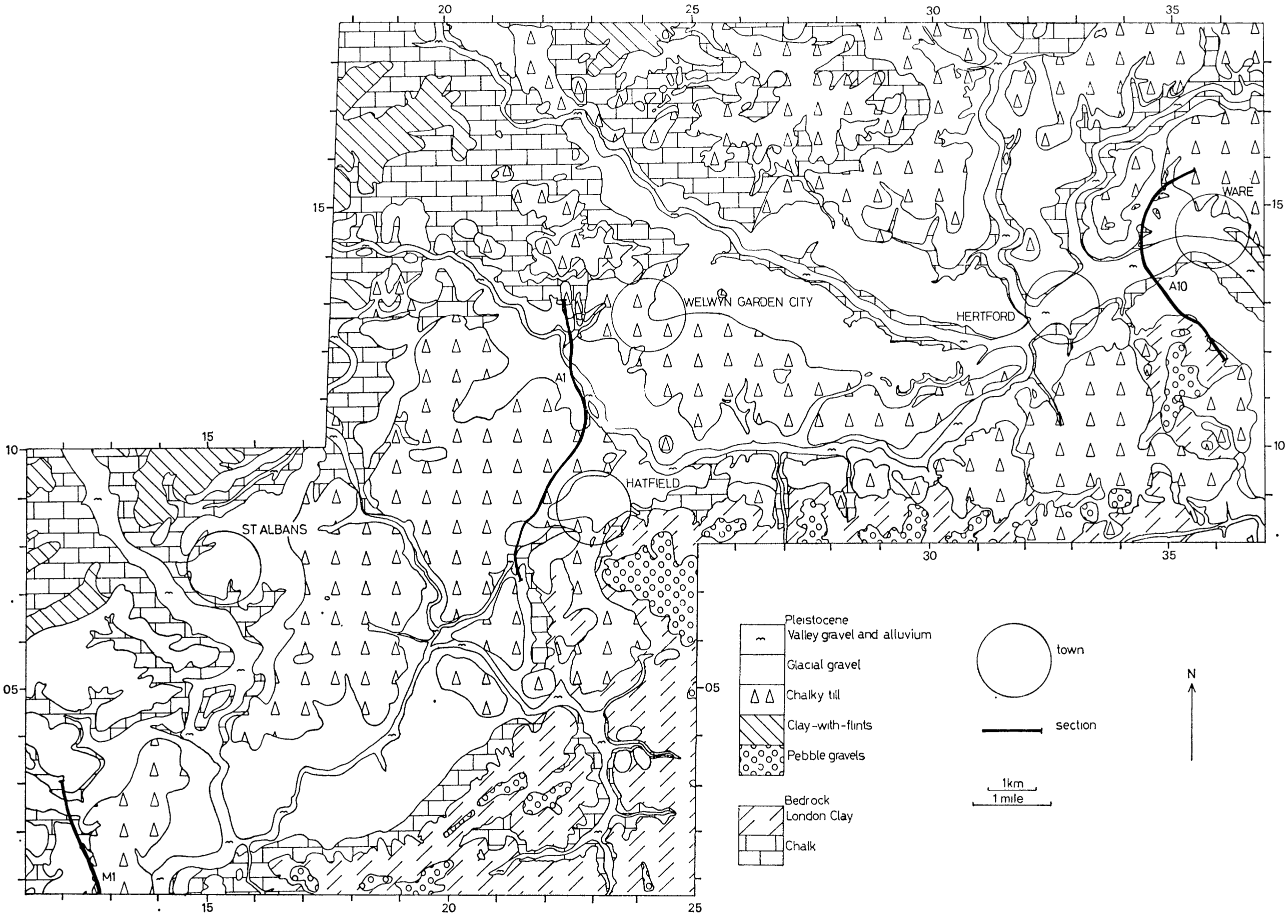


FIGURE 2. Drift geological map modified from Geological Survey one-inch sheet 239 'Hertford' (1924). The positions of the road borehole sections across the area are also shown.

(b) *Previous research*

The Pleistocene geology of the Vale of St Albans was first described by Hughes (1868) and later by Whitaker (1889) working for the Geological Survey. Woodward (1897) had earlier recognized the Chalky Till (chalky boulder clay) to be of glacial origin. Much controversy regarding the relative ages of deposits and valley formation took place (see, for example, Prestwich 1890; Gregory 1894), but the diversion of the Thames from an early course through the Vale by the Chalky Till ice was first suggested by Salter (1905). Sherlock & Noble (1912) and Sherlock (1924) proposed that a preglacial Thames flowing through the Vale was diverted first by an early ice advance and later by the Eastern (Chalky Till) ice. Their premise that this early Chiltern ice advance deposited the Clay-with-flints was supported by Barrow (1919).

In their studies on the drainage evolution in the London Basin, Wooldridge (1927, 1938, 1960) and Wooldridge & Linton (1955) divided the drift deposits into three stages:

I. summit and high level drifts, i.e. Red Crag and Pebble Gravels;

II. glacial deposits and plateau gravels, including the Eastern Drift (Chalky Till) and Chiltern Drift. (The drifts were subdivided into a series of gravel trains or terraces);

III. valley and Terrace Drifts.

With regard to the Vale, Wooldridge (1960) argued that in stage I times a 'proto-Thames' had flowed eastwards through it into Essex (Wooldridge & Henderson 1955), but that by stage II it had been diverted south by the Chiltern ice, and rejoined its old course near Ware. During this period the Vale was drained by a westward-flowing tributary, which deposited the Leavesden Gravel Train and joined the Thames at Rickmansworth but later by an eastward-flowing stream that entered the Thames at Ware (Wooldridge 1938). Subsequently, the Vale was overrun by the advancing Eastern (Chalky Till) ice, which caused the rivers' final diversion to the south (Wooldridge & Linton 1955). Hare (1947), examining the Thames terraces in Buckinghamshire, confirmed Wooldridge's stage II sequence. However, the first conclusive evidence of a 'preglacial' Thames flowing from Oxfordshire into Essex via a newly formed Vale was presented by Hey (1965) in his account of the Westland Green Gravels (stage I, Pebble Gravels).

In 1958, Clayton & Brown proposed the existence of a proglacial 'Lake Hertford' during the Eastern glaciation, the formation of which caused the southward diversion of the Thames. They related the retreat of the ice, which finally overrode the Lake to drainage diversions and present river patterns in eastern Hertfordshire (see also Wooldridge 1953). Brown (1959) suggested that the Hitchin–Stevenage Gap may have originated as a preglacial valley over-deepened by subglacial streams, since it is filled with thick glacial deposits. This valley was previously discussed by Hill (1896, 1908, 1912, 1914) and more recently by Woodland (1970).

Stone orientation applied to the tills of the area by West & Donner (1956) led them to distinguish two horizons of Chalky Till, the lower of which they correlated with the Lowestoft advance and the upper with the Gipping. They argued that the upper till, being the most widespread, probably represents the advance which diverted the Thames. Clayton & Brown (1958) suggested, however, that both till horizons may belong to a single complex unit deposited by Clayton's (1957) Springfield ice advance.

Sparks, West, Williams & Ransom (1969) gave an account of two interglacial sites near Hatfield, and showed that pollen-datable sediments of Hoxnian age occur within the 'glacial' succession. Previously the bulk of the Eastern Drift had been assigned both to the Wolstonian (Gipping) (West & Donner 1956) and to the Anglian (Lowestoft) (Clayton & Brown 1958) glaciations. However, Wooldridge & Linton (1955) had also opted for a pre-Hoxnian age, since the Thames had apparently already occupied its present valley by the Hoxnian stage.

2. Lithostratigraphy of the Pleistocene deposits

The deposits of the Vale of St Albans are assigned to lithostratigraphical units following the Code of Stratigraphic Nomenclature (1961) and the Recommendations on Stratigraphical Usage (1969) and are presented in order of succession. Each unit is defined, delimited and named from a type section. A generalized description of each unit is provided, together with its relation to other deposits. More detailed information may be found in Gibbard (1974). The locations of sites are shown in figure 1.

Standard methods have been used in investigating the deposits: stone orientation follows West & Donner (1956), palaeocurrent analyses follow Potter & Pettijohn (1963) and pebble counts follow Hey (1965) using sieve meshes of 32, 16 and 8 mm.

The Pleistocene deposits can be divided into two main groups: (i) those occurring as eroded remnants forming the interfluves including §§(*a*)–(*i*), and (ii) those occurring mainly in the present river valleys, i.e. §§(*j*)–(*m*).

The interpretations based on the descriptions below are given in §6.

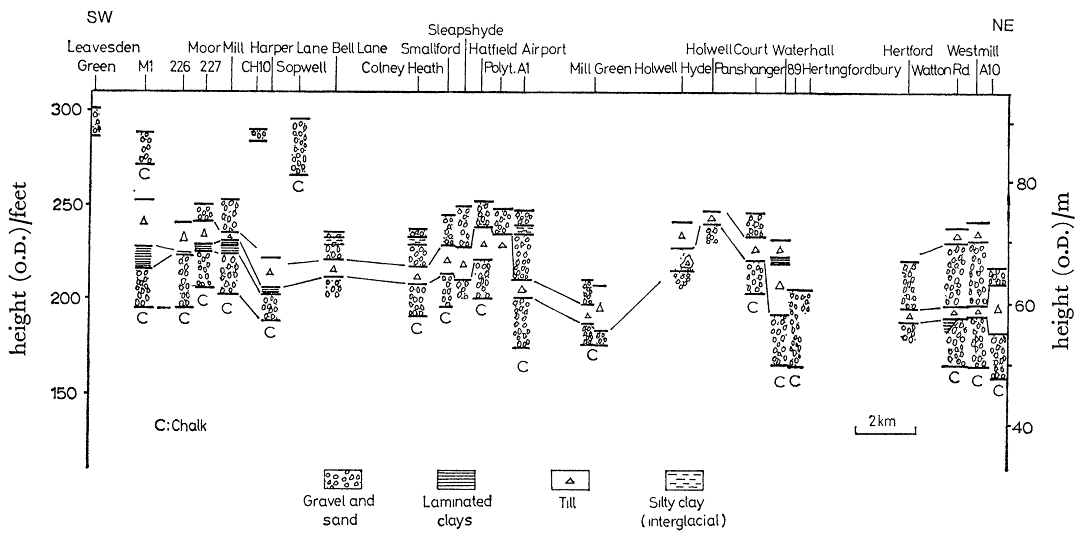


FIGURE 3. Section along the Vale of St Albans constructed from exposure and borehole information. The numbers refer to those given by Woodland (1945*a*). The positions of the localities are shown in figure 1.

(*a*) *Leavesden Green Gravel*

The oldest gravel deposits studied are those underlying Leavesden Green NE of Watford, where the ground surface is at 91 m O.D. Here a temporary section (TL105004) exposed 3.6 m of horizontally bedded fluviatile gravels (figure 3). This gravel is the same as that described from here by Wooldridge (1938). It can be traced eastwards to the M1 section (Figure 4, bed 2) where 5 m of gravel rest on bedrock Chalk at 80–84 m O.D., to beneath the A405 road and to the south of St Albans at Sopwell (TL144053) (Sherlock & Pocock 1924) where it is 9 m thick. The gravel forms an eastward grading dissected terrace remnant west of St Albans, on the north side of the Vale, but is absent to the east. A pebble count from Leavesden Green shows that the gravels contain a restricted lithological assemblage dominated by flint (79 %) and vein quartz and quartzite (14 %) but with a few pebbles of less durable chalk and stoneless brown clay.

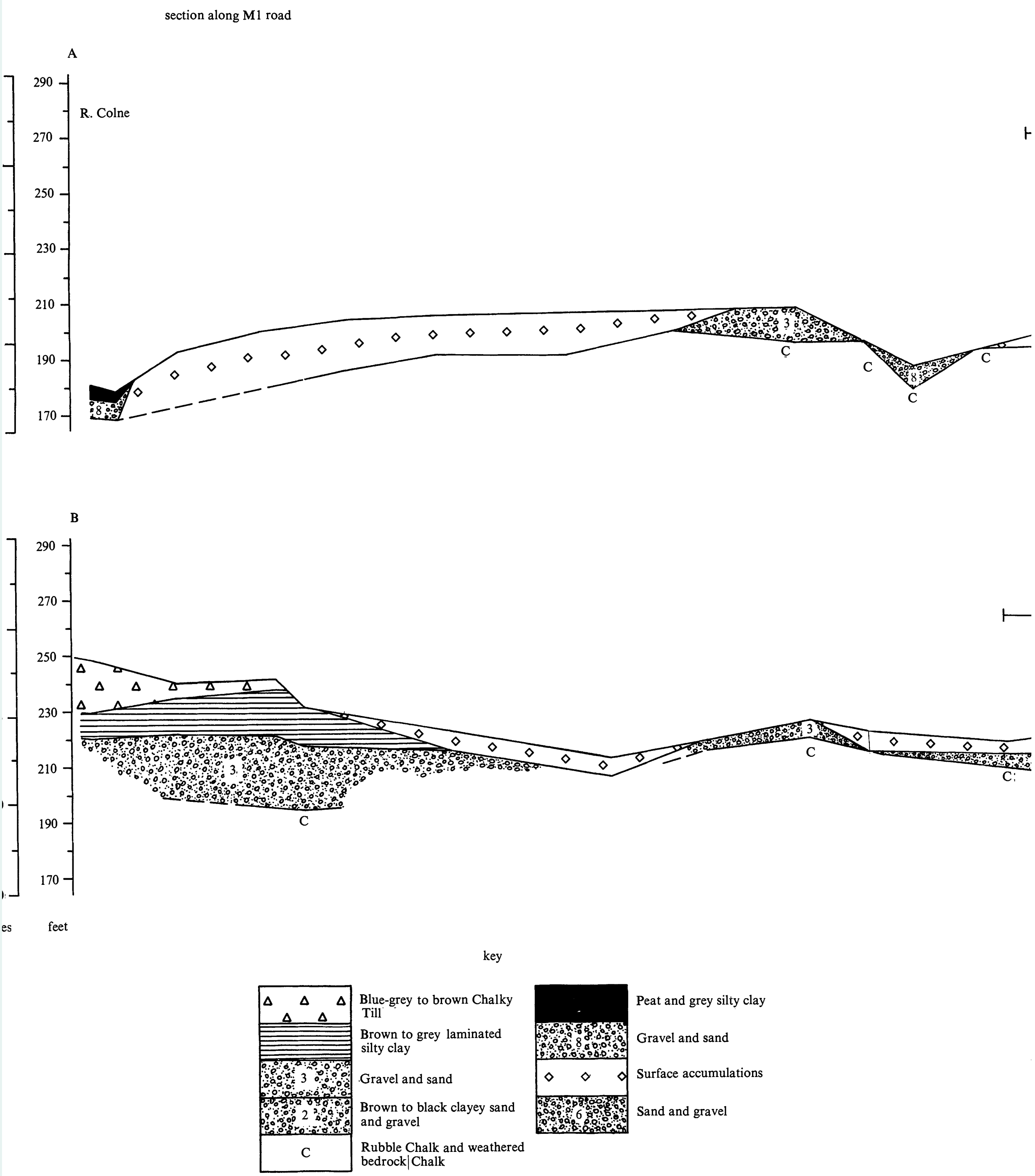
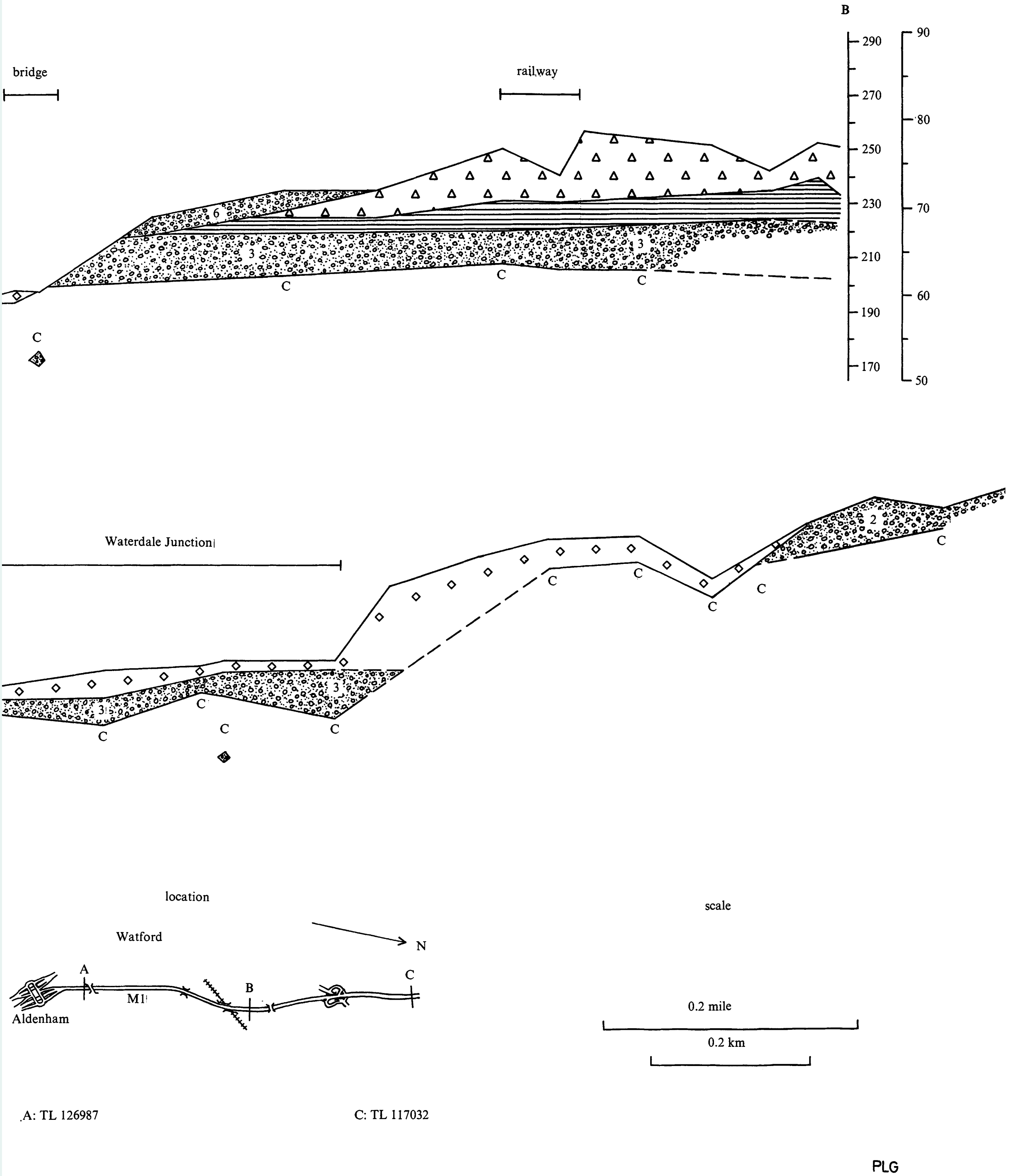


FIGURE 4. Section along the M1 roa
Eastern Road Constructio



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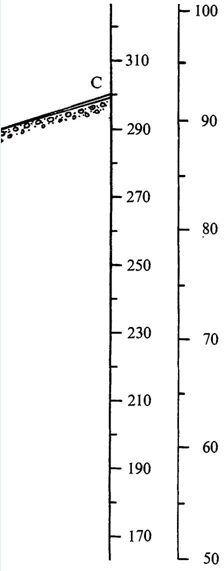

(*Facing p.* 450)

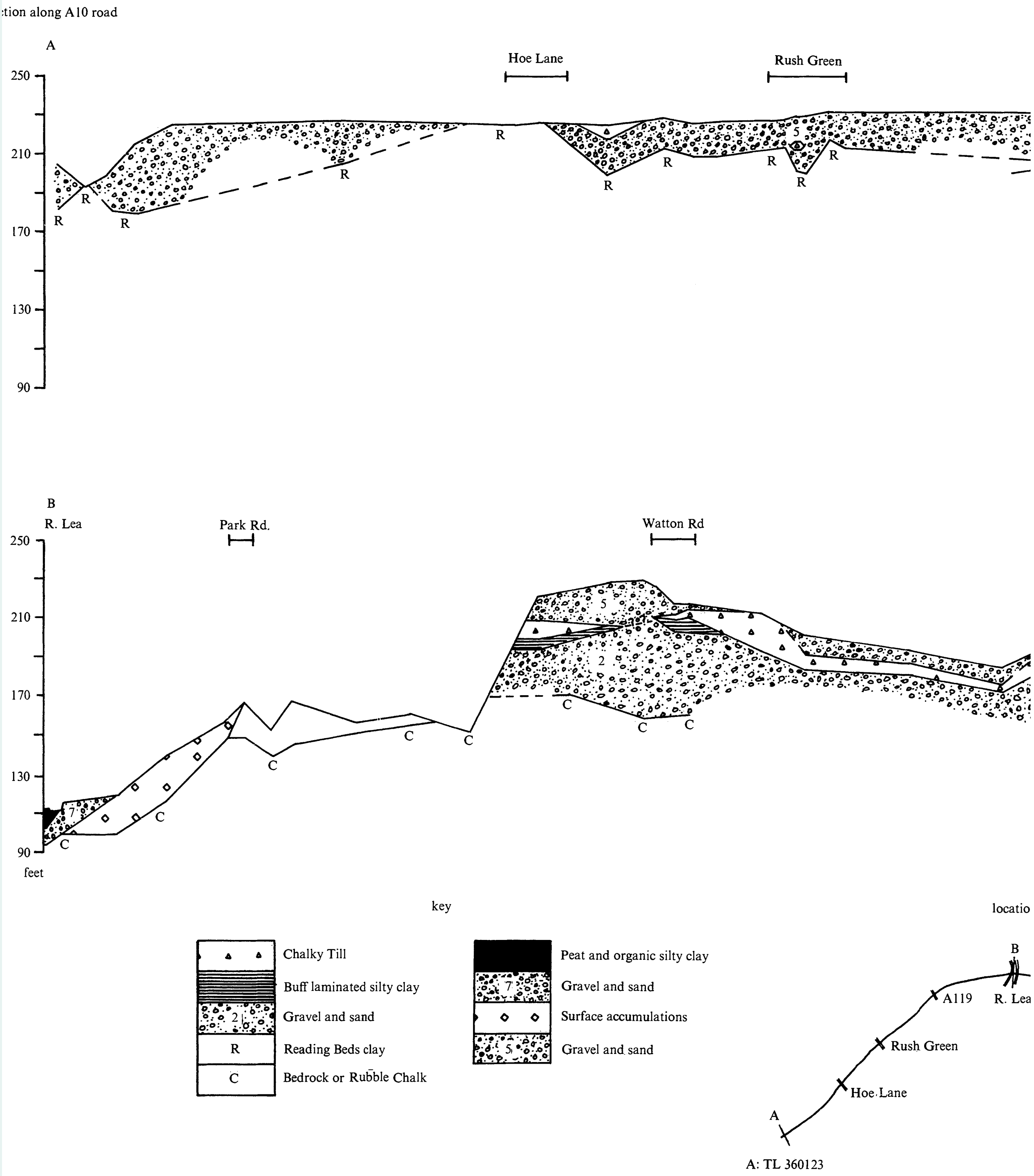

FIGURE 5. Section along the A10 road, constructed fr
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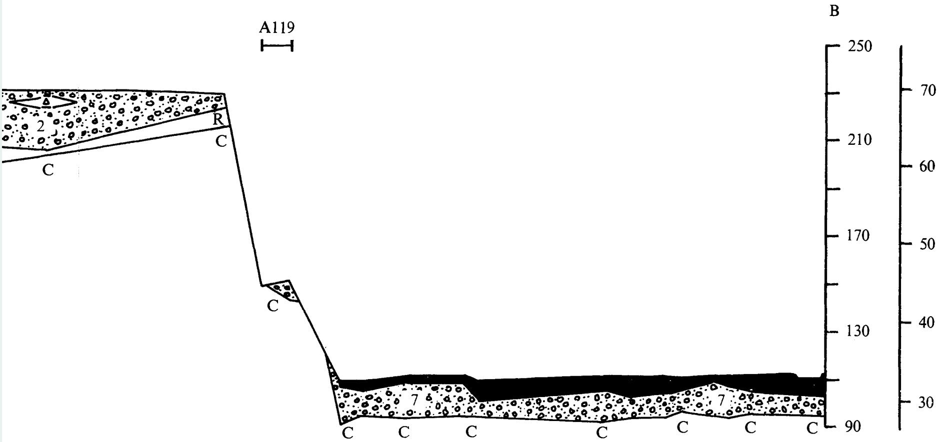

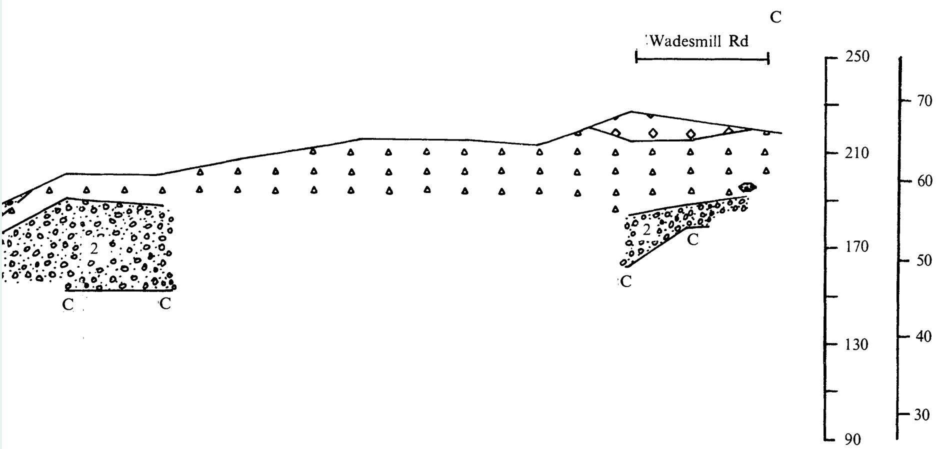

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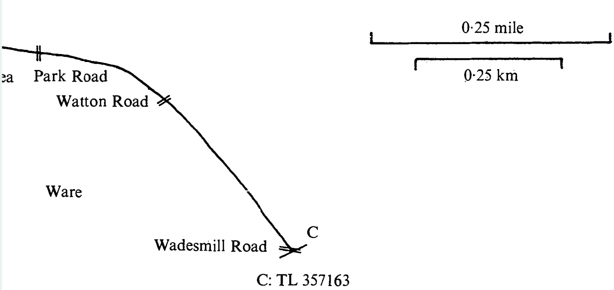

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ncil.

North of Leavesden Green, a brown stoneless clay overlies the gravels and thickens towards Abbots Langley (TL100012) (Wooldridge 1938) where it contains some gravel inclusions. Similar material rests on the gravels in the M1 section and resembles lithologically the Clay-with-flints which occur at higher elevations to the north.

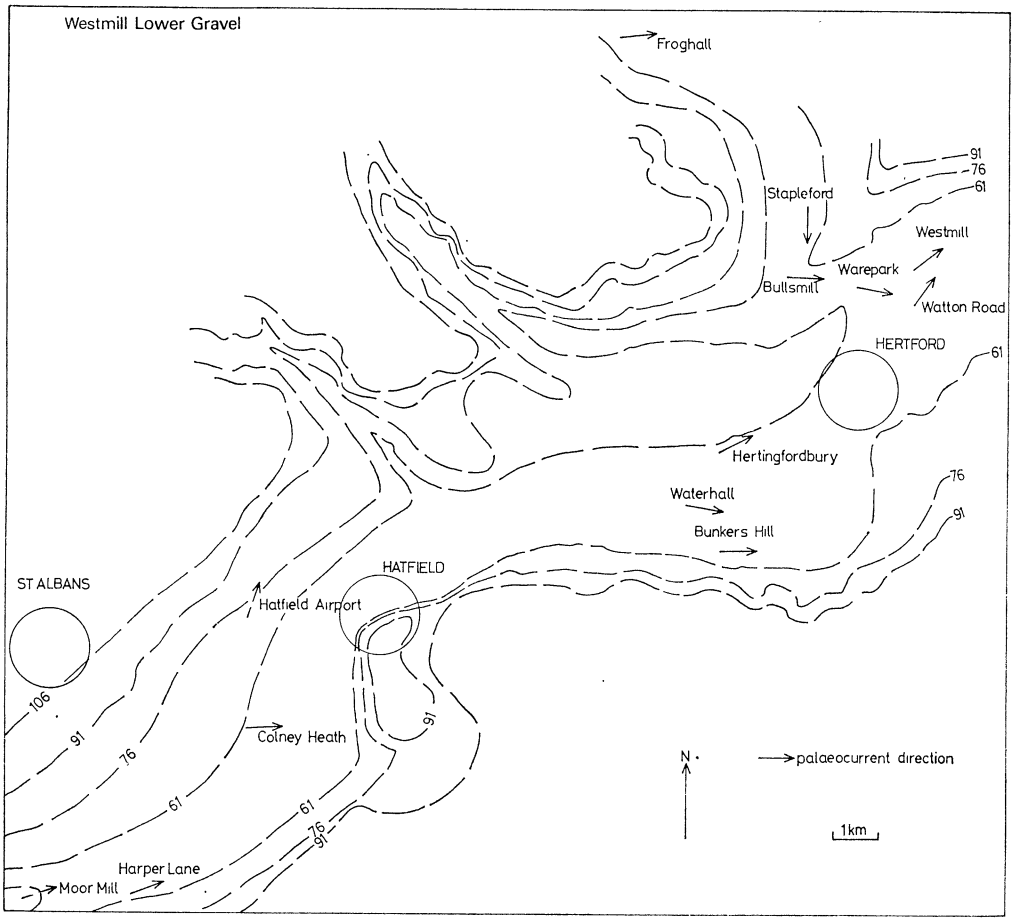

FIGURE 6. Palaeocurrent directions from the Westmill Lower Gravel. The contours are taken from the bedrock surface reconstruction (figure 13).

(*b*) *Westmill Lower Gravel and Westmill Gravel*

The lithological sequence at Westmill Quarry (TL342162) typifies that found in the area north of Hertford and Ware on river interfluves. Here a lower fluviatile gravel and sand is overlain by Chalky Till and this is in turn overlain by a second gravel horizon, above which there is a second till (Eastend Green Till, §2*g*). The lower till (Ware Till, §2*d*) therefore divides the gravels into the Westmill Lower and Upper Gravels. The absence of the Ware Till west of Hertford means that this division cannot be recognized (figure 3) and therefore the name Westmill Gravel will be used for this unit in the Vale of St Albans.

The deposits consist of large gravel lenses, sometimes showing internal stratification, associated with sand strata. The sands are often laterally impersistent and frequently show cross bedding. Silt and clay deposits are rare. At Westmill they rest on Chalk at 58 m O.D. and are overlain by till. They occur in a very similar stratigraphical position in exposures NNE of the type section. At nearby Watton Road Quarry (TL343152) and in the A10 section (figure 5, bed 2) they are overlain by laminated silts and clays (§2*c*). They can be identified south of the Lea Valley at Little Amwell (TL128355). To the west of Hertford the gravels may be correlated with those underlying the till horizon (Eastend Green Till, §2*g*) in the Vale of St Albans (figure 3). In the M1 section (figure 4, bed 3) the base of these gravels is at 62 m O.D., i.e. 18 m below that of the Leavesden Green Gravel. Palaeocurrent analyses

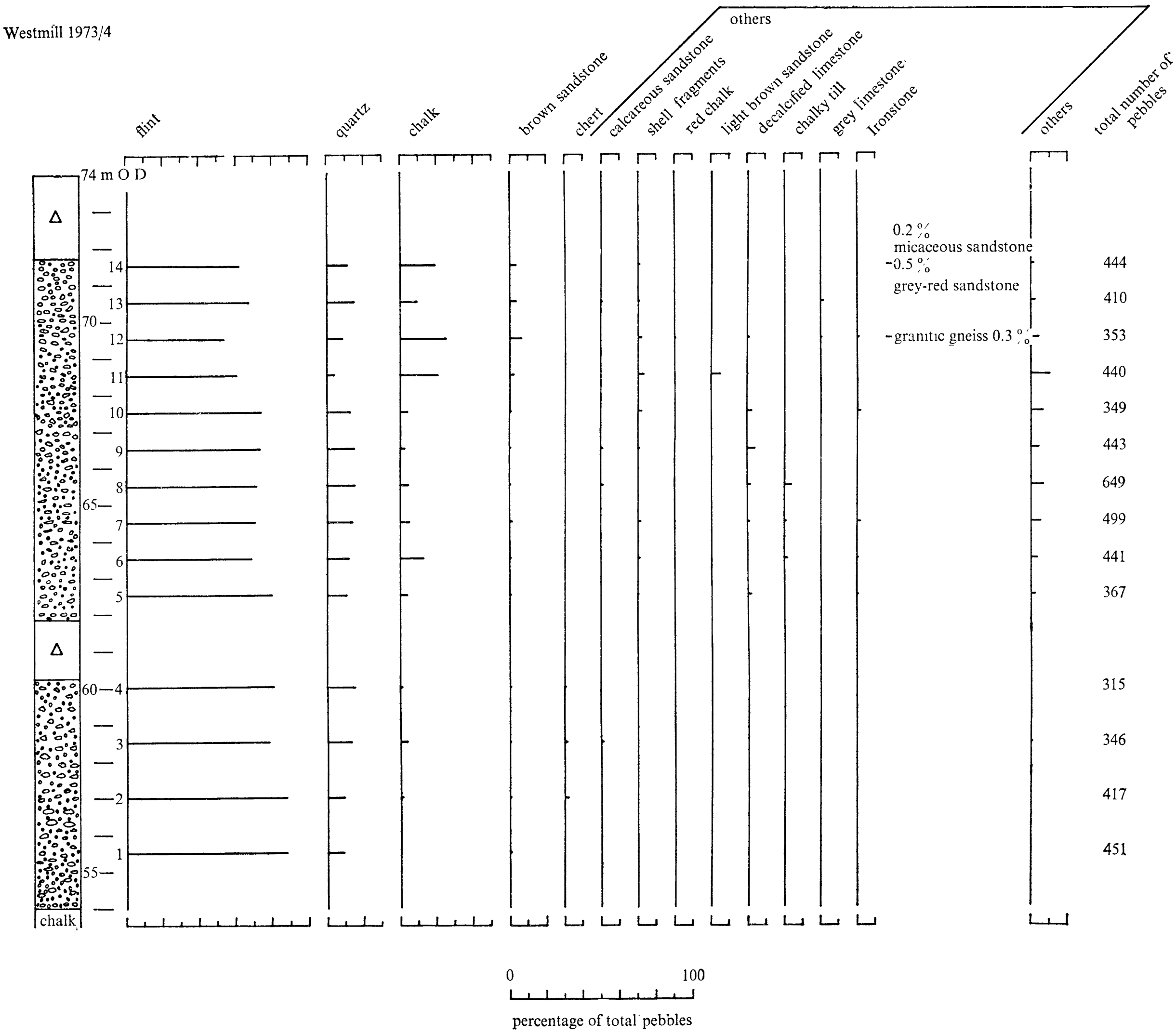

FIGURE 7. Vertical variation in pebble lithological composition from the gravel beds at Westmill Quarry.

(figure 6) and pebble counts substantiate these correlations. Two pebble lithological assemblages are present and characterize the two main gravel trains. The assemblages from the Vale are restricted and are predominantly composed of flint (82–91 %), subordinate vein quartz and quartzite (9–17 %) together with some minor lithologies including Lower Greensand sponge spiculed chert. However, assemblages from the exposures north of Hertford contain markedly less flint (75–88 %), whilst chalk (1.5–6 % compared with 0–2 % in the Vale) and erratic rock types are substantially more common. The confluence area of the two streams was in the Hertford district and the vertical sequence of counts of intermediate composition from Westmill Quarry bears this out (figure 7). Small ice wedge casts have been found in gravel correlated with this unit at Moor Mill Quarry (TL143025) and Hertingfordbury (TL302121). The facies proposed by Williams & Rust (1968) and Rust (1972) for braided river channel deposits can be recognized in these deposits.

(*c*) *Watton Road Laminated Silts*

At Watton Road Quarry (TL341149) 2.5 m of brown laminated clayey silts rest on sand correlated with the Westmill Lower Gravel and are overlain by the Ware Till. They are composed of alternating couplets of buff silt (up to 10 mm thick) and dark brown silty clay (2–3 mm thick). Concave slide planes, presumably resulting from rotational block slumping, divide the sequence into four units. Such structures have been observed in modern lakes by Coakley & Rust (1968) and may result from changes of water level, accumulation of unstable thicknesses of sediment or possibly from ice push or loading. Determination of the number of varves in the unit was achieved by counting the maximum in each block and the result was 485 pairs. The upper part of the silts is contorted, is overlain by unlaminated grey brown silty clay and grades upwards into the till above.

The laminated clays can be recognized in the A10 section (figure 5, bed 3) which crosses a quarry (Ware Quarry) where they have been extensively worked. Sections in this quarry described by Sherlock & Pocock (1924) exposed up to 5.6 m of brown laminated silty clays; however, only 2.2 m are recorded 200 m to the north beside Watton Road (TL348151). The laminated beds are clearly of local extent and the lithological change from clay to silt probably represents a facies change from deep to shallow water.

(*d*) *Ware Till*

The lower till at Westmill Quarry rests on the Westmill Lower Gravel at 60 m O.D. The till is light to dark grey in colour, but when weathered it is brown. It contains a variable pebble assemblage with abundant chalk and does not have a distinguishing particle size distribution, but is of typical Chalky Boulder Clay type (cf. Perrin, Davies & Fysh 1973). The base of the till is frequently waterlain. Where it is not, a brown horizon (30 cm thick) is commonly present. The till is laterally impersistent having been removed by erosion associated with the deposition of the Westmill Upper Gravel. As mentioned above, the till only occurs in the Hertford–Ware area in the Vale. It can be followed in sections to the north and NNE and is last seen at Froghall Quarry (TL208204). The till is apparently confined to this northern tributary valley (see bedrock surface, figure 13). It can also be found south of the Lea Valley in isolated lenses, e.g. at Little Amwell (TL128355) (figure 5, bed 4). At Stapleford Quarry (TL316170) a localized lens composed of hard lumps of chalk and flint in a finely divided chalk matrix (rubble chalk) 1 m thick is found. The lens is stratified at the base and the top and is overlain by Ware Till.

Stone orientation directions from the till are shown in figure 8.

(*e*) *Westmill Upper Gravel*

Like the Lower Gravel it is a complex deposit of large gravel lenses with associated sand beds. The sands often show cross-stratification and are laterally impersistent. Silt and clay beds are rare. At Westmill they rest on the eroded surface of the Ware Till or, where this

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has been removed, on the gravels beneath. Their base lies between 58 and 62 m O.D. and they are overlain by a second till (Eastend Green Till). The gravels can be distinguished as a separate unit up to 11 m thick in the sections NNW of Hertford and those around Ware (figures 3 and 7). They can also be identified south of the Lea Valley at Little Amwell (TL128355) and in the A10 section (figure 5, bed 5). West of Hertford the gravels can be correlated with the upper parts of the gravel beds beneath the Eastend Green Till on height. Gravel in a comparable lithostratigraphical position is also found at Wheathampstead in the Lea Valley (TL188148).

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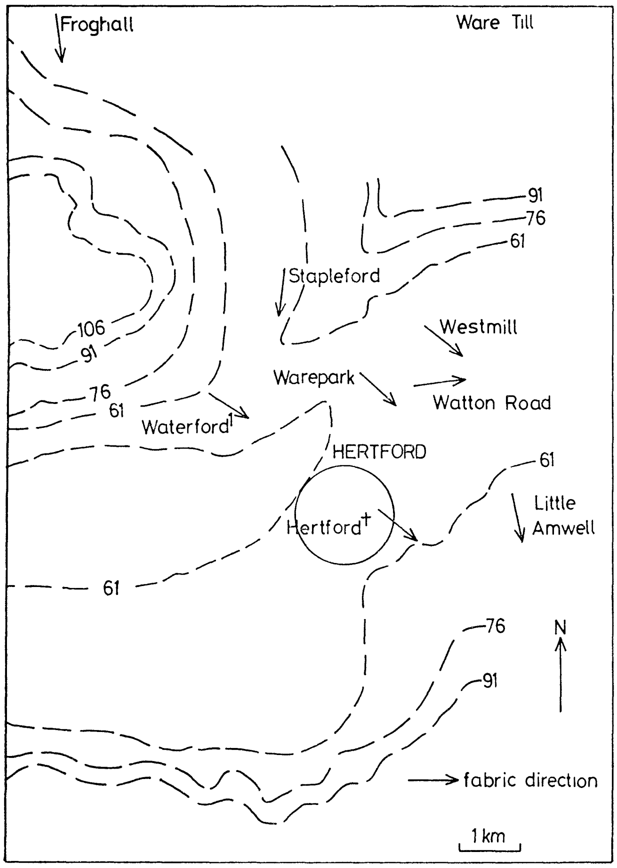

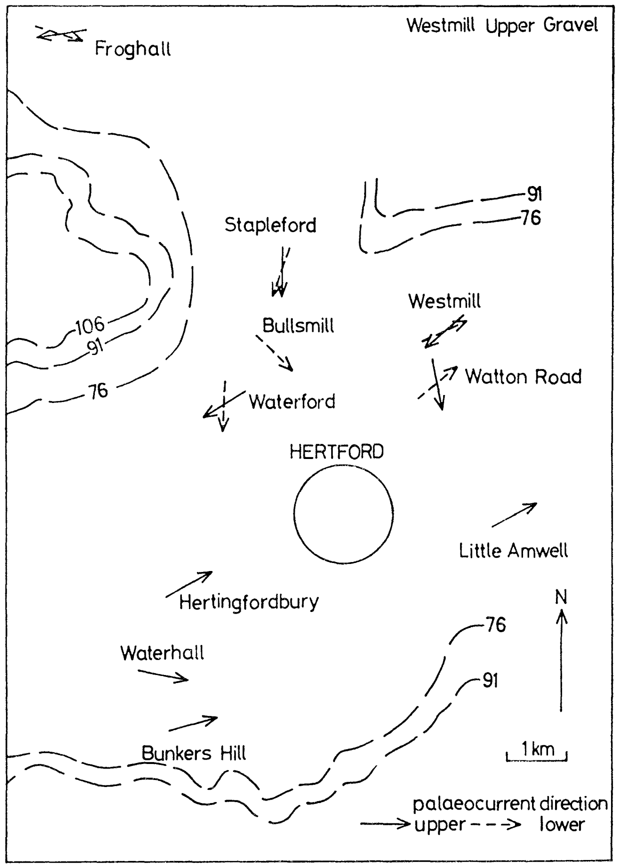

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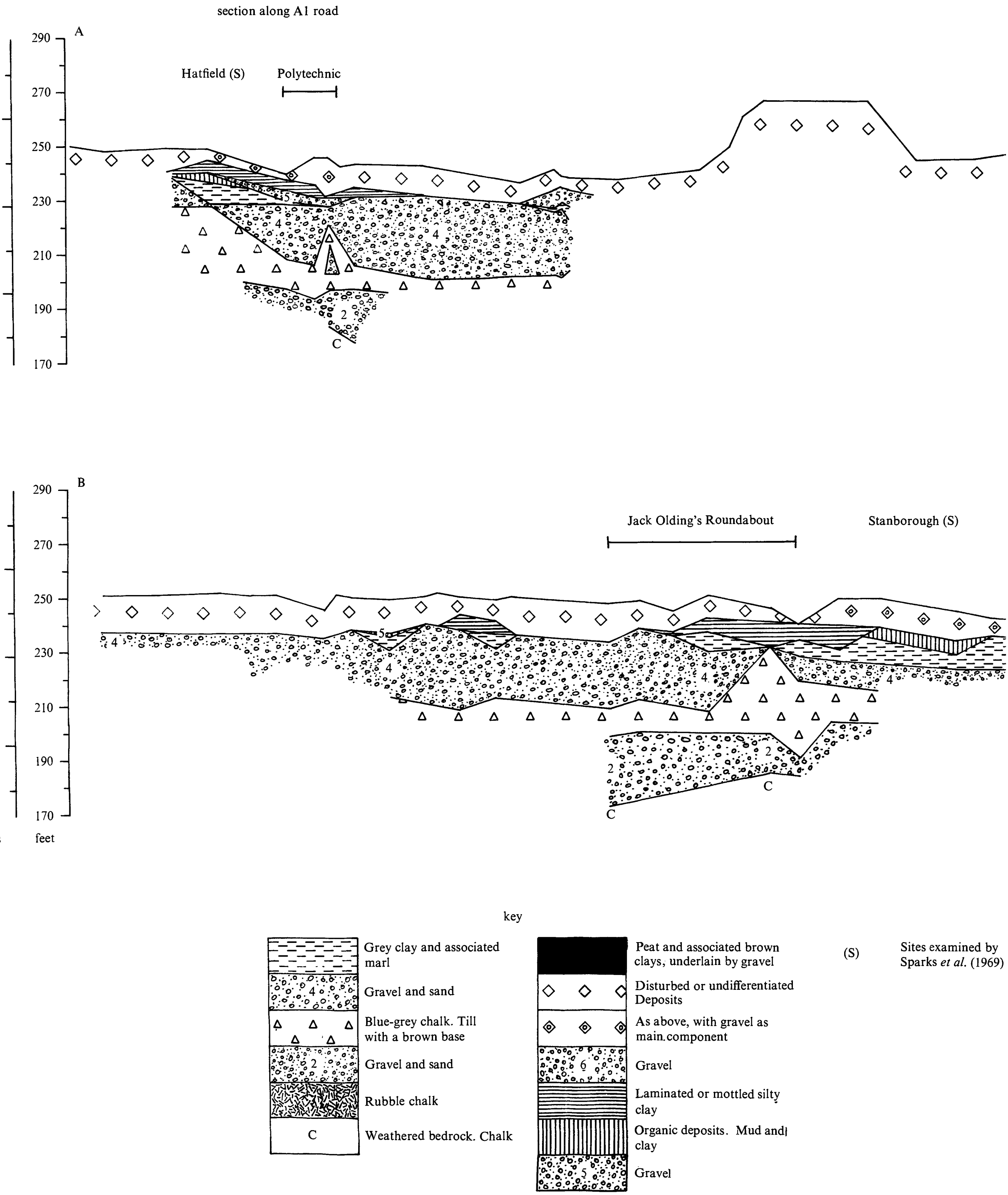
FIGURE 8. Ice movement direction as shown by stone orientation (till fabric) from the Ware Till. The contours are taken from the bedrock surface reconstruction (figure 13).
† West & Donner 1956.

FIGURE 9. Palaeocurrent directions from the Westmill Upper Gravel. Note the change of current direction within the unit. The contours are taken from the bedrock surface reconstruction (figure 13).

The gravels are more widely distributed than the Westmill Lower Gravel beneath. The correlations are supported by palaeocurrent (figure 9) and pebble count analyses. As in the Lower Gravels two main gravel trains can be distinguished, the main stream in the Vale and a second from the north. However, analyses from Westmill and other sites show that a marked change of flow direction occurred during the deposition of this unit. This change is borne out by the pebble counts. The vertical sequence from Westmill (figure 7) clearly shows that immediately above the Ware Till there is a high frequency of chalk (13 %) and erratic less durable rock pebbles. After this peak the chalk (2–4 %) and erratics become less frequent.


section along A1 road
A
Hatfield (S)
Polytechnic
290
270
250
230
210
190
170
B
Jack Olding's Roundabout
Stanborough (S)
feet
key
Grey clay and associated marl
Gravel and sand
Blue-grey chalk. Till with a brown base
Gravel and sand
Rubble chalk
Weathered bedrock. Chalk
Peat and associated brown clays, underlain by gravel
Disturbed or undifferentiated Deposits
As above, with gravel as main component
Gravel
Laminated or mottled silty clay
Organic deposits. Mud and clay
Gravel
(S)
Sites examined by Sparks *et al.* (1969)

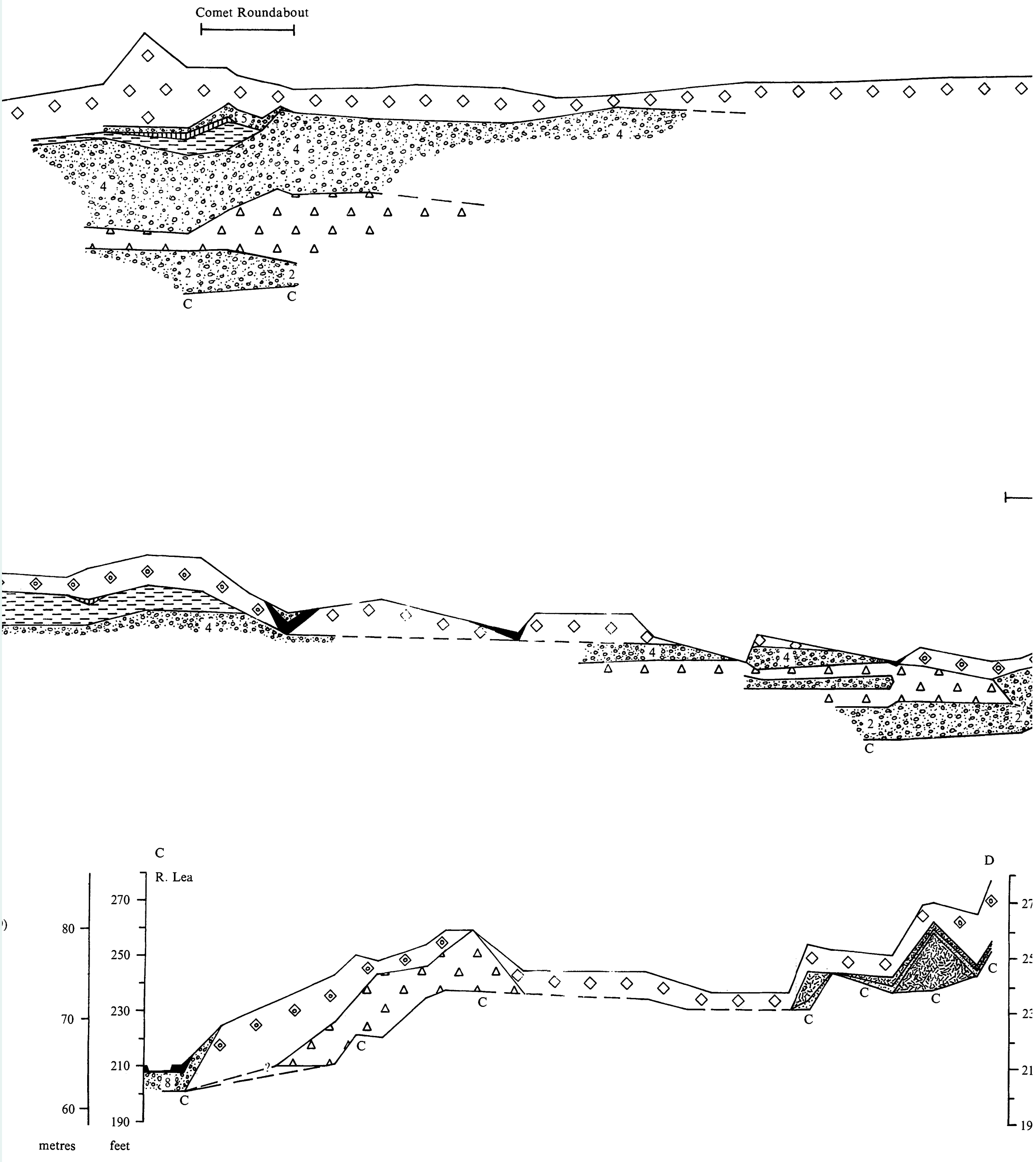
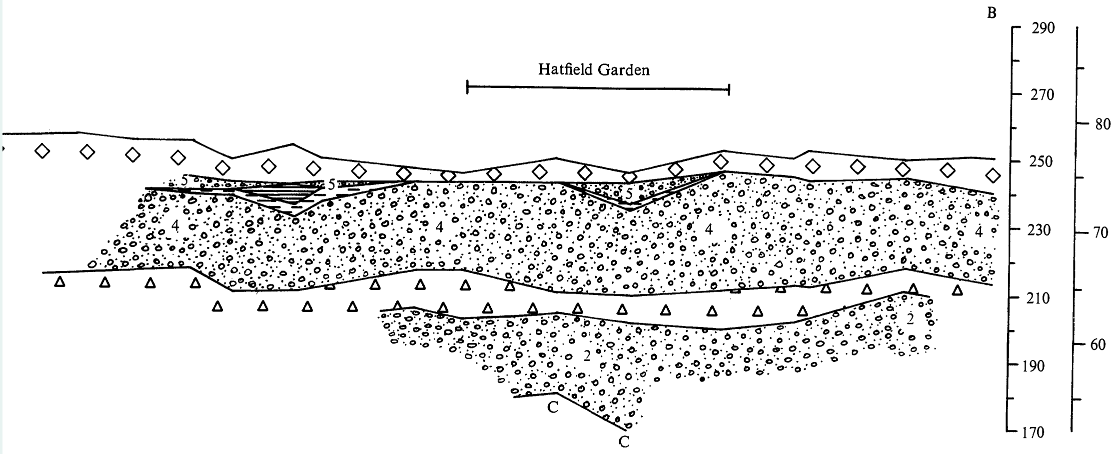
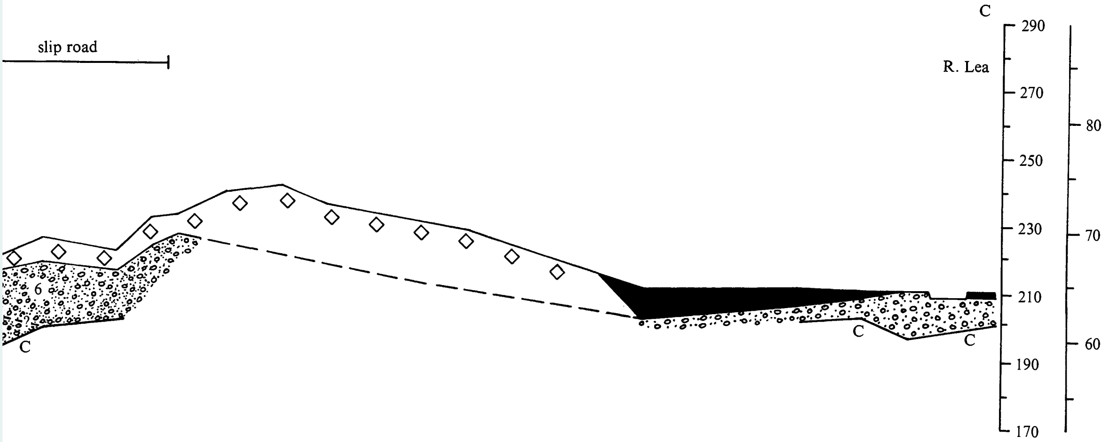


FIGURE 10. Section along the A1 road, constructed from borehole data supplied by the Eastern Road Construction Unit, Department of the Environment.


B
Hatfield Garden
5
5
5
4
4
4
4
2
2
C
C
290
270
250
230
210
190
170
80
70
60


C
slip road
R. Lea
6
C
C
C
290
270
250
230
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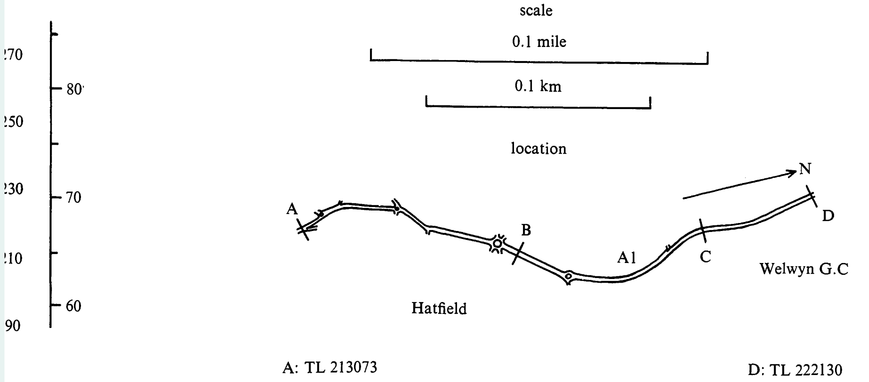
190
170
80
70
60


270
80
250
230
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210
60
190
scale
0.1 mile
0.1 km
location
N
A
B
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C
D
Welwyn G.C
Hatfield
A: TL 213073
D: TL 222130

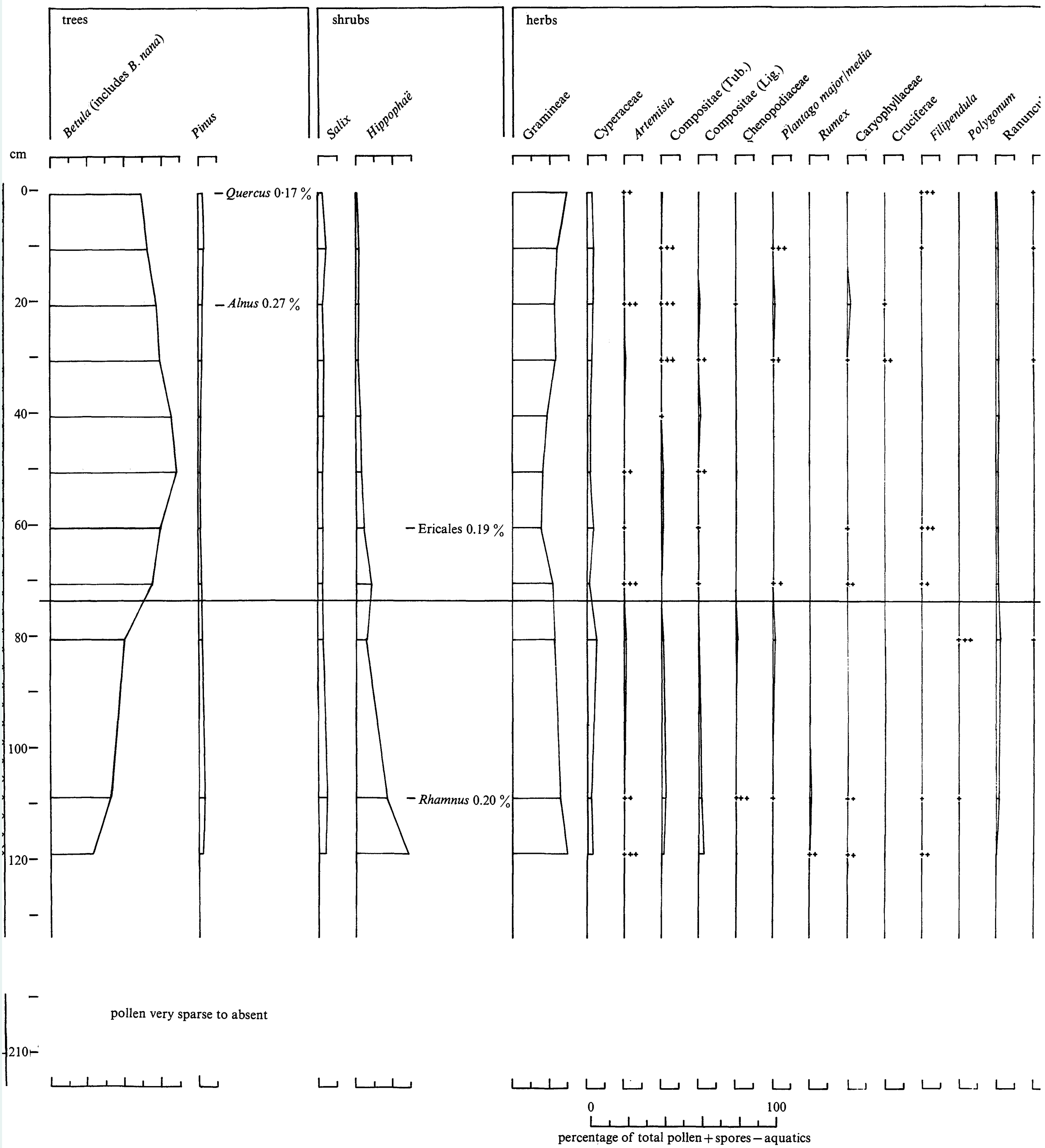
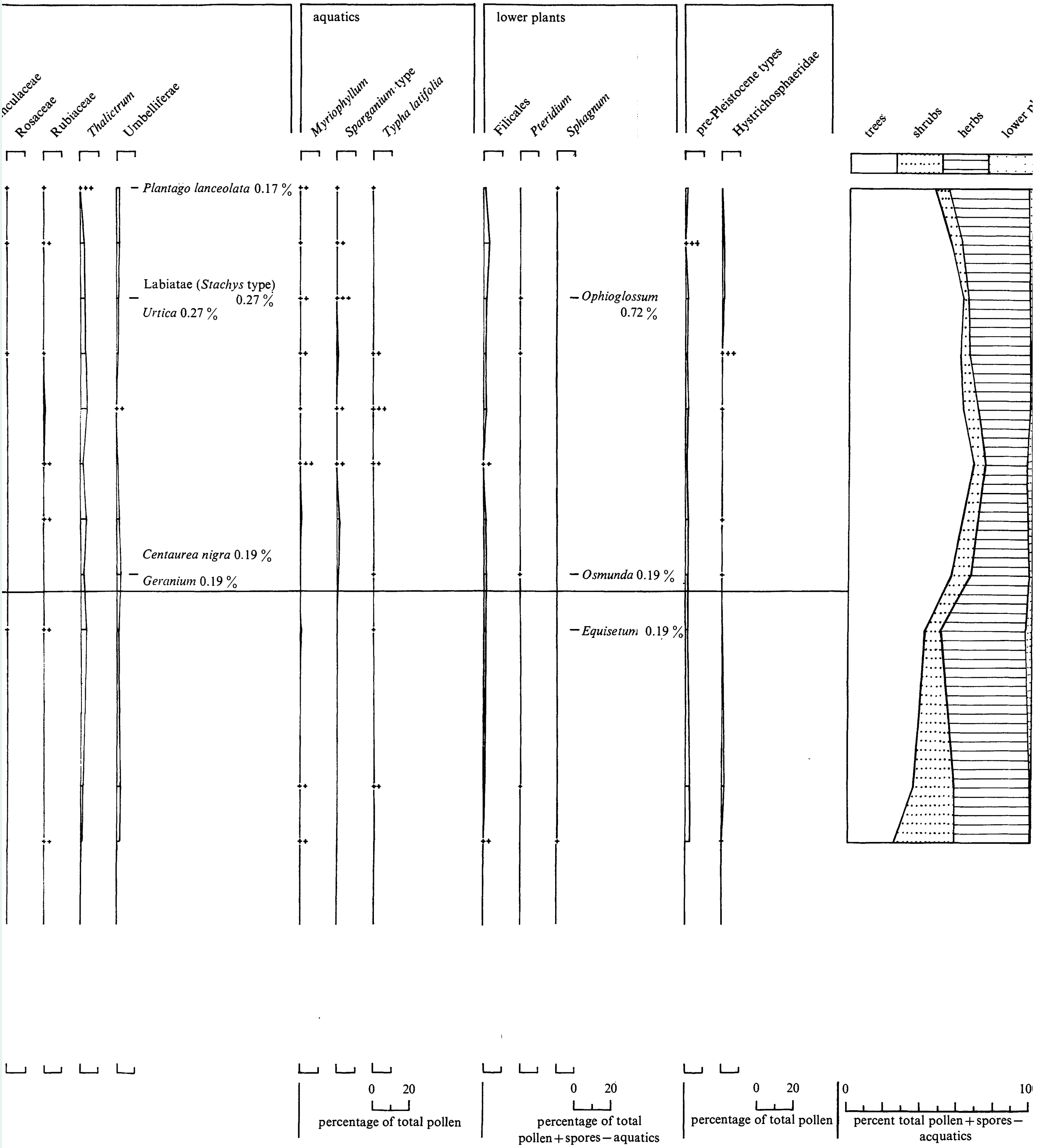
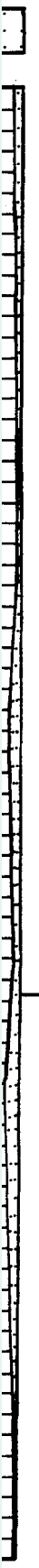


Figure 14. Pollen dia
marl



agram from the light grey silty clay and grey green
rl silt at Bell Lane Quarry, 1972/3.



r plants	total pollen + spores	no. of traverses/100 land pollen	local pollen assemblage zone	zone
	589	7.72		
	247	8.64		
	559	13.65		
	577	7.03		
			ii	Ho 1
	533	5.12		
	472	3.44		
	516	5.73		
	529	5.86		
	576	6.17		
	506	7.89		
			i	1 An
	607	10.52		

00

\+ one grain
++ two grains
+++ three grains

PLG

However, the change of current is accompanied by a second marked increase in chalk (9–25 %) and erratic pebbles. Samples from the sites to the NNW all show similar assemblages and changes of current flow. The Vale sites have restricted lithological assemblages dominated by flint and vein quartz and quartzite, as before. Braided river channel facies proposed by Williams & Rust (1969) and Rust (1972) can be recognized in these deposits.

At Watton Road Quarry (TL341149) a hollow 8 m wide in the Ware Till is filled with current bedded gravel and sand showing small-scale folds and normal faults. The structures closely resemble those caused by collapse associated with kettle hole formation. A lens of brown partially decalcified till 0.8 m thick rests in the gravel, and gives a preferred orientation of 335° and a strongly preferred dip of 8°. The deposit is probably therefore a slump or flow till (cf. Hartshorn 1958; Boulton 1972.) Similar flow till has been observed at Waterford (TL305147).

(*f*) *Moor Mill Laminated Clays*

At Moor Mill Quarry (TL143025) 2.6 m of silty clays, the lower 0.8 m of which are laminated, rest on gravel and sand correlated with the Westmill Gravel (figure 3). Their almost horizontal base is marked by red silty laminated clays. These pass into laminated beds consisting of cream to buff silt with dark brown clay horizons forming varve-like couplets up to 2 mm thick. The well-laminated units alternate with massive horizons of silty clay showing slump bedding structures 30–60 mm in thickness. Identical laminated clays are visible at Harper Lane (TL164019) and the individual 'varve-like' laminae from the two sites have been correlated (Gibbard 1974). The same clays have been recorded in the area of Smug Oak and Moor Mill, and as far west as the M1 section (figure 4, bed 4) where they are 3.5–5 m thick. Here, as at Harper Lane, the clays grade upwards into the Eastend Green Till. However, at Moor Mill the uppermost 2 m of the deposit contains angular, bedded buff sandy silt blocks up to 2 m long, together with some smaller blocks of till. The silty clay laminae are intensely folded about the blocks which have long axes orientated towards the SW, suggesting a possible derivation from the NE. Particle size analyses show that the material is well sorted and may have been deposited in standing water. The Eastend Green Till overlies these beds. Trace fossils discovered in the laminated beds were described by Gibbard & Stuart (1974).

(*g*) *Eastend Green Till*

The section at Waterhall Farm (TL297106) exposes 11 m of light grey to blue grey till which contains abundant chalk, flints and pebbles derived from Mesozoic rocks to the north. It rests on eroded gravel correlated with the Westmill Gravel and shows a narrow brown horizon at the base. The till may be traced to the east and north where it is equivalent to the upper till at Westmill and at the sites around Hertford and Ware, and to the west and south-west in the Vale, where it is the only till horizon (figures 3 and 10, bed 3). It can be recognized as far west as the M1 (figure 4, bed 5) and in the Lea and Mimram valleys. These correlations are based on height (figure 3), lithology, stratigraphical position and upon stone orientations (figure 11).

Work by Rose (1974) and the author shows that a consistent vertical change in orientation direction occurs at the type site. The basal till gives a direction from ESE to WNW, but at 2 m above the base it is from the ENE–WSW. At 5.5 m above the base, post-depositionally slumped till is encountered giving little preferred pebble orientation and this grades upwards nto 1.5 m of shallowly folded waterlain laminated sediments, with no apparent depositional break. The irregular laminae consist of silt and clay bands containing drop-stones. They become more sandy upwards and grade without hiatus into the till above. The overlying till of basal type gives a strongly preferred orientation indicating movement from NE to SW.

A comparable sequence is also recorded at Bunkers Hill pit opposite Waterhall on the opposite side of the Lea valley (TL301045). Here two till horizons occur, the lower 5 m thick and the upper 4–5 m thick. Lying between them are 6 m of current bedded gravel and sand.

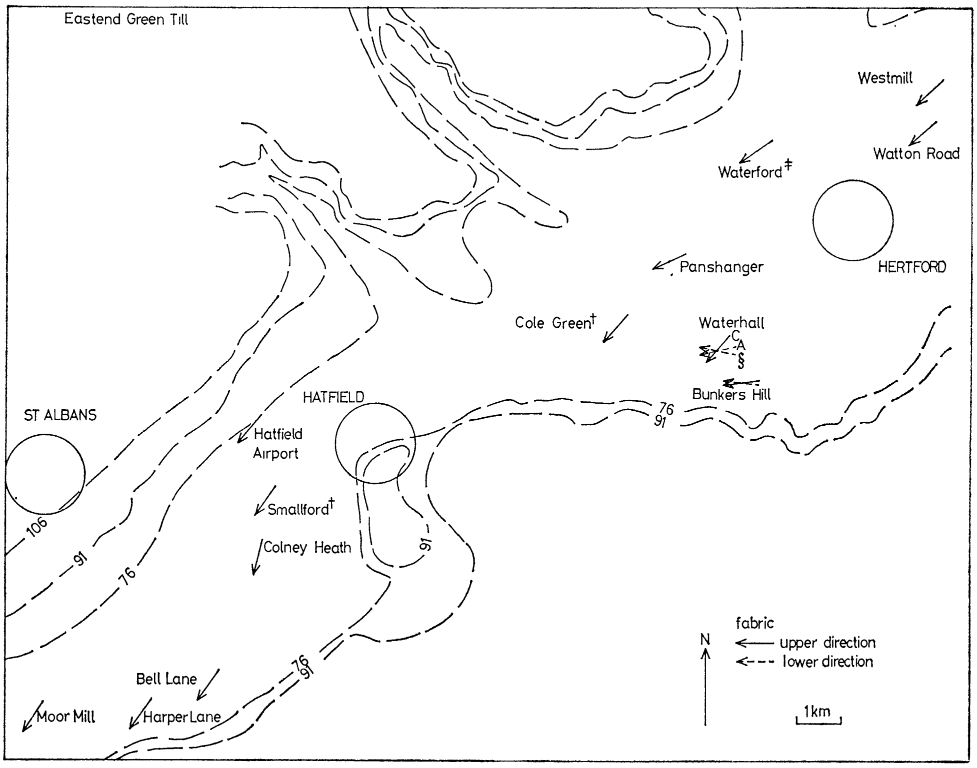


FIGURE 11. Ice movement direction as shown by stone orientation (till fabric) from the Eastend Green Till. Note the vertical direction change at Waterhall and Bunkers Hill Quarries. The contours are taken from the bedrock surface reconstruction (figure 13).
† West & Donner 1956.
‡ Clayton & Brown 1958.
§ Rose 1974.

Stone orientations from the lower till by the author and J. Rose (personal communication) parallel those seen in the lower part of the till at Waterhall, which occurs at a comparable height. The upper part of the lower till shows evidence of post-depositional slumping. The gravels and sands above were deposited by water flowing towards the east. A gradation upwards from the sands into laminated silts and then into the upper till occurs. The latter gives a stone orientation comparable to that from the uppermost part of the Waterhall section, i.e. NE–SW. Associated with this upper till is strong folding and overthrusting striking at right angles to the direction shown by the stone orientation.

Stone orientation analysis at Hatfield Polytechnic pit (TL211071) by Rose (1974) has shown that the Eastend Green Till is post-depositionally slumped at this site. Particle size analyses show that the till is of typical Chalky Boulder Clay type (cf. Perrin *et al.* 1973).

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

(*h*) *Smug Oak Gravel*

At Moor Mill pit (TL144026), 5.2 m of cross-stratified gravel with a few impersistent sand lenses rests on an uneven channelled surface of Eastend Green Till at 73 m O.D. Elsewhere sand horizons are more common and are cross-stratified. The gravels can be recognized at a number of localities in the Vale and as far east as Panshangar Quarry (TL296122) (figure 3). They are also recorded in the A1 and M1 sections (figure 10, bed 4; figure 4, bed 6). The similar stratigraphical position of gravel (2 m thick) overlying till at Wheathampstead (TL188148) suggests that it too can be equated with this unit. Palaeocurrent analyses (figure 12) support these correlations and show a consistent direction towards the west or southwest. Pebble counts indicate that the unit has a distinct lithological composition, consisting predominantly of flint (81–84 %), with vein quartz and quartzite (11–17 %) and a number of durable erratic pebble types including limestone and sandstone. Chalky till pebbles also occur. At several sections, small-scale normal step faulting, flexuring and ice wedge casts are found.

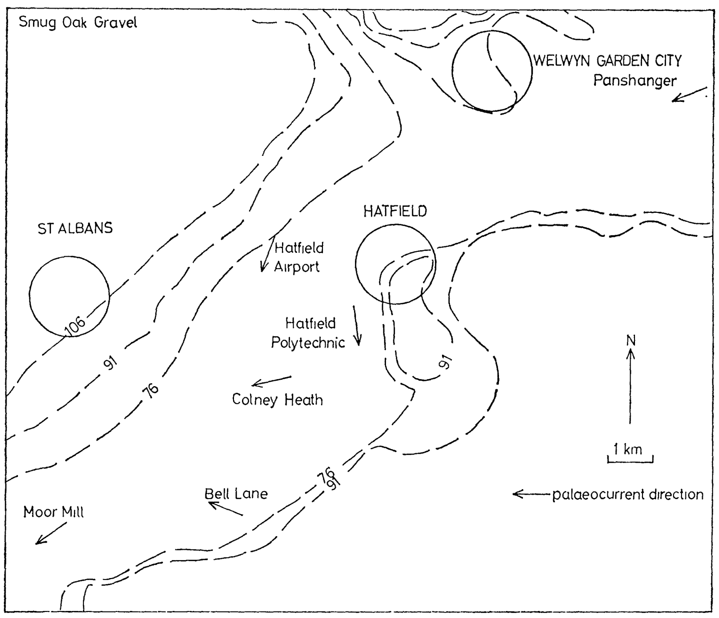


FIGURE 12. Palaeocurrent directions from the Smug Oak Gravel. The contours are taken from the bedrock surface reconstruction (figure 13).

It is possible to distinguish the braided channel facies of Williams & Rust (1969) and Rust (1972) in these deposits.

At Colney Heath Quarry (TL059192) up to 1.8 m of calcareous grey silty clay rest on gravels correlated with this unit. The lower half of the clay shows a varve-like alternation with light coarse to dark fine grey silty clay laminae 1 cm in thickness. The lighter blue grey upper half of the deposit is unlaminated, and has yielded macrofossil remains from the uppermost 20 cm which are discussed below (§4*a*). In the eastern corner of the pit the clay is totally replaced by 1.8 m of grey pebbly silty clay closely resembling chalky till. The pebbly clay interdigitates with the clay bed and is partially injected into the gravel beneath. The pebbly clay, which totally lacks chalk, gave a preferred orientation direction of 351° and preferred dip of 25°. The position, structures and stone orientation show that the pebbly clay is a mudflow till, similar to that at Watton Road (§2*e*). A sharp junction separates the overlying stratified gravel and sand (1 m thick) from the clays.

(*i*) *Hatfield organic deposits*

This complex unit comprises the deposits described by Sparks *et al.* (1969) which rest on pebbly sand and till exposed at Hatfield (Polytechnic) pit (TL212075). The sand is correlated with the Smug Oak Gravel. Strata D (dark grey silty clay) to G (black detritus mud) are included in this unit and represent the late Anglian to Hoxnian interglacial stage as shown by their contained plant fossils. The local extent of the beds, which fill a small kettle hole in the gravel surface, prevents direct correlation across the area. However, similar infills are seen at six localities in the A1 section (figure 10, bed 5) including that at Stanborough (Sparks *et al.* 1969). A similar basin infill occurs at Bell Lane (TL183031), where grey silty clays and green grey marl resembling those of Hatfield stratum D rest in a hollow in the Smug Oak Gravel (§4*b*). The grey silty clays at Colney Heath (§2*h*) are similar to those from Hatfield.

(*j*) *Rose Green Gravel*

Above the deposits at Hatfield (Polytechnic) pit are 130 cm of grey mottled silty clay (stratum H) overlain by 90 cm of cryoturbated pebbly sand (stratum I). The beds are of local extent and mark the continued infill of the hollow. Similar beds occur at several localities (figure 10, bed 5) and the so-called 'surface accumulations' may also consist partially of this unit. At Stanborough a similar sequence is present, but here the clays are laminated. At Bell Lane cryoturbated clayey gravel up to 2 m thick is found resting on the marl silt. Tongues of gravel penetrate the marl silt to a depth of 1 m. Particle size analyses from the gravel at Bell Lane and the pebbly sand at Hatfield show that the material is reworked fluviatile gravel.

(*k*) *Waterhall Farm Gravels*

On the north side of the Lea valley at Waterhall Farm (TL299099) a sequence of fluviatile deposits is found. The deposits rest in a channel cut parallel to the present valley into the Chalk at 59 m O.D. and in part abut against the Eastend Green Till and underlying Westmill Gravels which form the dissected interfluves. The sequence has been described and studied by W. G. P. Jarvis (unpublished Ph.D. thesis). Three separate horizons have yielded fossil faunal remains from these workings (see §5). Marl which rests on the basal current bedded gravel contains some small mammal and amphibian remains, but no plant material. A large fauna has been derived from the middle (red) gravel. This gravel overlies fossil ground ice structures including a large ice wedge cast which disturb the marl beneath. A more restricted fauna has been obtained from succeeding buff horizontally bedded gravels.

(*l*) *Spring Wood Silt*

The type section for this deposit is at Waterhall Farm (TL297102) where it rests on the Waterhall Farm Gravel, abuts against the Eastend Green Till and thickens southwards towards the Lea valley. It is up to 5 m thick and shows little evidence of bedding except in the upper 2.5 m where narrow impersistent bands of gravel that fine upwards are present. Irregular microtubular structures occur throughout the deposit in the upper 3–4 m which are decalcified. The latter is shown by a 'zone' 1–1.5 m wide of botryoidal calcite concretions beneath. A regular 'blocky' vertical polygonal weathering structure is very characteristic.

No fossils have been found in this material. Particle size analyses show that the deposit comprises two well-sorted sedimentary components. The largest component is medium to coarse silt and the secondary maximum is in the fine to medium sand range. A substantial clay fraction is also present. The present ground surface truncates this deposit and this shows that a subsequent period of erosion occurred after its deposition.

Although the greatest thicknesses of the silt are found in or adjacent to river valleys, e.g. Stapleford (TL309169), Frogmore (TL158034) and in the M1 section (figure 4, bed 7), hollows in the interfluve surfaces also contain very similar material. At Panshangar Quarry (TL296122) silt having the same particle size distribution as that from Waterhall fills an eastward trending channel 3.5 m deep and 8 m wide cut into the Smug Oak Gravel. Elsewhere a channel form cannot always be distinguished, e.g. Bell Lane (TL180030).

(*m*) *Colney Street Gravel*

At Colney Street (TL151014) 5.5 m of gravel underlies the floodplain of the Colne and Ver rivers and rests on Chalk at 59.6 m O.D. It is a complex deposit predominantly composed of gravel, frequently showing horizontal bedding. Current bedding is visible in some impersistent sand horizons. Organic horizons are rare and form irregular bodies of limited extent (§4*c*). The deposits are restricted to the river valley and are overlain by recent organic (floodplain) deposits. The gravels can be traced along the valley to the M1 section (figure 4, bed 8) and to Colney Heath, where several sections including that described by Godwin (1964) (called here Colney Heath A) penetrate them. Similar gravel deposits in an equivalent position occur in the other river valleys, for example in the Lea valley at Stanborough (figure 10, bed 8) and at Ware (figure 5, bed 7) and the Rib valley at Paynes Mill (TL337169). The braided river channel facies of Williams & Rust (1969) and Rust (1972) can be recognized in these deposits.

(*n*) *Recent organic deposits*

Immediately underlying the ground surface in the river valleys are peat, organic muds, shelley clays and marls. The horizons show great internal variation and often contain both plant and animal remains.

3. Bedrock surface beneath the 'glacial' deposits

The bedrock surface beneath the 'glacial' deposits (figure 13) gives the generalized 'preglacial' topography. Since the present subdrift topography is the result of several erosion cycles it is necessary to construct the surface from that underlying the 'glacial' (gravel and associated till) deposits. Points to be contoured were plotted from 85 boreholes, well records and the mapped bedrock/'glacial' drift boundaries where the junction was crossed by a contour. The latter were taken from the Geological Survey one-inch sheet 239 'Hertford'. Care was taken to check anomalous heights from the original six-inch scale survey maps or from nearby borehole records to ensure that later erosion or movement was excluded. The surface includes elements formed at several stages within the 'glacial' period.

Four features are noteworthy:

(i) A large central northeastward grading channel can be traced from SW to NE with a gradient of 47 cm/km. Tributary valleys occur, the largest of which enters the main channel north of Hertford and can be traced as far as Watton-at-Stone. Two steep consequent valleys also join the channel from the north.

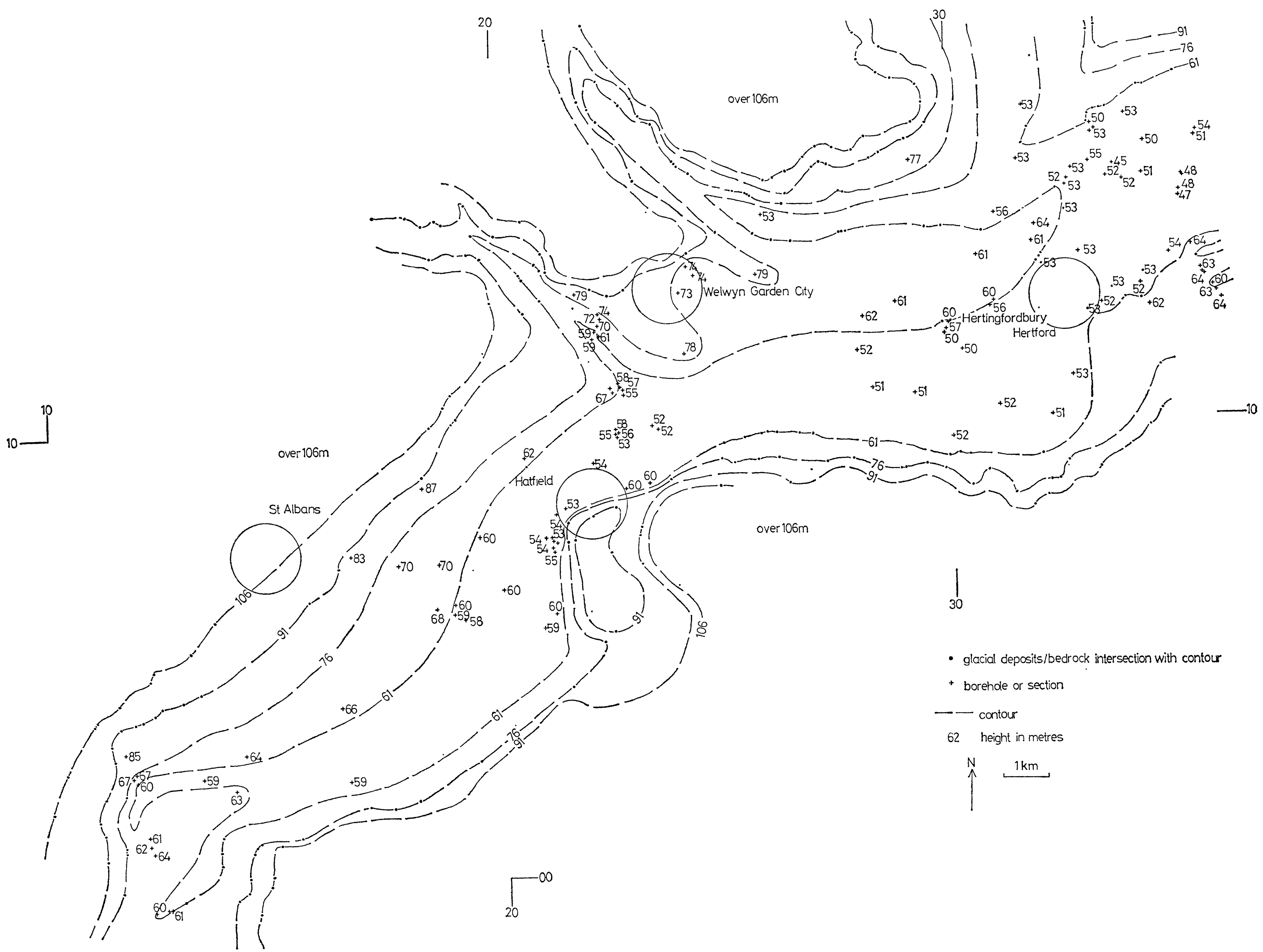


FIGURE 13. Reconstruction of the bedrock surface beneath the 'glacial' deposits. Information sources include Woodland (1945*a*), Hertfordshire County Council, Eastern Road Construction Unit (Department of the Environment), Geological Survey one-inch sheet 239 'Hertford' (1924) and the author's observations. For explanation see text.

(ii) A terrace-like feature can be recognized at approximately 61 m both north and south of Hertford and between Welwyn and Hertingfordbury.

(iii) A second fragmentary terrace-like feature can be traced westwards from Welwyn Garden City, where it is at 79 m to 74 m at Welwyn and then to the south of St Albans where it dies out. A 'meander' between North Mimms and Hatfield, on the south side of the Vale is at a similar height.

(iv) Pebble Gravel and Clay-with-flints deposits occur on the high ground to the south and north respectively and do not apparently reach below the 106 m contour. They probably, therefore, pre-date the downcutting which formed the channels.

Table 1. Macroscopic fossil remains from the blue grey silty clay deposit at Colney Heath quarry

	type of remain	number
Potamogeton compressus L.	fst	2
P. perfoliatus L.	fst	59
P. pusillus L.	fst	1
Salix herbacea L.	l	1
Ostracod shell valves	—	+
Insect remains	—	+

Abbreviations: fst, fruitstone; l, leaf; +, present.

4. Palaeobotany and biostratigraphy

The palaeobotany of three sites provides both biostratigraphical 'marker' horizons, which may be used to date the inorganic deposits, and evidence for a reconstruction of the flora present during the time represented. Pollen and plant macrofossil analyses were used. Pollen preparations follow standard chemical methods, and the pollen sum total land pollen and spores excluding aquatic types has been used. Plant nomenclature follows Clapham, Tutin & Warburg (1962) and pollen type conventions follow Andrew (1970). The pollen counts for *Betula* include *B. nana* type (Birks 1968). Macrofossils were extracted using standard chemical methods (West 1968). Organic sediments are described using the notation system of Troels-Smith (1955).

(a) *Colney Heath*

Macroscopic plant remains were recovered from the upper 20 cm of the light blue-grey silty clay horizon resting on the Smug Oak Gravel in this pit (TL059192). The remains are listed in table 1. This deposit is not equivalent to that described by Godwin (1964) which was located 600 m to the east (called here Colney Heath A).

All three *Potamageton* species are at present found in Northern Europe. *P. perfoliatus* grows on substrata of moderate organic content, while *P. pusillus* is common in highly calcareous waters. *Salix herbacea* grows today in arctic regions and favours fresh soils, and particularly areas with solifluction. The flora therefore indicates a shallow water calcareous pool with a possible inflow and a local growth of *Salix herbacea* shrubs in a cool or cold environment.

This deposit has a close lithological and stratigraphical similarity to the dark grey silty clay at Hatfield (stratum D or Sparks *et al.* 1969). It rests in the Smug Oak Gravel and thus it is of late Anglian age.

(*b*) *Bell Lane*

In the eastern corner of the pit contorted sands and gravels correlated with the Smug Oak Gravel are overlain by grey silty clay. The clay is thickest in the northeastern corner of the pit (TL183031), where the ground surface is at 71 m O.D. Here it was sampled for pollen analysis where the sequence is as follows:

depth/cm	description
	Involuted clayey gravel 150 cm thick at sample point.
0–77	Buff to grey-green marl silt (As2, Ag1, Ld1) with shell fragments and a mottled transition into the bed beneath.
77–121	Light grey silty clay (As2, Ag1, Ld1) with few shell and plant fragments. A marked impersistent band of plant fragments occurs in the basal 4 cm.
121–210	Light grey silty clay (As3, Ag1).
	Coarse pebbly sand.

Samples from 121 to 210 cm contained no plant remains and very little pollen, a few Gramineae pollen being identified at 145 cm. The sudden appearance of plant fragments and polleniferous sediments at 121 cm is problematical since no non-sequence is apparent at this level.

The pollen diagram from Bell Lane is shown in figure 14. The counts for *Betula* include *B. nana* type (Birks 1968) in all levels, reaching 3.2 % at 81 cm. (In other levels it is present as approximately 10 % of *Betula* pollen.) The diagram has been divided into two local pollen assemblage zones:

0–75 cm zone ii: *Betula*–Gramineae pollen assemblage zone
75–121 cm zone i: *Hippophaë*–Gramineae–*Betula* pollen assemblage zone

Zone i: *Hippophaë*–Gramineae–*Betula* pollen assemblage zone. The calcareous light grey silty clays of this zone were laid down under shallow water conditions. The pollen spectra are dominated by non-arboreal pollen and show high frequencies of Gramineae, *Hippophaë*, *Salix* and *Betula* pollen. Open herb vegetation is indicated by the pollen of *Artemisia*, *Rumex*, *Polygonum* and Chenopodiaceae. The pollen of the shrub *Rhamnus* indicates the occurrence of stoney calcareous soils. The vegetation represented probably grew on an irregular complex of damp hollows and drier hummocks forming a kettle topography. The drier possibly gravel-covered ground probably supported *Hippophaë* shrubs, herb-dominated grassland and *Betula* copses with both tree birch and *B. nana*. On damper sites and around the pool margins Cyperaceae, Filicales, *Salix* and marshland herbs grew. The vegetation depicted here is of late-glacial character. The upward decrease in reworked pollen, spores and Hystrichosphaerids indicates that inwash into the pool was diminishing, suggesting that ground colonization was becoming more complete. This trend continues into zone ii.

Zone ii: *Betula*-Gramineae pollen assemblage zone. Shallow water accumulation continued into this zone, but a lithological change from grey silty clay to grey-green marl silt occurs. In the lower half of the zone the pollen spectra indicate that *Betula* copses expanded to their maximum extent, to the eventual exclusion of the shade intolerant shrub *Hippophaë*. The reduction of Gramineae and Cyperaceae pollen continues the trend from zone i. However, herb-dominated grassland communities remained present and are indicated by the pollen of *Artemisia*, *Centaurea nigra* and Chenopodiaceae. Plants growing on the open birch woodland floor are represented by the pollen of *Urtica*, *Geranium* and spores of *Ophioglossum*. Pollen of the shore-line plant *Stachys* type is also present. Towards the top of the zone a recession of *Betula* pollen and its replacement by Gramineae pollen records a slight opening of the vegetation.

The age of the deposits is clearly indicated by their pollen flora. The high frequencies of *Hippophaë rhamnoides* pollen in the late-glacial zone i are characteristic of the late Anglian regional pollen assemblage zone (1An) preceding the Hoxnian (interglacial) stage (West 1970; Turner 1970). Such frequencies of *Hippophaë* pollen are not known from other late-glacial periods. The following zone ii may therefore be correlated with the pre-temperate zone Ho 1 of the Hoxnian stage.

The pollen spectra from Bell Lane zones i and ii correspond very closely with those from local pollen assemblage zones a and b at the nearby Hatfield site (Sparks *et al.* 1969). The configuration of individual pollen curves are very similar and indeed the zones differ only in their content of isolated herb pollen. Correlation made with the local zones and the regional zonal scheme for eastern England proposed by Turner & West (1968) is:

	local pollen assemblage zone	Hatfield pollen assemblage zone	regional pollen assemblage zone
pre-temperate	ii	b	Ho 1
late-glacial	i	a	1 An

The reversion of the *Betula* pollen curve in the upper part of the zone ii at Bell Lane parallels that at Hatfield in zone b discussed by Sparks *et al.* (1969). They suggest that such a change cannot be definitely ascribed to climatic causes, since shallow water basins are particularly sensitive to local environmental changes. The occurrence of a similar *Betula* decline at Bell Lane, Hatfield and also Fishers Green (Gibbard & Aalto 1977) suggests that the change took place over the immediate district. Such a change probably reflects a drop in the regional water table level, since sedimentation apparently ceased after this phase at Hatfield, Fishers Green and also at Bell Lane where no later sediment is preserved. The basins of all three sites are similarly situated and contain comparable sediments. The regional water level fluctuations in the Hoxnian shown by sites in Hertfordshire were discussed by Gibbard & Aalto (1977).

(*c*) *Colney Street*

The quarry at Colney Street is located on the floodplain between the Rivers Colne and Ver (TL152017). In the southeastern corner, gravel and sand (Colney Street Gravel) contain laterally impersistent beds of organic material up to 60 cm thick, 1.8 m above the base of the gravels. The sample blocks of the organic material were taken from two points. The thicker vertical sediment sequence from blocks II and III from which macroscopic remains were obtained did not contain pollen. Samples for the latter were taken from the laterally equivalent block I, some 5 m to the east. The stratigraphy of the blocks is as follows:

block	depth/cm	description
III C	0–13	Black silty clay mud with plant fragments, woody in parts (Ld2, As1, Ag1, Ga +, Gs +).
III B	13–22.5	Grey silty clay with some fine sandy bands and plant fragments (Ld1, As1 1/2, Ag1/2, Ga +).
	22.5–23.0	Yellow sand band.

IIIA	23.0–32.0	Dark grey sandy clay with plant fragments (Ga1, As2, Ag1, Ld+). Underlain by medium sand.
IIB	1–13	Black organic clay mud with broken plant remains and small stones (Ld1, As1, Ag1, Ga1, Gs+).
IIA	13–25	Alternation of black silty clay and silty sand with plant fragments (As1, Ag1, Ga1, Ld1, Gs+). Underlain by fine gravel and sand.
I	0–11	Black detritus mud composed of broken plant fragments in dark grey sandy clayey silt with some orange sandy bands (Ld2, Ag1, As1, Gs+). Underlain by sand.

The pollen spectra from block I are shown in figure 15. The regional vegetation represented by the pollen is one of open herb-dominated grassland with scattered birch trees or shrubs. This is indicated by the high frequencies of Gramineae and *Betula* pollen and substantial numbers of *Artemisia* pollen, *Botrychium* spores, *Centaurea nigra* and *Rumex acetosa* pollen. *Helianthemum*, *Linum anglicum* and *Valeriana officinalis* indicate the presence of calcareous soils. *Salix* grew locally near the river. An abundant marsh and aquatic flora is also represented in the pollen spectra. These assemblages closely resemble those of late- and full-glacial type and are very similar to that described as shrub tundra (West *et al.* 1974).

Table 2. Macroscopic fossil remains from the organic deposits at Colney Street Quarry (blocks II and III)

	type of remain	II A	II B	III A	III B	III C
Barbarea vulgaris R.Br.	s		4			
Campanula sp.	s					1
Carex appropinquata Schmach.	n+u				2	
Carex dioica L.	n					4
Carex cf. *panicea* L.	n+u				1	1
Carex paniculata L.	n+u			9		1
Carex pendula Huds.	n+u		1		2	1
Carex rostrata Stokes	n+u			2	2	1
Carex strigosa Huds.	n	1		1	1	
Carex vesicaria L.	n	4				
Carex sp.	n	1	4	2	6	8
Empetrum nigrum L.	l			1		
Filipendula ulmaria (L.) Maxim	fst					5
Filipendula sp.	fst		1			
Gramineae sp.	c			1		
Holsteum umbellatum L.	s			1		
Lychnis flos-cuculi L.	s		1			
Potentilla cf. *argentea* L.	a			1		
Rorippa islandica (Oeder) Borbas	s				1	
Rorippa sylvestris (L.) Besser	s					1
Rumex palustris sm.	n			1		
Urtica dioica L.	a	1	1	2	4	
moss leaf				3		
insect remains			+	+	+	
shell fragments (Mollusca)		+	+		+	

Abbreviations: c, caryopses; fst, fruitstone; l, leaf; n, nutlet; s, seed; a, achene; u, utricle; +, present.

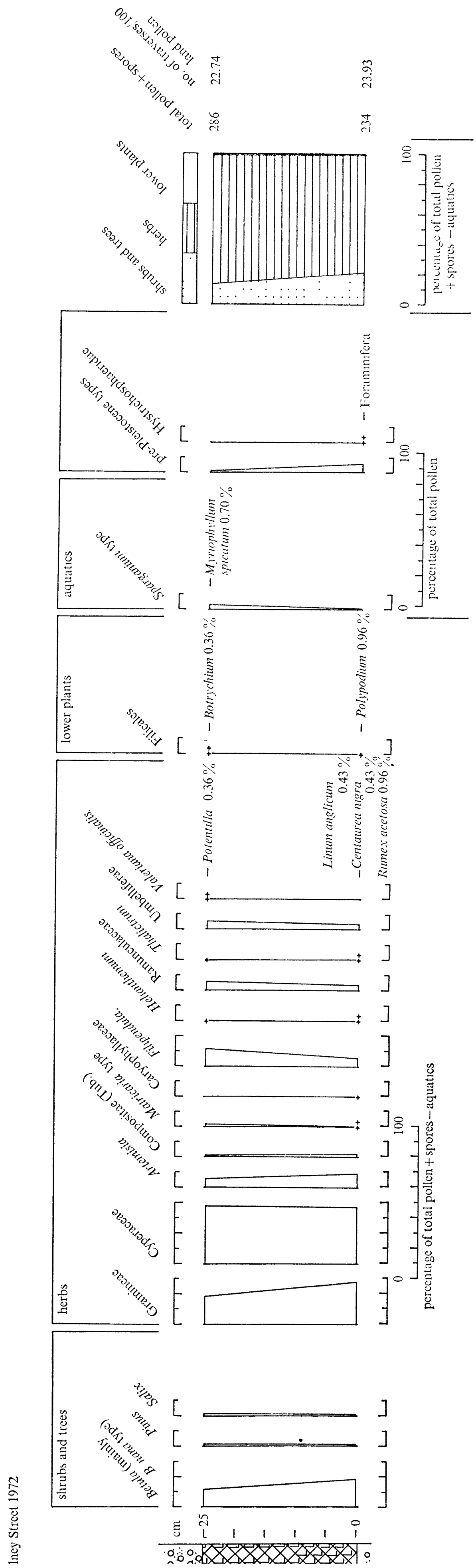


FIGURE 15. Pollen diagram from the organic deposits at Colney Street Quarry (block I).

The macroscopic plant remains are listed in table 2. The record of macroscopic remains from Colney Street displays an almost total predominance of marsh and fen plants. A base-rich, wet organic environment is indicated by the large number of *Carex* remains present. Herb taxa derived from these conditions include *Barbarea vulgaris*, *Filipendula ulmaria*, *Lychnis flos-cuculi*, *Rorippa islandica*, *Rorippa sylvestris*, *Rumex palustris* and *Urtica dioica*. These plants probably grew at or very close to the depositional site. *Holosteum umbellatum*, a species of sandy soils and southern aspect (cf. Bell 1969), *Empetrum nigrum*, which is more typical of dry places, *Potentilla* cf. *argentea* and possibly *Campanula* sp. probably colonized the drier sandy parts of the river floodplain or higher ground. There is a close correspondence between the pollen and macrofossil remains. The predominance of *Carex* remains matches the high frequencies of Cyperaceae pollen. The pollen of Cruciferae, *Filipendula*, Gramineae, *Potentilla* type and Caryophyllaceae correlate well with the macrofossils.

The organic deposits form a shallow abandoned flow channel fill in the braided river gravels. The sediments are highly organic, but show a trend towards increased organic content upwards. This may account for the greater numbers of preserved fossils in the upper levels. However, increased organic content may have encouraged further colonization of the pool. The lack of aquatic macrofossils suggests that shallow water *Carex* swamp occurred at the sample site.

The vegetation represented by the above may be summarized as follows: 1. Damp ground, marsh communities growing in and around the abandoned channel in the river floodplain. 2. Drier ground communities on exposed drift surfaces near the river. 3. Regional shrub-grassland.

The age of the deposits is shown by a radiocarbon date from level III C: Q-1120 14320 ± 210 B.P. (Switsur & West 1975). This places the deposit in the Late Devensian as defined by Shotton & West (1969).

Godwin (1964) has described erratic organic deposits in gravels that have been litho-stratigraphically correlated with those at Colney Street. The stratigraphical similarity is borne out by the radiocarbon dates (Colney Heath (A): Q-385 13560 ± 210 B.P.). Palaeobotanically, the sites show a close resemblance to each other and to other Late Devensian sites. The pollen of tree and shrub genera at Colney Heath (A) are represented by *Betula*, *Pinus* and *Salix*; however, *Pinus* frequencies are generally high suggesting the closer proximity of *Betula* communities at Colney Street. Characteristically high levels of *Carex*; the dry land herb *Linum anglicum*; abundant Gramineae; the marsh and waterside plants *Filipendula ulmaria*, *Rorippa islandica*, *Urtica dioica* and *Valeriana officinalis*; and plants of open habitat including *Artemisia* and *Helianthemum* are all recorded from both sites. The similarity of the two sites and indeed of others cited by Godwin (1964) is significant in that it indicates a period of relatively uniform environmental conditions during the Late Devensian in Hertfordshire.

5. Palaeozoology and biostratigraphy

Mammalian remains have been collected from Waterhall Farm. Two or probably three separate faunas have been recorded from this site.

The lower marl according to Sutcliffe & Kowalski (1976) contains the remains of:

Amphibia

Rana sp. and/or *Bufo* sp. (frog and/or toad)

Rodentia	
Microtus nivalis (Martins)	(snow vole)
M. oeconomus (Pallas)	(northern vole)
M. agrestis L.	(field vole)

Although all three rodent species are indicative of local open ground conditions, the presence of *Microtus nivalis* is very interesting. At present this animal has a discontinuous distribution in that it is restricted to mountainous central and southern Europe, i.e. the Alps, Pyrenees and the Carpathians. Therefore it probably indicates cold conditions.

Gravels overlie the marl and have yielded the following fauna (W. G. P. Jarvis, unpublished Ph.D. thesis):

Carnivora	
cf. *Crocuta crocuta* Erxleben	(spotted hyaena)
cf. *Panthera leo* (L.)	(lion)
Proboscidea	
Palaeoloxodon antiquus Falconer & Cautley	(straight tusked elephant)
Mammuthus primigenius Blumenbach	(woolly mammoth)
Perissodactyla	
Equus sp.	(horse)
Coelodonta antiquitatis Blumenbach	(woolly rhinoceros)
Artiodactyla	
Hippopotamus amphibius L.	(hippopotamus)
Megaloceras giganteus (Blumenbach)	(giant deer)
cf. *Cervus elaphus* L.	(red deer)
Bos sp. and/or *Bison* sp.	(aurochs and/or bison)

The faunal assemblage comprises several hundred specimens of bones and teeth that were discovered in gravels and sands deposited under fluviatile conditions. No articulated skeletons were found and many of the bones and teeth are fragmentary implying that some transport had taken place. However, the large number and good preservation of many of the remains precludes large scale reworking and suggests that they are of local origin.

In comparison with pollen-dated fossil vertebrate assemblages from elsewhere, the Waterhall faunal list is mixed, including mostly taxa of temperate interglacial type together with taxa usually associated with more open conditions, e.g. glacial stages.

The bulk of the faunal remains was, according to Jarvis, derived from the middle (red) gravel and is temperate in character suggesting a correlation with the Ipswichian stage. In particular, the occurrence of *Hippopotamus amphibius* which is apparently absent from the Hoxnian (Sutcliffe 1960) and the latter part of the Ipswichian, suggests an Ipswichian zone II–III age (Stuart 1974). The remains of *Mammuthus primigenius*, and probably those of *Coelodonta antiquitatis* and *Equus* sp., taxa generally associated with herb-dominated vegetation conditions, come from the upper (horizontally bedded) gravel, which may date from the latter part of the Ipswichian or the early Devensian (cf. Stuart 1974). However, since the remains of the last two taxa were not found *in situ*, they could equally be derived from the lower, Wolstonian deposits. The marl containing the cold fauna from beneath the gravels is probably of Wolstonian age.

6. Pleistocene History and Palaeogeography

The sequence of events which occurred in the Vale of St Albans during the Pleistocene inferred from the litho- and bio-stratigraphy is summarized in table 3. The main mass of the deposits dates from the Anglian (pre-Hoxnian) stage. The younger deposits form a discontinuous series at several localities. The history is presented here using the stage names following Shotton & West (1969) and Mitchell, Penny, Shotton & West (1973). The Anglian

Table 3. The inferred sequence of events in the Vale of St Albans during the Pleistocene

description §	event	dating evidence	climate	stage
h	aggradation of organic deposits on present river floodplains		t	Flandrian
g	deposition of braided channel gravel with organic horizons, e.g. Colney Street Gravel	^{14}C	c	Devensian
	downcutting and re-excavation of river valleys			
	Spring Wood Silt accumulation in river valleys – loess deposition		a, c	
f	deposition of Waterhall Gravel in Lea valley	V	t	Ipswichian
e	ice wedge in Waterhall Gravel		pf	Wolstonian
	deposition of lower gravel and marl of Waterhall Gravel		?c	
	initiation of modern rivers and downcutting			
	solifluction Roe Green Gravel at Hatfield and Bell Lane and ? involution		f/t, c	
	deposition of laminated silts in hollows		?c	
d	deposition of Hatfield Organic Deposits in hollows continues	P	t	Hoxnian
c	deposition of silty clays begins in kettle holes	P	?c	Anglian
	involution at Bell Lane		f/t, c	
	deposition of Smug Oak Gravel and stagnant ice melts *in situ*		g	
	readvance of Eastend Green Till ice		g	
	halt of advance and deposition of Moor Mill Laminated Clays		g	
	advance of Eastend Green Till ice across area from northeast		g	
b	west: deposition of Westmill Gravel; east: deposition of Westmill Upper Gravel		?g	
	east: readvance of Ware Till ice and stagnation		g	
	east: deposition of Watton Road Silts		g	
	east: advance of Ware Till ice from north		g	
	east: deposition of Westmill Lower Gravel		g, pf	
	downcutting to valley beneath 'glacial' deposits		?	
a	deposition of Leavesden Green Gravel		?	?Pre-Anglian
	downcutting			
	deposition of Westland Green Gravel			

Key: ^{14}C, Radiocarbon date; V, vertebrate remains; P, pollen; t, temperate; c, cold; g, glacial; pf, permafrost; f/t, freeze–thaw; a, aeolian activity.

is subdivided into two parts to simplify the description. The lithostratigraphical units assigned to each stage are shown after the stage name and full descriptions can be found in §2.

(*a*) *Pre-Anglian* (*Leavesden Green Gravel*)

The braided channel deposits occurring beneath Leavesden Green and southwest of St Albans were laid down by an eastward-flowing river (figure 16*a*). The gravels contain a mature pebble assemblage except for some Clay-with-flints 'pebbles' probably eroded locally (see §2*a*). The Leavesden Green Gravel occurs at a lower elevation than the main mass of the Clay-with-flints, which it truncates. There is little reason to doubt that the Leavesden Green Gravel was deposited by the same river which laid down the higher level Westland Green Gravel (Hey 1965). The latter is predated by the fluvial and marine relict '400' and '500 foot' Pebble Gravels (Wooldridge 1927). The substantial downcutting of 35 m between the deposition of the Westland Green and Leavesden Green Gravels suggests that one or more intervening terrace stages have not been recognized in the Vale, although these may be represented in the wide gravel spread southwest of St Albans (see geological map, figure 2).

(*b*) *Anglian I* (*Westmill Lower Gravel*, *Watton Road Laminated Silts*, *Ware Till*, *Westmill Upper Gravel*)

Downcutting and incision of the bedrock floor followed, resulting in the excavation of a wide, gently curving valley trending in a northeasterly direction from the present site of Watford to Ware. North of the sites of Ware and Hertford, a major tributary entered the main valley, while two tributaries entered from the Chiltern Hills to the NW. All the evidence, flow direction, pebble content and height, suggest that the Westland Green Gravel, Leavesden Green Gravel and Westmill Lower Gravel are the resulting aggradations of a river adjusting to successively lower base levels, but essentially unchanged in location and direction of flow – i.e. the ancestral Thames.

The main river in the Vale laid down the mature Westmill Gravel while the main northern tributary, probably a glacial outwash stream, deposited the immature gravels with a high chalk and erratic content. The presence of chalk and erratic pebbles in these deposits indicates that the local bedrock was being incorporated by active erosion together with material derived by reworking from other sources. The two braided rivers met north of the present sites of Hertford and Ware (figure 16*b*). That permafrost conditions prevailed in the area at this time is supported by the discovery of fossil ice wedge casts in the gravel.

The advance of the ice into the area of Hertford and Ware which deposited the Ware Till brought about the end of Westmill Lower Gravel sedimentation in the east. The ice advanced over the gravels which had aggraded to approximately 58 m O.D. in the area north of Ware. The ice lobe closely followed the main northern tributary valley, suggesting that the ice was confined and controlled by local topography. It travelled southwards to Waterford, where it turned towards the SE. At the confluence area near the present site of Ware, the ice met the Vale river. It appears from stone orientations that the ice continued directly across the Vale in a southeasterly direction and dammed the river. The laminated clays and correlative Watton Road Silts attest to the presence of a lake northwest of Ware. The extent of the lake is unknown, although the deposits are recorded from an area 0.6 km by 1.2 km northwest of Ware. The occurrence of shallow water deposits at Watton Road indicates that the shoreline was probably nearby. Therefore, there seems to be no reason to suppose that the lake had more than a local extent, i.e. the area covered by the deposits. The large thickness of laminated clays, reported by some authors, indicates that the lake was present for a considerable time. A count of the varve-like laminar pairs suggests that it existed for a minimum of 485 years, assuming that the pairs were deposited annually. To judge from the uniformity of the laminae, sediment supply seems to have remained constant for much of the time represented and although slumped horizons occur, it may be assumed that the ice slowed or even halted during this phase.

There is little evidence of an overflow for the lake water. Since the river returned to its original course after the ice retreat it seems likely that at least some of the water drained eastwards, over, through or beneath the ice. Such an occurrence might in part account for the slump horizons which could have resulted from changes in water level. Some modern glacial lakes are known to drain through or over their ice barrier and have been observed to undergo drastic changes of water level resulting from sudden drainage via a crevasse in the ice (Embleton & King 1968). It is, however, possible that the lake drained to the south of the ice, although no evidence of this has been discovered (figure 16*c*). Finally, the ice over-rode the lake and continued across the Vale to Little and Great Amwell. It is not known how far south the ice lobe reached or what course the drainage took at the time, but it may have been this advance which laid down the till at Finchley.

As the Ware Till ice advanced along the tributary valley from the north, weathered chalk regolith was locally soliflucted into the valley (e.g. at Stapleford, §2*d*), indicating that bare rock was exposed nearby to periglacial freeze–thaw weathering, possibly on the higher ground.

After a period the ice stagnated and began to decay, and fluvial sedimentation returned, marked by the deposition of the Westmill Upper Gravel around Ware and Hertford. The Vale river which had presumably been flowing throughout the preceding period resumed its 'pre-glacial' course and the northern tributary began to flow, again along a similar line to that followed by its ancestral river. The ice decayed *in situ*. This resulted in post-depositional slumping and flowing of till saturated in places with water. Deposition of the braided channel gravels and sands occurred at the same time and at least at Watton Road (§2*e*), seems to have been aggraded onto stagnant ice. When the ice melted, the deposits collapsed into the kettle hole thus formed. Prevailing permafrost conditions are shown by the presence of an ice wedge cast. Such kettle holes are commonly observed in modern glacial braided rivers. Fahnestock (1963) reports these features from the White River, Washington, U.S.A. At Watton Road a kettle hole of this type also includes a lens of till, which probably originated as ablation material capping an upstanding ice block, in a similar way to that described by Hartshorn (1958). As the ice melted the material possibly became saturated and slumped or flowed into the neighbouring hollow. Such ice blocks may also have been undermined by the river, thus encouraging slumping of material.

The migrating channels of the braided rivers deeply dissected the Ware Till and in many places removed it completely, resulting in the reworking of the morainic material.

Aggradation of the Westmill Upper Gravel in the Vale and the northern tributary continued. Erosion of bedrock took place during this stage, producing the terrace-like feature seen in the bedrock surface reconstruction (§3) between the present sites of Welwyn Garden City and Hertingfordbury and also a similar feature south of Hertford (based upon relative heights of the deposits near Ware). It appears that as the valley became infilled the river was able to migrate over a wider area including the flanks of the valley.

After an interval of unknown duration a new stream almost certainly the outwash from an approaching ice sheet, began to flow from the northeast (figure 16*d*). There is no evidence of its presence earlier, although it may have existed as a small tributary. This new stream seems to have quickly gained force and overwhelmed both the Vale and northern tributary streams. At the confluence area, north of where Hertford and Ware now stand, this inflow seems to have forced the main stream southwards and caused the confluence to migrate towards the present site of Hertford. At Westmill and elsewhere the river apparently cut deeply into earlier deposits and also brought further quantities of erratics and more particularly chalk, the latter probably derived predominantly from erosion of local bedrock. The northern tributary became progressively overwhelmed by this new supply of water, which at its climax seems to have entered the area through several channels. Because of this it is not clear whether the northern tributary was able to continue flowing or not, although it seems likely that it functioned as a minor tributary to the new stream.

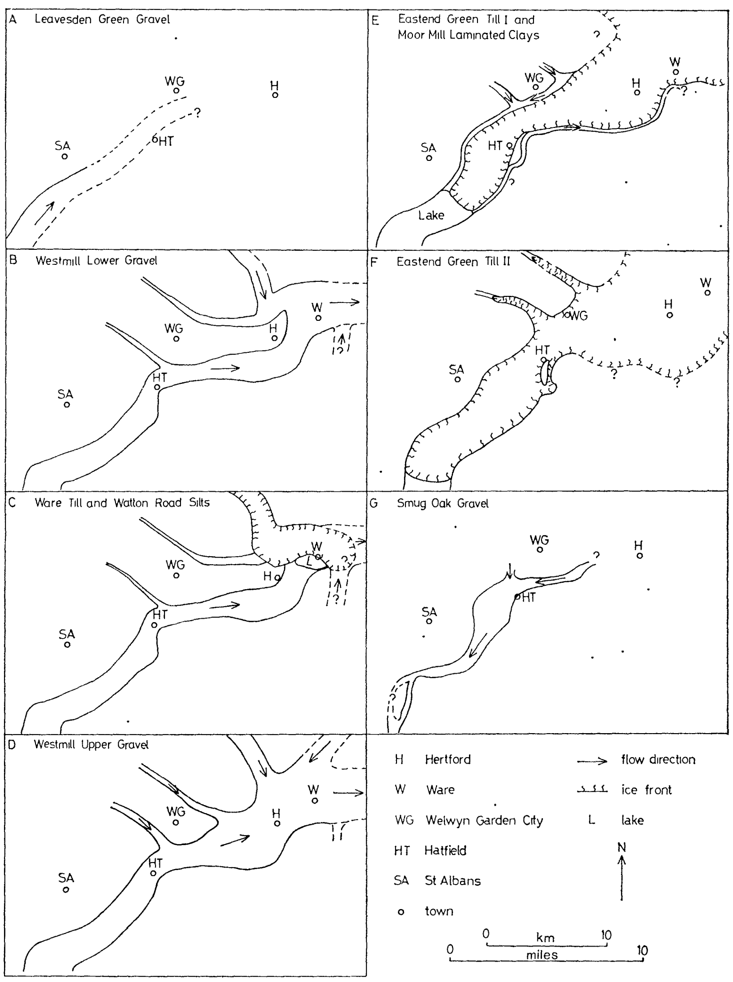


FIGURE 16. The changing palaeogeography of the Vale of St Albans during the ?pre-Anglian (A) and Anglian stage (B–G), as shown by these investigations.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The migration of the confluence probably caused further widening of the eastern end of the Vale, especially the terrace-like areas north of Hertingfordbury and south of Hertford. Reworking of gravel and erosion of local bedrock took place in the area of Waterhall and Bayford. Fahnestock (1963) notes that in modern braided rivers, maximum valley widening does not occur at the narrowest point, but at a junction with another river, particularly where this is situated on a curve. This closely parallels the situation seen in these deposits.

(c) *Anglian II* (*Eastend Green Till*, *Moor Mill Laminated Clays*, *Smug Oak Gravel*, *Hatfield Organic Deposits*)

The new powerful river from the northeast preceded the advancing ice sheet. The ice entered the area from the northeast on a broad front. As it advanced along the Vale towards the west and southwest, the ice eroded and incorporated the fluvial gravels beneath and deposited the Eastend Green Till. On the south side of the Vale near Waterhall and Bayford where the bedrock forms a large embayment, the ice was deflected towards the west and locally WNW. The relation of the drainage to this advancing ice lobe is not clear, but it is likely that the Vale river water continued to flow eastwards, possibly marginally to the ice. There is no direct evidence of this and it is possible that several stages of ponding occurred of which no evidence is preserved. However, the ice on reaching London Colney dammed the Vale river and a proglacial lake was formed. That the ice probably halted here is shown by the absence of the Moor Mill Laminated Clays east of Harper Lane (figure 16*e*).

The halting of the ice has also been recorded at Waterhall and at Bunkers Hill pits. At Waterhall the ice gradually ran out of energy and finally stopped. During this phase collapse and slumping of the till occurred beneath the melting ice, perhaps resulting from saturation. This was followed at Waterhall by the development of a local pond beneath the ice in which still-water sediments accumulated. Nearby at Bunkers Hill after a similar period of slumping and collapse of till, the ice temporarily retreated from the immediate area and deposition of braided glaciofluvial sediments occurred. A stream flowing eastwards, probably marginal to the ice still present at Waterhall, was reworking the local glacial debris. The presence of soliflucted Chalk lenses in these beds indicate that local bedrock was exposed at the time on the slightly higher ground to the south. The marginal gravel horizon has not been discovered elsewhere, although some of the deposits between Ware and Little Amwell may represent this phase. To the west, gravels of this stage have not been identified. It is possible, however, that the 'meander' cut into bedrock on the south side of the Vale at Hatfield (§3) was formed and exploited by this marginal stream (figure 16*e*).

The proglacial Moor Mill lake dammed by the ice must have been extremely extensive, since despite removal by later erosion its sediments still cover an area of 4 km by 1.2 km, west of London Colney. The occurrence of coarser silty deposits and their lower elevation at Harper Lane in comparison to those at Moor Mill and beneath the M1 reinforces the view that the ice barrier was nearby. Modern proglacial lakes are commonly deepest near to the ice front where erosion by subglacial streams often excavates a hollow (Embleton & King 1968). Assuming that the varve-like laminar pairs represent annual deposition, the lake probably existed at Harper Lane for a minimum of 342 years. It seems probable that the lake drained westwards during its existence and supplied some of the water which deposited the marginal channel gravel at Bunkers Hill, and possibly excavated the Hatfield meander.

The northern tributary valleys now occupied by the Lea and Mimram contained running water, which deposited minor gravel trains at this stage. The ice presented a barrier to these streams and so they followed a marginal course. Here they excavated the second terrace-like bench cut into bedrock on the north side of the Vale between Welwyn Garden City and the south of St Albans and deposited the gravels which rest upon it, recorded from Tyttenhanger and Hill End by Pocock (1914) and Williams (1918). The gravels contain faulting and folding structures which suggest that they were laid down in contact with the ice, forming part of a kame terrace (cf. Flint 1957). It seems very likely that the westward flowing marginal stream descended and entered the proglacial Moor Mill lake south of St Albans, since the terrace dies out in this area (figure 16*c*).

After a period, the ice again advanced towards the southwest. At Waterhall and Bunkers Hill it laid down further till and at the latter it advanced over a localized lake ponded between the ice and the bedrock, causing deformation of the deposits beneath. At Waterhall, the accumulation of the large thickness of till had almost filled the valley by this time, so that this advance was less controlled by the local relief. Further west, the ice advanced over the proglacial lake depositing firstly waterlaid and then lodgement till. This advance caused local folding of the lacustrine clays and gravels beneath, perhaps by ice push. At this stage, part of the ice was probably floating where the water was deep enough, thus causing minimal disturbance to the underlying deposits. However, some of the ice picked up large, perhaps frozen, blocks of silty sand, which it carried out over the lake and dropped or thrust into the laminated beds. The ice advance probably continued as far west as the present line of the M1 motorway and to Aldenham (Barrow 1919) where it appears to have halted (figure 16*f*). In this period the lake was drained and the river which flowed into it from the west (the Thames) was permanently diverted (§7*c*). Elsewhere, the ice seems to have overriden the gravels at Tyttenhanger and advanced up the tributary valleys, now containing the Lea and the Mimram, depositing till. It is, unfortunately, not possible at present to correlate the tills occurring on the high ground both on the north and south sides of the Vale with those within it. Fluvial deposits occur frequently in the till and record the presence of streams flowing beneath, upon or within the ice.

After a period of unknown duration the ice stagnated and began to waste *in situ*. This resulted in saturation of the till and reworking of the glacial material by small streams in places. Such conditions gave rise to post-depositional slumping of material. Soon, however, a westward flowing braided river fed by glacial meltwater from the receded ice front deposited the Smug Oak Gravel (figure 16*g*). The actual position of the front is not known, but it was probably some distance to the east, based upon the lithology of the gravel from Panshanger (the easternmost exposure of the Smug Oak Gravel) compared with those obtained from the erratic-rich Westmill Upper Gravel.

Erosion of the till took place during this phase. The river channel in places occupied much of the Vale, but particularly in the west it seems to have been restricted to a narrower course cut into the till deposits, e.g. at Moor Mill. This probably resulted from blocks of stagnant ice present within the river course. Aggradation of the gravels onto the buried ice blocks in a similar way to that described above caused collapse and contortion of bedding as the blocks melted to produce kettle holes. Such ice cores were almost certainly present throughout the deposition of these beds, since collapse features are extremely common in exposures of the gravels. Possible cessation of river flow, due to progressive retreat of the ice front, allowed a number of kettle holes to remain free from infill by coarse fluvial deposits. Instead, finer suspended load began to accumulate in the still-water of the hollows. At Colney Heath the earliest deposits of this type are laminated and may be compared either to those of abandoned channels in a braided river or to varve-like laminated beds originating from seasonal freezing of the water. The interdigitation of mudflow till probably having a very similar origin to that at Watton Road indicates that upstanding ice blocks blanketed by ablation material were still present at this time.

At Bell Lane a similar kettle hole was probably not filled with water immediately after its formation, since involutions probably resulting from periglacial freeze–thaw conditions occur in the sands below the hollow-fill sediments. Flooding of the kettle hole brought about grey silty clay sedimentation, very like that observed in the upper part of the Colney Heath horizon, in which plant remains indicative of cold climatic conditions are preserved. Similar accumulations are found at Hatfield and elsewhere. The river was probably still flowing at this time, since the deposit at Colney Heath is truncated by fluviatile gravel. There is no further evidence of deposits of this river and presumably it ceased to flow shortly afterwards. Subsequently, accumulation in the water-filled kettle holes seems to have occurred across the area. This was followed by the colonization of the landscape of hummocks and pond-filled hollows by plants and animals.

(*d*) *Hoxnian* (*Hatfield organic deposits*)

Sedimentation in the pools and small lakes continued into this stage giving rise to the Hatfield organic deposits. The progressive inward migration of boreal and then temperate mixed oak forest woodland clearly indicates that a climatic amelioration had taken place (see §4*b*). Throughout the period, the pools slowly filled with sediment and may at times have dried up completely as a result of changing water levels (Gibbard & Aalto 1977). After some time the sedimentation of organic material ceased and minerogenic deposition began once more.

There is no evidence of fluvial activity at this stage.

(*e*) *Wolstonian* (*Roe Green Gravel*, *Waterhall Gravel*)

The accumulation of silty clay, which is laminated in places, marks renewed erosion of the surface and deposition in the pools. The intensity of the weathering increased and the introduction of soliflucted gravel (Roe Green Gravel), almost certainly reworked fluviatile gravel, finally infilled the hollows and marked a return to periglacial freeze–thaw conditions. The cryoturbation associated with these gravel horizons at Bell Lane and Hatfield may have occurred soon after this phase or at some later stage. Slow reduction of relief by solifluction can result in smoothing and the eventual removal of surface irregularities in the landscape (Embleton & King 1968). Therefore it would seem that the gently undulating surface which is now visible on interfluves over most of the area of the Vale was probably initiated at this time.

Downcutting and erosion followed the initiation of the modern rivers. During this phase the rivers in some places cut down through the entire thickness of glacial deposits.

At Waterhall, after an initial phase of gravel accumulation post-dating maximum downcutting by the early River Lea, a cessation in flow permitted deposition of marl and clay under cool or cold conditions as shown by their contained faunas (see §5). The drying out of the pool or floodplain resulted in the formation of ground ice features.

(*f*) *Ipswichian* (*Waterhall Gravel*)

After a period, gravel and sand aggradation was resumed in the Lea Valley at Waterhall. During this time the surrounding landscape was colonized by a variety of mammals and probably also temperate woodland (see §5). The mammals undoubtedly congregated by the river to drink or feed. Deposition probably continued intermittently in all the river valleys during this stage.

(*g*) *Devensian* (*?Waterhall Gravel*, *Spring Wood Silt*, *Colney Street Gravel*)

The earliest Devensian or possibly late Ipswichian deposit is the upper buff (horizontally bedded) gravel at Waterhall containing a restricted vertebrate fauna (see §5). This phase marks renewed aggradation in the River Lea Valley.

The Spring Wood Silt was laid down upon the gravels at Waterhall. This material consists primarily of loess on the basis of its structure and composition. However, the sand content and gravel horizons indicate that it has a partially waterlain origin. The high content of fine sediment reinforces the view that this sediment was laid down by an aggrading river, the Lea, probably laden with soil formed during the preceding interglacial period. At the same time substantial volumes of loess were accumulating in the valley. The silt also accumulated in large thicknesses in the other river valleys of the area and in narrower stream channels on the interfluve surfaces. The presence of loess in these silts confirms that periglacial conditions prevailed at the time, and the association of these deposits with the Ipswichian interglacial sediments as a valley-fill sequence suggests that they were formed shortly after the interglacial, i.e. they are of early Devensian age.

Downcutting and erosion followed in the river valleys leaving the silt isolated on the valley sides. The interfluve surfaces were probably also dissected at this time since the modern stream valleys truncate earlier silt-filled channels. The river valleys of the Vale are frequently asymmetric with a steeper north-facing slope, particularly in those trending east–west. This feature was previously reported from the Chiltern valleys by Ollier & Thomasson (1957) and from southeast Hertfordshire by Thomasson (1961). Such asymmetry, where not bedrock controlled, probably originates under periglacial conditions (Embleton & King 1968) and as such may have been initiated at this time.

Deposition of gravel and sand by braided rivers took place in their newly deepened valleys during the Late Devensian. In the Colne Valley, the aggradation of gravel by the River Colne provided abandoned channels in which organic material accumulated. The more stable parts of the floodplain and the higher ground of the interfluves were colonized by plants. The vegetation was of a herb- or shrub-dominated type which indicates that a cold climate existed at this time (see §4*c*). Similar aggradation occurred in the other river valleys of the area.

(*h*) *Flandrian* (*Recent organic deposits*)

After gravel aggradation had ceased, marl and organic mud accumulation began in shallow pools on the river floodplains. As the hollows became infilled a gradual change to grey silty clay sediments occurred, possibly resulting from increased agriculture and forest clearance. During this stage the area supported a temperate mixed oak forest flora.

7. Relation of the sequence to deposits in neighbouring areas

It has been found possible to extend the stratigraphical scheme presented here, particularly for the Anglian deposits, into neighbouring areas to the north, east and west of the Vale of St Albans. Much of the work is dependent upon already published information which has been interpreted in the light of events proposed for the Vale itself.

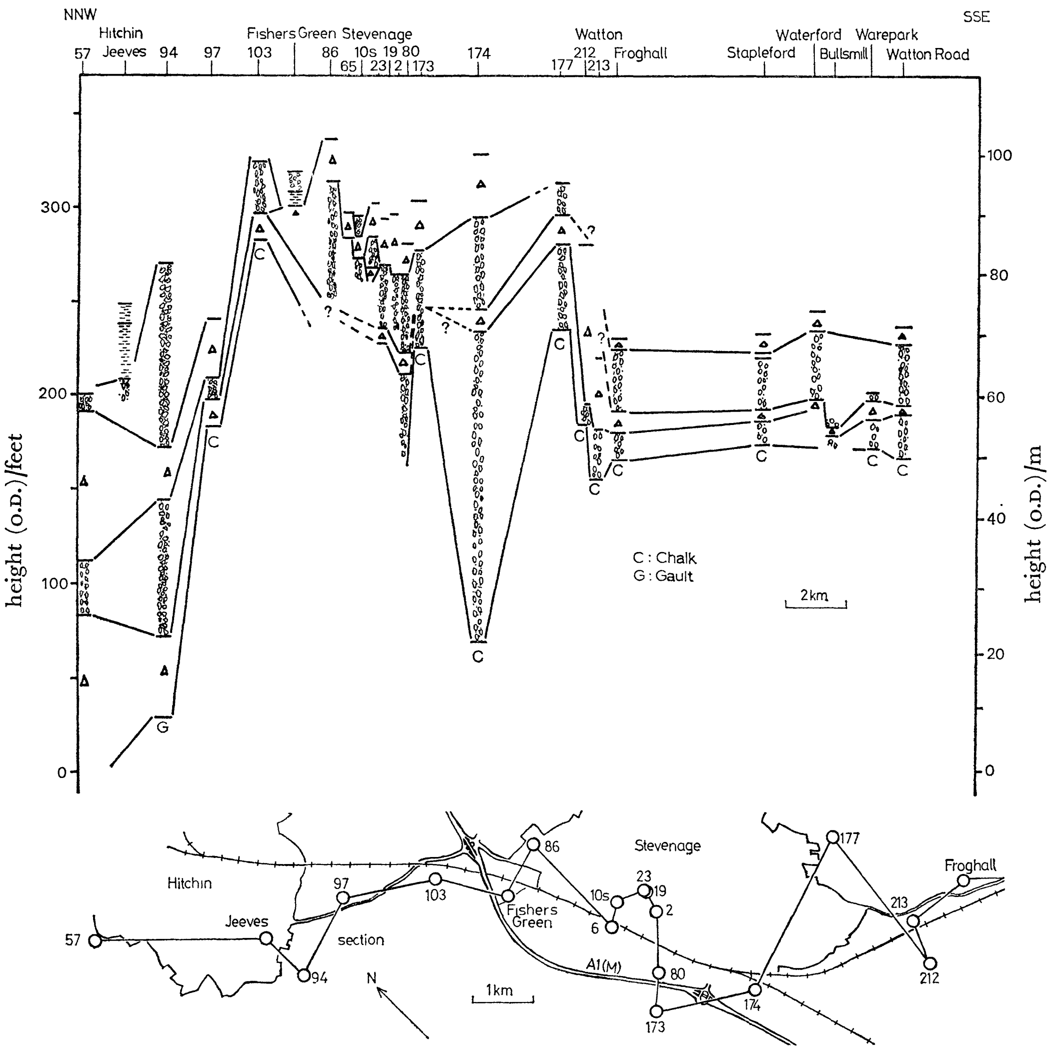


Figure 17. Section from Ware to Hitchin via the Hitchin–Stevenage Gap, constructed from exposure and borehole information. Borehole data was obtained from Stevenage Development Corporation, from Reid (1897), from Gibbard & Aalto (1977) and from Woodland (1945*b*) to whom the numbers refer. The position of the borehole section is shown on the map beneath. For explanation of sediment symbols see figure 3.

(*a*) *North of the Vale*

At present the large drift-filled channel extending from beneath Stondon to Hitchin, to Stevenage and finally to Watton-at-Stone (see §1*b*) is marked by a wide shallow valley in the Chiltern Hills. It is drained by the River Beane in the south and the River Hiz and its tributaries in the north. The channel floor falls towards the north and at Stondon the drift-fill extends over 60 m below o.d. This valley is the northwestern extension of the northern tributary valley which enters the Vale north of Hertford and Ware. Exposures found in this valley include Ware Park Farm, Bullsmill, Waterford, Stapleford and Froghall. Using borehole data obtained from Woodland (1945*b*) and Stevenage Development Corporation the stratigraphy can be extended through the valley to Hitchin. The localities of the boreholes and the section constructed from them are shown in figure 17.

The lithostratigraphical sequence observed at these sites may be traced as far as Hitchin, with the exception of the Westmill Lower Gravel which is not recorded northwest of Stevenage. At Hitchin, boreholes 57 and 94 record a gravel which overlies the upper or Eastend Green Till. This gravel is therefore in an equivalent position to the Smug Oak Gravel in the Vale of St Albans; however, they cannot be correlated.

The valley was probably excavated at an early stage by overdeepening of a pre-existing valley by meltwater from an ice sheet (e.g. Brown 1959). After initial deposition of the Westmill Lower Gravel, ice advanced along the valley towards the present sites of Hertford and Ware to deposit the Ware Till. The retreat of the ice brought a return to fluviatile conditions during which time the Westmill Upper Gravel was laid down. Re-advance of the ice, which entered the southern part of the valley from the NE, resulted in the deposition of the Eastend Green Till. The retreat of this ice marked a return to fluviatile conditions. Interglacial organic material fills kettle-type hollows in the glacial deposits at Hitchin (Gibbard 1974) and Fishers Green (Gibbard & Aalto 1977). Pollen spectra from sediments at both these sites indicates that they are of Hoxnian age. They suggest that the topography of this area was somewhat similar to that of the Vale during the Hoxnian. They also reinforce the view that the drift-filling of the valley is of Anglian age.

(*b*) *East of the Vale*

At Ware, the Chalk surface beneath the 'glacial deposits' reaches a minimum height of 48 m O.D. Extension of the gradient on this surface (47–56 cm/km) eastwards to the line of the M11 motorway, a distance of 16 km, gives a height of 39 m O.D. Baker (1971) constructed a section along the line of the M11 motorway between Sheering (east of Sawbridgeworth) and Great Hallingbury (south of Bishop's Stortford) showing a marked drift-filled depression, which he called the 'mid-Essex depression' (after Wooldridge & Henderson 1955). At its maximum depth the depression is at 36.5 m O.D. The fill comprises up to 12 m of gravel and sand, overlain by up to 26 m of Chalky Till (Baker 1971). The depression is probably therefore the eastward extension of the Vale. Extrapolation of gravel unit thickness from the sites near Ware to the M11 section suggests that both the Westmill Upper and Lower Gravels are represented in this section; however, Baker (1971) records only one till unit. Considering the gravel thickness and the extent of the till sheet, the till can only be an horizon equivalent to the second advance in the Vale, i.e. the Eastend Green Till. The Ware Till may have been eroded during the Westmill Upper Gravel stage or more likely was never deposited here. Well records between Ware and Sawbridgeworth do not clarify the relations. The proposed correlations, which show that the Thames flowed eastwards from the Vale until the Eastend Green Till ice advance, are given in table 5.

(*c*) *West of the Vale*

Beyond the M1 motorway the Vale continues westwards and becomes progressively more dissected by modern rivers flowing into the River Colne. Watford and Rickmansworth are sited on the drift-covered interfluves. West of the Colne valley a large area of Thames gravel terraces covers much of south Buckinghamshire, south of the Chiltern Hills (§1*b*). It is shown above that an eastward-flowing River Thames was present in the Vale until the final advance of the Eastend Green Till ice. Therefore, the terrace sequence must be examined to determine its relation to the deposits in the Vale.

TABLE 4. PEBBLE COUNTS FROM THE HAREFIELD AND WINTER HILL TERRACE GRAVELS, SUPPLIED BY DR R. W. HEY

locality	% flint	% quartz and quartzite	% Lower Greensand Chert	total pebbles
Harefield Terrace gravel				
Beaconsfield (M40) (SU966867)	69.4	28.5	1.6	250
Egypt Woods (SU956863)	72.5	25.0	2.1	242
Denham (TQ019895)	82.0	16.0	1.25	190
Harefield (SU051906)	79.5	20.6	1.3	152
Winter Hill Terrace gravel				
Hedgerly (SU984866)	84.9	18.8	2.5	250
Denham (TQ028859)	76.5	21.0	2.5	348
Denham (TQ032895)	91.5	7.5	1.0	—
North of Harefield (SU049924)	75.6	22.6	1.8	—

Pebbles from 32 mm and 16 mm fractions only.

(i) *Leavesden Green Gravel*

The gravels at Leavesden Green formed part of Wooldridge's (1938) westward grading Leavesden Gravel Train, which he equated with the Higher Gravel Train. The Higher Gravel Train, recognized from a few drift remnants between 112 m and 121 m O.D. near Beaconsfield (Hare 1947), if correlated directly with the Leavesden Green Gravel would produce a gradient of approximately 125 cm/km. This gradient would seem to be rather steep (cf. Hare 1947) when compared with those for the Westland Green Gravel of Hey (1965) (47 cm/km) and the Harefield Terrace of Hare (1947) (56 cm/km). It therefore seems unlikely that the Leavesden Green Gravel is the lateral equivalent of the Higher Gravel Train. It is more reasonable to correlate the Leavesden Green Gravel with the Harefield Terrace gravel of Hare (1947). The surface of this terrace is at 97 m O.D. on the meridian of Slough, where it is 3 m thick. At Harefield, east of the Colne, it is at 89 m O.D., whilst on the Misbourne–Colne interfluve traces of the terrace occur at 92 m O.D. If this terrace is projected northeast into the Vale of St Albans rather than via the 'Middlesex Depression', it may be correlated with the gravels in the M1 section and at Leavesden Green, the surfaces of which are at 88 m and 91 m O.D. respectively. The former point gives a gradient comparable with that described by Hare (1947). Pebble counts by Dr R. W. Hey (personal communication) from the Harefield Terrace gravels are given in table 4. These counts appear to correspond closely with that from the Leavesden Green Gravel (see §2*a*).

It appears that it is possible to correlate the Harefield Terrace gravels with the Leavesden Green Gravel, and thus during this stage, as with the Westland Green Gravel stage, the early Thames would seem to have flowed across Buckinghamshire and into the Vale of St Albans (figure 18*a*).

(ii) *Westmill Gravel*

Boreholes from Watford town centre show that the surface beneath the ‘glacial’ gravels is at a minimum of approximately 61 m O.D. (Gibbard 1974). West of the M1 motorway, both the Moor Mill Laminated Clays and the Eastend Green Till appear to be absent since only a gravel sequence is preserved beneath the west of Watford. Although the ice probably did not reach beyond the east of the present site of Watford, the absence of the clay and possibly also the till is almost certainly a result of later erosion by the westward flowing Smug Oak Gravel river. Thus it is not possible to distinguish between the Smug Oak and Westmill Gravel in these boreholes.

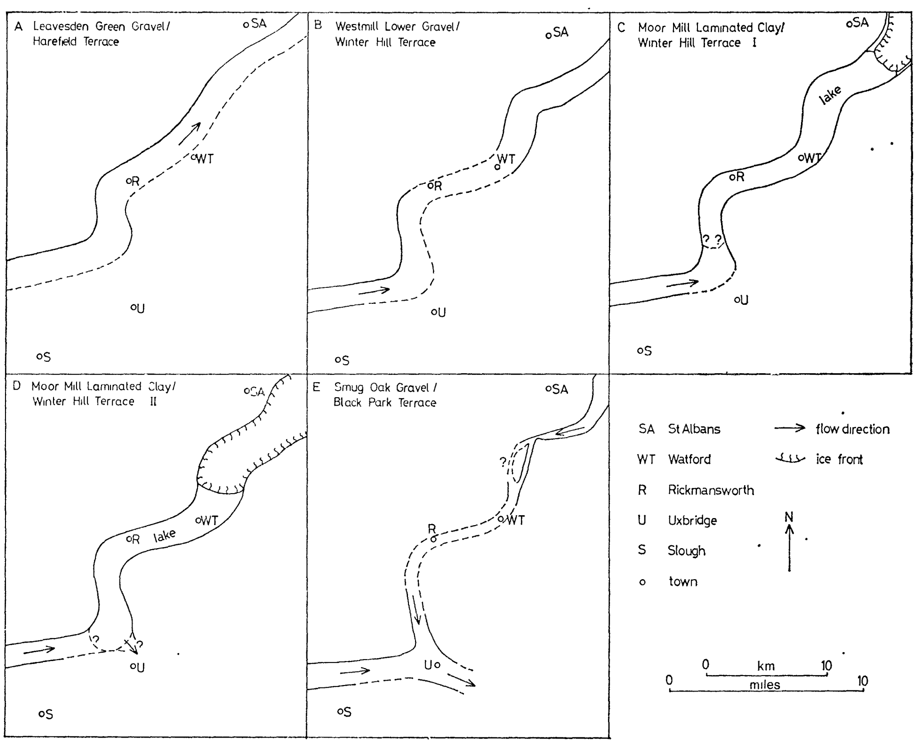


FIGURE 18. Palaeogeography of the Thames during the ?pre-Anglian (A) and Anglian stages (B–E) showing the inferred events leading to the river’s diversion to the south. The course of the river west of Uxbridge is based upon that shown in Hare (1947). Compare also figure 16, for related events in the Vale of St Albans.

Extension of the gradient of 47–56 cm/km on the Chalk surface beneath the ‘glacial’ deposits towards the west, gives a surface at 72 m O.D. at Hedgerly on the Slough meridian. At this point, Hare (1947) records that the base of the Winter Hill Terrace gravels lies at 74 m O.D. According to Hare, the amount of downcutting between the base of the Harefield Terrace gravel and that of the Winter Hill Terrace on the Slough meridian is 16.5 m. This compares favourably with a figure of 18 m in the M1 section from the base of the Leavesden Green Gravel to the base of the Westmill Gravel. Pebble counts from the Winter Hill Terrace gravel by Dr R. W. Hey (personal communication) are shown on table 4. The restricted pebble content is similar to that found from the Westmill Gravel, in the western part of the Vale. However, the variability of the sample compositions is quite high, particularly that of vein quartz and quartzite. It is not possible to draw any firm conclusions from these counts. It does, however, seem acceptable to correlate the Westmill Gravel with the Winter Hill Terrace gravel on the basis of altitude. It therefore seems that during Westmill Gravel times the early Thames continued to flow across Buckinghamshire and into the Vale of St Albans (figure 18*b*).

TABLE 5. PROPOSED CORRELATIONS OF ?PRE-ANGLIAN AND ANGLIAN LITHOSTRATIGRAPHICAL UNITS OF THE VALE OF ST ALBANS WITH ADJACENT AREAS TO THE WEST AND EAST

<table>
<tr><th rowspan="2">Middle Thames</th><th colspan="2">Vale of St Albans</th><th rowspan="2">West Essex</th><th rowspan="2">stage</th></tr>
<tr><th>west</th><th>east</th></tr>
<tr><td>Black Park Terrace Gravel†</td><td colspan="2">Smug Oak Gravel</td><td></td><td rowspan="7">Anglian</td></tr>
<tr><td>¶</td><td colspan="2">Eastend Green Till</td><td rowspan="2">Chalky Boulder Clay||</td></tr>
<tr><td rowspan="5">Winter Hill Terrace Gravel†</td><td>Moor Mill Laminated Clays</td><td></td></tr>
<tr><td rowspan="4">Westmill Gravel</td><td>Westmill Upper Gravel</td><td rowspan="4">Sub-Boulder Clay Gravels||</td></tr>
<tr><td>Ware Till</td></tr>
<tr><td>Watton Road Laminated Silts</td></tr>
<tr><td>Westmill Lower Gravel</td></tr>
<tr><td>Harefield Terrace Gravel†</td><td>Leavesden Green Gravel</td><td></td><td></td><td rowspan="3">?Pre-Anglian</td></tr>
<tr><td>Higher Gravel Train†, ‡</td><td></td><td></td><td></td></tr>
<tr><td>Westland Green Gravel§</td><td colspan="2">Westland Green Gravel§</td><td>Westland Green Gravel§</td></tr>
</table>

† Hare 1947.
‡ Wooldridge 1938.
§ Hey 1965.
|| Baker 1971.
¶ No lateral equivalent of the Eastend Green Till is known from the Middle Thames Area.

(iii) *Moor Mill Laminated Clays*

Hare (1947) commenting on the gradient of the Winter Hill Terrace says 'the Winter Hill has little slope and this fact may have been due to prolonged aggradation in a ponded-up valley'. If the Winter Hill Thames deposited the Westmill Gravel in the Vale, it was almost certainly also dammed by the Eastend Green Till ice (figure 18*c*). The Moor Mill Laminated Clays were then laid down in the resulting, probably extensive, proglacial lake. Unfortunately no laminated clays have been found west of the M1 motorway and so no definite evidence is available, but it seems reasonable to relate the ponding of the river with the flattening of the gradient of the Winter Hill Terrace. The final advance of the Eastend Green Till ice overrode the lake and probably caused it to spill southwards near Uxbridge (figure 18*d*).

(iv) *Smug Oak Gravel*

After the retreat of the Eastend Green Till ice, a westward flowing river occupied the Vale and laid down the Smug Oak Gravel. Therefore by this time the Thames must have been diverted. The post-depositional collapse of the Smug Oak Gravel makes it difficult to draw a gradient at the base of the deposits. However, at the M1 motorway the base was undoubtedly between 64 m and 70 m O.D. The next terrace in Hare's (1947) sequence is the Black Park Terrace which is the first terrace to follow the present course of the Thames. The surface of this terrace occurs at between 61 m and 64 m O.D. at Uxbridge Common. The deposits of this terrace are approximately 3 m thick and therefore their base lies at between 58 m and 61 m O.D. at this point. Hare (1947) also noted a fragment of this terrace at Uxbridge, apparently grading northwards, which he suggests might be a relic of the Colne Valley equivalent of the Black Park Terrace. If the base of the Smug Oak Gravel at the M1 motorway is extended southwest via Rickmansworth and thence south to Uxbridge (a distance of 20 km) to join the Black Park Terrace gravel, a resulting gradient of approximately 56 cm/km is obtained. This is exactly the gradient recorded by Hare (1947) from the Black Park Terrace further west, and strongly suggests that the correlation of this terrace gravel with that of the Smug Oak stage is correct.

Thus the final advance of the Eastend Green Till ice forced the proglacial Moor Mill Lake to spill southwards (figure 18*d*) and caused the early Thames to adopt a more southerly course close to that which it follows today. After the ice retreated the westward flowing Smug Oak Gravel river, from the Vale of St Albans, entered the Black Park Thames near Uxbridge (figure 18*e*).

The correlations proposed above are shown in table 5. It appears that from its initiation the Thames flowed through the Vale of St Albans and into Essex until the later phases of the Anglian glacial stage when it was diverted.

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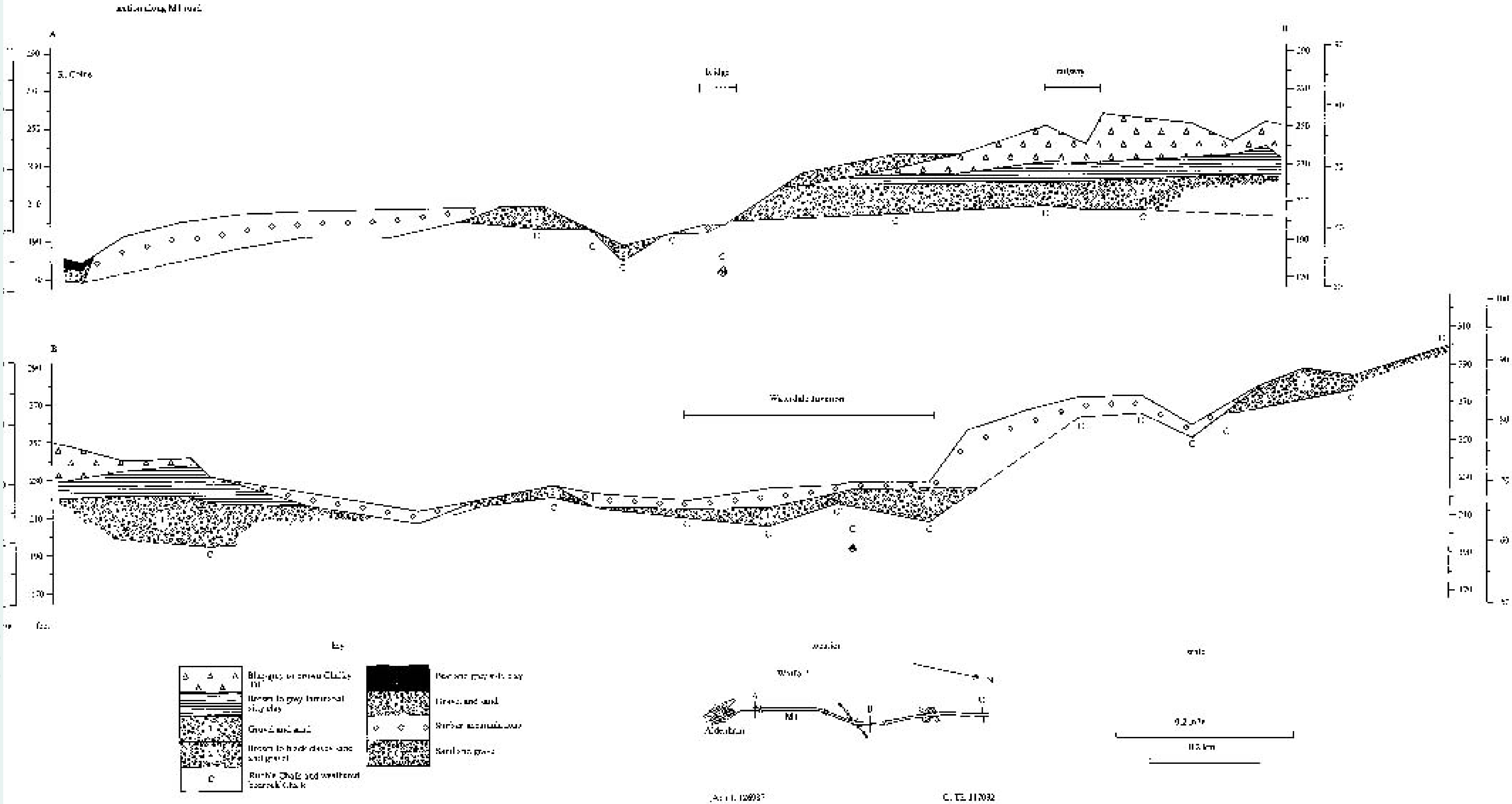

FIGURE 4. Section along the M1 road, constructed from borehole data supplied by the Eastern Road Construction Unit, Department of the Environment.

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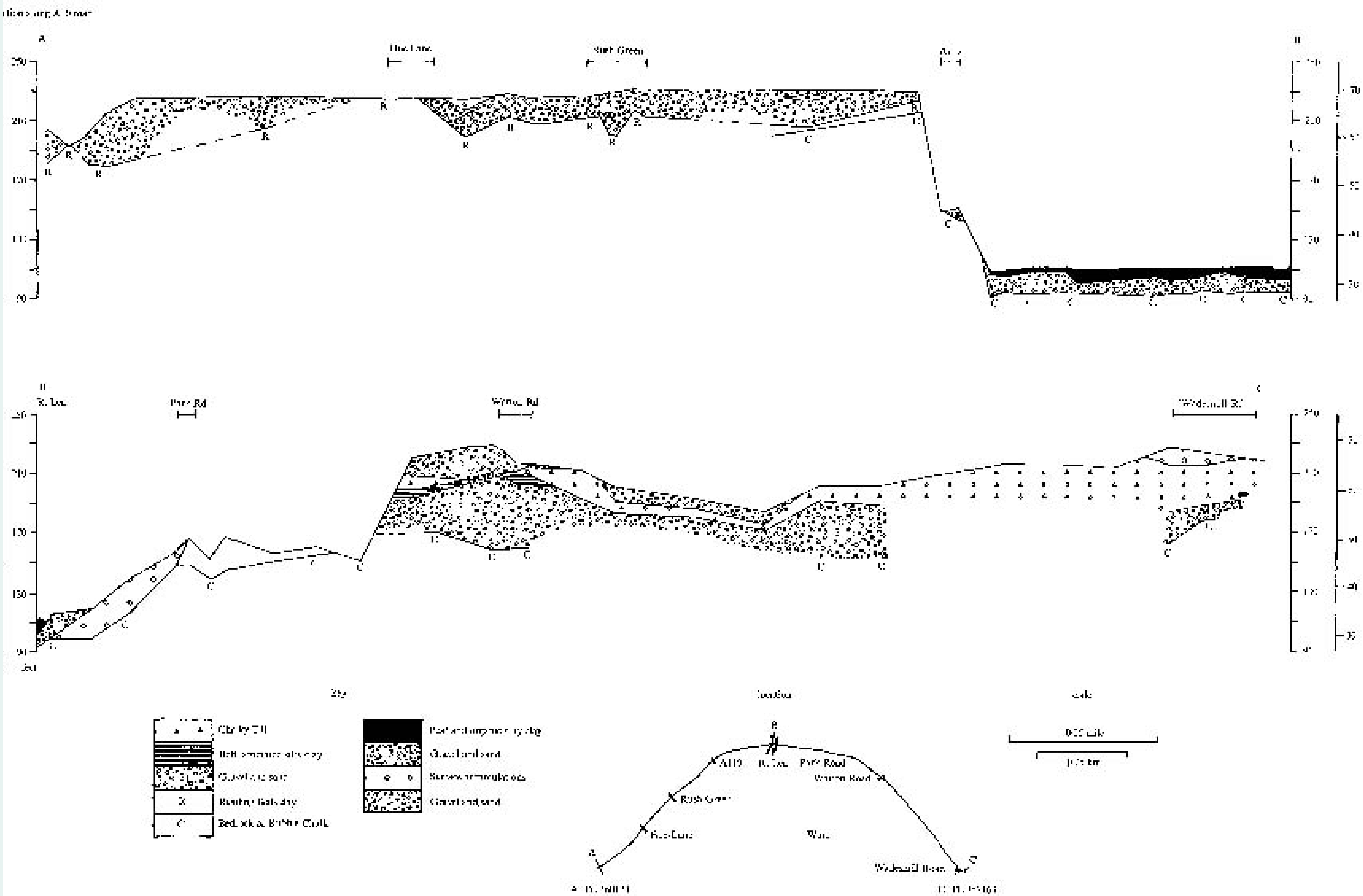

Figure 5. Section along the A10 road, constructed from borehole data supplied by Hertfordshire County Council.

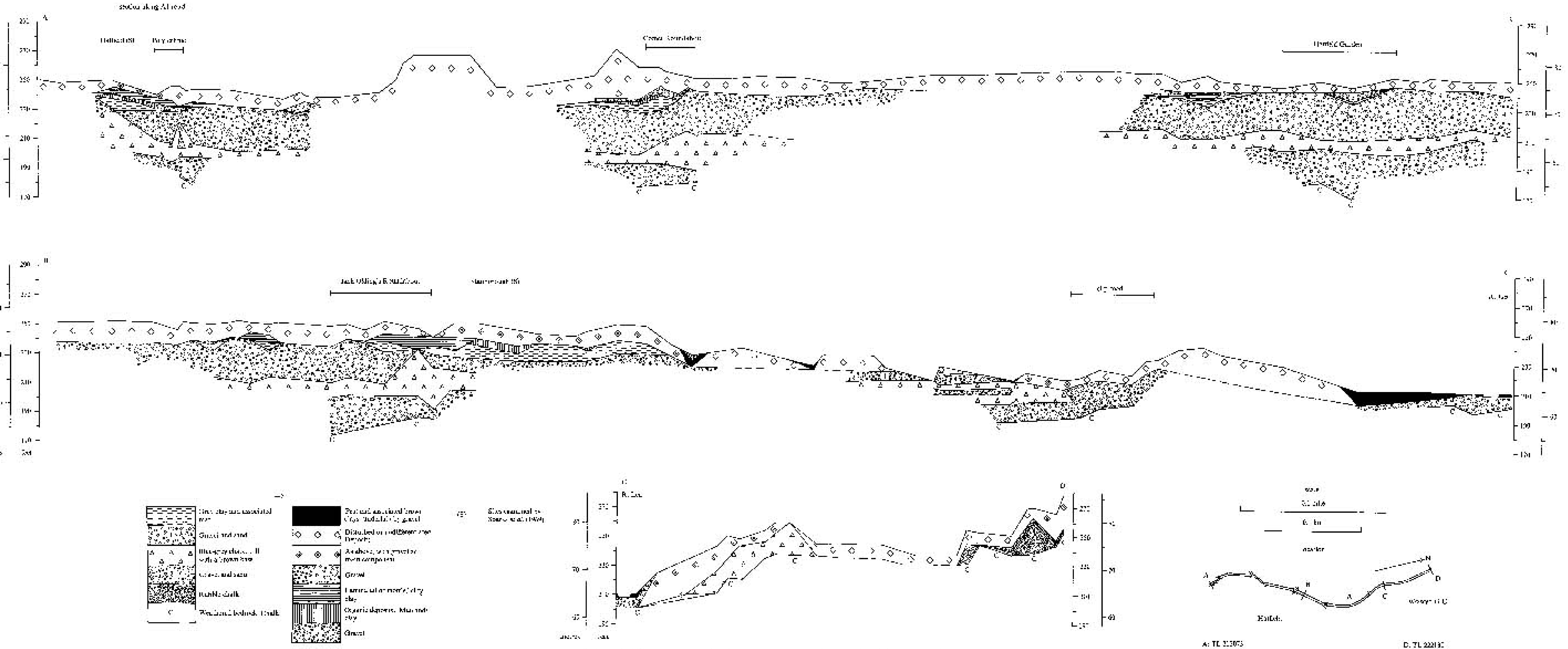

Figure 10. Section along the A1 road, constructed from borehole data supplied by the Eastern Road Construction Unit, Department of the Environment.

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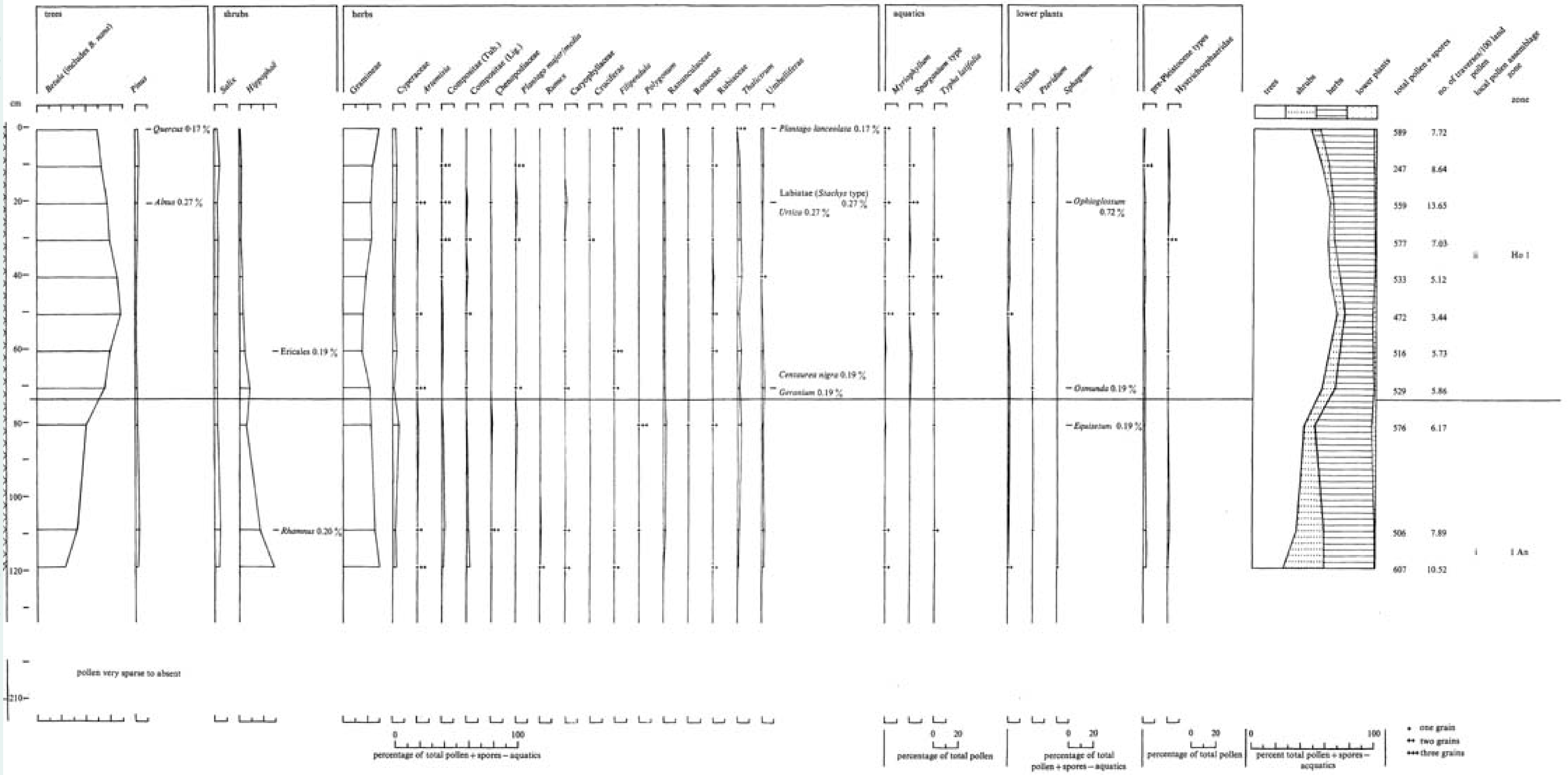

Figure 14. Pollen diagram from the light grey silty clay and grey green marl silt at Bell Lane Quarry, 1972/3.

PLG