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THE GEOLOGY AND SIGNIFICANCE OF THE INTERGLACIAL SEDIMENTS AT LITTLE OAKLEY, ESSEX

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At Little Oakley, near Harwich, an interglacial deposit has been identified and mapped over a distance of *ca.* 1 km by means of boreholes and from temporary sections. The interglacial sediments are chiefly silts and sands, which occupy a large river channel (150–175 m wide) trending W.S.W.–E.N.E. The channel sediments are variously underlain by London Clay, Red Crag and another fluvial deposit, the 'Oakley Gravel' (one of 15 newly defined lithostratigraphic units), against which they also abut on their northern margin. The channel occurs at an elevation of between 18 and 24 m O.D. and is thought, on the basis of clast lithology, to have been occupied by the pre-diversion Thames at a point immediately upstream of its confluence with the Medway.

The interglacial deposits are rich in fossils, which indicate accumulation during the pre- and early temperate substages of an early Middle Pleistocene interglacial stage. Pollen spectra from the base of one borehole may possibly relate to the terminal phase of the preceding late-glacial period. The balance of the palaeontological evidence suggests correlation of the main sequence with the Cromerian *sensu stricto*. The essential facts leading to this conclusion are given here, but detailed discussions of the palaeobotany, vertebrates, molluscs and ostracods are given in a series of separate papers. This correlation gains some support from amino acid epimerization data from the shells of certain aquatic molluscs. Palaeomagnetic measurements, indicating normal geomagnetic polarity, are also consistent with this correlation.

The relation of the Little Oakley sequence to the regional geology is discussed, and the palaeogeographic history of the Thames–Medway river systems in this area is briefly reviewed.

1. Introduction

Little Oakley lies near the eastern end of a ridge of London Clay, capped with Pleistocene gravels and small remnants of Red Crag, lying between the Stour estuary to the north, Hamford Water to the south and the North Sea to the east (figure 1). Interglacial deposits were first discovered at Little Oakley in 1939, when S. H. Warren identified Pleistocene shells among piles of dumped material excavated from a series of sewer trenches. A. S. Kennard, who accompanied Warren in the field shortly afterwards, recognized the close similarity of the molluscan fauna to that of the 'Cromer Forest Bed'. It is obvious from Warren's notes in the British Museum (itemized by Sutcliffe *et al.* (1979)) that a substantial paper had been planned (S. H. Warren & A. G. Davis, unpublished manuscript), but only a brief note on the Little Oakley deposit has ever been published (Warren 1940: 9–11). The importance of this site as a basis for resolving a number of problems relating to the British Pleistocene sequence has been stressed on several occasions (Oakley 1943; Kerney 1959; Sutcliffe *et al.* 1979), but only recently has any successful attempt been made to re-sample the deposit and to determine its extent and precise age (Bridgland 1988; Bridgland *et al.* 1988). This work has confirmed that the sediments are directly relevant to the history of Thames drainage in East Anglia. The present paper introduces the study by describing the geology of the sediments, giving details of their form, lithology and stratigraphical context. A discussion on the age of the deposit is also given, largely based on palaeontological data presented in the four subsequent related papers (Gibbard & Peglar 1990; Lister *et al.* 1990; Preece 1990; Robinson 1990).

By using Warren's notes, attempts were made to relocate the fossiliferous channel sediments by augering near to the site of his original observations. An initial borehole (LOA) was therefore put down close to Harwich Road (TM 22332938; figures 1 and 2), which penetrated 2.35 m of fossiliferous sediment resting on London Clay and provided a major source of palaeontological evidence. A detailed borehole programme was subsequently carried out to determine the form of the sedimentary body, its internal variability, its relation to the neighbouring sediments and to the land surface. This information was supplemented by observations from occasional temporary exposures.

Finally, a series of larger holes were excavated mechanically near the site of borehole LOA (figures 1 and 2). These exposures provided an opportunity to view sedimentary relations in open section and to collect large samples. From these various sources of information (data lodged with the British Library) four sections have been constructed (figures 1–3).

This detailed geological appraisal of the Little Oakley site has been combined with a wider study of the Pleistocene fluvial deposits in this part of Essex, predominantly based on the analysis of gravel composition and detailed mapping (Bridgland 1988). On both the local and the regional scale this work involved the recognition of various sedimentary units which can be defined lithologically (table 1) and mapped in three dimensions. In addition to the spatial distribution, an important altitudinal element is also considered in the recognition of individual units. Following the recommendations of Hedberg (1976), all fluvial sedimentary units differentiated are formally defined (table 2).

2. Local geology

The post-Palaeogene deposits in the immediate Little Oakley area comprise the following lithostratigraphic units:

(*a*) Red Crag; (*b*) Oakley Gravel; (*c*) Little Oakley Silts and Sands; (*d*) Pebbly clay and sand (not formally defined); (*e*) Upper Dovercourt Gravel.

(*a*) *Red Crag*

Sediments of typical Red Crag lithology (red–orange ferruginous, coarse–medium shelly sand) survive as occasional small remnants in this area. They were described by Harmer (1900), who assigned them to the 'Oakley Horizon' of the 'Waltonian Stage'. The Red Crag at Little Oakley is extremely fossiliferous and produced much of the material for Harmer's monographs (1914–1925). A photograph of a former pit appears in Harmer (1918, p. 483). More recently, Red Crag was exposed in sewer trenches at Dovercourt (TM 232304; DB, figures 1 and 2), where it is overlain by Oakley Gravel at approximately 20 m O.D. (ordnance datum). In the present study two boreholes also penetrated Red Crag beneath the fossiliferous sediments infilling the Little Oakley channel (boreholes LOM, LOC, figures 1–3). Warren & Davis (ms) recorded Red Crag near the site of borehole LOC, resting on London Clay. They also found patches of Crag beneath sand and gravel (probably Oakley Gravel) 'in and near Maze Lane' (TM 222299).

(*b*) *Oakley Gravel*

The only available geological map (Old Series, Sheet 48) shows a sheet of 'Glacial Gravel' covering much of the Little Oakley–Upper Dovercourt area (Whitaker 1877). It has been recognized for some years that this deposit was laid down by the Thames (Rose *et al.* 1976; Bridgland 1988). The gravel in the immediate Little Oakley area, here termed the 'Oakley Gravel', is a subdivision of the Kesgrave Sands and Gravels of Rose *et al.* 1976; see below and table 2).

Various temporary exposures at Dovercourt (TM 232304; DA and DB, figure 1) and at Little Oakley itself (LOAD, LOAE and LOQ), revealed a variety of sand and gravel units within the Oakley Gravel, ranging from silty sand to matrix-supported medium gravel, crudely

Table 1. Lithological composition of the units in northeast Essex defined in this paper, based on counts of the 16–32 (roman type) and 11.2–16 mm (italic type) fractions

			local				exotic						
gravel	site	sample no.	Tertiary flint	ratio non-Tertiary: Tertiary flint	total flint	total southern	quartz and quartzites	Carboniferous chert	*Rhaxella* chert	total exotics	ratio southern: quartz and quartzites	total count	location site on figure 4
Upper Dovercourt Gravel	Upper Dovercourt	1	29.5	1.71	80.0	0.7	16.9	1.4	—	19.1	0.04	414	*
	11.2–16	*1 (a)*	*30.7*	*1.43*	*74.4*	*1.9*	*19.2*	*2.5*	*0.2*	*23.7*	*0.09*	*473*	*
	11.2–16	*1 (b)*	*35.6*	*1.13*	*75.7*	*1.3*	*18.7*	*2.6*	*0.2*	*23.0*	*0.07*	*461*	*
Wigborough Gravel	Wigborough	1 A	42.9	0.98	85.0	4.4	8.3	0.3	—	10.1	0.53	387	1
	Wick	1 B	40.4	0.97	79.7	7.1	11.5	0.5	—	13.1	0.62	565	1
	Jaywick	1	51.0	0.59	81.3	4.8	12.3	0.2	—	13.7	0.39	416	2
	11.2–16	*1*	*42.1*	*0.96*	*82.4*	*6.0*	*9.2*	*0.7*	*0.2*	*11.6*	*0.65*	*813*	2
Mersea Island Gravel	West Mersea	1	38.6	1.13	82.4	14.2	2.8	—	0.3	3.5	5.13	578	3
		2	44.8	0.95	87.7	10.0	1.4	0.5	—	2.3	7.17	431	3
	Fen Farm	1	47.6	0.83	87.2	10.7	1.8	0.2	—	2.2	5.50	553	4
		2	52.3	0.72	90.0	7.6	1.8	0.2	0.4	2.3	4.33	512	4
	11.2–16	*2*	*47.5*	*0.86*	*88.2*	*8.7*	*2.3*	*0.4*	*0.1*	*3.1*	*3.86*	*1573*	4
	Cudmore Grove	1	47.1	1.10	89.9	6.8	2.6	0.3	0.2	3.3	2.57	1061	5
		2	45.3	0.88	85.0	11.6	2.4	0.7	—	3.4	4.88	671	5
	Point Clear	1	33.1	1.34	77.3	20.1	0.9	0.7	0.4	2.6	22.80	568	6
Brightlingsea Gravel	Brightlingsea	1	26.4	2.05	80.5	0.3	19.2	1.9	—	21.4	0.01	364	7
	11.2–16	*2*	*27.8*	*1.63*	*73.0*	*0.9*	*22.3*	*2.5*	*0.4*	*26.1*	*0.04*	*800*	7
Tollesbury Gravel	Garlands Farm	1 A	37.8	1.21	83.6	—	12.9	1.1	0.1	16.2	—	805	—
	(TL 947106)	1 B	40.4	1.04	82.6	0.1	15.4	0.4	—	17.3	0.01	987	—
	11.2–16	*1 B*	*33.9*	*1.28*	*77.5*	*0.5*	*17.8*	*1.8*	—	*22.0*	*0.03*	*1475*	—
Clacton Channel Gravel	Lion Point	1	28.2	1.81	79.2	17.8	2.7	0.3	—	3.1	6.57	259	8
		2	42.3	1.05	86.9	9.2	3.3	0.3	—	3.9	2.80	305	8
	11.2–16	*2*	*46.5*	*0.91*	*88.9*	*6.1*	*2.9*	*0.7*	*0.4*	*4.9*	*2.10*	*721*	8
	Butlins	1	46.0	0.96	90.1	7.2	1.8	0.6	—	2.4	4.00	335	9
Anglian glacial Gravels[a]	Ugley	1	41.9	1.10	87.9	—	5.0	1.5	0.4	11.9	—	520	—
	(TL 516278)	2	3.6	23.4	87.1	—	4.3	2.1	1.7	12.6	—	420	—
Upper St Osyth Gravel	Fingringhoe	1A	15.4	4.23	80.8	2.4	8.4	4.1	1.4	16.8	0.29	369	10
		1B	15.9	4.13	81.7	0.7	12.6	0.9	0.9	17.7	0.05	453	10
	St Osyth	2	8.7	9.35	89.8	2.1	5.1	2.1	—	8.1	0.41	530	11b
	11.2–16	*2 (b)*	*14.9*	*4.28*	*78.4*	*2.4*	*12.9*	*2.7*	*0.4*	*18.8*	*0.18*	*714*	11b
Upper Holland Gravel	Bypass Road	1A	9.9	7.31	82.1	9.5	4.2	1.9	—	8.4	2.27	263	12
		1B	12.6	4.93	74.8	19.6	3.2	1.3	—	5.7	6.20	317	12
	Earls Hall	1	11.5	5.57	75.8	21.7	1.1	0.5	—	2.2	19.75	364	13
	11.2–16	*1 (b)*	*16.0*	*4.02*	*80.3*	*10.5*	*5.7*	*2.7*	*0.3*	*9.1*	*1.86*	*932*	13
		2	13.6	4.71	77.6	15.0	3.3	2.8	—	7.2	4.50	361	13
	Burrs Road	1	10.8	5.00	64.8	31.4	0.7	1.4	1.4	3.8	45.00	287	14
		2	11.6	4.70	66.0	28.8	3.1	1.3	0.6	5.3	9.20	320	14
	Holland-on-Sea	1	15.5	3.56	70.7	24.7	2.4	1.0	0.5	4.6	10.20	413	15
		2A	15.7	3.38	68.9	25.1	3.7	0.7	—	6.0	6.70	267	15
	(transitional?)	2B	23.7	2.01	71.3	16.1	10.0	1.4	0.2	12.6	1.62	422	15

[a] Non-durables excluded from these counts.

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TABLE 1 (*cont.*)

gravel	site	sample no.	local: Tertiary flint	local: ratio non-Tertiary: Tertiary flint	local: total flint	total southern	exotic: quartz and quartzites	exotic: Carboniferous chert	exotic: *Rhaxella* chert	total exotics	ratio southern: quartz and quartzites	total count	location site on figure 4
Lower St Osyth Gravel	Fingringhoe	1 C	31.4	1.71	85.1	—	12.8	1.9	—	14.9	—	376	10
	Moverons	1	29.0	1.79	80.8	0.6	15.4	1.4	—	18.3	0.04	929	16
		2	30.8	1.57	79.6	1.1	16.5	0.7	—	19.3	0.07	1031	16
	11.2–16	*2*	*32.3*	*1.28*	*73.5*	*1.7*	*21.8*	*1.7*	—	*24.7*	*0.08*	*1330*	16
		3	31.8	1.44	77.5	0.7	19.2	1.3	—	21.7	0.04	994	16
	St Osyth	1 A	35.4	1.17	77.1	0.5	18.8	1.8	—	22.4	0.03	559	11 a
		1 B	30.6	1.59	79.8	1.6	15.4	1.3	—	18.6	0.10	748	11 a
	11.2–16	*1 B*	*30.1*	*1.58*	*78.0*	*1.7*	*17.3*	*2.0*	—	*20.2*	*0.10*	*1325*	11 a
Lower Holland Gravel	St Osyth	3	31.6	1.63	83.1	1.4	13.0	1.6	—	15.3	0.11	561	11 b
		5	21.8	2.65	80.0	4.9	12.6	1.8	—	15.1	0.39	325	11 c
		6	29.5	1.76	81.2	2.5	14.1	1.3	—	16.0	0.18	319	11 c
	Bush Paddock	1	43.3	0.94	83.9	5.1	9.6	0.8	—	11.0	0.53	647	17
	11.2–16	*1*	*40.8*	*0.85*	*75.6*	*10.8*	*11.6*	*0.8*	*0.1*	*13.6*	*0.79*	*1215*	17
	Holland-on-Sea	2 C	32.8	1.46	80.6	2.2	15.5	1.0	—	17.2	0.14	412	15
		2 D	26.7	2.05	81.5	1.8	14.8	1.1	—	16.5	0.12	655	15
	Holland Haven	1 A	24.9	2.38	84.0	2.9	11.0	1.6	0.3	13.1	0.26	382	18
		1 B	34.6	1.40	83.1	3.1	12.7	0.4	—	13.9	0.24	260	18
		2	25.3	2.24	82.2	3.0	12.4	1.7	0.2	14.8	0.24	534	18
	11.2–16	*2*	*31.4*	*1.45*	*76.8*	*5.2*	*14.6*	*1.4*	*0.2*	*18.0*	*0.36*	*939*	18
	Clacton cliffs	4 C	33.9	1.39	81.3	9.0	7.6	1.2	0.7	9.7	1.18	433	19
		4 D	38.7	1.11	81.5	5.6	9.2	2.0	—	12.9	0.61	357	19
Wivenhoe Gravel	Wivenhoe	1 B	25.1	2.19	80.1	0.8	15.1	2.7	—	18.3	0.05	371	20
		2 A	30.4	1.45	74.6	0.7	21.9	1.4	—	24.7	0.03	283	20
	Arlesford	1	36.0	1.04	73.6	0.4	22.3	2.6	—	26.0	0.02	458	21
	11.2–16	*1*	*31.1*	*1.12*	*66.1*	*1.4*	*28.4*	*2.1*	—	*32.4*	*0.05*	*716*	21
		2	21.5	2.83	82.6	0.9	14.2	1.5	—	16.6	0.06	344	21
Cooks Green Gravel	Cooks Green	1 A	21.3	2.92	83.8	3.2	10.7	1.0	—	13.0	0.30	625	22
		1 B	27.2	2.09	84.2	2.0	10.6	2.8	—	13.8	0.19	492	22
	11.2–16	*1 B*	*26.9*	*1.70*	*72.6*	*3.7*	*21.2*	*1.2*	—	*23.7*	*0.17*	*1205*	22
		2	29.4	1.82	83.0	3.3	12.2	0.3	—	13.5	0.27	394	22
	Great Holland	1	25.5	2.29	84.0	1.7	14.3	0.7	—	16.0	0.12	419	23
	11.2–16	*1*	*25.9*	*2.10*	*80.3*	*3.2*	*14.4*	*1.8*	*0.1*	*16.5*	*0.22*	*1289*	23
Little Oakley Silts and Sands	Little Oakley	AB	33.6	1.60	87.4	0.8	10.1	1.7	—	11.8	0.08	119	*
	11.2–16	*AB*	*26.4*	*1.68*	*72.9*	*2.0*	*21.0*	*2.0*	—	*24.8*	*0.09*	*295*	*
		AC	33.7	1.48	83.7	0.4	14.3	0.4	—	15.9	0.03	252	*
	11.2–16	*AC*	*29.7*	*1.47*	*73.1*	*1.6*	*22.3*	*1.2*	*0.1*	*25.2*	*0.07*	*674*	*
		AF	26.0	2.09	80.3	1.8	15.7	1.3	—	17.9	0.11	223	*
	11.2–16	*AF*	*28.8*	*1.46*	*70.8*	*2.3*	*21.9*	*3.4*	—	*26.9*	*0.11*	*640*	*
Ardleigh Gravel	Ardleigh	1	26.8	1.82	75.6	0.7	19.3	0.8	—	23.6	0.04	590	24
	11.2–16	*1*	*27.1*	*1.67*	*72.3*	*1.7*	*22.7*	*2.2*	—	*25.9*	*0.07*	*1008*	24
		2	23.7	2.40	80.0	1.5	14.6	2.0	—	17.7	0.10	615	24
	11.2–16	*2*	*29.0*	*1.41*	*69.9*	*1.0*	*24.4*	*3.0*	—	*29.1*	*0.04*	*1219*	24
		4 A	33.3	1.16	72.0	0.4	25.3	1.1	—	27.5	0.01	553	24
		4 B	29.3	1.57	75.4	1.3	19.2	1.1	—	23.0	0.07	447	24
Oakley Gravel	Dovercourt	DA	30.3	1.61	79.2	2.4	14.5	1.6	—	18.5	0.17	379	*
	11.2–16	DA	25.3	1.96	75.0	4.9	17.2	1.7	—	20.1	0.28	783	*
	Little Oakley	KA	30.3	1.65	80.2	2.0	15.8	0.6	0.2	17.8	0.13	653	*
	11.2–16	KA	25.7	1.97	76.4	2.2	18.7	1.9	0.1	21.3	0.12	673	*

* Sites are shown on figure 1.

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TABLE 2. DEFINITIONS OF LITHOSTRATIGRAPHIC UNITS IN NORTHEAST ESSEX

(Key: g, gravel; s, sand; si, silt.)

Name (lithology)	Type site (grid reference)	Thickness (height OD)[a]
Upper Dovercourt Gravel (g, s)	Upper Dovercourt (TM 241243)	3.5 m (26.5 m)
Wigborough Gravel (g, s)	Wigborough Wick (TM 117146)	5 m+ (13 m)[b]
Mersea Island Gravel (g, s)	East Mersea (TM 067145)	*c.* 15 m (12 m)[b]
Brightlingsea Gravel (g, s)	Brightlingsea (TM 087164)	? (8 m)[b]
Tollesbury Gravel (g, s)	Tollesbury (TL 947016)	10 − (25 m)
Clacton Channel Gravel (g, s)	Lion Point (TM 140128)	up to 6 m (2 m)
Upper Holland Gravel (g, s)	Holland-on-Sea (TM 211166)	1.5 m+ (17.5 m)
Upper St Osyth Gravel (g, s)	St Osyth (TM 120171)	2.5 m+ (18.5 m)
Lower Holland Gravel (g, s)	Holland-on-Sea (TM 211166)	7–12 m (14 m)[c]
Lower St Osyth Gravel (g, s)	St Osyth (TM 120171)	7–12 m (16 m)[c]
Cooks Green Gravel (g, s)	Cooks Green (TM 188187)	4 m+ (24 m)
Wivenhoe Gravel (g, s)	Wivenhoe (TM 046224)	up to 9 m (30 m)
Oakley Gravel (g, s)	Little Oakley (TM 219294)	7 m+ (26 m)[b]
Ardleigh Gravel (g, s)	Ardleigh (TM 052081)	10.5 m (36 m)
Little Oakley Silts and Sands (si, s)	Little Oakley (TM 223295)	up to 3 m (22.5 m)

[a] Maximum surface height in area of type site; [b] surface believed to be erosional; [c] overlain by Upper St Osyth/Upper Holland Gravel.

stratified and iron-stained throughout, with considerable cryoturbation of the upper levels. At Dovercourt these sediments extended from 18.8 m O.D. (DA) to 23 m O.D. (DB). As the contact with the underlying London Clay was exposed at DA, an overall thickness of approximately 9 m is indicated for this unit. Tabular cross-stratification in sand beds at Dovercourt showed a palaeocurrent towards the E.S.E. Further exposures of Oakley Gravel, dominated by pebbly sand, were recognized at TM 223301 (LOQ) and beneath the Little Oakley Silts and Sands in exposures LOAD and LOAE (figures 1 and 2). On the basis of its three-dimensional distribution (figures 3–6) it is believed that the Oakley Gravel represents only a single aggradational unit. The clast lithological characteristics of this unit and its relation to others in the area are discussed below (§4*b*).

The variability and character of the sediments included within the Oakley Gravel suggest deposition in a bedload-dominated river system, with migrating channels and bars and an abundant supply of coarse debris. The conditions required to support such a river are not those occurring during temperate periods in lowland Britain (Gibbard 1988) and it is concluded that these sediments were laid down during a cold stage.

(*c*) *Little Oakley Silts and Sands*

The Little Oakley deposits were not recognized in the early Geological Survey mapping (Whitaker 1877) and were possibly mistaken for Red Crag, which is shown at their approximate location. Before the present study, the interglacial deposits were known from trenches adjacent to Harwich Road between Foulton Hall and Sea View Avenue (S. H. Warren & A. G. Davis, unpublished manuscript). The present work has shown them to be of considerable extent, underlying a substantial part of the village (figure 1). Their characteristics have been determined from a combination of three borehole transects (figures 1–3) and various trial pits (figure 1).

In the easternmost borehole transect (LOA-LOF; figure 3:2) and in the neighbouring excavations (LOAA-LOAH; figure 1), the Little Oakley Silts and Sands predominantly comprise poorly bedded silty sand to sandy silt with occasional thin (less than 1 cm) laminae

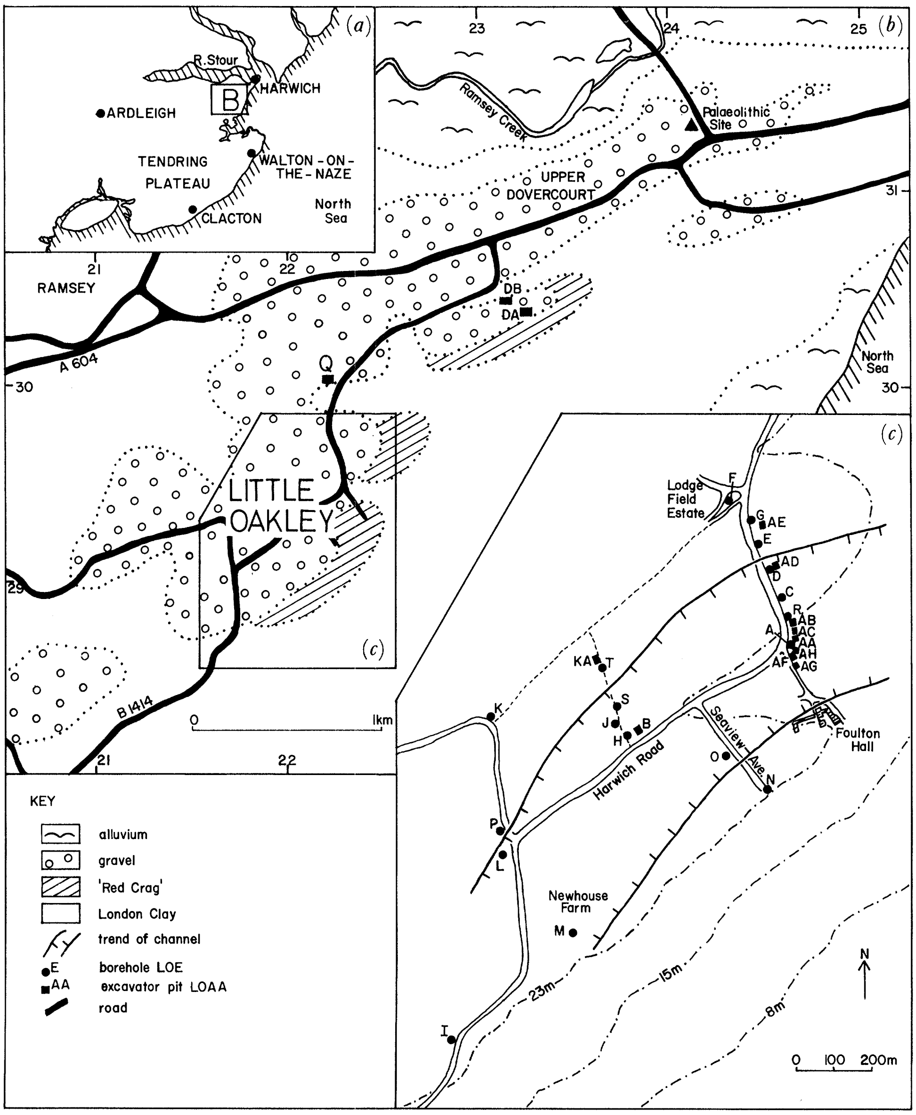

Figure 1. Location map of Little Oakley showing the position (*a*) on the Tendring Plateau, (*b*) in relation to the local geology (after Geological Survey Sheet 48) and (*c*) of individual boreholes, temporary exposures and sample points.

of coarser sand. However, in the transect LON-LOT, 0.25 km to the southwest, there was considerable lithological variation. Near the southern margin, beneath Seaview Avenue, the channel sediments are banked against Red Crag (borehole LON), as originally noted by Warren & Davis (1955). Sediments filling the southern side of the channel were recorded in borehole LOO, comprising light grey clay silt with occasional stones, passing upwards into light grey (2.5Y 6/4) silty clay with Mollusca (Preece 1990), oxidized to light olive brown (2.5Y 5/6) in its upper 30 cm. By contrast, the LOH sequence consists of light grey sandy silt, overlain by yellow to cream medium sand containing scattered pebbles and Mollusca. This grades upwards into grey to light brown sandy silt. Comparable profiles are present in LOB, LOJ and LOS.

Further to the southwest, the deposits were again recovered in borehole LOM, close to Newhouse Farm (figures 1–3). Here, they overlie a thin (4–5 cm) bed of Red Crag that is

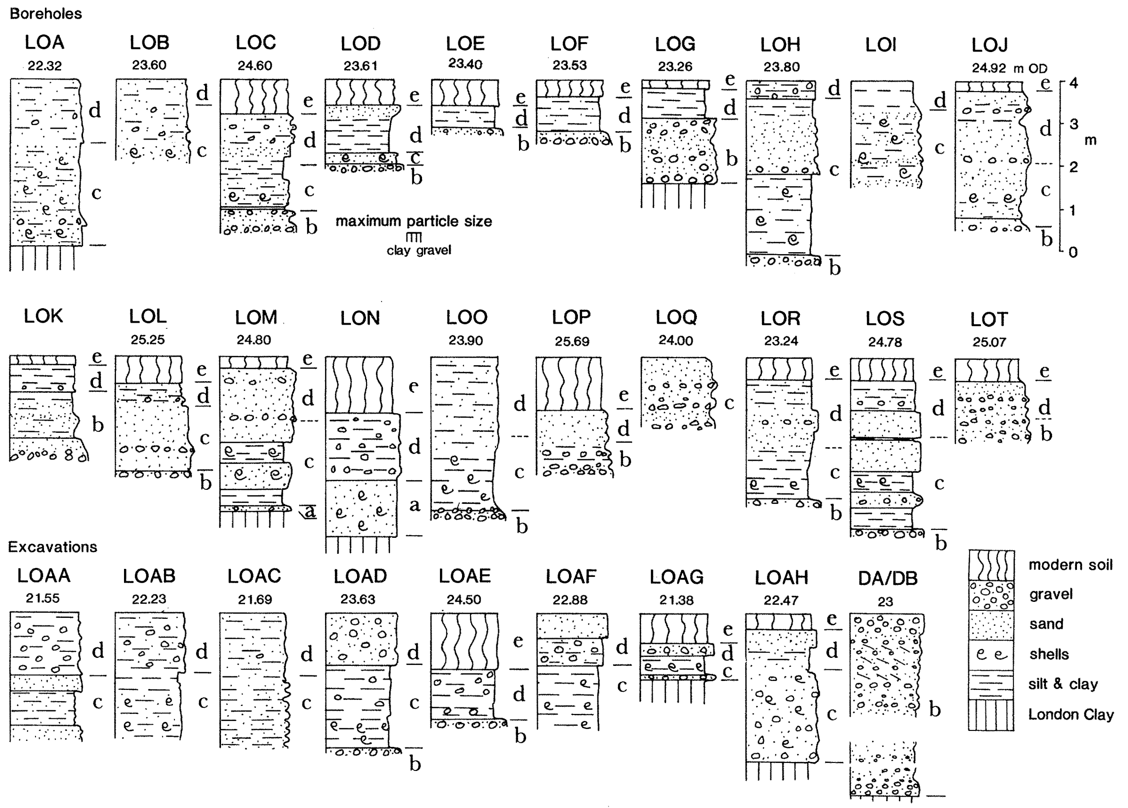

FIGURE 2. Sedimentological logs of boreholes and excavations in the Little Oakley (LO) and Dovercourt (D) areas. Full data lodged with the British Library. a, Red Crag; b, Oakley Gravel; c, Little Oakley Silts and Sands; d, Pebbly clay and sand; e, soil.

interstratified with the overlying grey clay silt which contains an increasing sand component upwards. It also yields Mollusca, including many reworked Red Crag fossils. This bed is truncated by yellow coarse sand, which in turn is overlain by a light grey silty clay and then a coarse to medium sand. Palynological analysis has shown that the last follows a significant erosional break (Gibbard & Peglar 1990). In contrast, borehole LOL consists almost entirely of grey to orange medium sand with shells. The fossiliferous sediments are absent in boreholes LOP and LOK and therefore their northern limit must occur between boreholes LOL and LOP, that is, beneath the road junction at the western end of the village (figure 1).

The deposits are formally named the Little Oakley Silts and Sands, reflecting the predominance of these grades. Discrete gravel beds do not occur, but isolated clasts were frequent, particularly at some localities at the eastern end of the village. In excavations LOAA-LOAH, gravel clasts scattered throughout the sediment were collected for lithological analysis (table 1). Additionally, in LOAG a veneer of gravel occurred as a discontinuous lag at the base of the unit, immediately above the London Clay.

On the basis of the data collected, the approximate three-dimensional limits of the deposit have been reconstructed (figures 1–3), confirming its channel-like form. The reconstructed margins of the channel show a gentle bend (figure 1). The channel is variously excavated in London Clay, Red Crag and Oakley Gravel (figures 2 and 3). Reworked fossils from the first two are common in certain parts of the channel-fill. It is difficult to determine the precise width of the palaeochannel in which the Little Oakley Silts and Sands were deposited because of

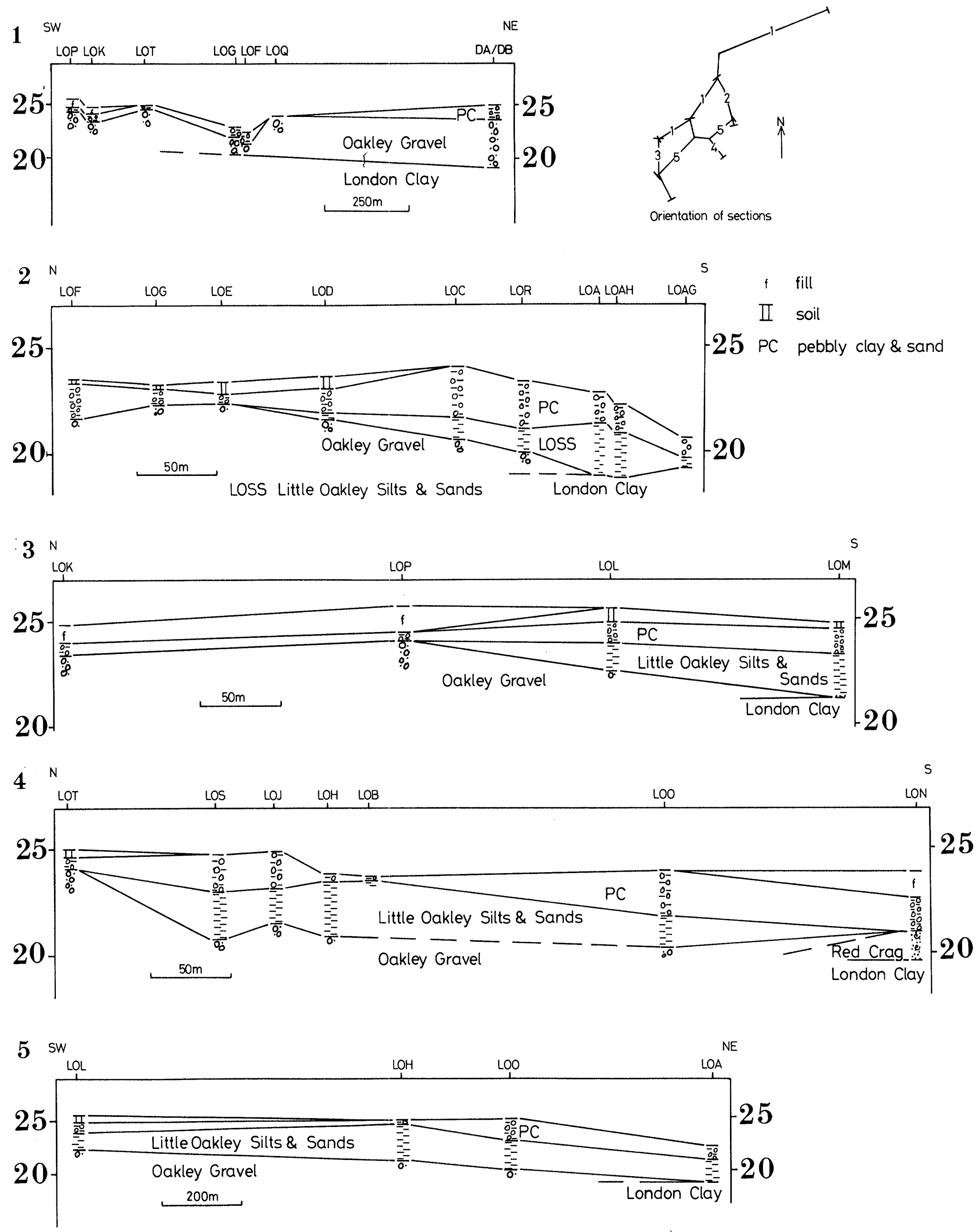

Figure 3. Profiles through deposits in the Little Oakley area constructed from borehole data. 1, long profile from Little Oakley to Dovercourt showing the relation of sections through the Oakley Gravel. 2, transverse profile at the eastern end of Little Oakley, showing the relation of the Little Oakley Silts and Sands to adjacent deposits. 3, transverse profile across the channel beneath the central part of Little Oakley. 4, transverse profile at the western end of Little Oakley. 5, long profile of the Little Oakley channel parallel to Harwich Road.

subsequent erosion and lack of detailed exposure, but it may be in the order of 150–175 m. The longitudinal profile (figure 3) shows an apparent downstream (eastward) gradient of 3 m km^{-1}, somewhat steeper than might be expected from comparisons with the existing Thames floodplain and with the fluvial gravels preserved locally. However, data collected over such short downstream distances (approximately 850 m in this case) may reflect local variations, perhaps related to scouring.

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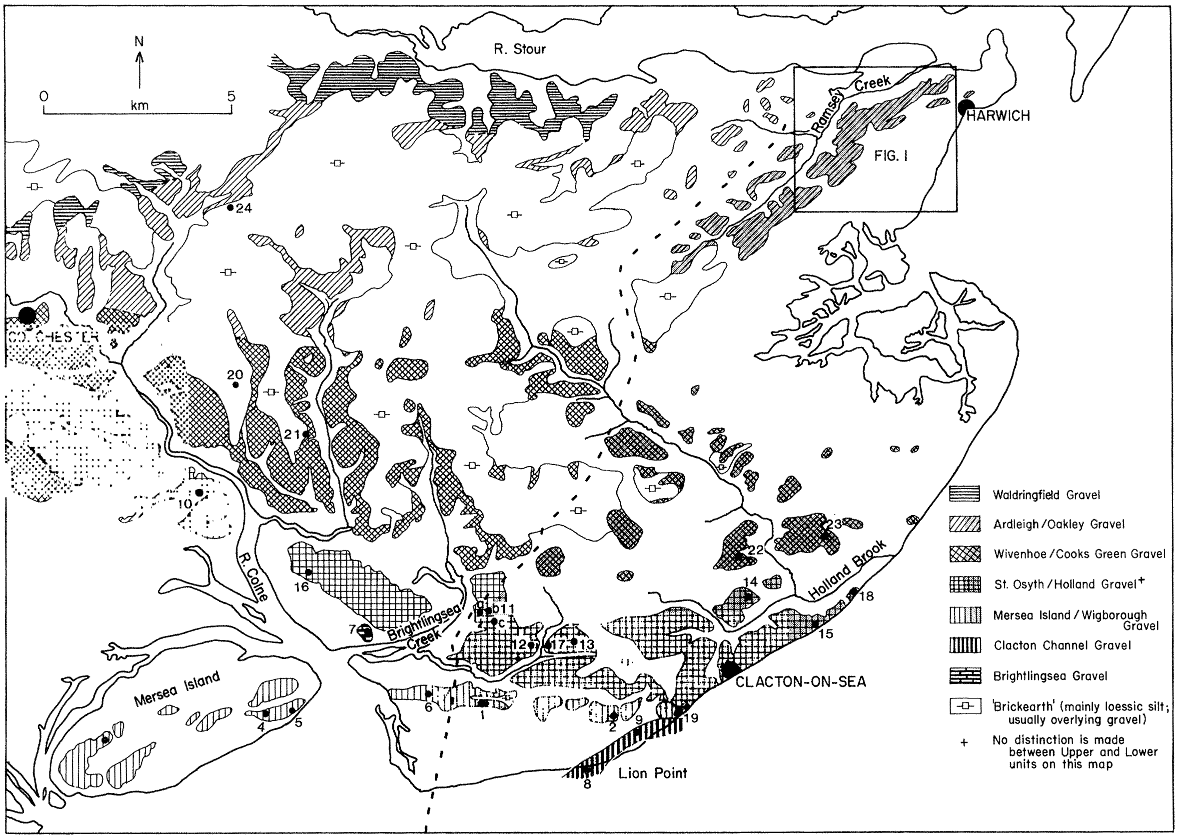

FIGURE 4. The Pleistocene gravels of the Tendring Plateau. Numbered sample sites are as in table 1. The dashed line delineates the boundary between Thames and Thames-Medway gravels.

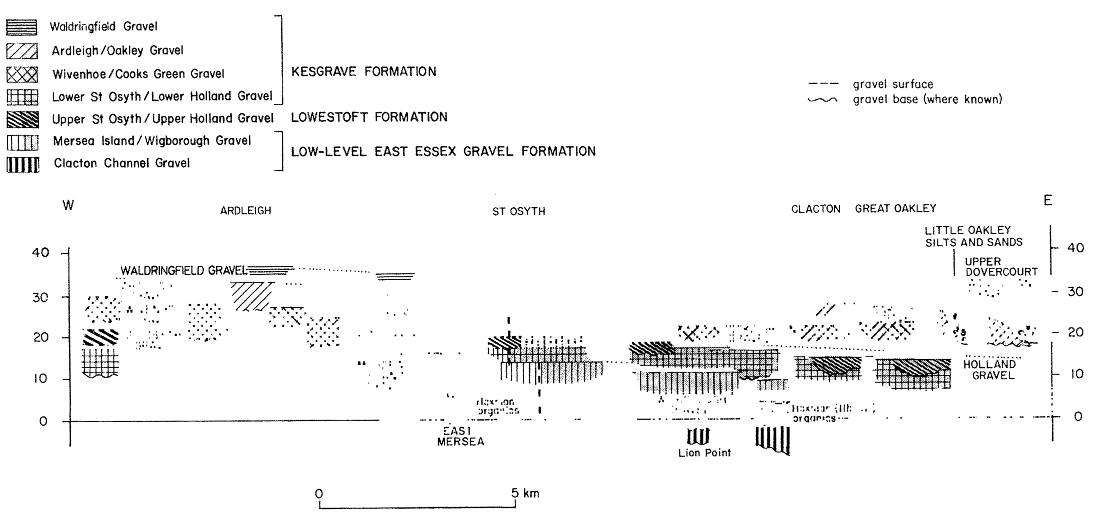

FIGURE 5. Long profiles of the gravel deposits of the Tendring Plateau. Vertical dashed lines delineate the boundary between Thames and Thames-Medway gravels.

The spatial distribution of sediments composing the channel fill (figures 2 and 3) reveals a meaningful pattern. Finer sediments, silts and silty clays, occur predominantly on the southern side of the channel, beneath Seaview Avenue (for example, borehole LOO) and to a lesser extent on the north side of the channel (figures 2 and 3). These sediments imply a relatively low-energy regime. However, on the northern side, silt is generally subordinate to sand-rich

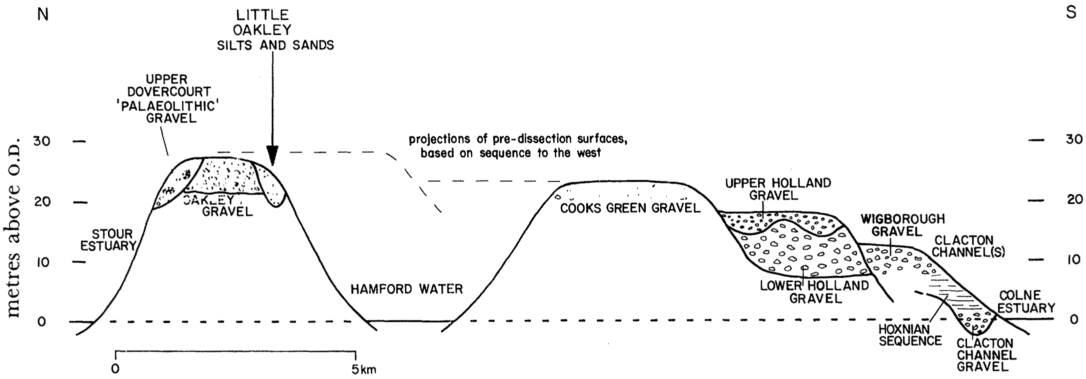

FIGURE 6. Transverse section through the terraces and gravel deposits of the Tendring Plateau.

sediments, showing higher energy conditions. Indeed, in boreholes LOH, LOJ, LOS, LOB and LOL, sand clearly dominates the sequence. From this pattern it would appear that the main flow was concentrated on the northern side of the channel, beneath the western and central parts of the village, whereas at the eastern end no substantial sand bodies were deposited.

Detailed facies analysis of the sediments was precluded, as most of the sites were boreholes or small excavations. However, the spatial distribution of sediment types within the Little Oakley Silts and Sands suggests that the river was apparently confined to a single channel. The main channel flow is represented by the sands, whereas the fine sediments are concentrated in point bar-like accumulations on the inside of the bend, such as that beneath Seaview Avenue and north of Foulton Hall (figures 1–3). Comparison of this pattern with existing fluvial lithofacies models suggests that the sequence most closely resembles Jackson's (1978) types 1 or 2 for meandering streams. If this is correct, the Little Oakley Silts and Sands were deposited by a substantial meandering river comparable to those in southeastern Britain today.

S. H. Warren & A. G. Davies (unpublished manuscript) mentioned the occurrence of a 'patch of highly calcareous white marl', but did not give any details of its exact location or stratigraphical relations. No trace of this deposit was found in any of the boreholes or excavations described above.

(*d*) *Pebbly clay and sand*

The fluvial deposits at Little Oakley (Oakley Gravel and Little Oakley Silts and Sands) are overlain by a complex unit of variable thickness, reaching a maximum of 215 cm in borehole LOR (figures 1–3). This unit predominantly comprises a silty or clayey sand with pebbles either scattered irregularly throughout or concentrated at some horizons. It is variable in colour from orange to brown and grey and is frequently mottled and stained with oxides of both iron and manganese. Irregularly shaped calcareous nodules up to 2.5 cm in diameter are distributed throughout. These appear to represent pedogenic redeposition of carbonate. Clasts of sand and clay are also present (pits LOAA-LOAE). The deposit thickens generally downslope (figure 3) and shows evidence of the downslope displacement of material. For example, in the excavated sections, the base of the unit was frequently indistinct, with the underlying sediment incorporated as laminae or 'streaks', gently rising in a downslope direction. Elsewhere, the unit had an abrupt erosional base (for example, pit LOAC). The considerable lateral and vertical variations in lithology suggest that derivation from local underlying material was the main factor determining its character. The poor sorting, distribution and other characteristics of this unit suggest an origin by some form of slope process (? solifluction), perhaps accompanied by pedogenesis.

(*e*) *The Upper Dovercourt Gravel*

This deposit, found in pits at Pound Farm (TM 241313; also known as Gant's pit, and now built over), is the richest source of hand-axes in Essex (Wymer 1985). Large numbers of well-made hand-axes were found here, together with finishing flakes and mammalian remains, the latter comprising extinct rhinoceros (*Dicerorhinus kirchbergensis*), large fallow deer (*Dama dama*), horse (*Equus* sp.), halibut (*Hippoglossus* sp.) and indeterminate elephant (see Underwood 1913; Warren 1933; Sutcliffe *et al.* 1979; Wymer 1985). The precise limits of this deposit are as yet unknown, but Warren's notes include a sketch map showing the relation between gravel containing artefacts and the 'normal gravel of the plateau, without implements'. Warren (1933) believed this gravel to be later than the 'plateau gravel' and to be a Stour deposit. The deposit has recently been studied as part of a wider regional reappraisal of Pleistocene geology (see below).

3. The age of the Little Oakley Silts and Sands

Two main kinds of evidence are available regarding the age of the Little Oakley Silts and Sands; that based on correlation of the biostratigraphical information and that based on interpretation of amino acid and palaeomagnetic data.

(*a*) *Biostratigraphical evidence*

The presence of abundant fossils in the Little Oakley Silts and Sands is clearly of much importance, not only in enabling detailed palaeoecological reconstructions, but also in providing good evidence for their relative age. As already stated, the channel sediments consist primarily of silts and sands and are devoid of macroscopic plant remains and insect fossils. However, they have yielded abundant Mollusca and Ostracoda and a reasonably rich vertebrate fauna together with a good pollen record. Detailed discussion of these fossils, including an appraisal of the material collected by Warren and Kennard, is contained in the four papers that immediately follow this account. Consequently, the minimum of facts that establish the age of the Little Oakley Silts and Sands will now be considered.

(i) *Palaeobotany* (*P. L. Gibbard and S. M. Peglar*)

The pollen assemblages belong to the pre- and early temperate substages of an early Middle Pleistocene interglacial. The absence of *Carpinus* and 'Tertiary relicts' (for example, *Tsuga*, *Carya*, *Eucommia*) suggests that the deposits are not pre-Cromerian (*sensu lato*) in age. The early expansion and subsequent dominance of *Ulmus*; presence of *Picea* throughout; late expansions of *Quercus*, then *Corylus* pollen, strongly suggests a Cromerian age (cf. West 1980). The vegetational development is similar to that of the Cromerian stratotype at West Runton, Norfolk, with which it is provisionally correlated. Pollen spectra from the base of borehole LOM may possibly relate to the immediately preceding late-glacial period.

(ii) *Vertebrates* (*A. M. Lister, J. M. McGlade and A. J. Stuart*)

The presence of the deer *Megaloceros verticornis* and probably *M. dawkinsi*, together with the vole *Mimomys savini*, provide good evidence of an early Middle Pleistocene age. The two deer species are known from dated deposits only of Cromerian and early Anglian–Elsterian age in Britain and continental Europe, whereas *M. savini* spans the late Lower/early Middle

Pleistocene up to its latest occurrence in the type Cromerian Stage. The Little Oakley fauna is fully temperate in character and clearly indicates an interglacial age later than Pastonian, but pre-dating Westbury-sub-Mendip fauna 2 and the Anglian glacial Stage of Britain. It is entirely consistent with a Cromerian age, although its correlation with pre-Cromerian interglacial events in the early Middle Pleistocene cannot be ruled out.

(iii) *Mollusca* (*R. C. Preece*)

The Mollusca provide strong support for a Cromerian age. In Britain the genus *Tanousia* (formerly *Nematurella*) is known only from the Cromerian, whereas *Valvata naticina*, *Bithynia troscheli* and *Unio crassus* are unknown in Britain before this Stage. The presence of *Bithynia troscheli* to the exclusion of *B. tentaculata* is another feature that characterizes virtually all British Cromerian sites.

(iv) *Ostracoda* (*J. E. Robinson*)

The ostracod fauna is also consistent with a Cromerian age. Notable species include *Candona tricicatricosa*, *Ilyocypris quinculminata*, *Sclerocypris clavata prisca* and *Scottia browniana*, which although not restricted to the Cromerian, nevertheless together impart a Middle Pleistocene character, since they are not known from any British post-Hoxnian deposit.

(*b*) *Amino acid epimerization data*

It has been shown that the extent of amino acid diagenesis in carbonate fossils can be used for subdividing and correlating sequences (see, for example, Miller *et al.* 1979; Wehmiller 1982; Bowen *et al.* 1989). The degree of epimerization is dependent on age, diagenetic temperature and species. In this study, amino acid epimerization data were obtained from the shells of certain aquatic snails submitted to the Amino Acid Geochronology Laboratory of the University of London (Professor D. Q. Bowen and Dr G. A. Sykes) and the Amino Acid Laboratory of INSTAAR, University of Colorado (Dr J. T. Hollin and Dr G. H. Miller). The analytical procedures adopted by each laboratory are summarized by Bowen *et al.* (1985) and Miller & Mangerud (1985), respectively. The results are expressed as the ratio of D-alloisoleucine to L-isoleucine (D:L) in the total amino acid population (free plus peptide-bound amino acids) determined as peak heights by automated integration. They are as follows:

	laboratory reference	D:L ratios	means
Valvata piscinalis	LOND-311	A 0.321	0.324 ± 0.004
		B 0.327	
	LOND-330	A 0.328	
		B 0.302	
		C 0.345	0.336 ± 0.027
		D 0.367	
Valvata naticina	LOND-312	A 0.292	
		B 0.323	
		C 0.247	0.292 ± 0.032
		D 0.304	
Valvata naticina	AAL-4614	A 0.272	
		B 0.247	0.280 ± 0.038
		C 0.321	

The results obtained from the two laboratories are in broad agreement. The *V. piscinalis* ratios are somewhat higher than those obtained from *V. naticina* from the same deposit, which may imply that the former epimerizes at a faster rate. To put these ratios into perspective, it is necessary to cite comparable data from other critical sites. Results with *V. piscinalis* include:

LOND-331	West Runton (Cromerian stratotype)	0.348 ± 0.011	$(n = 5)$
AAL-4615	Sugworth (Cromerian)	0.286 ± 0.016	$(n = 2)$
LOND-313	Sugworth (Cromerian)	0.300	$(n = 1)$
AAL-4819	Hoxne (Hoxnian stratotype)	0.243 ± 0.023	$(n = 3)$

The Little Oakley ratios are therefore consistent with a 'Cromerian' age assignment. Further interpretation of these results clearly necessitates full consideration of species differences in rates of epimerization and wider ranging comparisons with other sites. These are considered in a fuller report on amino acid measurements from the two laboratories concerned (Bowen *et al.* 1989).

(*c*) *Palaeomagnetism*

Since the Bruhnes–Matuyama boundary occurs within the 'Cromerian Complex' in The Netherlands (Zagwijn 1985), it is clearly important to establish the geomagnetic polarity of the Little Oakley Silts and Sands. This has been done by T. J. F. Austin (University of East Anglia), who has shown that these sediments have normal magnetization. Other evidence, discussed above, shows that they are early Middle Pleistocene and it would seem, therefore, that accumulation occurred during the early part of the Bruhnes magnetozone with an age somewhat less than 730 Ka (the date of the Bruhnes–Matuyama boundary). A full account of these palaeomagnetic results is provided in the Appendix.

4. The relation of the Little Oakley sequence to the regional geology

(*a*) *Review of previous work*

Little Oakley lies near the northeastern corner of the peninsula between the estuaries of the Colne and Stour. This peninsula, known as the 'Tendring Plateau', is a dissected plain underlain by gravel. The plateau surface falls from 38 m O.D. in the northwest, near Horsley Cross (TM 133276) to approximately 12 m O.D. in the southeastern corner, in the vicinity of Clacton-on-Sea. Apart from the major estuaries that form its northern and southern boundaries, the plateau is dissected by a number of lesser streams, notably the Holland Brook and various streams flowing into Ramsey and Brightlingsea Creeks (figure 4).

At the southeastern extremity of the Tendring Plateau, at Clacton, there occurs an important channel fill of Hoxnian age (Pike & Godwin 1953; Turner & Kerney 1971). This has yielded abundant Palaeolithic artefacts and represents the type locality of the Clactonian Industry (Warren 1923, 1924, 1955; Oakley & Leakey 1937; Turner & Kerney 1971; Singer *et al.* 1973; Wymer 1985). Interglacial deposits also occur on the peninsula at Ardleigh (Spencer 1966; Bridgland *et al.* 1988), Wivenhoe (Bridgland *et al.* 1988) and Walton-on-the-Naze (Boatman *et al.* 1973). Palaeolithic material has been recovered from the northern margin of the Oakley Gravel outcrop at Upper Dovercourt (Underwood 1913; Warren 1933; see above), Wivenhoe (Bridgland *et al.* 1988), Weeley (TM 156233; Warren 1957; Wymer 1985) and from the Frinton Cliffs (TM 238196; Warren 1907, 1933, 1957), although there is considerable doubt whether any finds have been made from *in situ* Kesgrave Sands and Gravels.

Although some of the important sites in the area have received considerable attention, there has been little study of the more widespread gravels and 'brickearths'. The geological map (Old Series sheet 48) divides the Pleistocene deposits covering the plateau into gravels and loams of so-called 'Glacial' and 'Post-Glacial' origin. The 'Post-Glacial' types occur as patches fringing the Colne and Stour and are also represented by gravels forming the plateau surface in the southeastern part of the area, between St Osyth and Holland-on-Sea. According to Oakley & Leakey (1937), however, 'river gravel', covers the whole of the eastern part of the plateau as far north as Great Oakley and the Harwich district.

Warren reviewed the gravels of the Tendring Plateau on several occasions and suggested (Warren 1923, 1924) that they could be attributed to the Boyn Hill Terrace of the Thames. He later considered that their lower elements (14–18 m O.D.) might be equated with the Lower Gravel at Swanscombe. However, his discovery of the fossiliferous sediments at Little Oakley (which he recognized as 'Forest Bed' deposits) led him to conclude that the deposits of the Tendring Plateau were much older than any of the Lower Thames terraces (Warren 1940). Warren (1942) ascribed the Little Oakley deposits to the Medway, as they contain Kentish (Greensand) chert, although in an unpublished note (dated November 1947) K. P. Oakley interpreted the Little Oakley sediments as products of a 'Cromerian river of the Thames–Medway system'. In his later work Warren (1955, 1957) reinterpreted the Tendring gravels as an ancient Thames deposit, pre-dating the 'Northern Drift' (that is, pre-dating the Anglian glaciation), which he believed could be traced across Essex from the modern Middle Thames Valley to Holland-on-Sea. He believed that a progressive input of material of Wealden provenance occurred as southern tributaries joined this early Thames. This culminated eastwards in the gravel outcropping in the cliffs north of Clacton, rich in Lower Greensand chert, which he had earlier (Warren 1923) termed 'Holland Gravel'.

In an extensive study of gravels in southern East Anglia, Rose *et al.* (1976) reaffirmed Warren's (1955) conclusions by including gravels at St Osyth and Thorpe-le-Soken in their Kesgrave Sands and Gravels Formation. This they interpreted as a periglacial river deposit, of Beestonian age, laid down by the early Thames. Recently, Bridgland (1988) proposed subdivisions of the Kesgrave Sands and Gravels in this area and recognized a number of individual aggradational units on the basis of three-dimensional field relations (figures 4–6).

This work involved the recognition of individual aggradational terraces by a combination of three-dimensional mapping and examination of the various gravels. The latter was done by using the technique of clast lithological analysis, in which the clasts within a certain size range are identified and their relative proportions calculated (table 1). These analyses (table 1) followed procedures outlined by Bridgland (1986*a*); except that the 16–32 mm size fraction was used, for compatibility with work to the south (Bridgland 1988), and north (Allen 1983, 1984).

(*b*) *The Kesgrave Sands and Gravels of the Tendring Plateau*

The sequence of terrace aggradational units within the Kesgrave Sands and Gravels of the eastern part of the Tendring Plateau is as follows (from Bridgland (1988); see also table 2 and figures 4–6):

Oakley Gravel	surface	28 m O.D.	base	19 m O.D.
Cooks Green Gravel	surface	24 m O.D.	base	≈ 15 m O.D.
Lower Holland Gravel	surface	18 m O.D.	base	9 m O.D.

The highest and oldest of these units, the Oakley Gravel, is that into which the channel at Little Oakley has been cut and has been described above. The lowest, the Lower Holland Gravel, is the lower of two superimposed sedimentary units underlying a terrace surface at 18 m O.D. The overlying 'Upper Holland Gravel' (table 2) is a deposit of considerable stratigraphical importance, as it has been interpreted as a direct correlative of sediments associated with the Anglian glacial maximum in the Vale of St Albans (Bridgland (1988); see below).

As Warren (1955) recognized, gravels containing conspicuous quartz and quartzite material (up to 25%) can be traced from Hertfordshire and central Essex, where they underlie the Anglian till sheet, to the Tendring Plateau. These deposits are composed largely of flint, much of which occurs as pebbles derived from the Palaeogene. There are minor quantities of southern material (mainly Lower Greensand chert), greatly exceeded by the exotics, which, in addition to the quartz and quartzites, include Carboniferous chert and certain characteristic igneous lithologies. These are the gravels included by Rose *et al.* (1976) in their Kesgrave Formation, attributed to the pre-Anglian Thames.

On the eastern side of the Tendring Plateau these Kesgrave Thames gravels pass eastwards into deposits whose composition suggests an increased southern influence. The latter is shown by a small but significant rise in Lower Greensand content and a corresponding fall in exotics (Bridgland 1980, 1983, 1988). This change in composition, which takes place within each of these Kesgrave aggradations, is attributed to the confluence with the Thames of an extended River Medway. Before the diversion of the Thames (see below), the Medway flowed northwards across eastern Essex from Southend to the Blackwater estuary (Bridgland 1980, 1983, 1988). The three gravel units on the eastern side of the Tendring Plateau, described above, are therefore Thames–Medway aggradations. Each passes westwards into separately defined Thames units, laid down by the river upstream from its confluence with the Medway. These are in conventional stratigraphic order, the Ardleigh, Wivenhoe and Lower St Osyth Gravels (Bridgland 1988; figures 4, 5 and 7). A further, higher Thames aggradation has been recognized immediately south of the Stour estuary on the western side of the plateau (figures 4 and 5), the Waldringfield Gravel of Allen (1983).

The analysis of gravel clast lithology on the eastern side of the plateau shows that the influence of the Medway confluence is restricted to the area east of St Osyth, where a change from 'normal' Kesgrave (Thames) composition first occurs (table 1). The westward limit of the 'confluence area' may be different for the three aggradations, but it has so far only been located precisely for the Lower Holland Gravel, which has been more intensively sampled than the higher units.

A clear indication of the effect of the Medway confluence on gravel composition within the Kesgrave Sands and Gravels is given by the southern: quartz/quartzite ratio (table 1, figure 8). It seems that the approximate level at which a significant Medway influence is shown is when a southern:quartz/quartzite ratio of 0.10 is reached. Ratios below 0.10 characterize the Kesgrave Thames, whereas ratios above 0.10 indicate confluence area deposits (figure 8). The western edge of the confluence area at the time of Lower St Osyth Gravel/Lower Holland Gravel deposition apparently lay within the complex of pits at St Osyth, so that samples from here give ratios both above and below 0.10, depending on whether they are from the western or eastern part of the area (Bridgland *et al.* 1988; table 1, figure 8). The use of intercomponent ratios in the interpretation of clast lithological analyses, as employed here, was advocated by Green & McGregor (1986).

It appears from the analyses of Lower Holland Gravel that complete mixing of Thames and Medway material may not be achieved before the deposits are lost at the present coastline. Several factors are apparent from the analyses of samples from the Lower Holland Gravel outcrop. First, Medway influence is strongest immediately to the east of the St Osyth pits. Within a sequence of sites here (eastern St Osyth pits, Bush Paddock, Clacton) there is a progressive eastward increase in southern:quartz and quartzite ratio (figure 8). Secondly, at Holland-on-Sea and Holland Haven, which are further downstream (figure 4), this ratio is

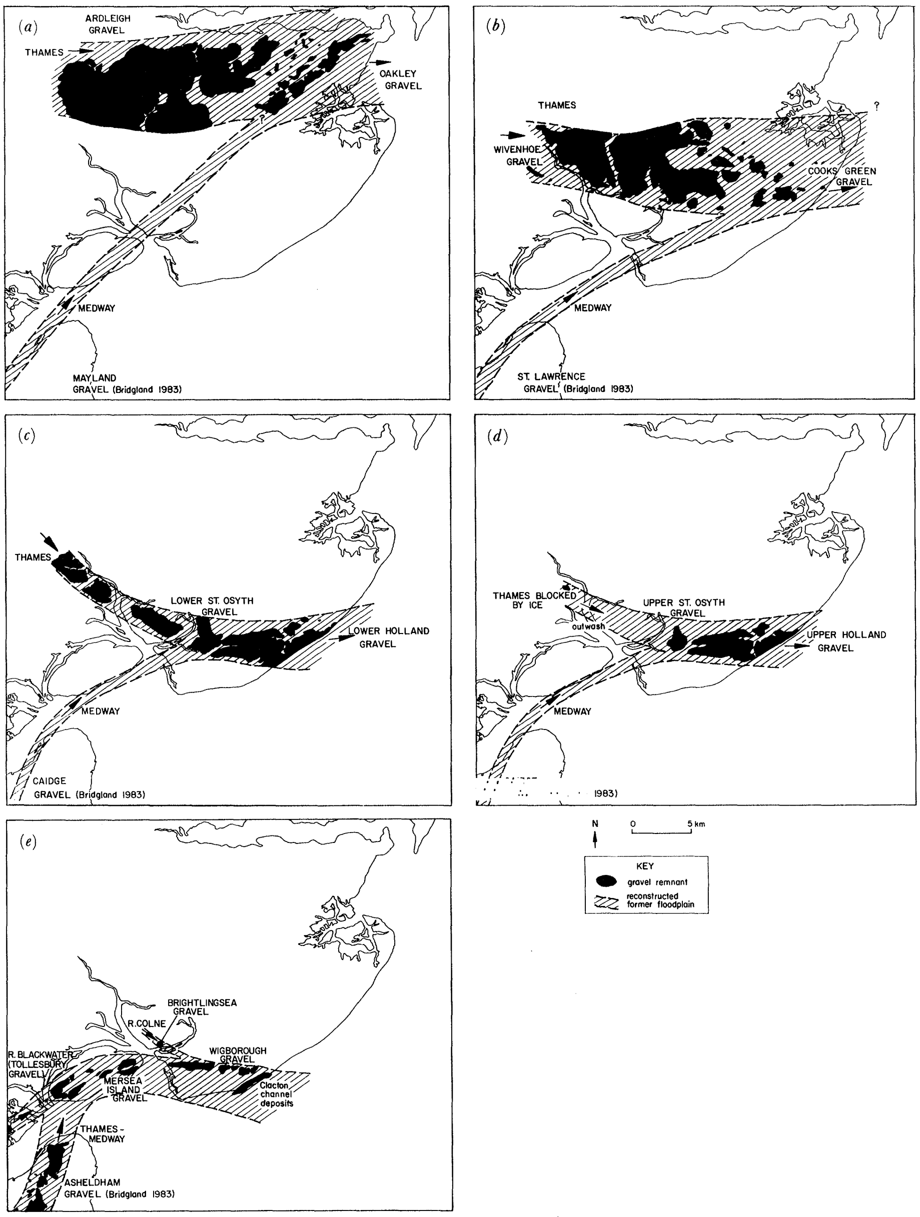

Figure 7. Reconstruction of palaeodrainage in the region of the Tendring Plateau in (*a*) Oakley Gravel times (pre-Cromerian), (*b*) Cooks Green Gravel times (immediately post-Cromerian), (*c*) Lower Holland Gravel times (early Anglian), (*d*) Upper Holland Gravel times (Lowestoft Stadial, Anglian glacial maximum) and (*e*) Wigborough Gravel times (late Anglian to early Wolstonian).

lower, although still well within the Thames–Medway envelope (figure 8). This last observation may reflect the geographical situation of these two sites near the northern margin of the outcrop, furthest from the Medway input on the southern side of the contemporary floodplain. Conversely, the St Osyth–Bush Paddock–Clacton sequence may represent the sudden influx of southern material at the confluence, which locally dominates the gravel before being diluted by mixing with Thames-derived material further downstream. Localized abundances of southern material (Greensand chert), attributed to south-bank tributary confluences, have also been observed in the early Thames gravels of Hertfordshire and Essex (Green *et al.* 1982).

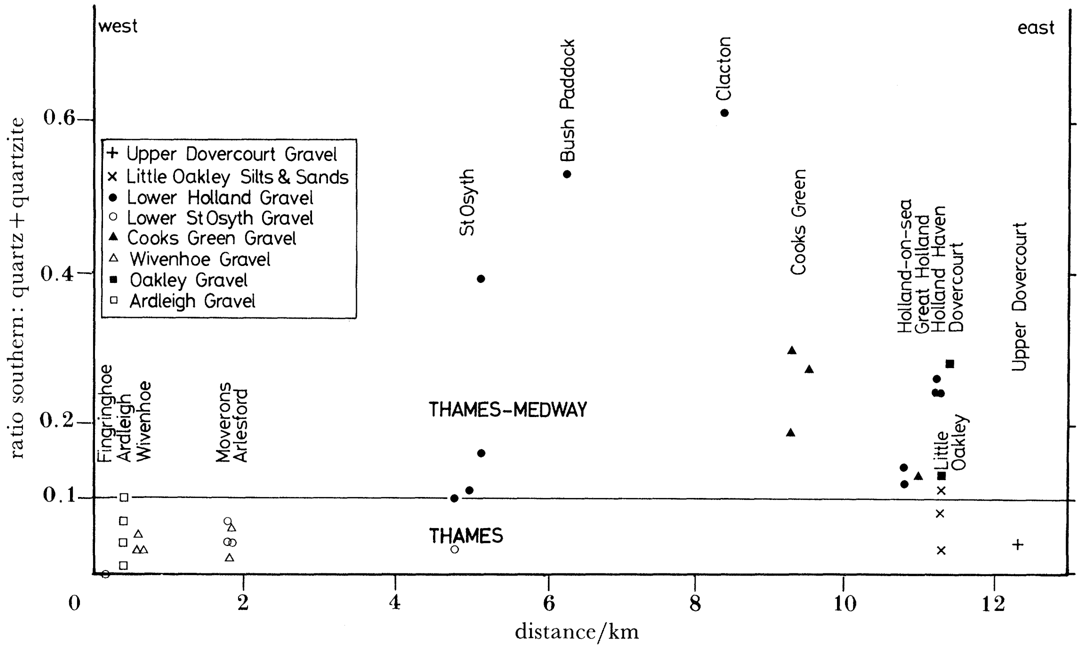

FIGURE 8. West to east variation in clast lithology within the Kesgrave Sands and Gravels of the Tendring Plateau. Ratio southern : quartz and quartzites plotted against downstream distance. The boundary between Thames and Thames-Medway composition is delineated by the 0.10 ratio (i.e. one southern clast to every ten quartz and quartzites.

Counts of Oakley Gravel (sampled at Little Oakley and Dovercourt) have southern : quartz and quartzite ratios in the range 0.10–0.30, indicating deposition downstream of the contemporary confluence (figures 7 and 8). The same is true of the Cooks Green Gravel at its type locality and at Great Holland. However, no Thames–Medway equivalent of the Waldringfield Gravel has been found and it appears that the confluence during the aggradation of this unit lay east of the present coastline (Bridgland 1988).

The composition of gravel clasts within the Little Oakley Silts and Sands shows much less of a Medway influence than the Oakley Gravel on which they rest. The southern : quartz and quartzite ratios from these counts (table 1, figure 8) fall either side of the 0.10 boundary, although the majority (and the overall ratio when all counts are summated) are slightly below 0.10, suggesting a position just upstream of the confluence. If the Little Oakley Silts and Sands are assumed, for the moment, to represent the main river (see below), they clearly reflect a period when it was confined to a single channel. It is to be expected therefore that a less gradual change in gravel composition would result from the Thames–Medway confluence than in a wider, multichannelled gravel braidplain, as represented by the Oakley Gravel. A rapid change from Kesgrave Thames to Thames–Medway composition, with southern : quartz and quartzite ratios well above 0.10, would be expected. The fact that the Little Oakley Silts and Sands show less Medway influence than the Oakley Gravel suggests that they result from deposition by the Thames upstream of the contemporary confluence. The southern material they contain, over and above that which characterises 'normal' Kesgrave Thames gravel, has probably been reworked from the underlying Oakley Gravel. This interpretation contradicts the views of Warren and Oakley (see above), that the Little Oakley interglacial sediments were of Medway or Thames–Medway origin.

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A possible alternative interpretation of the Little Oakley Silts and Sands, equally compatible with their clast composition, is that they are the product of a tributary stream, reworking Kesgrave Sands and Gravels from both above and below the Medway confluence. Such a stream would have deposited material intermediate in composition between the Ardleigh and Oakley Gravels. This alternative hypothesis is not favoured for two reasons. First, the Little Oakley Silts and Sands appear to be the product of a sizeable river (see above). Secondly, on the basis of correlation with the sequence in the Thames Valley (see below), it is believed that the Thames continued to flow across the Tendring Plateau until at least the Anglian Stage (Bridgland 1988). These two facts together suggest that the Little Oakley deposits are likely to be the product of Thames drainage.

A significant difference between the gravel content of the Little Oakley Silts and Sands and the various cold stage Kesgrave aggradations (including the Oakley Gravel) is the presence in the former of a small proportion of calcareous clasts. Although not apparent in the general compositional details given in table 1, calcareous clasts occurred in all three samples from this deposit, at both sizes analysed. Most could be interpreted as septarian or cementstone material from the local London Clay, others are poorly consolidated calcareous sand from the Crag, but some are clearly derived from further afield. These comprise a clast of Chalk in the 11.2–16 mm fraction of LOAC, and two of oolitic limestone, one in the same count as the Chalk and the other from the 16–32 mm fraction of LOAF. The 11.2–16 mm fraction of this last sample also contained abundant rolled Crag shells and a clast of bedded sandy limestone of indeterminate source (although not like any known London Clay lithology).

Whatever this last lithology is, there are two clasts of oolitic limestone and one of Chalk, that cannot have been derived from the local bedrock. Robinson (1990) also found derived Chalk microfossils in the channel sediments. A possible source which must be considered is the underlying Red Crag, since clasts of various lithologies have been recorded from this formation (see, for example, Double 1924). However, the only record of oolitic limestone, believed in this case to come from Lincolnshire, is from the Norwich Crag in Norfolk (P. G. Cambridge, personal communication). There is very little available information about the occurrence of clasts in the local Red Crag, but Lomas (in Harmer 1990) recorded the presence of hard, brown-stained Chalk. It is worth recording that among Warren's original collections from Little Oakley there was a boulder ('$15\frac{1}{2}$ inches × 10 inches × 5 inches'†) of '? Lower Corallian' limestone containing rhynchonellid brachiopods, which were studied by Dr H. M. Muir-Wood (S. H. Warren & A. G. Davis, unpublished manuscript). Unfortunately neither her report nor the boulder can be traced. Kennard (in Bull 1942, p.24) also reported that 'a boulder of Lias Marlstone' was discovered in the Little Oakley channel.

The occurrence of non-durable, in particular calcareous, clasts is rare in any of the fluvial deposits of the London Basin, except where they overlie Chalk bedrock (Bridgland 1986*b*). If these clasts have not been reworked from the Crag(s), there are two other possible sources. They may be secondarily derived from some nearby pre-Cromerian glacial deposit, perhaps an equivalent to that described by Sejrup *et al.* (1987). Alternatively, normal fluvial transport from areas upstream within the Thames basin must be considered. In the latter case the oolitic limestones can only have been derived from the Cotswolds, approximately 200 km upstream, while the Chalk has probably come from the Chilterns. Oolitic limestone pebbles from the Upper Thames Basin are apparently entirely lacking in the gravels of the Middle Thames

† 1 inch = 2.5 cm.

(Gibbard 1985). However, Jurassic limestones and fossils have been found in the Lower Gravel at Swanscombe (Bridgland *et al.* 1985), although here these could be secondarily derived from Anglian glacial deposits, which impinge on the Lower Thames valley in the Hornchurch area (Holmes 1892). Chalk is virtually unknown in fluvial deposits in the London Basin except where it forms the local bedrock. The preservation of calcareous clasts in the Little Oakley Silts and Sands probably owes much to the calcareous nature of the deposits themselves, which would have enhanced ground water alkalinity.

(*c*) *Later deposits in the area*

The stratigraphical subdivision of the St Osyth and Holland Gravels has been based on studies at the St Osyth quarries, in various trial pits and from degraded cliff sections (Bridgland 1983, 1988). At St Osyth the lower and major part of the sediments comprise typical coarse, matrix-supported gravels of Kesgrave type. Palaeocurrent data from cross-bedded sandy intercalations indicate flow to the southeast. This is in keeping with the general interpretation of the sediments as products of the early Thames, flowing from the Colchester area towards Clacton (figure 7). In the western part of the workings the upper part of the Lower St Osyth Gravel either comprises or is overlain by *ca.* 3 m of sand, into which is channelled a gravel of quite different character. This material, termed 'Upper St Osyth Gravel', consists of fine gravel contained in a matrix of coarse sand. It contains a higher proportion of flint than the lower gravel and very much less of the flint component is of Tertiary origin. Furthermore, the Upper St Osyth Gravel contains fewer exotics than the Lower, while those present show greater affinities to Anglian glacial deposits than to the underlying Kesgrave gravels (Bridgland 1983, 1988; Bridgland *et al.* 1988; see below). The unit therefore represents a gravel highly charged with distal outwash material derived from the Anglian ice sheet. The upstream continuation of this unit has been recognized at Fingringhoe (TM 042202), on the southern side of the Colne estuary, some 8 km upstream of St Osyth (table 1, figures 4 and 8).

Equivalent stratigraphic subdivisions of the Holland Gravel have also been identified. The Lower Holland Gravel is recognized in the eastern workings at St Osyth and in the lower stratigraphic situation in all outcrops between there and the coast (see above; figures 4–7). It has a composition typical of the pre-diversion (Kesgrave) Thames–Medway deposits (table 1; figure 8). The Upper Holland Gravel, which has at present only been identified to the east of the St Osyth gravel workings, contains much larger proportions of southern lithologies than any other deposit on the Tendring Plateau, comparable in some counts to samples of Medway gravel (High-level East Essex Gravel) from south of the Blackwater (table 1 and Bridgland (1983, 1988)). The deposit is otherwise similar in composition to the Upper St Osyth Gravel, suggesting a strong influx of Anglian glacially transported detritus.

The similarities in clast composition between the Upper St Osyth/Upper Holland Gravels and Anglian glacial sediments (table 1), as well as the corresponding differences between these deposits and typical Kesgrave aggradations, indicate that these gravels post-date the arrival of Anglian ice in the Thames catchment. The studies of gravel composition also show that the Upper Holland Gravel was probably laid down by the combined waters of the Upper St Osyth Gravel ('outwash-charged') Thames and the Medway, but was very much dominated by the latter. This is surprising, as results from all the earlier aggradations show that the Thames supplied by far the major part of the gravel in the combined system (table 1). Furthermore, at this time the Thames would be expected to be swollen with meltwater from the approaching ice sheet. A probable explanation is that the Upper Holland Gravel, in fact, represents a time when the Thames was totally blocked and only meltwater from the Colchester area was flowing down its beheaded valley to join the Medway at St Osyth (figure 7 (*d*)). This would also explain the strong similarities between the composition of the Upper St Osyth and Upper Holland Gravels and the non-calcareous component of Anglian outwash. All of these show a scarcity of Tertiary flint, quartz and quartzites when compared with Kesgrave Thames deposits, as well as a relative richness in other exotics, notably *Rhaxella* chert (Bridgland 1983, 1988; Bridgland *et al.* 1988; table 1).

The occurrence of *Rhaxella* chert in the various gravels of this area is of considerable interest. In the Middle and Lower Thames regions and in central Essex this rock type is consistently present only in deposits related to or post-dating the Anglian glaciation and its introduction in quantity into these areas is attributed to that glacial event, the source being the Oxfordian of north Yorkshire (Bridgland 1986*b*). However, in northeastern Essex and further north (P. Allen, personal communication), *Rhaxella* chert is also found in the Kesgrave Sands and Gravels (which pre-date the Anglian glaciation), its appearance broadly corresponding to the edge of the Crag basin. It is present in samples from the Oakley, Cooks Green and Lower Holland Gravels and a single example was encountered in the Little Oakley Silts and Sands (table 1). In these instances the chert is presumed to have been derived from the Red Crag, in which it occurs as an important minor constituent (Double 1924).

Blockage of the Thames valley by Lowestoft Till ice is known to have occurred during the Anglian Lowestoft Stadial, an event that resulted in the diversion of the river into its present valley through London (see, for example, Gibbard 1977, 1985). Bridgland (1983, 1988) concluded that the Upper St Osyth Gravel and the Upper Holland Gravel were deposited at the time of this blockage, when waters of the Thames were filling an ice-dammed lake in the Vale of St Albans. These units would therefore be time equivalents of the Moor Mill Laminated Clays (deposited in that lake) and the Winter Hill Upper Gravel (aggraded as a delta at the western end of the lake) of Gibbard (1977, 1985). At this time the Medway, its valley unaffected by the glaciation, was joined at its former confluence with the Thames (at St Osyth) only by an outwash stream much smaller than itself. This is the only way in which the Medway-dominated Upper Holland Gravel can have been deposited in the pre-glacial Thames valley between St Osyth and Holland-on-Sea.

The stratigraphic interpretation outlined above is supported by the identification of the Lower St Osyth/Lower Holland Gravel as the last pre-diversion Thames aggradation. It is further strengthened by the recognition of a later (altitudinally lower) aggradation to the south of the St Osyth/Holland Gravel. This, the 'Wigborough Gravel' (Bridgland 1988; table 2), is interpreted on lithological grounds as a continuation northwards of the earliest Thames aggradation associated with the post-diversion route of the river through London (Bridgland 1983, 1988). This aggradational unit has been traced from the Lower Thames Valley, across eastern Essex, where it follows the pre-established course of the Medway to Mersea Island and the Clacton area. It may be concluded that the Thames, when blocked by ice, was diverted into the Medway valley, thereby rejoining its old course east of Clacton (figure 7; Bridgland 1980, 1983, 1988). The Wigborough Gravel is believed to represent the culmination of the aggradation that began with the infilling, during the Hoxnian Stage, of the Clacton

Channel(s) at Clacton-on-Sea, although recent erosion has removed it from the vicinity of the Clacton type site (Bridgland 1983, 1988; Bridgland *et al.* 1988; figure 6). It is therefore not only post-Anglian, but also post-Hoxnian (table 3). The Clacton Channel can also be traced upstream along this new route, equivalent channels being recognized at East Mersea, Ashheldham and Southend (Bridgland 1988). The Clacton Channel Gravel appears, therefore, to be the first deposit to be laid down on the Tendring Plateau by the post-diversion Thames.

The Wigborough Gravel can be traced upstream into a further subdivision of the Low-level East Essex Gravel, the 'Mersea Island Gravel' (Bridgland 1983, 1988; Bridgland *et al.* 1988; table 2). These differ in that the Wigborough Gravel has a much larger exotic component (table 1). The change from Mersea Island Gravel to Wigborough Gravel occurs within the linear outcrop on the mainland opposite Mersea Island (figure 7*e*). The explanation of this change lies in the reconstruction of the contemporary drainage. It is apparent that the Thames–Medway received a tributary at this point, a river that must have been the ancestor of the present Colne. An outlier of Colne gravel believed to be contemporary with the Mersea Island/Wigborough Gravel underlies Brightlingsea and is here termed the Brightlingsea Gravel (table 2; figures 4 and 7*e*). The confluence with this ancestral Colne, revealed by changes in gravel composition, is clearly equivalent to the confluence between the Kesgrave Thames and the Essex Medway, recognized in the earlier aggradations of the Tendring Plateau. This underlines the fact that the diverted Thames travelled via the old Medway Valley and rejoined its former course south of St Osyth. It also shows that the Essex Colne is the descendant of the Kesgrave–Thames in that, upstream from St Osyth, it occupies the beheaded valley of that river. Studies on and to the west of Mersea Island show that the Blackwater had also been initiated at this time, when it was depositing the Tollesbury Gravel (Bridgland 1983; table 2; figure 7(*e*)).

The Palaeolithic site at Upper Dovercourt (see above), appears to fall within the same outcrop of Oakley Gravel as the Little Oakley Silts and Sands. This outcrop extends from Little Oakley to Dovercourt–Harwich, reaching a surface height of 26 m O.D. to the east of Ramsey. At both Little Oakley and Upper Dovercourt the land surface is well below this maximum level, probably as a result of erosion. Gravel containing worked flint flakes has recently been located and sampled near the site of the old pit, at TM 241263. Its clast composition is comparable with Kesgrave Sands and Gravels deposits from upstream of the Medway confluence, with a lower southern:quartz and quartzite ratio than the local Oakley Gravel (table 1; figure 8). This seems to confirm Warren's (1933) conclusion, from the archaeological evidence, that the Upper Dovercourt Gravel is a later Stour deposit cut into or banked against the Oakley Gravel (figure 6). The Stour had presumably largely reworked the gravel from the Kesgrave deposits to the west.

(*d*) *Regional significance of the Little Oakley Silts and Sands*

It is apparent that the Tendring Plateau is of considerable potential importance as an area in which correlation between the Thames fluvial succession and the Pleistocene sequence of East Anglia may be established. It has been argued that the Upper St Osyth/Upper Holland Gravel may be equated with the Winter Hill Upper Gravel of the Middle Thames and assigned to the Lowestoft Stadial (Anglian Stage). This strongly suggests the equivalence of the Winter Hill Lower Gravel (Gibbard 1977) and the Lower St Osyth/Lower Holland Gravels. These, with the Westmill Lower Gravel of the Vale of St Albans (Gibbard 1977), probably represent a laterally continuous aggradational unit, the last to be deposited by the Thames along its pre-

TABLE 3. LITHOSTRATIGRAPHIC UNITS OF THE TENDRING PLATEAU AND SUGGESTED CORRELATIONS WITH THOSE OF THE THAMES SYSTEM

Middle Thames (Gibbard 1985)	Vale of St Albans (Gibbard 1977)	Tendring Plateau (Bridgland 1988; Bridgland *et al.* 1988)		Stage
Boyn Hill gravel	—	Upper Dovercourt gravel Low-level East Essex Gravel Mersea Island/Wigborough gravel		Wolstonian
Swanscombe lower loam/ lower gravel	Hatfield organic deposits	Clacton Channel interglacial deposits		Hoxnian
Black Park gravel	Smug Oak gravel	Clacton Channel gravel		
-----	-----	Diversion of River Thames	-----	-----
		Lowestoft Formation		
Winter Hill Upper gravel	Moor Mill laminated clay	Upper St Osyth gravel	Upper Holland gravel	Anglian
		Kesgrave, Sands and Gravels		
		Upstream of Thames–Medway confluence	*Thames–Medway confluence area*	
Winter Hill Lower gravel	Westmill gravel	Lower St Osyth gravel Wivenhoe gravel	Lower Holland gravel Cooks Green gravel	
			Little Oakley silts and sands	Cromerian
		Ardleigh gravel Waldringfield gravel	Oakley gravel	pre-Cromerian

diversion route. An Anglian (pre- or more likely early Lowestoft Stadial) age is suggested (Gibbard 1977; table 3).

This is the first time that an Anglian age has been suggested for a subdivision of the Kesgrave Sands and Gravels. When this formation was originally defined it was believed to be, in its entirety, of Beestonian age (Rose *et al.* 1976; Rose & Allen 1977), although its composite nature has since been recognized (Hey 1980; Allen 1983, 1984; Bowen *et al.* 1986; Bridgland 1988). An important line of evidence in this dating was the identification of a rubified soil, the 'Valley Farm Soil', developed in the top of the Kesgrave Formation gravels. This soil was believed to have developed under temperate conditions during the Cromerian Interglacial, as it was present in sections capped by Anglian till (Rose *et al.* 1976; Rose & Allen 1977). However, recent studies have shown that at many sites the soil must have formed during at least three stages, two temperate (Pastonian and Cromerian) and one cold (Beestonian) before burial by Anglian sediments (Hey 1980; Kemp 1985). As large hiatuses, which encompass multiple climatic oscillations, are known to exist between the Pastonian and Cromerian (West 1980; Mayhew & Stuart 1986) it is very likely that this pedogenesis operated over even more stages (cf. Bowen *et al.* 1986).

The Valley Farm Soil has been recognized at the present land surface in the upper parts of the Ardleigh/Oakley and Wivenhoe/Cooks Green Gravel where these have not suffered subsequent erosion. The palaeosol here has been assigned to the 'Tendring Association' by the Soil Survey of England and Wales (Kemp 1985). This palaeosol has not been recognized in the immediate area of Little Oakley, probably because the gravel surface in this district is entirely erosional and all traces of it have been removed. More importantly, it has not been recognized on the Lower St Osyth/Lower Holland or Upper St Osyth/Upper Holland Gravels, attributed here to the Anglian, strongly reinforcing this attribution. Its presence on the Wivenhoe/Cooks Green Gravel, lower within the terrace sequence than the Oakley Gravel and the Little Oakley Silts and Sands, might suggest that the Cromerian (as recognized at Little Oakley) is separated from the Anglian by an additional warm climate interval. This may be represented by the organic sediments at Wivenhoe (Bridgland *et al.* 1988). The stratigraphic evidence for this additional climatic oscillation relies on the identification of the relict 'Valley Farm Soil' at the modern land surface and must be equivocal, since comparable soils have formed during post-Anglian temperate periods (Rose *et al.* 1978; Sturdy *et al.* 1979).

Correlation of the fluvial sequence on the Tendring Plateau with the Middle Thames, based on counting backwards from the marker level of the Thames diversion (the Upper St Osyth/Upper Holland Gravel in the former area, the Winter Hill Upper Gravel in the latter), led Bridgland (1988) to suggest that the Wivenhoe/Cooks Green Gravel is equivalent to the Gerrards Cross Gravel of Gibbard (1985), and the Ardleigh/Oakley Gravel equates with the Beaconsfield Gravel (table 3). However, recent work by C. A. Whiteman (personal communication) in central Essex shows that additional units were deposited by the Thames downstream from the Vale of St Albans for which no correlatives have yet been identified in the Middle Thames. According to Whiteman, the sequence on the Tendring Plateau is entirely made up of these additional units, all of which post-date the Gerrards Cross Gravel. If this is correct, the Little Oakley Silts and Sands fall within a significant hiatus in the Middle Thames sequence, between the Gerrards Cross and Winter Hill Gravels.

5. Discussion

This section summarizes not only the data presented in the present account, but also the main conclusions of the four related papers that immediately follow. By integrating all the data here it is possible to present a comprehensive review of all aspects of the work undertaken at Little Oakley. Critical sites referred to in this account and in the papers that follow are shown in figure 9.

Detailed mapping of the Little Oakley Silts and Sands has shown that they fill a wide (*ca.* 150–175 m), single-thread channel trending from W.S.W. to E.N.E. This channel is excavated variously into London Clay, Red Crag and Oakley Gravel and reworked fossils from the former two units are common. The channel sediments are chiefly composed of silts and sands although there is also a significant gravel component.

The channel sediments have yielded rich fossil assemblages that indicate deposition in the lower reaches of a large, well-oxygenated, calcareous river, upstream of any tidal influence (Preece 1990; Robinson 1990). Land snails washed into the river indicate that it had wide, open floodplains. Fringing marsh habitats were present and extensive areas of dry, calcareous grassland also existed (Preece 1990). Pollen analyses again show widespread grassland, but show the additional presence of woodland elsewhere in the catchment during most of the time represented (Gibbard & Peglar 1990). The vertebrates also show the presence of fluviatile, marsh and both grassland and woodland environments (Lister *et al.* 1990). The occurrence of a variety of large herbivores possibly helped maintain local grassland communities by browsing and trampling.

The palynology (Gibbard & Peglar 1990) reveals that an early herb-dominated vegetation gave way to boreal forest (with *Betula*, then *Pinus* with subordinate *Picea* and *Alnus* values) and subsequently to deciduous forest in which *Quercus*, and more particularly, *Ulmus* were major constituents. This vegetational history has been reconstructed from the palynology of several boreholes and is nowhere represented in its entirety at a single point. The pollen assemblages can be assigned to the pre- and early temperate substages of an early Middle Pleistocene interglacial stage. The basal spectrum from borehole LOM, with high values of non-tree pollen, may even relate to the preceding late-glacial period.

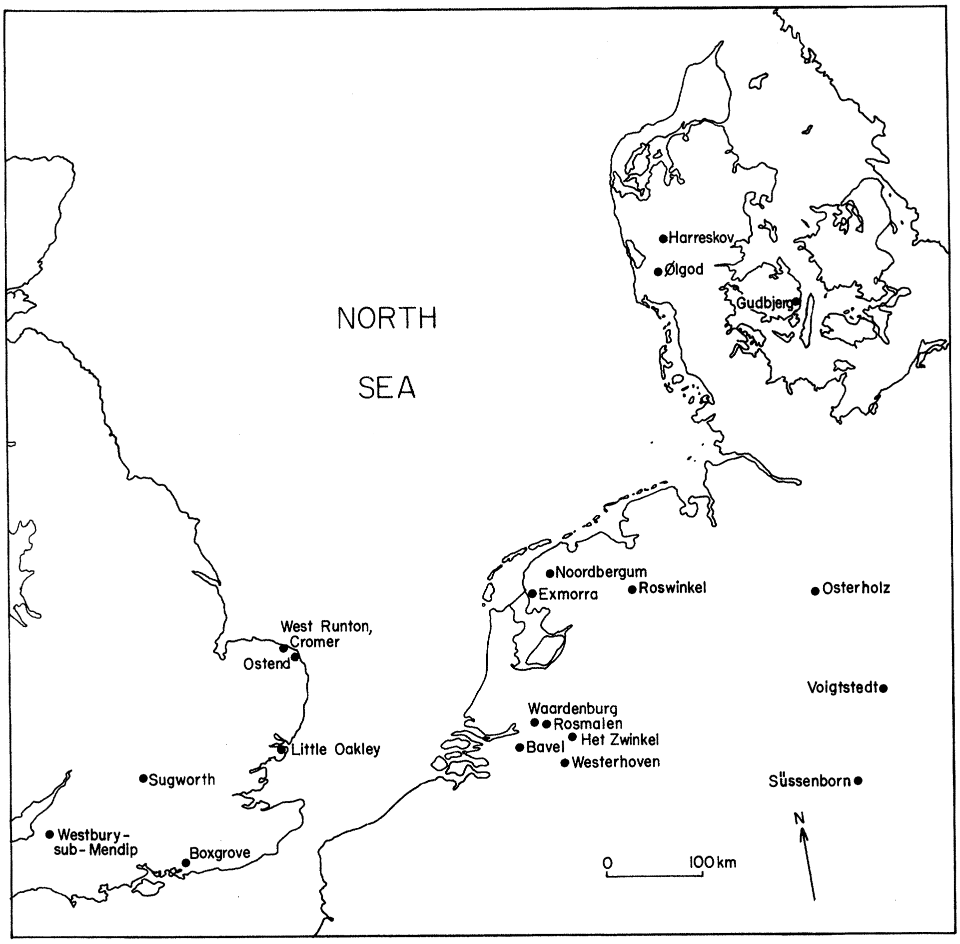

FIGURE 9. Location map showing critical sites in northwest Europe referred to in the text of this and the four subsequent papers.

The assemblages from the main sequence are fully temperate in character. Knowledge of the modern breeding biology of certain fish species recovered from Little Oakley suggests that during the months May–August, the water temperatures must have reached a minimum of 15 °C and a maximum of 22 °C, and during December–March, must have fallen to no less than 0.5 °C. Moreover, the occurrence of the pond tortoise (*Emys orbicularis*) implies mean July temperatures well in excess of 18 °C, if, as seems likely, this represents a breeding population (Lister *et al.* 1990).

The earliest fossiliferous sediments, shown by pollen analyses to belong to the pre-temperate substage, have been found only on the southern margin of the channel (Gibbard & Peglar

1990). The Mollusca from borehole LOO record a progressive replacement of aquatic taxa by hygrophilous snails, showing a shallowing sequence (Preece 1990). This evidence, together with the fact that the basal channel sediments become progressively younger northwards (Gibbard & Peglar 1990), suggests that the active channel shifted northwards during the interglacial. The precise width of the active channel must therefore have been somewhat less than the maximum widths cited above.

The palaeontology is unanimous in suggesting a broadly Cromerian age for the channel sediments. Thus the vertebrates include *Mimomys savini*, *Megaloceros verticornis* and probably also *Megaloceros dawkinsi*. Significant features of the molluscan fauna include *Tanousia* (= *Nematurella* auctt.) at values of *ca.* 30 % and *Bithynia troscheli* to the exclusion of *B. tentaculata*. The ostracod fauna, which includes *Candona tricicatricosa*, *Sclerocypris clavata prisca* and *Ilyocypris quinculminata*, is also consistent with a Cromerian age.

In addition to the palaeontological evidence, the amino acid ratios determined from species of *Valvata* from Little Oakley are similar to those obtained from the same species from both West Runton and Sugworth. These therefore provide additional, independent, support for a Cromerian age.

Exactly how the Little Oakley sequence relates to the Cromerian Complex of the Netherlands is harder to determine as the four interglacials comprising this complex were distinguished by using palynology alone. Correlation with 'Interglacial I' (or earlier temperate intervals) can be eliminated because of the absence of Tertiary relicts such as *Eucommia* and *Tsuga*. Moreover, correlation with 'Interglacial I' can also be eliminated because the latter has a reversed geomagnetic polarity (Zagwijn *et al.* 1971), whereas the Little Oakley Silts and Sands are normal (Appendix 1). Similarly, the absence of high values of *Taxus* and/or *Carpinus* in the early temperate substage suggests that the sequence is not equivalent to 'Interglacial II' or 'III'. However, there are similarities between the palynology of Little Oakley and Noordbergum, which is the type site of 'Interglacial IV'. Noordbergum has also been tentatively correlated with the Cromerian stratotype at West Runton (Zagwijn 1985) and has produced amino acid ratios consistent with this suggestion (Miller & Mangerud 1985), although it is not yet clear whether this technique can discriminate between the interglacials comprising the 'Cromerian Complex'.

It has recently been suggested from vertebrate evidence from cavern infills at Westbury-sub-Mendip that an additional interglacial stage may have occurred between the Cromerian *sensu stricto* and the Hoxnian Stage (Bishop 1982). This suggestion is based on the occurrence in the upper levels at Westbury of *Arvicola cantiana*, together with taxa such as *Dicerorhinus etruscus*, *Sorex savini*, and *S. runtonensis*, which are unknown from the Hoxnian and subsequent Stages. *Mimomys savini*, common at West Runton and present at most Cromerian vertebrate sites, is absent in this fauna. This fauna is similar to that of Ostend, Norfolk, where the fossiliferous beds are overlain by Anglian till. Although opinions differ as to whether the Ostend sequence belongs to the late Cromerian (Stuart & West 1976) or represents an additional post-Cromerian interglacial (Bishop 1982), there is no doubt of its pre-Anglian age. The recently excavated fauna from Boxgrove, Sussex, associated with an Acheulian industry, has also been tentatively assigned to this 'Westbury' stage (Roberts 1986). The occurrence of *M. savini* in the limited vertebrate fauna at Little Oakley shows that this site pre-dates both the upper faunas of Westbury-sub-Mendip and those of Ostend and Boxgrove (Lister *et al.* 1990). The suggestion that there may have been an additional temperate interval separating the Little Oakley

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interglacial from the Anglian Stage gains some support from the regional stratigraphy of the deposits of the Tendring Plateau and, in particular, on the distribution of the 'Valley Farm Soil' in relict form.

Recent appraisal of mammalian fossils from the Noordbergum boreholes has shown the presence of *Arvicola cantiana* (van Kolfschoten 1988; Lister *et al.* 1990). This has led van Kolfschoten (1988) to question the correlation of Noordbergum with West Runton and to suggest that the latter is older. As there are good reasons, described above, against correlating West Runton and Little Oakley with any of the Dutch interglacials prior to Noordbergum (IV), it is possible that the British sites represent a stage not yet recognized in The Netherlands (Gibbard & Peglar 1990).

A synthesis of the Pleistocene geology of this part of Essex shows it to be a critical area, in which the Thames and East Anglian stratigraphies can be linked. Clast lithological analysis shows that the Oakley Gravel and associated deposits are part of the pre-diversion Thames drainage system, as represented by the Kesgrave Sands and Gravels. These gravels and sands were deposited during cold stages by a bed-load dominated river. Detailed clast compositional data show that, in Oakley Gravel times, the present site of Little Oakley lay within the area where the Thames was joined by the important southern tributary, the Medway. In fact, the site lies near the western (upstream) margin of the Thames–Medway confluence area. The Little Oakley channel, on the other hand, represents a single thread river course cut through the Oakley Gravel and infilled during an interglacial towards the end of the 'Cromerian Complex'. The balance of evidence from clast lithologies suggest that it was occupied by the Thames. The contemporary confluence with the Medway was probably a short distance downstream.

Later deposits within the terrace sequence in this area record the advance of Anglian ice, which blocked the Thames but initially left the Medway unaffected. The Thames was diverted into the Medway by this glacial advance, so that by the early Hoxnian (Clacton Channel) the confluence of these rivers lay well to the south, close to its present position. A complete sequence of fluvial aggradations has been described which relate, in terms of fluvial stratigraphy, the Little Oakley and Clacton deposits. This allows the reconstruction of drainage evolution of the region from pre-Cromerian to post-Hoxnian times. It also provides important new evidence, through the correlations recently proposed by C. A. Whiteman (see above), for the relative dating of the Middle Pleistocene portion of the Thames sequence throughout the London Basin.

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7. Appendix

Palaeomagnetic results from Little Oakley

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Introduction

The polarity reversal history of the Pleistocene is well defined as a consequence of palaeomagnetic studies combined with K–Ar dating of continental basalts (Berggren *et al.* 1985). This has proved to be a very useful tool in dating Quaternary stratigraphic sequences, for both continental deposits (e.g.: Montfrans 1971; Opdyke *et al.* 1977; Liddicoat *et al.* 1980) and oceanic sediments (Opdyke 1972).

To establish the age of the Little Oakley deposits a number of orientated samples were collected from two separate exposures to determine the palaeomagnetic polarity of the sediments. If the sediments were found to be reversely magnetized this would imply an age of greater than 730 ka BP, whereas if they were found to be normally magnetized then an age of less than 730 ka BP is most likely, although an older age cannot be ruled out without some independent chronological information.

Palaeomagnetic methods

The natural remanent magnetization (NRM) of the samples was measured by using a Digico spinner magnetometer (Molyneux 1971) interfaced with a minispin controller unit and BBC computer. The samples were spun ($\approx$ 7 Hz) successively about three orthoganol axes in each sense (that is, a total of six spins). Random noise is reduced by increasing the total spin time, which is the time over which the signal is integrated. In this study the spin time was set such that the noise level was kept to at least an order of magnitude smaller than the NRM signal.

Alternating field (AF) demagnetization of the samples was done with a Highmoor demagnetization unit, based on the design of de Sa & Widdowson (1975). The sample is demagnetized within an ambient low direct field ($\leqslant$ 50 nT), achieved by the use of Helmholtz coils. The samples were unfortunately too large to fit into the tumbler unit, and thus the unit was used as a single axis demagnetizer. The samples were demagnetized by successively applying the demagnetizing field along their three orthoganol axes. The remaining remanence was then measured by using the Digico magnetometer. Pilot samples were stepwise demagnetized up to peak fields of 50 mT in steps of 5 or 10 mT. These measurements indicated that after the removal of a fairly weak viscous component, the samples are characterized by astable remanent magnetization with a median destructive field of 20–25 mT. The remaining samples were then all AF demagnetized in a peak field of 15 mT to remove any viscous component from the NRM signal.

Results and discussion

The palaeomagnetic results from the Little Oakley site are listed in table 4. Both the NRM directions and the remanent directions after AF demagnetization in a peak field of 15 mT are listed. The declination values are given relative to True North and the inclination values are relative to the top face of the box, which is assumed to be horizontal (see discussion below). The results are listed as a mean of each sampled level, as a mean of each separate pit, and as a total mean for the Little Oakley site. The mean directions were calculated using Fisher statistics (Fisher 1953).

Table 4. Palaeomagnetic results

sample level (cm)	no. of samples N	mean NMR direction DEC (°)	INC (°)	R	k	α_{95} (°)	mean 15 mT AF-demag direction DEC (°)	INC (°)	R	k	α_{95} (°)
(a) Main sequence, LOAH (north face)											
175	4	359.4	70.7	3.8844	26	18.3	343.2	69.4	3.9768	129	8.1
200	5	338.4	84.4	4.9711	138	6.5	5.6	77.8	4.9695	131	6.7
225	5	13.1	76.6	4.8718	31	13.9	323.7	77.5	4.7129	14	21.2
250	5	12.7	75.0	4.9789	190	5.6	3.1	75.4	4.9893	375	4.0
275	6	14.7	72.9	5.8948	48	9.8	0.5	69.2	5.8826	43	10.4
mean	25	7.8	76.3	24.4980	48	4.2	352.9	74.3	24.4181	41	4.6
(b) Marginal sequence, LOAG (south face)											
100	5	340.3	68.9	4.9503	80	8.6	355.0	71.6	4.9003	40	12.2
140	5	353.2	69.1	4.9556	90	8.1	352.7	58.7	4.9602	100	7.7
mean	10	346.7	69.1	9.8977	88	5.2	353.6	65.1	9.7978	45	7.3
(c) Main sequence and marginal sequence combined											
total mean	35	0.0	74.4	34.3016	49	3.5	352.9	71.9	34.1211	39	3.9

R, length of vector resultant; k, precision parameter; α_{95}, radius of cone of 95% confidence of mean direction.

The samples all yield normal magnetisations, with declinations averaging close to 0° and inclinations comparable to the axial dipole dip expected for the Little Oakley locality (68.6°). There also appears to be only minor differences between the NRM directions and the AF demagnetised directions, which suggests that any viscous component of the magnetisation is small relative to the NRM signal. It is immediately apparent that the samples are providing very consistent results, with only a small scatter within each sampled level and only minor differences between sampled levels. The following factors may have contributed to the observed scatter and differences in the palaeomagnetic signals from the different sample levels. However, it must be noted that these factors are not capable of producing a NRM of opposite polarity to that of the ambient geomagnetic field.

(a) *Sampling errors*

The samples were obtained by pushing perspex boxes into an orientated vertical sediment face by hand. Unfortunately this method is intrinsically inaccurate, as it is difficult to maintain an even pressure on the box to prevent twisting and to retain an orthoganol relation with the prepared face as it enters the sediment. Thus sampling orientation errors as large as ±10° in the vertical and horizontal planes may be expected. The use of a sampling device such as that described by Austin & Baldwin (1984) would have been preferable as sets of samples with the same field orientation could have been obtained, but this was not available to the samplers. A more serious problem related to the technique of pushing specimen holders into the sediment has been observed by Gravenor *et al.* (1984) where sidewall shear seriously distorts both the magnetic fabric and the magnetic remanence results, the distortion being related to the direction of push. However, in this study the samples from the two pits were taken from two differently orientated sediment faces and yet consistent results have been obtained. This suggests that the sediment has not been distorted by the sampling method.

(*b*) *Measurement errors*

The error in measuring the remanent signal of the samples by using the Digico magnetometer has been established to be less than $\pm 5°$ in declination and less than $\pm 3°$ in inclination. These are therefore significantly less than the potential sampling errors.

(*c*) *Depositional errors*

Depending upon whether the NRM is of depositional or post-depositional origin the remanent magnetization may not truly reflect the ambient geomagnetic field at the time of deposition of the Little Oakley sediments. This is because the orientation of the magnetic particles in the sediment can be affected by their shape, or the nature and slope of the substrate, or by the presence of water currents (see the review by Verosub (1977)).

(*d*) *Secular variation*

Even if the remanent magnetization is of purely geomagnetic origin, a difference between sampled levels of a few tens of degrees in declination and of up to ten to twenty degrees in inclination may be expected as a result of secular variation of the Earth's magnetic field. As it is not known what period of time is represented by this sedimentary sequence, it is difficult to assess what differences may have been caused by secular variation patterns.

Conclusion

The Little Oakley sediments were deposited during a period of normal geomagnetic polarity. As the deposits are believed to be of Pleistocene age, it is most likely that they were deposited during the Brunhes Magnetozone (not more than 730 ka BP) although ages of 910–980 ka BP (the Jaramillo Event) or 1.66–1.88 Ma BP (the Olduvai Event) are also possible, but unlikely in view of other evidence.

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