PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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Phil. Trans. R. Soc. Lond. A 1975 **279**, 269-277
doi: 10.1098/rsta.1975.0059

Phil. Trans. R. Soc. Lond. A. **279**, 269–277 (1975) [269]
Printed in Great Britain

Some aspects of Late Pleistocene–Holocene drainage of the River Thames in the eastern part of the London Basin

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Since 1967 the area of the Thames Estuary has been extensively surveyed using reflexion seismic techniques. The interpretation of these records coupled with the logs and samples from some 140 boreholes has led to the reconstruction of the Late Pleistocene/Early Holocene palaeodrainage pattern of the River Thames. The relationship of this drainage system to the tectonic pattern would indicate that there has been Late Pleistocene re-emphasis of the existing dominant structures. Also a large NW–SE trending monocline would appear to be still a positive area within this subsiding sector of SE England.

Some evidence for the existence of a Late Pleistocene ice-sheet is presented. That this might well have dammed the existing drainage systems creating a large lake (Lake Tamesis) is a possibility that requires further investigation.

1. Introduction

The study of the landforms and sediments within the valley of the River Thames has long afforded workers with what appeared to be a suitable vehicle for the elucidation of the development of a large drainage system: in this case since its probable inception during the mid-Tertiary earth movements. That this drainage system has been affected by eustatic and isostatic level changes associated with the Pleistocene ice-ages has served to underline the importance of this area in an understanding of the late Tertiary and Quaternary history of southeast England. These early hopes so ably advanced by T. V. Holmes, Sherlock, Hawkins and more recently by Wooldridge and others have not yet been fully realized. This is partly because deposits are only to be found as small, widely dispersed outcrops of terrace gravels and sands, which lack good correlative faunal and floral evidence. It was therefore felt that a study of the geomorphology and of the sediments of that portion of the Thames Basin inundated by the Flandrian transgressive sea might disclose some further clues, even though that study must include the 'marine' factor thereby adding to the complexity.

Wooldridge (1960) traces out these early stages of river development. He asserts that originally the Thames flowed in a northeasterly direction through the Watford Gap to Ware and beyond. Later due to a pre-Anglian ice advance the river was diverted southwards to a more easterly course. Again, due to a further ice advance during Anglian times the river was once more diverted, this time southwards into the valley it occupies at present. Subsequently the river has been affected by a series of base level changes which have resulted in a comparatively well-preserved group of terraces and terrace deposits on the flanks of the valley. The earliest, the Boyn Hill Terrace, some 30 m above O.D. at Swanscombe and which Zeuner (1959) believes slopes to about 10 m above O.D. at Clacton is therefore unlikely to be evident in the submerged section of the London Basin. The deposits that cloak this terrace have been

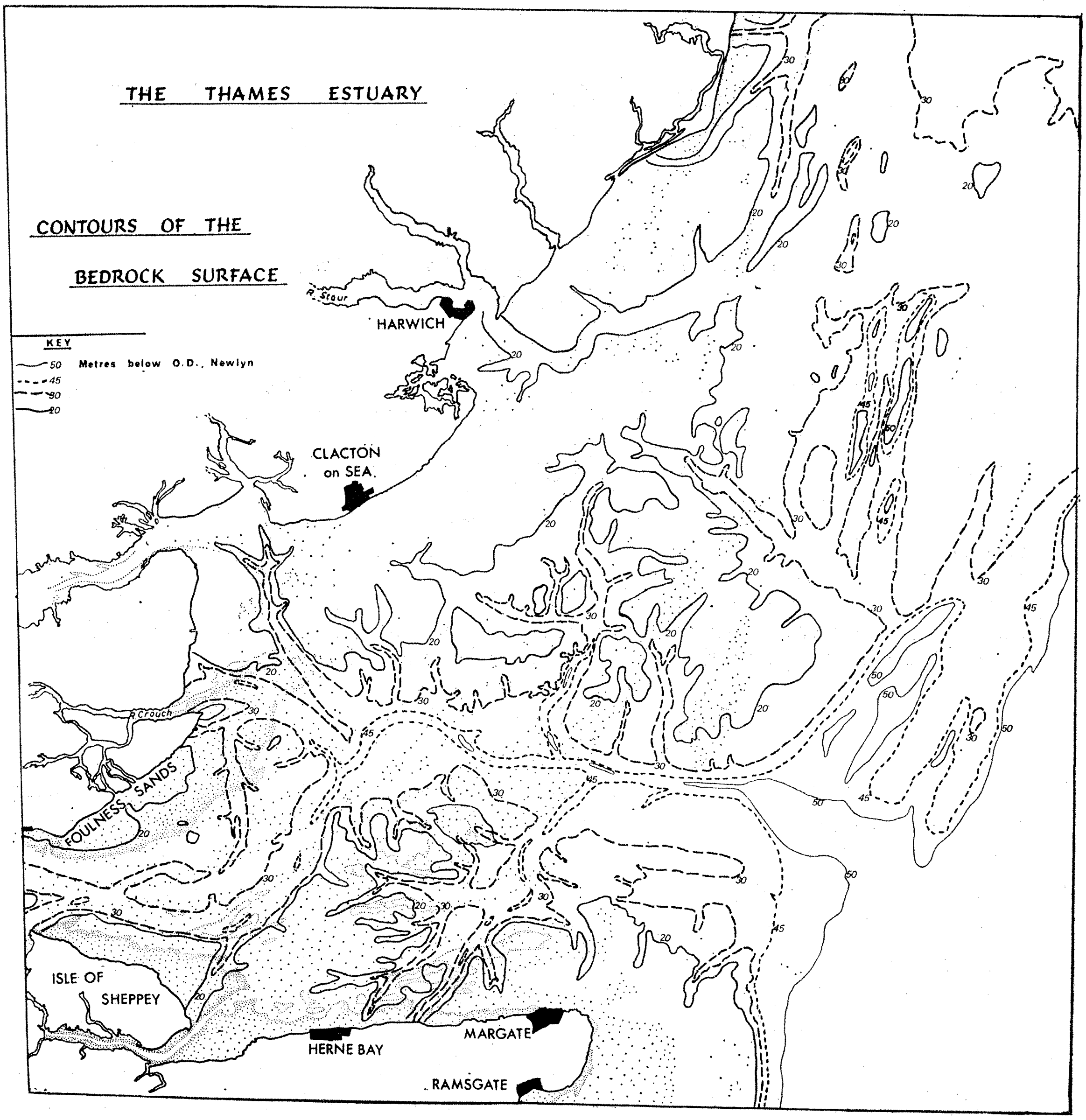

Figure 1. Contours of the bedrock surface of the Thames Estuary.

correlated on faunal and archaeological evidence as of the Hoxnian temperate stage. They are covered by a chalky solifluxion deposit called the 'Main Coombe Rock' which is believed to have been deposited in the periglacial zone immediately in front of the Wolstonian ice-sheets. The river, due to lowered base level, was at this time cutting down below the Boyn Hill Terrace forming the Taplow Terrace surface. Later, aggradation occurred on this terrace of coarse gravels with an included cold fauna, to a level of approximately 20 m O.D. As Zeuner (1959) states, the fluvial aggradation of the Taplow stage corresponds to an estuarine level of between 18–22 m O.D. in the London area. Gravels assigned to the Taplow stage are, however, found at a similar height near Southend some 60 km to the east. Evidence will be presented to suggest that this estuarine level for the Taplow gravels might instead mark the water level of a huge ice-dammed lake (Lake Tamesis) created when the river was blocked by a Wolstonian ice-lobe that moved into the southernmost parts of the North Sea. On the retreat of the Wolstonian ice the river once more cut down, forming the Upper Flood Plain Terrace on which the subsequent Ipswichian sea and the Thames Estuary, thus created, laid down sediments. At the close of that period when the growing Devensian ice-sheets began to have their effect upon world sea-level, the river once more cut down, forming eventually the Lower Flood Plain Terrace and, later again, possibly after the Chelford Interstadial, the Buried Channel.

Since 1967 some 2800 km of continuous reflexion seismic profiling has been carried out over much of the Thames Estuary. This information, coupled with the evidence from some 140 boreholes, has allowed a detailed reconstruction of the now mostly buried, completely submerged valley of the River Thames and its tributaries to be attempted (figure 1). The velocity of sound within these buried valley sediments has been calculated from borehole evidence as being 1570 m/s, and all the geophysical interpretation of the recent sedimentary features, have been based upon this figure.

2. Buried valley system

Spurrell (1889) expressed an opinion that it was possible to follow the path of the buried valley of the River Thames from a study of Admiralty charts. He reasoned that it ran from the area of Southend, in a northeasterly direction, approximately parallel to the Essex and Suffolk coasts, to empty into the North Sea off Suffolk. Holmes (1896) expressed a similar opinion. However this was not found to be the case (figure 1).

The proto-Thames after being joined by the proto-Medway flowed ESE parallel to the present coast of the Isle of Sheppey. It was then joined by the proto-Swale which flowed in from the SW, after which the Thames turned sharply NE. It flowed for some 15 km in that direction before being joined by the proto-Crouch and then by the proto-Blackwater/Colne flowing in from the NW. The proto-Crouch had two important tributaries of its own: one, the proto-Maplin which drained from the south across the area now covered by the Maplin and Foulness Sands, the other the proto-Roach that ran into the latter from the west, before they both joined the proto-Crouch under the eastern Foulness Sands. At this point the proto-Thames turned and ran for some 30 km in an easterly direction, being joined in the position of the present Knock Deep tidal channel by the proto Great Stour and its tributaries. The Great Stour, which at the present day runs eastwards through Kent reaching the sea at Pegwell Bay south of Ramsgate, during the Pleistocene ran north through the Wansum valley and drained across the now submerged area offshore of the North Kent Coast. Draining from the north was another river system with its source in a formerly elevated tract of London Clay. The latter, due to transgression and erosion, now lies submerged off Clacton on Sea and Walton on the Naze. I propose to call this river the proto-Sunk after an important mid-estuary sandbank which lies over part of this channel and with which it had an early formational relationship. The proto-Thames at its most easterly seemed then to turn south towards the Dover Straits and the English Channel, to run in the deep, now submerged channel lying to the east of the more recently formed Goodwin Sands. To the north off the Suffolk coast can be traced a shallow buried channel system of the rivers Stour, Orwell, Hanford Water, Deben, Butley and Alde. These ran to the NE before turning east toward the deep channel in the North Sea.

On the flanks of all the buried river channels previously described, are to be found well-formed terrace systems. As yet no sediments of an age older than Flandrian have been positively identified lying in the channels or on the terraces. However, it is felt that the erosive action of the transgressive Flandrian sea probably accounts for this. In the deeper, most easterly parts of the channel system, deposits can be identified on the geophysical records that may well be pre-Flandrian fluvial sediments covered during the early, rapid phases of sea-level rise. Boreholes are to be sunk into these sediments to ascertain their relevance to the late Pleistocene and early Flandrian history.

So far, two well-developed terraces can be identified, with the possibility of a third, much less complete one at a higher level. The first terrace lies some 15 m above the floor of the buried channel, though this elevation decreases towards the east. This may well be the Lower Flood Plain Terrace of early Devensian age. On average, some 8–10 m above lies the second terrace, which I believe is the Upper Flood Plain Terrace mentioned by Wooldridge, Zeuner and others. In the east of the area under consideration, the Upper Flood Plain Terrace has in some places been partially and sometimes almost completely obliterated or cross-cut by a submerged cliff-line. The Lower Flood Plain Terrace is, however, clearly unaffected in any way by this feature and must have been cut afterwards. This cliff may therefore be a feature of the Ipswichian shoreline. Its base lies at approximately 24 m below O.D. but further evidence suggests that this feature and also the terraces may be useful as a means of ascertaining differential subsidence over the area. However the Upper Flood Plain Terrace may appear from this evidence to be late Wolstonian or early Ipswichian in age.

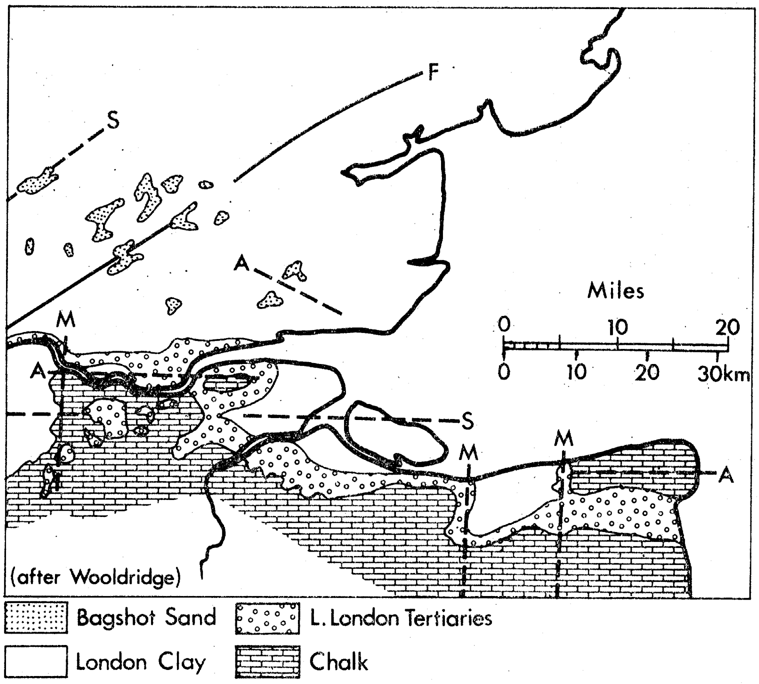

FIGURE 2. Minor structures of the London Basin. F, Fault; A, anticline; S, syncline; M, monocline.

3. STRUCTURAL CONSIDERATIONS

Wooldridge (1955) pointed out some of the minor structural features of the London Basin and emphasized some of the dominant elements (figure 2).

(i) A series of elongated domes that are found along the Thames Valley. The distinct constituent elements include from east to west, the Thanet Dome, the Cliffe Dome and the Purfleet-Grays Dome.

(ii) A NW–SE 'Charnian' fold trend seen in the Rayleigh area of East Essex.

(iii) A N–S monoclinal fold trend seen affecting the outcrop of the Tertiary beds in North Kent.

This work has been extended to cover the area of the Thames Estuary and all of the three aforementioned elements have been recognized in this offshore area (figure 3).

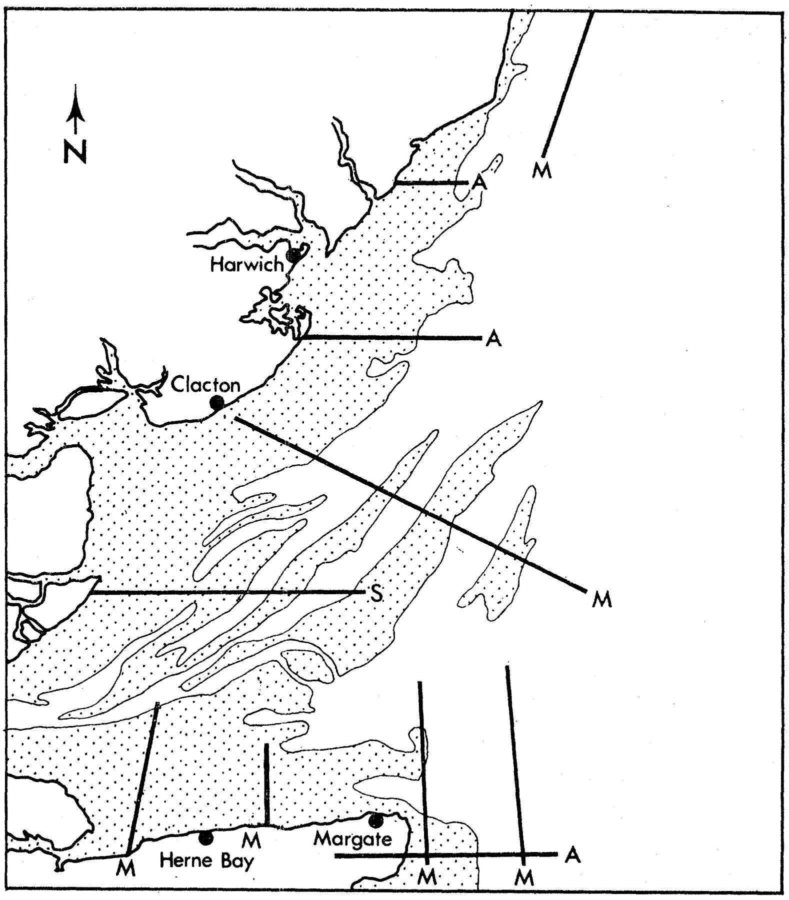

FIGURE 3. Minor structures of the Thames Estuary.

It is not intended to describe in detail the structures at this stage, but instead to show the relationship of the late Pleistocene drainage with the tectonic framework.

The Thames Estuary is floored almost entirely by the Lower Eocene, London Clay, a very uniform stiff blue clay containing in parts bands of hard septarian nodules. It is only in the southeast corner of the area that the Chalk, and the sands and silts of the Lower Tertiary occur about the Thanet Dome. However, the Late Pleistocene drainage, incised almost entirely into the London Clay, does appear to have been strongly influenced by the structure. Wooldridge concludes his discussion of this relationship by stating that there appears to be a measure of correspondence, of valleys with anticlines and ridges with synclines within the western part of the London Basin. This does not appear to be the case in the Thames Estuary. Instead, by a comparison of figure 1 with figure 3, it will be seen that the minor drainage appeared to run off the monoclinal ridges and for the major rivers to run in the synclinal areas between. The proto-Thames ran round the eastern end of the Cliffe Dome toward the Sheppey syncline. It then turned northeast under the influence of the most westerly of the north–south trending monoclines and round the southeastern end of the NW–SE trending Rayleigh Anticline. The proto-Maplin river appeared to run north off this same Rayleigh anticline toward the main synclinal area. The Thames at its confluence with the rivers Crouch, Blackwater and Colne turned eastwards abruptly under the influence of the most dominant structural element in the estuary, the large monocline trending NW–SE from the Brightlingsea, Clacton and Walton area. This monocline with a southwestwards facing steep limb has an amplitude of around 60 m. However, it is not a simple structure, being faulted in places and also having a three step structure in others. The proto-Thames skirted south of this monocline receiving the northerly proto-Sunk river flowing directly off the monoclinal area and the proto-Stour drainage from the south. This latter drainage system was strongly influenced by the most westerly of the monoclines but only slightly by the rapidly diminishing seaward expression of the next most westerly, the Herne Bay/Reculver Monocline: it was strongly affected again by the monocline running north just off the east coast of Thanet.

To the north the Suffolk Stour ran across the very slight dip slope of the Clacton Monocline, seemingly partially affected by two small E–W trending structures, before running down the eastern limb of a monocline off the east Suffolk coast.

This relationship, of the main drainage within the synclinal troughs and the tributaries running directly off the anticlinal ridges, would suggest that there has been fold movement and uplift during the Pleistocene which has re-emphasized the main structures of the area. Boswell (1915) in describing an axis of instability which approximates closely in trend and position with the Clacton Monocline, gives evidence that this axis has been repeatedly active since the Late Cretaceous. He states that there has been a rejuvenation of the Essex and Suffolk rivers since the Glacial period brought about by uplift on this monoclinal axis.

There is some evidence that this axis is still a positive element compared to the areas to the northeast and southwest. Rossiter (1972) in describing tidal data from Sheerness/Southend, Felixstowe and Holland, found a relative sea-level rise of 3.3 mm/year at Sheerness, 3.4 mm/year at Southend, 1.6 mm/year at Felixstowe and 2.0 mm/year on the Dutch coast. This would indicate that with sea-level rising equally at all three spots then relative land movements must account for the differences. Felixstowe on the monoclinal axis would therefore appear to be subsiding the least, if indeed it is subsiding at all. Again, if the very few radiocarbon-dated samples from the Thames Estuary thought to have been deposited close to high tide mark during the Flandrian transgression are compared with the data of Jelgersma (1961), then it is found that the Foulness samples are consistently at a lower level than their Dutch equivalents (figure 4). Furthermore, those samples taken on the monoclinal area or close to it, at Dengie and Orfordness, are either at a shallower or approximately the same depth. This might imply that subsidence has been greater in the Foulness and Southend areas than either the monoclinal area to the northeast or on the coast of Holland. An extension of this reasoning would indicate that subsidence has been of a lesser amount towards London where age equivalent samples are found at shallower depths. However, caution must be exercised with such evidence. The problems of obtaining uncontaminated samples and of the uncertainty of these organic rich deposits having been deposited near to high tide mark, are very real. In the Foulness area, all the samples obtained were upper tidal-flat deposits in an area which was extremely sensitive to change in the off-shore tidal régime, and to rapidly changing coastal physiography as the Flandrian sea transgressed over the relatively rugged landscape of the outer estuary of the

Thames (D'Olier 1973). Also any changes in the frequency and height of storm surges, and large-scale climatic fluctuations, will have had a great influence on high tide levels without necessarily any change in the vertical height of absolute sea-level. Further effects such as varying degrees of sediment compaction and the influence of human activities during the last 3000–4000 years also complicate the picture. It is therefore of great importance that tidal observations at Sheerness, Southend and Felixstowe are continued, as it would seem to be one of the best methods aimed at resolving this important question of differential subsidence.

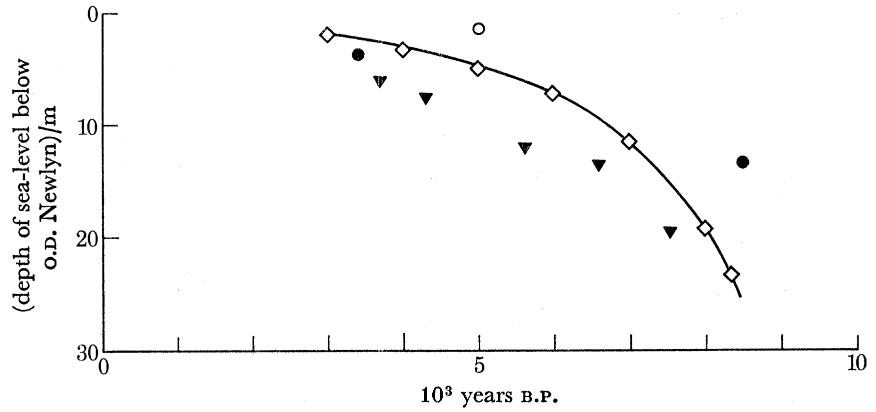

FIGURE 4. Sea-level variation. ○, Dengie; ▼, Foulness; ●, Orford; ◇—◇, Holland.

4. GLACIAL DRAINAGE IN THE THAMES ESTUARY

One element of the Pleistocene drainage system in the Thames Estuary which has not yet been mentioned, is the series of linear deeps trending between NNE–SSW and NE–SW across the entrance to the estuary (figure 1). These are variable in length but otherwise share several features which are peculiar to this series of channels.

(i) They are straight in course with relatively flat floors and quite steep sides.

(ii) They vary in depth along their length having a characteristic 'up and down' thalweg.

(iii) They are considerably overdeepened compared with the nearby drainage system of the Thames being some 70–75 m below O.D. in parts.

(iv) They are closed elongate basins beginning and ending abruptly and steeply.

(v) They bear evidence of a drainage system having flowed both into them and out of them at a later stage when the channels were presumably lakes or *Rinnenseen*.

(vi) They contain little or no sediment at the present except for a thin veneer of recent shelly sand with locally, some included gravel.

All these characteristics suggest they are either glacial chute valleys or tunnel-valleys formed by subglacial meltwater channels running under the ice near its margins with a considerable hydrostatic head. Similar features have been described by Valentin (1957), Dingle (1971), Woodland (1970) and Donovan (1973). Woodland describes a series of tunnel valleys nearby in East Anglia which only differ in that they appear to be more sinuous than those occurring offshore.

The three most northerly of the offshore tunnel valleys are to be found lying *en echelon* some 8–18 km off the East Suffolk coast (figure 1). They are steep-sided, with closed ends and are up to 4 km in length.

Farther south are two more tunnel-valleys, running parallel to each other, though together continuing the *en echelon* formation of the previous three. Both are of much greater dimension than those lying immediately to the north, being some 25 km in length and between 2–3 km in width. They display all the usual tunnel-valley characteristics as outlined previously. Again, even farther southwards, are three more overdeepened channels lying immediately to the north of the Pleistocene mouth of the Thames. Two of them are not so steep-sided as the previous tunnel valleys, and this may indicate a rather protracted period of erosion, when the sea on transgressing into the Thames mouth broke through the barrier separating them, turning them for a period of time into tidal inlets.

If indeed all these overdeepened channels were tunnel valleys, and work is continuing on their shape, structure and sediments in order to check this view, then the ice that formed them would not have had to be in advance of a further 5–10 km to the south, before coming in contact with the rising ground of the then much more extensive Thanet Dome. This would have resulted in the proto-Thames becoming blocked by ice with the consequent ice-dammed lake (Lake Thamesis) covering large tracts of the eastern part of the London Basin. If this view is correct, then some of the high level gravels on the valley sides in North Kent and Essex, and within the Thames Valley, might well be lake shore deposits. I have previously suggested that the Taplow gravels might be such a deposit. Destombes, Shephard-Thorn & Morzadec (this volume) indeed suggest that an ice-lobe continued some 40 km farther south, penetrating through the Dover Straits into the English Channel.

5. CONCLUSIONS

Preserved largely under a blanket of Late Pleistocene and Holocene sediments, the various effects of fluvial, glacial, marine and possibly lacustrine conditions can be ascertained. Adding to this complexity, is evidence that differential subsidence has occurred in the area of the outer Thames Estuary during and possibly since Pleistocene times. Further work is being carried out in order to clarify the importance of these various effects.

I gratefully acknowledge the help given by N.E.R.C. both for an original grant of money and more recently for the use of boats and equipment. I am most grateful to the staff and crew of the M.V. *Sir John Cass* for their splendid cooperation.

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