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An appraisal of the early Palaeogene deposits of North Kent

Lands and Resources Programme

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BRITISH GEOLOGICAL SURVEY

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An appraisal of the early Palaeogene deposits of North Kent

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(For, and Co-Funded by, the Environment Agency).

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After an introduction and a brief outline of the main sources of geological information on the area, this report describes the early Palaeogene deposits of North Kent (the area between the River Medway and the River Great Stour). These are the Thanet Formation, the Upnor Formation, the Woolwich Formation and the Harwich Formation. The main types of overlying superficial deposits are also described briefly.

Although these Palaeogene formations are predominantly silty, sandy or pebbly, clay-rich facies also occur, notably in the lower part of the Thanet Formation. This suggests that there is potential for an aquifer within the early Palaeogene sequence to be hydraulically separated from the Chalk aquifer in at least part of the area.

It is probable that the delineation of certain Palaeogene formation boundaries could be significantly improved by a new, detailed, geological survey. It seems unlikely that the individual formations could be subdivided in any significant or useful way by new geological surveys. Even if such improvements in the geological information were achieved, there is no guarantee that they would significantly advance the hydrogeological understanding of the North Kent marshes.

Acquisition and interpretation of natural gamma logs from currently available boreholes is most likely to produce useful new information about lithological variation in the Palaeogene sequence, relatively quickly and cheaply, if further opportunities for this exist.

This report is part of a wider project co-funded by the Environment Agency to investigate the geology of the North Downs aquifer.

1 Introduction

1.1 BACKGROUND AND PURPOSE OF THIS REPORT

This report is concerned with the early Palaeogene deposits (that is, the strata between the Chalk and the London Clay) occurring in an area between the River Medway at Chatham and the River Great Stour at Canterbury in North Kent (Figure 1).

This part of North Kent includes a large section of the North Downs, together with lowlands on the east side of the River Medway and either side of the River Swale, and the Isle of Sheppey.

The North Downs are underlain by the Upper Cretaceous Chalk Group, generally dipping towards the north-north-east, where it is progressively covered by Palaeogene deposits of the south-eastern margin of the London Basin. The lower northern slopes of the North Downs, the coastal lowlands and the Isle of Sheppey are underlain by the early Palaeogene Thanet Sand Formation, Lambeth Group and Thames Group. In this area, the Lambeth Group comprises the thin basal Upnor Formation and the Woolwich Formation. The Thames Group comprises the relatively thin basal Harwich Formation (previously known locally as the Oldhaven Beds) and the London Clay Formation.

The Chalk Group is the major aquifer of the region. The Palaeogene sequence beneath the London Clay, previously known as the 'Lower London Tertiaries', includes a large proportion of sandy, relatively permeable strata and is also an aquifer. Parts of the Palaeogene sequence are, however, relatively clay-rich (and presumably less permeable). The extent to which groundwater in the early Palaeogene strata is separated from that in the Chalk is unknown. This report arises from studies intended to address this matter.

Two aspects of the Palaeogene geology are thought to be relevant. These are, firstly, the lateral and vertical variation in lithological composition, especially as these affect permeability, particularly in the Thanet Formation, and secondly, stratigraphic subdivision, as a guide to variation in bulk lithological composition, location of stratigraphically controlled aquitard horizons and local geological structure, such faults or local changes in dip.

This report is intended to assess the feasibility of revising the geological mapping the Palaeogene of North Kent in terms of either bulk lithological composition or the current understanding of the Palaeogene stratigraphy.

1.2 INFORMATION SOURCES

1.2.1 Published BGS geological maps (1:50 000 scale)

The early Palaeogene of North Kent is shown on four 1:50 000 scale geological maps, published by the BGS (Figure 1). The presently available published maps are essentially reprints of the 'New Series' one-inch (1:63 360) sheets transferred onto new 1:50 000 scale base maps with only minor revision.

Most of the Palaeogene outcrop occurs on the two more northerly sheets.

Sheet 272 (Chatham) is based mostly on field surveys at 1:10 560 scale in 1937-38. It was republished at 1:50 000 scale in 1977 with only minor revision.

Sheet 273 (Faversham) is based on field surveys at 1:10 560 scale in 1937-46. It was republished at 1:50 000 scale in 1974 with only minor revision.

Small outcrops of the Thanet Sands are shown on Sheet 288 (Maidstone). This is based on field surveys at 1:10 560 scale in 1946-1950. It was republished at 1:50 000 scale in 1976 with only minor revision.

Somewhat more extensive outcrops of the Palaeogene are shown on Sheet 289 (Canterbury). This is based on field surveys at 1:10 560 scale in 1938-1955. It was republished at 1:50 000 scale in 1982 with only minor revision.

1.2.2 Unpublished BGS geological maps (1:10 560 scale)

Observations made during the field surveys on which the published maps are based were recorded on paper copies of the 1:10 560 scale 'County series' topographic maps. The data density and quality is variable, depending on the degree of exposure and the surveyor. These, and the fair-drawn 'standards' at the same scale, are held in the National Geological Records Centre (NGRC) at BGS Keyworth.

1.2.3 Borehole logs (lithological and lithostratigraphical)

Thousands of lithological borehole logs for the area between the River Medway and the Stour are held in the National Geological Records Centre at BGS. These logs are of variable age and quality.

Logs from boreholes in the north of the area (in grid squares TQ76NE, TQ77SE, TQ86NW, TQ86NE, TQ86SW, TQ86SE, TQ96SW, TQ96SE, TR05NW, TR05NE, TR06SW, TR06SE) were examined for lithological information about the Palaeogene sequence. Summary lithological logs were plotted for each grid square, relative to the top of the Chalk, to provide an overview of lithological variation (Section 2.2).

1.2.4 Borehole logs (geophysical)

Natural gamma and resistivity logs of boreholes were collated from BGS archives, the Environment Agency and Southern Water (Woods, 2002). Portions of boreholes passing through the Palaeogene sequence are generally cased or screened, so that resistivity logs provide no useful information about the geological sequence. Natural gamma logs can detect lithological variation even in cased boreholes, with clay-rich intervals emitting greater levels of gamma radiation than sand- or silt-rich sequences. Gamma logs are available for only eight boreholes within the Palaeogene outcrop of North Kent. These are discussed where relevant in Section 2.2.

1.2.5 Sheet Memoirs and other publications

Sheet memoirs are available for each of the four districts in which the early Palaeogene of North Kent occurs (Figure 1). They are the Chatham memoir (Dines et al., 1971), the Faversham memoir (Holmes, 1981), the Maidstone memoir (Worssam, 1963) and the Canterbury and Folkestone memoir (Smart et al., 1966). Each gives a generalised description of the formation as it occurs in that district, together with detailed descriptions from specific localities.

Other publications are mentioned where relevant in the following text.

2 The early Palaeogene of North Kent

2.1 EARLY PALAEOGENE STRATIGRAPHY OF THE LONDON BASIN

The laterally variable strata occurring between the top of the Chalk and the base of the London Clay were referred to collectively as the 'Lower London Tertiaries' by Prestwich (1850; 1852;

1854). This has proved to be a useful 'bucket' term where it was impractical or unnecessary to differentiate between the components of this sequence.

The names and classification of the component units were gradually revised and formalised (Curry et al., 1978; King, 1981), in part reflected by the terminology used on the published 1:50 000 scale geological maps (Section 1.3.1). Work by the BGS Regional Mapping Programme in the early 1990s, together with the results of various studies of high quality borehole core, led to the revision of the lithostratigraphical classification of the early Palaeogene strata of the London Basin and East Anglia (Ellison et al., 1994).

In North Kent, the consequences of this revision were mostly confined to renaming some of the mapped units. With the exception of the Upnor Formation, the same subdivisions, with the same boundaries, occur in the older and the revised schemes (Table 1).

Subdivision of the Thanet Formation is discussed in the next section.

The stratigraphy of the Chalk Group, on which the Thanet Formation rests unconformably, is described by Farrant and Aldiss (2002), Mortimore (1986; 1987), Mortimore et al. (2001) and Robinson (1986).

2.2 THANET SAND FORMATION

The Thanet Sand Formation, previously known as the Thanet Beds, or Thanet Sands, is of Late Palaeocene age.

The co-stratotype sections are at Herne Bay [TR 203 687 to 215 693] and Pegwell Bay [TR 3545 6440] (Ward, 1977, 1978; Ellison et al., 1994).

The Thanet Formation is typically composed of homogeneous, bioturbated, glauconitic silty sand of fine to very fine grade. Parts of the formation include sandy silt or sandy, silty clay. The deposits are generally pale yellow-brown in colour, typically with a 'peppering' of dark-coloured glauconite grains. Patchy calcareous or ferruginous cement occurs locally. The top of the formation can locally include some medium- to coarse-grained sand, and a shelly bed occurs near Goodnestone (Holmes, 1981). The formation is generally thicker and more argillaceous in the eastern parts of the London Basin, including parts of North Kent.

The base of the formation everywhere rests on the Chalk, often on an irregular, karstic surface modified by dissolution of the underlying Chalk in groundwater. A thin pebble bed (the 'Bullhead Bed') is generally present at the base. Typically 0.1 m to 0.3 m in thickness, this consists of unworn, green-coated flints (up to 0.3 m diameter) in a matrix of bright green, glauconite-rich clayey sand or sandy clay.

The Pegwell Bay section has been subdivided into four members (Ward, 1977, 1978), following Whitaker (1872) and Gardner (1883). These are the Base Bed, the Stourmouth Clays, the Pegwell Marls and the Reculver Silts (Figure 2). The Base Bed Member comprises glauconitic, sandy siltstone (about 1 m thick) with a layer of glauconite-coated, pitted and fractured angular flint pebbles at the base (i.e. the Base Bed includes the Bullhead Bed). The Stourmouth Clays comprise a unit up to 4.4 m in thickness of interbedded silty claystones and siltstones. The Pegwell Marls, comprising clayey silty sands and sandy or silty marls, are about 13 m in thickness. The Reculver Silts comprise silty sandstones with shelly lenses. No more than about 5 m are exposed at Pegwell Bay.

According to sections constructed by Whitaker (1872) and Gardner (1883) (reproduced by Ward, 1977), the Stourmouth Clays and the Pegwell Marls extend westwards through Sittingbourne, where they become separated by a fifth member, the Kentish Sands, which progressively replaces them eastwards. The Reculver Silts are cut out beneath the Woolwich Formation in the vicinity of Sittingbourne (Figure 2).

Subsequent opinions differ about the confidence with which Whitaker's five units can be traced through North Kent.

Surveys in the Canterbury district found that the Base Bed, the Pegwell Marls and the Reculver Silts occur throughout, but that although recognisable locally, the Stourmouth Clays and Kentish Sands seem to appear less consistently. The base of the Reculver Silts is commonly marked by a series of small springs, implying that the Pegwell Marls are relatively impermeable (Smart et al., 1966).

Holmes (1981), however, held the opinion that in the Faversham district, only the oldest of these five divisions is distinctly represented. He observed that in that area the sandy Base Bed may be followed by clay, silty loam (silty, sandy clay), sandy marl or sand, locally with ironstone or calcareous sandstone layers in the top half. He found that the lower beds tend to be clayey and the upper dominantly sandy, but considered that otherwise it is not possible to subdivide the formation. He stated that 'lateral variations are considerable, if local'.

In the east of the Chatham district, the lower part of the formation is again clayey. Although this facies is thought to diminish in thickness westwards (occupying only the basal 3 m near Thrognall [TQ 85 63]), clay is usually present in the basal metre or so (Dines et al., 1971).

Summary lithological logs from boreholes in the Palaeogene outcrop held by BGS are plotted in diagrammatic form in Figure 3 (Section 1.2.3). The borehole records are of rather variable quality, from very brief 'driller's logs' to modern site investigation borehole logs, although the latter are few in number. Excluding the obviously doubtful records, the level of each log has been adjusted relative to the top of the Chalk, to provide an overview of lithological variation. Note that no attempt has been made in this diagram to separate the Thanet Formation from the overlying sandy formations.

This overview supports Holmes' (1981) view that there is, generally, a consistent layer of sandy or silty clay in the lower part of the Thanet Formation in North Kent. Between Sittingbourne and Faversham this is as much as 19 m thick, albeit with some relatively thin sand or silt interbeds. Eastwards from Faversham, a silt and sand unit comes in at the base, and the clayey unit is pinched out eastwards. The clay-rich facies apparently continues southwards, and a gamma log from the Graveney Monkshill Borehole [TR 057 629] suggests that it also persists to the north of Faversham.

The gamma log from a borehole at Oare Creek [TR 00 62] just west of Faversham corroborates the lithological information by suggesting that the basal 10 m or so of the Thanet Formation is relatively clayey. There is then a gradual upwards decrease in clay content. Gamma logs from Sittingbourne Sewage Works and Wilford Court Farm are rather short, but are consistent with this interpretation.

The lithological logs also indicate a sandy basal layer of about 5 to 7 m thickness locally to the west of Faversham (Figure 3). The presence of this sandy basal layer in grid square TQ 96SE, just west of Faversham, is substantiated by natural gamma logs from two boreholes in that area (Section 1.2.4) (Teynham Church and Tonge boreholes) (Woods, 2002).

Westwards from Sittingbourne a similar relationship is found as to the east of Faversham, with the sand apparently wedging in from the south. Thus in grid square TQ86SE, there is a sand wedge beneath the clayey interval, but in TQ86NE and NW, the clayey interval is still at the base. There are then no lithological borehole records between Otterham Quay and west Gillingham, where a relatively few boreholes suggest the sequence is mostly silt and sand with only occasional clayey layers.

The gamma log from a borehole at Lower Halstow [TQ 85 67] (in TQ 86NE) demonstrates a 'cleaning-up' sequence in about 38 m of Palaeogene strata. That is, the lower 15 m or so of the sequence are mostly clayey, but above that the proportion of sand appears to gradually increase upwards. The gamma log from another borehole in that area (Motney Hill) [TQ 838 681] (in

TQ86NW) (Woods, 2002), which penetrated some 27 m of the Thanet Formation, suggests a predominantly clayey facies.

The presence of springs emerging from within the upper part of the Thanet Formation north-east of Newington implies that relatively clay-rich beds occur at least locally in that part of the sequence (Section 2.3.2).

Surface observations noted in the memoir and on the 1:10 560 scale fair-drawn maps are broadly consistent with this interpretation of lithological variation in the Thanet Formation.

The Thanet Formation was deposited on an inner marine shelf, above fair weather wave base (Ellison et al., 1994). Knox (1996) considers the Thanet Formation to represent deposits laid down during up to three regionally-developed marine transgressive cycles. Thus a clay-rich facies present in the formation, as seen in North Kent, is likely to be laterally continuous on a local to regional scale.

The thickness of the formation is greatest in North Kent, where it generally ranges from about 20 m up to 30 m, increasing to as much as 37 m in the Canterbury district. It is overlain unconformably by the Upnor Formation and in places significant parts of the Thanet Formation having been removed by erosion prior to deposition of the Lambeth Group (Curry, 1981). At Beacon Hill, west of Faversham, the thickness is about 24 m, whereas at Goodnestone it is little more than 18 m (Holmes, 1981).

2.3 LAMBETH GROUP

In North Kent, the Lambeth Group comprises the basal Upnor Formation and the overlying Woolwich Formation.

2.3.1 Upnor Formation

The Upnor Formation, previously known as the Woolwich Bottom Bed or similar, is of Late Palaeocene age.

The stratotype section is in the Lower Upnor Pit [TQ 759 711] (Kennedy and Sellwood, 1970; Ellison et al., 1994).

The Upnor Formation is typically composed of variably glauconitic, fine to medium-grained sand with beds and stringers of well-rounded, black flint pebbles. When fresh, the sands are dark grey brown to dark green, depending on the proportion of glauconite (which can exceed 25 per cent). They weather pale brown to yellow brown, but the glauconite remains dark green. The sands are extensively burrowed but locally cross-bedding remains. Shelly fossils are common in unweathered sections.

The base of the formation rests unconformably on the Thanet Formation. The boundary is generally sharply defined, being marked by an upward change to medium-grained sand, with burrows of glauconitic sand extending as much as 0.5 m downwards into the Thanet Formation. A basal flint pebble bed is usually present. In the far east of the London Basin, bioturbation has resulted in a gradational junction, and the grain size contrast is difficult to pick in the type section and elsewhere in north-east Kent.

In the Faversham and Chatham districts, the Upnor Formation (recognised as the rusty glauconitic basal bed of the ‘Woolwich Beds’) is usually traceable in the field, especially where a few pebbles occur (Dines et al., 1971; Holmes, 1981).

The formation was deposited in a marine shelf to coastal environments, predominantly with high energy, and partly influenced by tidal currents (Ellison et al., 1994).

At Upnor, the formation is about 7.5 m in thickness. In much of North Kent, the topmost part was locally removed by erosion prior to the deposition of the Harwich Formation.

The upper boundary is generally well-defined, being overlain by the Woolwich Formation.

2.3.2 Woolwich Formation

The Woolwich Formation, previously known as part of the Woolwich and Reading Beds, is of Late Palaeocene age.

The stratotype section is in the Charlton pit in east London [TQ 417 786]. The Lower Upnor Pit [TQ 759 711] provides a reference section (Kennedy and Sellwood, 1970; Ellison et al., 1994).

The Woolwich Formation is typically composed of grey to grey-brown, interlaminated fine- to coarse-grained sands, silts and clays. Plant debris is common in parts of the outcrop. Sporadic burrows occur throughout but bioturbation is more common in higher beds in which sparse glauconite has been recorded. Shelly beds, particularly in the basal two metres, consist of brackish water shells in a dark grey clay matrix. Other lithofacies occurring locally are shelly limestone beds, medium- to coarse-grained ferruginous sand, and pebble beds (Ellison, 1983). In the Faversham district the sands are glauconitic (Holmes, 1981).

The base of the formation is sharp, with burrows extending as much as 0.5 m into the Upnor Formation.

The Woolwich Formation is the most laterally variable of the Palaeogene units in North Kent. At Herne Bay, for example, it comprises very fine silty sand indistinguishable in the hand from the Thanet Formation. By contrast, medium- to coarse-grained, brown to purplish-brown coloured ferruginous sand is present near Faversham, and in the Chatham and Canterbury districts. This ferruginous sand is typically poorly bedded, with a few burrows, and some carbonaceous detritus. It is sparsely glauconitic. It is locally cemented to a thin sandstone. In east Kent a horizon of ferruginous sandstone doggers or bed of nodular fossiliferous ironstone up to 1.2 m thick is known as the Winterbourne Ironstone. The ferruginous cement has been attributed to localised emergence or lowering of water table during deposition. The ferruginous sand is apparently cut out eastwards by erosion at the base of the Harwich Formation (Ellison, 1983).

In the field in the Faversham district, the Woolwich Formation was recognised as being generally composed of rather coarser sand than the Thanet Formation, which overlies the glauconitic Upnor Formation (Holmes, 1981). Difficulties can arise where the sand at the top of the Thanet Formation is coarser than usual, as occurs locally, or where the Woolwich Formation is composed of fine-grained sand (as at Herne Bay).

In the eastern part of the Chatham district, the Woolwich Formation consists mainly of sand but from the Newington area [TQ 85 65] westwards clay beds occupy up to about one-third of the unit, especially near the top and the base (Dines et al., 1971). The presence of such clay beds might have a controlling influence on springs emerging from within the Palaeogene outcrop, for example north-east of Newington (Section 2.2).

The formation was deposited in a variety of marginal marine environments, of low to high energy, with some freshwater deposits (Ellison et al., 1994).

In North Kent the Woolwich Formation was wholly or partly removed by erosion prior to deposition of the Harwich Formation (Holmes, 1981). It generally ranges up to 12 m in thickness, but can reach 18 m in the Chatham district.

It is overlain unconformably by the Harwich Formation.

2.4 THAMES GROUP

In North Kent, the Thames Group comprises the basal Harwich Formation and the overlying London Clay Formation.

2.4.1 Harwich Formation

The Harwich Formation, previously known generally as the London Clay Basement Bed, in North Kent as the Oldhaven Beds and in the London area as the Blackheath Beds, is of Early Eocene age.

Reference sections relevant to the North Kent area are exposed at Herne Bay [TR 203 687 to 215 693] and Upnor [TQ 759 711] (Ellison et al., 1994).

The Harwich Formation varies regionally. Occurrences in the north-east part of the London Basin (including parts of Essex) are in a relatively argillaceous 'distal facies'. Elsewhere the Harwich Formation displays a sandy or pebbly 'proximal facies', being typically composed of highly glauconitic silty sands, sandy silts, sandy silty clays and a basal pebble bed. Coarse-grained sand is locally found at the base. Fine-grained, glauconitic, cross-bedded, pebbly sands occur in North Kent. East and south of Faversham, a very pebbly facies is developed. No indigenous fossils are known.

The base is sharply defined, being formed by a planar or slightly undulose discontinuity with a basal lag of very well-rounded flint pebbles and fine to coarse quartz grains in a finer glauconitic matrix. Burrows commonly extend down into underlying beds.

The formation was deposited on a shallow marine shelf, with slow, interrupted sedimentation, and periodic storm-generated activity.

The thickness is laterally variable, ranging from 2.5 m up to about 10 m in North Kent. In the Faversham district the unit is generally about 6 m thick, but around Oare and north of the town of Faversham it is significantly thinner, with thicknesses in the range 2.4 to 4.0 m.

The Harwich Formation is overlain disconformably by the London Clay.

2.4.2 London Clay Formation

The London Clay Formation is of Early Eocene age.

Reference sections relevant to the North Kent area on the Isle of Sheppey and at Herne Bay [TR 203 687 to 215 693] are described by King (1981).

The London Clay Formation is typically composed of silty clays and clayey silts. It can be glauconitic near the base, and tends to be sandy towards the top.

On the Isle of Sheppey, the London Clay is up to about 153 m thick (King, 1981).

2.5 SUPERFICIAL DEPOSITS

The published geological maps (Section 1.3.1) show a variety of superficial (drift) deposits, of Quaternary age. These are of direct significance in that they mask the underlying bedrock formations to some extent. They are also of significance to the hydrogeology of the region through their potential effect on recharge rates, and the extent to which they might protect the bedrock aquifer from the infiltration of pollutants, but these matters are not considered here.

Four types of superficial deposit occur on the outcrop of the early Palaeogene formations in North Kent: brickearth, head, river terrace deposits and alluvium.

2.5.1 Brickearth

Brickearth typically comprises a variably sandy or clayey silt, with a small proportion of chalk or flint gravel. It tends to be massive, or weakly bedded, and fairly homogeneous. Most of that seen at the surface is considered to have been redeposited by solifluction processes (Head Brickearth) or fluvial processes, or both (River Brickearth).

Brickearth forms a discontinuous but widely developed blanket in excess of 1 m in thickness, overlying either bedrock or other types of superficial deposit. Parts of the original deposit have been removed for brick-making.

In Kent and Essex, where the local brickearth sequence exceeds about 2 m, there is usually a distinct upper non-calcareous part and a lower calcareous part of the sequence. Although one might assume that this layering has arisen by leaching of the calcareous fraction by water percolating downward from the surface, recent work by BGS suggests instead that the lower layer is a primary aeolian deposit, and that the upper is a solifluction (head deposit). Both layers are composed principally of silt, although the upper layer tends to contain rather more clay.

2.5.2 Head

'Head' refers to superficial deposits formed by solifluction processes: mainly down-slope mass movement of unconsolidated materials under the prolonged influence of freezing and thawing in a periglacial environment, but including rain wash and soil creep in more temperate climatic conditions.

Head occurs on some slopes and in valley floors throughout the area. It is assumed to have formed gradually during the successive Quaternary glacial periods, presumably most recently during the Devensian, and to be of fairly uniform age irrespective of topographic situation.

Head is very variable in composition depending on local sources of material and details of landscape evolution. It is typically composed of very stony, sandy and silty clays, or clayey gravels. It can be clast-supported or matrix-supported. It tends to include a large proportion of angular, frost-shattered flint gravel.

Head with a large proportion of material derived from river terrace deposits gives rise to conspicuously gravelly soils, but such head deposits lack the characteristic flat-topped landforms. Head composed of clayey sand, with little admixed gravel, would be expected on parts of the Palaeogene outcrop.

Head can be difficult to distinguish from weathered, in situ bedrock. It tends to be more widely distributed than shown on geological maps. It is commonly too thick or too stony to penetrate with a hand auger. Head deposits can thus present a significant obstacle to geological field survey of bedrock formations.

2.5.3 River terrace deposits

River terrace deposits were laid down predominantly during periods of cold climate in the Quaternary, and occur at various levels depending on their age.

The river terrace deposits typically comprise gravels and pebbly sands, commonly clayey. Flints (and clasts of other rock types) tend to show signs of being water-worn. These deposits can be expected to pass upstream or upslope into head.

The older terrace deposits have been extensively dissected by subsequent erosion of the river valleys to progressively lower levels. Those remnants which have escaped erosion will have undergone cryoturbation and solifluction during the periods of cold climate following their deposition. These processes lead to a gradual degradation of the original landform as their component material is reworked into head, or into younger river terraces.

Some brickearth deposits appear to overlie river terrace deposits. Some head gravel deposits could possibly be mapped as river terrace deposits. The distribution of river terrace deposits is thus likely to be more extensive than indicated by the geological maps.

2.5.4 Alluvium

Alluvium comprises the predominantly fine-grained deposits (including silt, clay, shell marl, and peat) underlying the flood plains of modern streams and the low-lying marshland area. It can include gravel lenses and commonly has a basal gravel lag, or overlies gravelly river terrace deposits.

3 Geological surveying methods

3.1 PAST SURVEYS

Examination of the published geological maps in the light of present understanding of the Palaeogene lithostratigraphy suggests that the interpretation remains robust, for the most part. Mapped units can be identified with named formations, with the exception of the Upnor Formation (Table 1), and the criteria used to place the mapped boundaries is consistent with the definition of the formations.

Although the Upnor Formation was not separated from the Woolwich Formation (so that what is shown on the published maps as 'Woolwich Beds' is now treated as 'Lambeth Group, undifferentiated'), this unit is relatively thin and of predominantly arenaceous composition. It seems unlikely that leaving the Lambeth Group undivided would have a significant effect on a hydrogeological model of the early Palaeogene sequence.

In North Kent the Woolwich Formation was wholly or partly removed by erosion prior to deposition of the Harwich Formation (Sections 2.3.2, 2.4.1). However, the published geological maps show the outcrop of the Lambeth Group to be continuous, and that of the Harwich Formation to be discontinuous (Figure 1). This suggests that parts of what was previously mapped as part of the Woolwich Beds might now be assigned to the Harwich Formation. However, it appears likely that the areas where the Harwich Formation is not shown on the map coincide with particularly thin developments of that unit, perhaps of only a few metres thickness (Section 2.4.1). In addition to being rather thin, the Harwich Formation is underlain by predominantly arenaceous sequences, so it seems unlikely that the local omission of its outcrop would significantly influence the hydrogeological interpretation of the area.

3.2 POSSIBLE NEW INVESTIGATIONS

It seems possible that the geological interpretation of the early Palaeogene of North Kent could be refined in several respects:

1. Investigation of lithological variation in the Thanet Formation and the Woolwich Formation
2. Subdivision of the Lambeth Group, allowing a better appreciation of the depth of erosion at the base of the Harwich Formation
3. Re-mapping the Harwich Formation, to establish its lateral continuity.

Various survey techniques could be used, but each has limitations. Given that previous systematic large-scale surveys were carried out with knowledge of Whitaker's proposed subdivision of the Thanet Formation, Holmes' (1981) conclusion that four of Whitaker's five members could not be traced through the Faversham district is significant. As suggested in Section 3.1, it seems unlikely that new mapping of the Upnor Formation or of the Harwich Formation would greatly add to the hydrogeological knowledge of North Kent.

3.2.1 Field survey

Geological field survey proceeds by direct observation of bedrock or of superficial deposits in exposures, observation of soil materials and vegetation, sampling of subsoil material by hand auger, and detailed interpretation of small to medium-scale landforms (boundaries between mapped units can often be placed at a break of slope, for example).

Information from existing records, including records of boreholes and trial pits, is taken into account.

A fairly detailed revision survey would be required to make significant improvements to the existing geological map of the Palaeogene. Fieldwork for such a survey would typically proceed at about 1 km^2 per person-day, or 4 km^2 per working week. Typically, 1.5 to 2 days would be required on office work for each day in the field, for preparation, and for map and report compilation. A full revision survey is thus a relatively time-consuming and costly exercise.

A field survey of the Palaeogene of North Kent would encounter certain difficulties.

There seem to be very few exposures of the early Palaeogene sequences in the North Kent block. Those which were seen during two days reconnaissance survey had already been noted in the relevant Memoirs, and many of those described previously (for example those in railway cuttings) are obscured or otherwise unavailable. No new sections were found.

As indicated in Section 2.5, superficial deposits are commonly too thick or too stony to penetrate with a hand auger. Many of them obscure any topographic expression of the bedrock. They can thus present a significant obstacle to geological field survey of bedrock formations.

A significant proportion of the early Palaeogene outcrop in North Kent is built over. This severely restricts the value of observations of soil materials and the use of a hand auger. Some topographic features can be traced successfully through built-up areas, although opportunities to validate their geological interpretation tend to be few. However, temporary excavations (e.g. for foundation works, or trenching for utilities) can be more common in built-up areas than in rural areas.

Where the bedrock is not obscured by superficial deposits or buildings, there seems to be a good chance of being able to delineate the Upnor Formation and the Harwich Formation. However, information from existing records, and from a brief field reconnaissance between Faversham and Gillingham, suggests that lithological variation within the Thanet Formation is likely to be both gradual and subtle. Even if considerable effort were to be devoted to a field survey, there is little expectation of being able to subdivide the Thanet Formation or the Woolwich Formation according to rock type in any consistent or meaningful way.

Moreover, the parts of these formations which are most likely to be water-bearing occur largely within the marshes beneath superficial cover. Information on the Palaeogene would have to be extrapolated down dip from the outcrop into the productive aquifer, with consequent uncertainty in the interpretation.

3.2.2 Aerial photograph interpretation

In some areas, interpretation of large-scale (typically 1:10 000 scale) aerial photographs can be used as a supplement to field survey in order to trace topographic features which indicate the position of geological boundaries (Section 3.2.1).

Mappable boundaries between, or within, the early Palaeogene of North Kent appear to be relatively poorly expressed by topographic features. The clearest features (those most likely to be visible on aerial photographs) are those most likely to have been traced accurately by previous surveys. Features attributable to variations in the bedrock seem prone to being confused with those reflecting the distribution of superficial deposits. Also, even where the bedrock is not covered by superficial deposits, the formation boundaries are widely obscured by woodland, which severely diminishes the value of the aerial photographs.

It appears unlikely that the use of aerial photographs would allow the existing mapping of bedrock boundaries in the Palaeogene of North Kent to be significantly improved (although the mapping of some superficial deposits, such as the river terrace deposits, might be improved) or for existing mapped units to be further subdivided.

3.2.3 Pitting

Where conventional field survey methods (Section 3.2.1) fail to provide sufficient information about the bedrock formations, they could be supplemented by pitting and trenching. Such excavations could also provide opportunities for physical testing, although these are likely to be mostly in the weathered zone.

Excavation and logging of temporary exposures is slow and relatively expensive. Difficulties in gaining the cooperation of landowners can be expected. Mechanical excavators have to be hired and transported to site. Excavations deeper than 1.5 m must be supported by shuttering, or observations confined to the excavated material.

For these reasons, it is impractical to use an excavator as a mapping tool. Excavations can, however, be useful in site-specific investigations, or in order to create temporary exposures to supplement conventional field survey, for example to examine stratigraphic boundaries and test their relationship to topographic features. Even so, in gently dipping sequences they are a far from ideal means of establishing a local stratigraphic sequence: cored boreholes are much better suited to that purpose.

3.2.4 Cored boreholes

Cored boreholes are used to establish a local stratigraphic sequence, and to provide unweathered material for physical testing, and for geochemical, mineral, petrographical or biostratigraphical analysis. The borehole is usually available for geophysical logging and hydrogeological testing.

Drilling costs are estimated as being £120 to £150 per metre, with simple backfill on completion. In addition, time is required to arrange for access to a suitable site, letting a drilling contract, logging, analysing and reporting on the core.

A hole about fifty metres in depth might be required to sample the early Palaeogene near Faversham. Such a borehole is likely to give a reasonable indication of the broad stratigraphic sequence in that area, although it could be expected to show some very local variation as well.

3.2.5 Geophysical borehole logging

Sand-rich and clay-rich beds and sequences can be expected to be expressed by distinctive signatures on geophysical borehole logs, particularly natural gamma and resistivity. Water boreholes which pass into or through the Palaeogene can be expected to be cased-off or screened. Even so, natural gamma logs can reveal lithological variation in the geological sequence outside the borehole casing.

Some control from lithological logs of one or more of the boreholes in an area greatly assists interpretation of the corresponding geophysical borehole logs.

Gamma logs are available for eight boreholes in the early Palaeogene sequence of North Kent. These could be supplemented relatively quickly and cheaply by logging any further available boreholes, such as observation boreholes, which are thought to pass through part or all of the Palaeogene, if such exist. This would provide additional data points in overviews such as Figure 3, and would help further test the validity of Whitaker's five subdivisions of the Thanet Formation, for example.

4 Conclusions and recommendations

4.1 PALAEOGENE GEOLOGY

Although the strata between the top of the Chalk and the base of the London Clay in North Kent are predominantly silty, sandy or gravelly, some parts of this sequence include a significant proportion of clay, namely:

- the basal 'Bullhead Bed' of the Thanet Formation
- the lower part of the Thanet Formation, especially east of Easting 585000
- parts of the Woolwich Formation, especially west of Easting 585000

Available information suggests that the Bullhead Bed and the clay-rich facies in the Thanet Formation are likely to be present continuously across the North Kent block, although the thickness of the latter seems to vary considerably. Clay-rich beds are likely to be present in the Woolwich Formation but are less likely to be continuously developed.

The presence of these clay-rich facies suggests that there is potential for an aquifer within the early Palaeogene sequence to be hydraulically separated from the Chalk in at least part of the area. This inference is supported by the presence of springs, some ephemeral, within the Palaeogene outcrop.

However, although parts of the Palaeogene sequence seem likely to be relatively impermeable, it is not possible to describe the permeability even semi-quantitatively from the geological information available to the present authors.

4.2 PAST SURVEYS

Previous systematic large-scale mapping delineated all but one of the Palaeogene formations currently recognised in the eastern part of the London Basin, albeit under different names. Differences between the published maps and a re-interpretation in terms of the modern lithostratigraphy seem unlikely to make a significant difference to a hydrogeological model of the area.

4.3 POSSIBLE FURTHER INVESTIGATIONS

It is likely that **conventional field survey** could refine the mapping of certain Palaeogene formation boundaries. However, there is little expectation of being able to subdivide the individual formations in a consistent or helpful way. In order to achieve either objective, a new field survey would require relatively intensive fieldwork, and would be consequently slow and expensive to carry out. Even then, the net permeability of the Palaeogene sequence in a given area would remain unknown.

Aerial photograph interpretation is unlikely to allow significance refinement of the existing bedrock mapping, even in combination with a new field survey.

Pitting or trenching would be useful to create temporary exposures to supplement a geological field survey, but are unlikely to be cost-effective in isolation. They would provide opportunities for physical testing, albeit mostly in the weathered zone.

One or more **cored boreholes** would be expected to provide a good description of the geological sequence of the area, and would provide material for physical tests, such as permeability.

Acquisition and interpretation of new **geophysical borehole logs** (specifically, natural gamma logs) is most likely to produce useful new information about lithological variation in the Palaeogene sequence, relatively quickly and cheaply, if opportunities exist.

However, even if the geological mapping were to be refined, or improved descriptions of the sequence obtained from boreholes, there would no guarantee that the likely improvements in geological information would significantly advance the hydrogeological understanding of the North Kent marshes, particularly when considered in relation to the cost of such work and the time required to carry it out.

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Terminology of Ellison et al. (1994)		**Terminology on published BGS maps**
Thames Group	London Clay Formation	London Clay
	Harwich Formation	Blackheath and Oldhaven Beds *or* Oldhaven Beds
Lambeth Group	Woolwich Formation	Woolwich Beds
	Upnor Formation	*(included with Woolwich Beds)*
	Thanet Sand Formation	Thanet Beds

Table 1: Stratigraphic terminology of the early Palaeogene of North Kent

Figure 1: Location and solid geology of the project area (based on published BGS 1:50 000 geological maps)

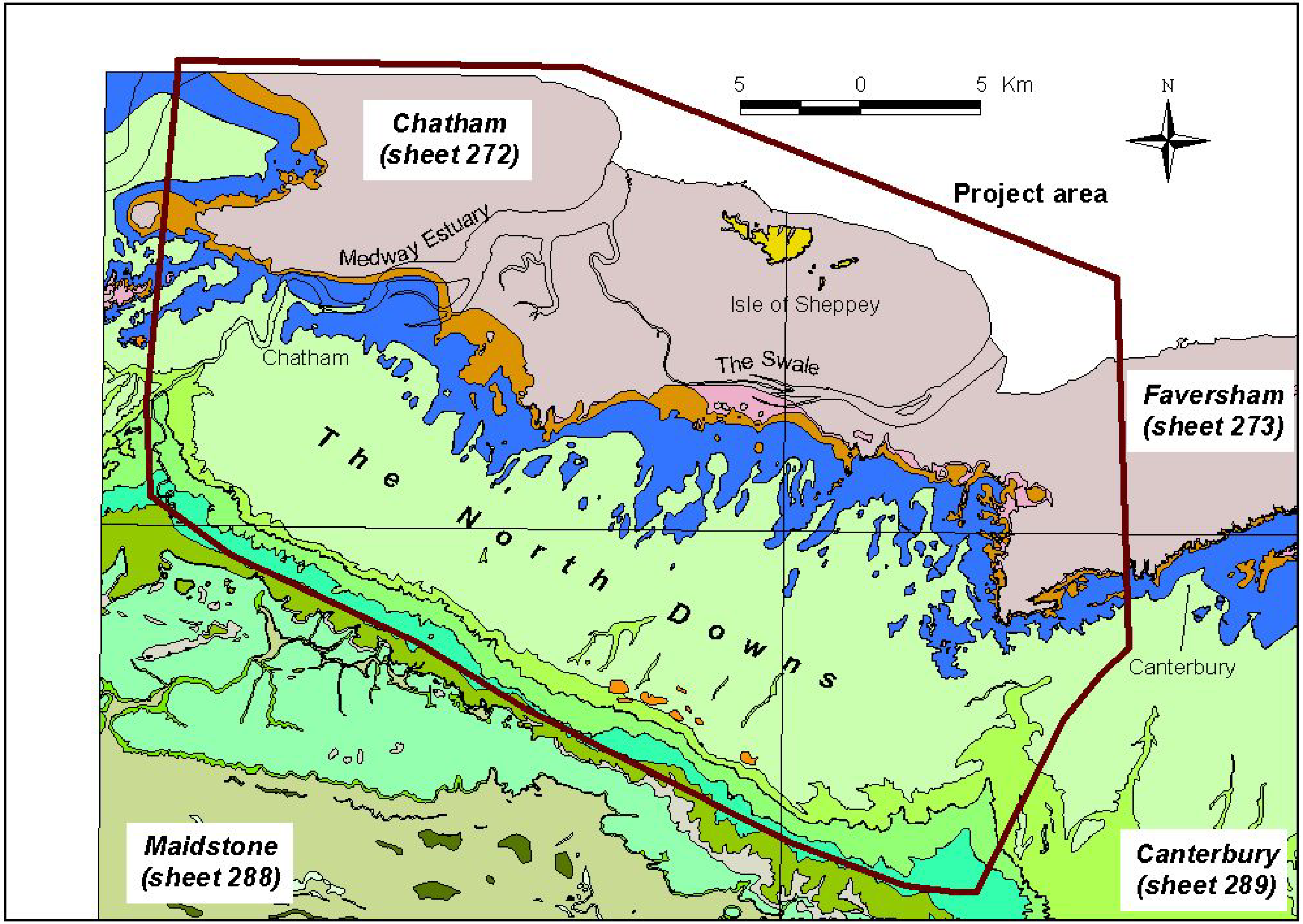
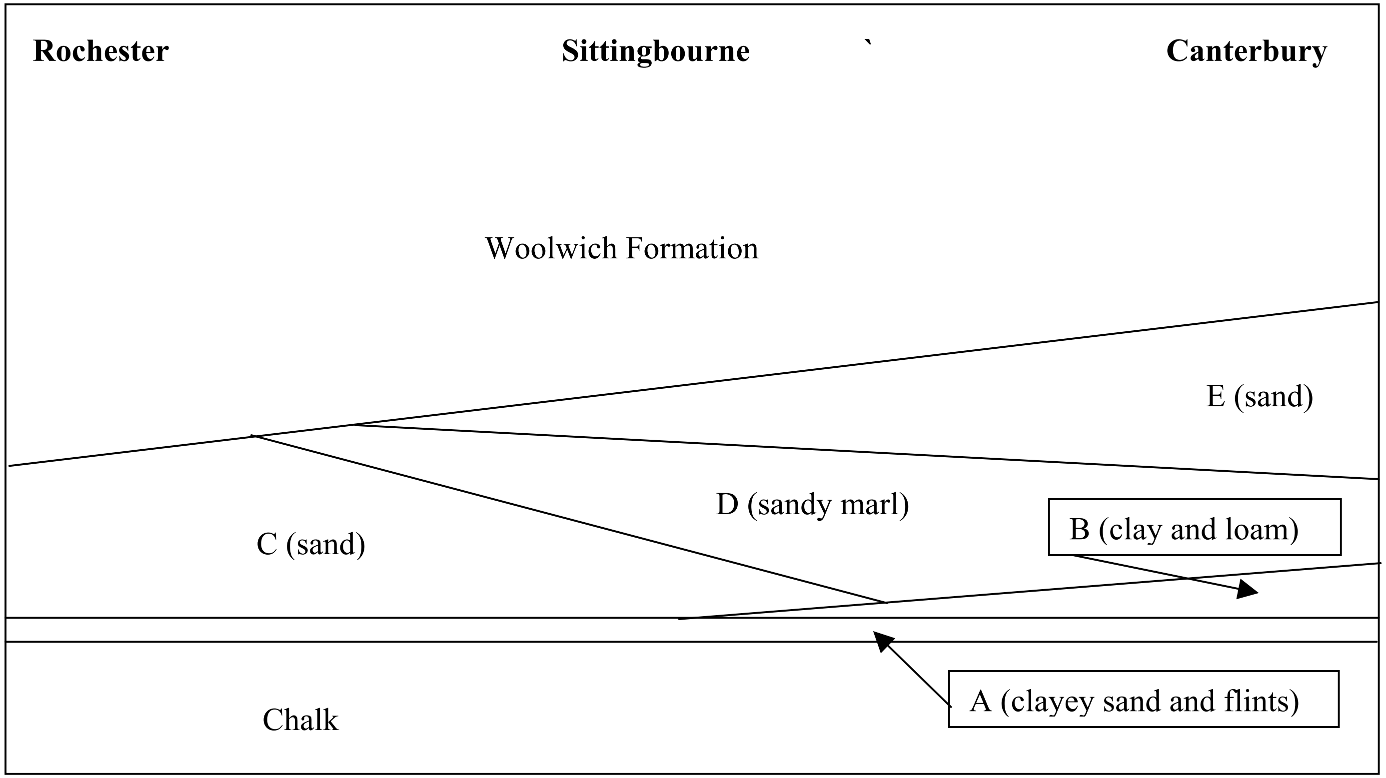


Figure 2: Whitaker's (1872) subdivision of the Thanet Formation



Diagrammatic relationships of divisions of the Thanet Formation in north east Kent, after Whitaker (1872). Not to scale.

A: Base Bed Member; B: Stourmouth Clays; C: Kentish Sands; D: Pegwell Marl; E: Reculver Silts

Figure 3: Lithological variation in the Thanet Formation of North Kent