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The stratigraphical framework for the Palaeogene successions of the London Basin, UK

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Key words

Stratigraphy; Palaeogene; southern England; London Basin; Montrose Group; Lambeth Group; Thames Group; Bracklesham Group.

Front cover

Borehole core from Borehole 404T, Jubilee Line Extension, showing pedogenically altered clays of the Lower Mottled Clay of the Reading Formation and glauconitic sands of the Upnor Formation. The white bands are calcrete, which form hard bands in this part of the Lambeth Group (Section 3.2.2.2 of this report)

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Foreword

This report provides a summary of the lithostratigraphical scheme proposed by the British Geological Survey (BGS) Stratigraphical Framework Committee (SFC) that aims to describe and rationalise group, formation and member nomenclature for the Palaeogene of the London Basin, southern England.

This framework report provides detailed descriptions for units occurring in the onshore area of the London Basin and adjacent parts of East Anglia. Existing names are used wherever appropriate, although where unit names have not previously existed or are unsatisfactory, the report proposes revisions.

Acknowledgements

The author would like to thank current and former BGS colleagues for helpful discussion and suggestions, in particular R A Ellison, D C Entwisle, P M Hopson, C N Waters and I T Williamson, who advised on parts of this document and who created many of the Lexicon entries on which it draws. Outside BGS, Dr Jackie Skipper, Dr Chris King, D P Page and T Newman are thanked for helpful comments and discussions, and for the provision of documentation, some unpublished.

The report was reviewed within BGS by David Entwisle and Richard Ellison, who contributed significantly to its accuracy.

The author has benefited from the sight of various unpublished documents, including an incomplete draft description of the Upper Palaeogene of the London Basin, dated 1998, by Richard Ellison, Ian Williamson and Chris King; a provisional stratigraphical framework for the Palaeogene and Neogene rocks of the onshore areas of the Hampshire Basin, the London Basin and East Anglia, dated July 2003, by Robert Knox and Chris King; and advanced drafts of parts of a Geological Society of London (GSL) Special Report on the stratigraphy of the British Palaeogene and Neogene by Chris King. Many details have been drawn from the latter report, especially of inferred environment and age of deposition. However, sections of the latest draft of the GSL Report was received on 30 August 2011, just as work on this BGS report was drawing to a close. This late draft of the GSL Report was subject to review and so liable to be altered further before publication. The present BGS report therefore does not take full account of this latest version of the GSL Report, especially in respect of the proposed formal naming of subdivisions in the Woolwich and Reading formations.

Production of this report was funded by the Standards and Best Practice Project (formerly the Geoscientific Standards and Nomenclature Project).

This report has been compiled on behalf of the BGS Stratigraphy Committee, and reflects a degree of pragmatism and compromise. It is believed to provide a workable scheme within which any new data and subdivision can be accommodated.

If users of this document discover inconsistencies or factual errors in the specifications given for the various lithostratigraphical units, they are encouraged to notify The Chairman, BGS Stratigraphy Committee, British Geological Survey, Keyworth, Nottingham, NG12 5GG (email cnw@bgs.ac.uk).

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1 Introduction

This document is the formal statement of the lithostratigraphy of Palaeogene[1] deposits of the London Basin, in south-east England, as adopted by the British Geological Survey. It contains a review of the nomenclature used in BGS publications, including maps, and sets out the currently preferred scheme. This review draws heavily on the work of BGS staff, including that published outside BGS, as well as publications and some unpublished work from outside BGS.

The unit descriptions will also appear in the BGS Lexicon of Rock Unit Names (http://www.bgs.ac.uk/Lexicon/home.html) (Section 1.5), although as time passes the content of the Lexicon may be revised or expanded.

1.1 SCOPE OF THE REPORT

The Palaeogene Stratigraphical Framework of England is concerned mainly with the Palaeogene successions found onshore in the London Basin and in adjacent parts of East Anglia. These are mostly considered as formal groups, formations and members. This document does not describe the Palaeogene rocks of the Hampshire Basin, south-west England, Lundy, northern England, Scotland and Northern Ireland, including the 'British Tertiary Igneous Province', nor those found offshore in the North Sea, the English Channel, the Western Approaches, the Bristol Channel and Cardigan Bay.

Certain onshore deposits with a relatively restricted distribution resembling that of 'superficial deposits', but whose age pre-dates the Quaternary, have been described in the Stratigraphical Framework Report for the Great Britain Superficial Deposits Supergroup (McMillan et al., 2011). These include units of Neogene age: the Crag Group (Plio-Pleistocene) and the St Erth Formation (Pliocene), and the karstic fissure-fill sediments, of Palaeogene–Neogene and possible latest Mesozoic (Cretaceous) age, that are found on the Durham coast and in the Peak District. These deposits, together with the Castle Eden Fissure-fill Formation and the Brassington Formation, have been assigned formal status but currently remain unattached to a group. Remanié deposits originating during the Palaeogene or Neogene (including the Clay-with-flints Formation, the Lenham Formation and the Buchan Gravels Formation) are assigned to the Residual Deposits Group of the Superficial Deposits Supergroup.

1.2 COMPARISON WITH THE GEOLOGICAL SOCIETY OF LONDON SPECIAL REPORT ON THE TERTIARY

By coincidence, the production of this report took place during the later stages of compilation of a new Geological Society of London (GSL) Special Report on the Tertiary (King, in prep.; see also Acknowledgements).

Both the GSL Special Report and the BGS Stratigraphical Framework Report (SFR) are intended to provide a summary and synthesis of existing knowledge, incorporating new and unpublished information as appropriate and possible.

[1] Currently, BGS uses the earlier spelling of 'Palaeogene' for the first Period of the Cenozoic Era, in contrast to Ogg et al. (2008), which uses 'Paleogene'. Both authorities use 'Paleocene' for the first Epoch of the Palaeogene.

The BGS SFRs have a largely retrospective role: they are intended to set out the stratigraphical framework as it has been used in BGS publications. They can also be used to recommend future practice, and to refer to alternative practice.

This BGS report specifies future usage in BGS output. Neither the BGS nor the GSL report confers any obligation on other users, who are free to choose which report to follow, or neither.

While the respective authors of these two reports largely agree with each other on the geological interpretation of the Palaeogene sequences, there are some differences in the lithostratigraphical schemes presented in the two reports. In some instances these differences reflect different interpretations of stratigraphical relationships or different judgements about the status (especially the rank) of the units described. In others, they reflect differences in approach by geological surveyors and by stratigraphers.

Stratigraphers seek to base their lithostratigraphical interpretations on the highest quality data, from good exposed sections and cored boreholes. However, outside of BGS their work does not, in general, include systematic geological mapping of the units defined by that work.

The BGS 1:50 000 scale geological maps show units that can be recognised in the field, within the limitations of normal field survey in country where geological exposures are rare. While BGS may accept a certain stratigraphical interpretation of a particular section, it will not adopt a stratigraphical subdivision that cannot be traced across largely unexposed ground in favour of one that can.

Indeed, the concept of ‘mappability’ contributes to the definition of a ‘formation’, although what can be mapped with useful accuracy depends on several factors including the scale of mapping. Moreover, it can be argued that (in general) a stratigraphical boundary that is reflected by topographical features is a better indication of broad lithological assemblage than one that is not. The current geological maps show lithostratigraphical units that can be traced in the field, and this BGS framework report primarily reflects what is shown on the geological maps.

However, the evolving change within BGS from production of geological maps based mainly on survey of surface information to production of 3D geological models based largely on available subsurface information (mainly borehole records) may bring about a change in emphasis, and it is possible that stratigraphical interpretations based on exposed sections will then prove to be more useful than those based on ‘mappability’ in open ground. For this reason, amongst others, this report refers to alternative stratigraphical interpretations where appropriate.

1.3 PALAEOGEOGRAPHY AND DEPOSITIONAL BASINS

An overview of the Palaeogene depositional basins in the United Kingdom and adjacent offshore areas is given by King (2006, pp.395–396 and 400–440).

The London Basin forms the middle and lower parts of the Thames Valley and also underlies Essex and coastal areas of North Kent[2], extending eastwards offshore into the southern North Sea Basin. The Late Paleocene to mid-Eocene successions that occur in these onshore areas were deposited mainly in near-shore marine to coastal plain environments, although a

[2] This report refers to the areas of the traditional English counties, prior to the formation of the modern Boroughs, Districts and Unitary Authorities.

relatively deep-water marine unit (the London Clay Formation) was laid down during times of high sea level in the Ypresian.

The Palaeogene sequences of the London Basin thin northwards over a poorly-defined structural axis in southern Suffolk (the Ipswich-Felixstowe High; Jolley, 1992) and thicken into East Anglia. The onshore occurrence of the Palaeogene in East Anglia coincides approximately with the local western margin of the southern North Sea Basin, and comprises Late Paleocene and Early Eocene deposits of marine origin. These crop out in south-east Suffolk, but otherwise are mostly unconformably overlain by formations of Pliocene age (McMillan et al., 2011) and more generally by Quaternary deposits.

At the present day, the London Basin (as defined by the extent of the onshore Palaeogene outcrop as far north as the Ipswich-Felixstowe High) is elongated south-west to north-east, parallel to a regional set of linear structures in the pre-Mesozoic basement of the region (Figure 1). This is seen most clearly at the end of the Chalk dip slope between Reading and Ipswich, and on the southern edge of the London Basin between Guildford and south-east London with the parallel Wimbledon to Greenwich fault system. The Hampshire Basin lies along strike to the south-west, on the same structural trend. This set of structures can be expected to have controlled basin formation.

The southern margin of the London Basin, however, is extensively controlled by east-west structures related to Late Cretaceous to Miocene inversion of the Mesozoic Weald Basin and reactivation of underlying fault structures in the Variscan fold belt of southern England, so creating the London Basin synform (Figure 1). These east-west structural elements, including anticlinal and monoclinal folds and faults, occur in West Berkshire and North Hampshire, in the Hog's Back area of Surrey, between central London and the Isle of Grain, and in the Isle of Thanet in north-east Kent. In West Berkshire the northern margin of the basin also follows this trend. These east–west segments are offset by structures parallel to the south-west – north-east trend.

Chadwick (1993) regarded the London Basin as a foreland basin on the northern margin of the inverted Wealden Basin, but viewed in a broader context it is clearly a south-western extension from the southern North Sea towards depocentres in the Western Approaches. The London Basin can be perceived as an east–west-oriented syncline but it is more usefully described as a north-east–south-west-oriented synform.

King (2006, and in prep.) refers to a long-running debate about structural control of the London Basin and the extent to which the present outcrop reflects the shape of the original basin. He concludes that during the Eocene, at least, the London Basin and the Hampshire Basin were part of a single depositional basin, while noting that there may have been limited tectonic control of Palaeogene sedimentation. Given the similarities between the sequences in the two areas, it does seem likely that they formed a single essentially continuous depositional basin. However, the terms 'London Basin' and 'Hampshire Basin' are retained as convenient terms to refer to geographically-separated structural entities.

1.4 STRATIGRAPHICAL FRAMEWORKS

This report is specifically concerned with lithostratigraphy but many other aspects of the stratigraphy of the Palaeogene have been studied in considerable detail. The following notes are summarised from Knox (1996a) and Ogg et al. (2008), and from the other cited sources. The various stratigraphies are also discussed and summarised by Daley (1999a) and, in more detail, by King (2006) and King (in prep.).

1.4.1 Chronostratigraphy

The subdivision of the Palaeogene into epochs and stages has evolved during the course of research over the past century or so, in terms of the number of divisions, their names, their defining concepts and the perception of their geochronometric age. The currently accepted scheme is shown in Table 1. Care should be taken over usage when considering the correlation of these units as described in older literature.

King (2006, p.397) points out that the base of the Eocene has been placed at the base of a prominent global negative carbon isotope excursion (Aubry et al., 2003), and that in southern England this lies within the Lambeth Group (Collinson et al., 2003). However, he also points out that the base of the Ypresian, the earliest Eocene stage, lies at approximately the base of the London Clay Formation. There is thus a time interval, during which the upper part of the Lambeth Group was deposited, which is currently not assigned to a named stage.

1.4.2 Biostratigraphy

Comprehensive micropalaeontological schemes of biostratigraphical zonation exist for several faunal or floral groups, including planktonic and benthonic foraminiferids (King, 1989; King and Hughes, 1983), calcareous nannofossils (Aubry, 1986; Aubry et al., 1996; Ellison et al., 1996; Ellison et al., 2004; Knox et al., 1994), radiolaria, diatoms (King, 2006; Mitlehner, 1996), dinoflagellate cysts and other palynomorphs (Islam, 1983; Jolley, 1992, 1996; Jolley, 1998; King, 2006; Powell, 1992; Powell et al., 1996), and molluscs (Curry, 1966; King, 1981, 2006). Some groups are of limited applicability in some environments, and some present difficulties of correlation between deep-water and shallow-water facies, so that the zonal schemes applicable to the whole of north-west Europe, for example, are less detailed than those developed for individual basins. Palynomorphs seem to provide the most effective means of cross-regional correlation. Macrofossil schemes based on mammal faunas are available for each continent (Hooker, 1991, 1996, 1998, 2010; Vasileiadou et al., 2009).

The marine faunas of the Hampshire and London basins are related to those of the North Sea Basin, which reflect its partial isolation from the open ocean and the fact that its main opening was at a relatively high latitude, so that the oceanic influence it received was from the cooler northern ocean, rather than from lower latitudes in the Atlantic (King, 2006).

1.4.3 Magnetostratigraphy

During most of the Palaeogene, the resolution of magnetic polarity chrons is comparable with that of microfossil zones, although the polarity remained constant over certain relatively long periods, notably including the Paleocene-Eocene boundary (Ali, 1994; Ali et al., 1996; Ali and Jolley, 1996; Ali et al., 1993; Ali et al., 2003; Ellison et al., 1996; Rhodes et al., 1999; Townsend and Hailwood, 1985).

The magnetostratigraphy of individual units in the London Basin is summarised from these sources, together with some unpublished data, by King (in prep.), who notes that calibration of some Early and Middle Eocene units in the London Basin is based partly on lithostratigraphical correlation with the Hampshire Basin, where available biostratigraphical and magnetostratigraphical data are more extensive.

1.4.4 Stable-isotope stratigraphy

Variations in the stable isotopes of carbon and oxygen in oceanic carbonate-rich sedimentary sequences, in particular, have been used to interpret global climatic variation during the

Cenozoic, and can be of value in correlation. Certain periods of exceptional warming are associated with global 'dissolution events' found in oceanic sequences, notably the PETM (Paleocene-Eocene Thermal Maximum), at the start of the Eocene (Beerling and Jolley, 1998; Collinson et al., 2003). Other examples are mentioned by Ogg et al. (2008) and discussed in references therein.

1.4.5 Radiometric dating

Radiometric dating has been performed on minerals of volcanic origin and on glauconite (Curry and Odin, 1982). Aside from providing calibration of the time-scales, the age of volcanic material helps to demonstrate the relationship between phases of volcanism and the tectonic and sea-level history of the region as shown by the sedimentary successions.

1.4.6 Tephrostratigraphy

As more ash layers have been found, especially in offshore successions, so their value as a long-distance correlation tool has been recognised and developed. Several phases of ash deposition have been recognised, with compositional changes that can be related to the development of crustal rifting in the north-east Atlantic (Knox, 1984, 1985, 1996a; Knox and Ellison, 1979; Knox and Morton, 1988; Morton and Knox, 1990).

1.4.7 Cyclic stratigraphy

Rhythmic variation in carbonate or clay content in deep sea sediments has been correlated with the various Milankovitch cycles for much of the Palaeogene (Ogg et al., 2008; Westerhold et al., 2009; Westerhold et al., 2008).

1.4.8 Sequence stratigraphy

Analysis of global sea-level variation and correlation of the corresponding sedimentary successions has been a very useful tool for stratigraphical analysis, and in hydrocarbons exploration. However, as Knox (1996a, b) points out, the Palaeogene sequence stratigraphy of north-west Europe should not be considered without reference to the tectonic development of the region, influenced as it was by crustal rifting in the North Atlantic and crustal compression in the Alpine zone.

1.5 THE BGS LEXICON OF NAMED ROCK UNITS

The BGS Lexicon of Named Rock Units, sometimes also known as the BGS Stratigraphic Lexicon or simply 'the Lexicon', is a digital database that defines stratigraphical terms that appear on BGS maps and in other BGS publications. Further information can be found on the BGS website, which also provides free access to the Lexicon (http://www.bgs.ac.uk/Lexicon/home.html).

Each unit in the Lexicon is given a unique alphabetical or alphanumeric computer code that identifies the unit in digital applications, including digital geological maps such as DiGMapGB. In this report, the code is given in parenthesis after the unit name in section headings. The codes are also listed in the Appendices of this report. The Lexicon Code, or 'Lex Code', is commonly not the same as the 'Map Code', which is a non-unique code used to identify a geological unit on the face of a non-digital BGS geological map.

The Lexicon is complementary to the BGS Stratigraphical Framework Reports, of which this is one. Published Stratigraphical Framework Reports can be downloaded free of charge from the BGS website (http://www.bgs.ac.uk/downloads/browse.cfm?sec=1&cat=2).

1.6 CONVENTIONS

In the text and definitions below, National Grid References are given in square brackets, with the 100-kilometre grid square denoted by its Ordnance Survey two-letter code.

Onshore boreholes are identified by the BGS Registration Number in the form SP57SW9 where the first six characters indicate the 1:10 000 National Grid sheet.

BGS 1:50 000 (or 1:63 360) scale sheet numbers are given in parentheses after the sheet name in the form Cirencester (E&W 235) or Broadford (S 71W) indicating England & Wales or Scotland sheets, respectively.

2 An introduction to the Palaeogene Groups of southern England and some terminological conventions

2.1 PALAEOGENE GROUPS IN SOUTHERN ENGLAND

This stratigraphical framework uses four well-established major subdivisions for the London Basin, three of which extend into the Hampshire Basin: the Bracklesham Group, the Thames Group and the Lambeth Group. In the central and eastern part of the London Basin and in East Anglia, the Lambeth Group is underlain by the oldest subdivision, comprising onshore components of the Montrose Group (Table 2).

2.2 ‘LOWER LONDON TERTIARIES’

In some areas, notably the north-eastern part of the London Basin, it has proved difficult to subdivide the strata between the Chalk and the London Clay with confidence and at times they have been assigned to a broad category known as the ‘Lower London Tertiaries’ (Prestwich, 1852), corresponding to strata between the Chalk Group and the London Clay. This term survives on some published geological maps covering northern Essex. It should be taken to refer to ‘undifferentiated Harwich Formation, Lambeth Group and Thanet Formation’ and this composite term should now be preferred, if such an expression is required.

2.3 ‘PEBBLES’ AND ‘GRAVEL’

Historically, clasts found in British Palaeogene deposits that are larger than sand-size and smaller than cobbles have been described as ‘pebbles’. This use is reflected in much of the literature, including many BGS reports. The term ‘pebble’ was defined in the Udden-Wentworth scale as having a diameter between 2 mm and 64 mm. A modified form of the Wentworth scale used by BGS geologists also includes the term ‘granule’ for very fine gravel between 2 mm and 4 mm in diameter.

Some descriptions, however, prefer the term ‘gravel’, and this has been adopted by the geotechnical industry, which uses ‘gravel’ to describe clasts between 2 mm and 63 mm in diameter.

In practice, although many existing descriptions have used the term ‘pebble’ without reference to a particular definition, ‘pebbles’ and ‘gravel’ can normally be treated as interchangeable with no significant loss of accuracy. In this report, ‘pebble’ is used to honour long-established use (as in ‘Blackheath Pebble Beds’ and the like), and ‘gravel’ is used in formal descriptions of lithology. It should be borne in mind, however, that such descriptions are generalised and are not based on systematic grain size measurements.

Although both ‘pebble’ and ‘gravel’ are defined according to size and not to shape, vernacular use of ‘pebble’ carries a connotation of being rounded.

2.4 ‘TERTIARY PEBBLES’

Most, if not all, of the Palaeogene formations described in this report include a component of gravel of very characteristic appearance, sometimes referred to colloquially as ‘Tertiary pebbles’ (that is, pebbles in – or derived from – Cenozoic, or Tertiary, deposits).

These pebbles are typically composed almost exclusively of flint. The clasts are typically very well-rounded and subspherical in shape, commonly with a surface network of numerous short arcuate or crescentic percussion fractures known as ‘chatter marks’. These features arose in very high-energy coastal depositional environments (Gibbard, 1986; Plint, 1982) and essentially similar pebbles and cobbles can be found on many modern beaches in the region, for example on the Sussex coast. Where not bleached or stained by Quaternary weathering, they are generally black or dark grey in colour although some have a green-coloured glauconitic veneer, or have been stained red.

The pebbles are most abundant in some ‘pebble beds’ in the Upnor Formation and Harwich Formation but gravelly layers, or in some cases pebble strings or isolated clasts, occur at unit bases in most of the other formations. Isolated pebbles are recorded in some boreholes in the Thanet Formation in London.

In the following descriptions, references to gravel or ‘pebbles’ should be taken to refer to ‘Tertiary pebbles’, unless otherwise stated.

3 Lithostratigraphy of the London Basin and East Anglia

3.1 MONTROSE GROUP (MONT)

This unit was defined by Deegan and Scull (1977) (see also Knox and Holloway, 1992) to encompass the offshore Lista and Maureen formations in the North Sea Basin. King (in prep.) has proposed that it be extended to include the partial lateral equivalents onshore, namely the **Thanet Formation** (previously the Thanet Sand formation) and the **Ormesby Clay Member**, previously classified as a formation but now assigned to the Lista Formation. This proposal is adopted here.

Offshore, the Montrose Group is characterized by mudstones that are variable in character but which differ from those of the overlying Moray Group in containing an abundant microfauna and in being poorly bedded, non-pyritic and mostly non-carbonaceous. Sandstones deposited as submarine fans are also present, as are subsidiary limestone and tuff. In its type area it comprises the Lista Formation and the Maureen Formation, of which only the Lista Formation extends into the more southerly parts of the Southern North Sea. A systematic description is beyond the scope of this report.

3.1.1 Thanet Formation (TAB)

Name

The term ‘Thanet Formation’ was introduced by Ward (1978), following ‘Thanet Beds’ (Whitaker, 1866) and ‘Thanet Sands’ (Prestwich, 1852). The definition was broadened to apply to a larger area by Ellison et al. (1994), who also modified the name to ‘Thanet Sand Formation’. The name is taken from the Isle of Thanet, north-east Kent (Prestwich, 1852).

Although much of the unit is composed of fine-grained sand, in the London area it comprises a coarsening-upwards sequence, in which the lower parts are more silty and clayey than sandy. The clay content of the upper part of the formation may be as little as 10 per cent, but even this can significantly affect its behaviour with respect to civil engineering works. The term ‘Sand’ has therefore proved to be misleading in some contexts. Indeed, in the type area in Kent, several members have been recognised, none of which are dominated by their sand content (Ward, 1978). Therefore it is proposed here and in King (in prep.) that the unit name should revert to ‘Thanet Formation’.

Previous names

Thanet Beds (Whitaker, 1866), Thanet Sands (Prestwich, 1852), Thanet Sand Formation (Ellison et al., 1994).

Type section

Co-stratotype: Cliffs near Little Cliffsend, Pegwell Bay, Kent [TR 3545 6440] (Curry, 1981; Daley, 1999b; Ward, 1977) expose the lower part of the formation.

Co-stratotype: Cliffs and foreshore east of Herne Bay, Kent [TR 203 687 to 215 693] (Curry, 1981; Daley, 1999b; Ward, 1978) expose the upper part of the formation as Beds A to I of Ward (1978), probably with several metres overlap with the more proximal sequence at Pegwell Bay (Knox et al., 1994, p.49). See also King (in prep.).

Reference sections

Reference section: Charlton Pit (or Gilbert's Pit), just south-west of Maryon Park, Charlton, London Borough of Greenwich [TQ 418 786] (Daley, 1999b; Ellison et al., 1994; Whitaker, 1889)

Reference section: Loats Pit, Blackheath, London Borough of Lewisham [TQ 382 766] (Greater London Authority, 2009)

Reference section: Cray Valley Golf Course sand pit, London Borough of Bromley [TQ 489 692] (Greater London Authority, 2009)

Reference section: Bradwell Borehole 217 (TM00NW43) [TM 01769 09156], Essex, from 60.2 to about 82.3 m depth (Jolley, 1992, p. 211)

Reference section: Stanford-le-Hope Borehole (TQ68SE33) [TQ 6965 8241], Essex, from 29.04 to 57.05 m depth (Lake et al., 1986)

Reference section: Jubilee Line Extension Borehole 404T (TQ37NW2118) [TQ 33638 79604], Bermondsey, London, 41.1 to 53.05 m depth, (Ellison et al., 1994) (Front cover illustration)

Formal subdivisions

In Kent the Thanet Formation has been subdivided into five members (Siesser et al., 1987; Ward, 1977, 1978), following Whitaker (1872), Gardner (1883) and Haynes (1956). These units have been named the **Base Bed Member** (which includes the **Bullhead Bed**), the **Stourmouth Silt Member**, the **Kentish Sands Member,** the **Pegwell Silt Member** and the **Reculver Sand Member**. These subdivisions are described in the following section.

A revised lithostratigraphical subdivision of the Thanet Formation is presented by King (in prep.) but not adopted here. His newly defined members are named in the following descriptions.

Lithology

Typically composed of homogeneous, bioturbated, glauconitic silty fine-grained sand, with sandy silt, silt or sandy, silty clay especially in the lower part, forming a coarsening-upwards sequence. The deposits are generally pale yellow-brown in colour, typically with a 'peppering' of dark-coloured glauconite grains. Sparse white mica occurs throughout. Rare coarse gravel is present in places in London. Patchy calcareous, siliceous or ferruginous cement occurs locally. A thin gravel and cobble bed (the 'Bullhead Bed') is generally present at the base. It comprises unworn green-coated flints in a matrix of green, glauconite-rich clayey sand. Dispersed and degraded volcanic ash occurs at least locally in the Thanet Formation (Ellison and Lake, 1986; Knox, 1979).

In Kent, the top of the formation can locally include some medium- to coarse-grained sand, and a shelly bed occurs near Goodnestone (Holmes, 1981). However, the formation is generally more sandy in the west, and less sandy and more silty and clayey in the eastern parts of the London Basin, including parts of North Kent. In the western part of its subcrop, the Thanet Formation is composed of fine- to medium-grained glauconitic sand with a thin basal gravel bed.

Mudstone is present in the upper part of the formation in north-east Essex, for example at Bradwell, indicating the start of the lateral northwards transition into the Ormesby Clay Member. Pink and red-coloured silts just above the base of the Thanet Formation in the Ipswich area are correlated with red clays (Unit OC2) in the Ormesby Clay Member (Jolley, 1992).

Genetic interpretation

The Thanet Formation was deposited on an inner to outer marine shelf, above fair-weather wave base (Ellison et al., 1994). The heavy mineral content of the sands suggests a Scottish provenance, in contrast to that of the overlying Upnor Formation, but similar to that of most of the younger Palaeogene formations (Morton, 1982).

Knox (1996b) considers the Thanet Formation to represent deposits laid down during up to three regionally-developed marine transgressive cycles. The base of the Reculver Sand can be correlated with one of these sequence boundaries and so appears to be of regional significance (Knox et al., 1994).

Definition of upper boundary

Overlain unconformably by the Upnor Formation (Lambeth Group) in most areas but by the Reading Formation (Lambeth Group) in parts of Essex. Generally, an upwards change from yellow-brown, glauconitic silty fine-grained sands of the Thanet Formation to greenish glauconitic medium- to coarse-grained, locally gravelly, variably clayey sand of the Upnor Formation. In the type section and in some other places, the grain-size contrast is less and the boundary correspondingly more difficult to identify.

Definition of lower boundary

Base of basal sandy, clayey flint gravel bed, which rests on the Chalk Group, often on an irregular, karstic surface modified by dissolution in groundwater.

Thickness

In central London, the Thanet Formation is typically 10 to 15 m thick, diminishing westwards to where it is overstepped by the Lambeth Group in west London and Surrey. The formation is generally thicker in the eastern parts of the London Basin, and 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 (Hester, 1965; Smart et al., 1966). In places significant parts of the Thanet Formation have 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).

The Thanet Formation thins northward to less than 2 m over the Ipswich-Felixstowe structural axis, just south of the lateral transition into the upper part of the mudstone-dominated Ormesby Clay Member to the north. In much of south-east Suffolk, the upper parts of the Thanet Formation were eroded prior to deposition of the Upnor Formation but thicker, more complete sections occur in the Dedham Mill [TM 0568 3358] and Flatford Lock [TM 0762 3326] boreholes, neither of which is registered at BGS (Jolley, 1992).

Distribution

Central and eastern London Basin, as far north as southern Suffolk, where it passes laterally into the Ormesby Clay Member. To the west of London, the Thanet Formation is overstepped by the Upnor Formation.

Age

Late Paleocene; early to mid-Thanetian (Blake, 1903; Ellison et al., 1994; King, in prep.).

3.1.1.1 Subdivisions of the Thanet Formation

The Pegwell Bay section of East Kent has been subdivided into four members (Siesser et al., 1987; Ward, 1977, 1978), following Whitaker (1872), Gardner (1883) and Haynes (1956). These units have been named the **Base Bed Member** (which includes the **Bullhead Bed**), the **Stourmouth Silt Member**, the **Pegwell Silt Member** and the **Reculver Sand Member**. According to sections constructed by Whitaker (1872) and Gardner (1883) (reproduced by Ward, 1977), the Stourmouth and Pegwell silt members extend westwards through Sittingbourne, where they become separated by a fifth member, the **Kentish Sands Member**, which progressively replaces them westwards, becoming the typical facies in the London area. The Reculver Sand is cut out beneath the overlying Woolwich Formation in the vicinity of Sittingbourne. The Pegwell Bay section and its correlation is also discussed by Daley (1999b).

Subsequent opinions differ about the confidence with which these units can be traced through North Kent. Surveys in the Canterbury district found that the Base Bed, the Pegwell Silt and the Reculver Sand occur throughout, but that although recognisable locally, the Stourmouth Silt and Kentish Sands seem to appear less consistently (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 (as is typical for the Thanet Formation in general), but considered that otherwise it is not possible to subdivide the formation. He stated that ‘lateral variations are considerable, if local’.

A review of borehole records in this area 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 (Aldiss and Farrant, 2002), which appears to be the lateral continuation of the Pegwell Silt. 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 natural gamma log from the Graveney Monkshill Borehole (TR06SE31) [TR 0572 6288] suggests that it also persists to the north of Faversham.

Westwards from Sittingbourne a similar relationship is found as to the east of Faversham, with the sand apparently wedging in from the south. 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 (Dines et al., 1971). 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.

Base Bed Member (BSBD)

The Base Bed Member (formally defined by Ward, 1977), previously known as the Thanet Base-bed (Whitaker, 1866), comprises glauconitic, very fine-grained sand and silt, some clayey, with scattered flint gravel, and with a layer (about 1 m thick) of glauconite-coated, pitted and fractured angular flint gravel and cobbles at the base. The basal gravel corresponds to the **Bullhead Bed (BLHB)**. Ward (1977) named the overlying glauconitic sand the **Cliffs End Greensand Bed (CEGB)**. Dispersed volcanic ash that occurs in the basal Thanet

Formation (Ellison and Lake, 1986; Knox, 1979) can be attributed to pyroclastic Phase 1 of (Knox and Morton, 1983).

This unit corresponds to the Lower Division of the Bradwell area of north-east Essex comprising about 10 m of fine-grained glauconitic sand above the Bullhead Bed (Knox, 1996b).

This unit has been re-named the Redcliff Member by King (in prep.), who states that it underlies his Pegwell Member or his Reculver Member. However, the name 'Redcliff' is already in use; for a formation and a member in the Jurassic succession elsewhere in England.

The **Bullhead Bed** is a distinctive unit that is commonly present at the base of the Thanet Formation. The name (in some form) dates from the 19th century (Curry, 1958). The Bullhead Bed usually comprises small well-rounded flint gravel ranging in size and shape to cobbles and fine boulders of unworn nodular flint, within a dark greenish grey or black glauconitic sandy clay or clayey sand matrix. The flint nodules (the 'bullheads'), which can be up to 0.3 m in diameter, are characteristically green-coated. Fossils derived from the Chalk occur in places. The unit is generally up to 0.5 m thick, but in parts of North London it is up to 1.5 m thick, with an average of about 1 m (Newman, 2009, p.18).

The Base Bed Member is early Thanetian in age, and is inferred to represent Zone NP6 by inference from magnetostratigraphy (Ali and Jolley, 1996; Knox et al., 1994) and dinoflagellate cyst occurrence (Jolley, 1992; Powell et al., 1996).

Stourmouth Silt Member (STMH)

The Stourmouth Silt Member, formerly the Stourmouth Clays of Haynes (1956), comprise a unit up to 4.4 m thick of interbedded greenish or greyish brown glauconitic silt, some sandy, and silty clay. A thin pink to reddish-brown layer that occurs in the Bradwell area of north-east Essex (Knox, 1996b) is probably regionally developed (Jolley, 1992).

Pegwell Silt Member (PGWS)

The Pegwell Silt Member, formerly the Pegwell Marls of Haynes (1956), comprising interbedded silty sands, some clayey, and sandy or silty clays with sparse bivalve fossils, is about 13 m in thickness, diminishing westwards.

Generally, this unit has been differentiated only in north-east Kent but according to King (in prep.) similar lithologies comprise almost the entire thickness of the Thanet Formation in south-east and north-east Essex, and occur below the Kentish Sands Member in west Kent and south-west Essex (King, in prep.).

King (in prep.) considers that the distinction between the Stourmouth Silt Member and the Pegwell Silt Member is doubtful and merges them as his Pegwell Member. In north-east Essex and south-east Suffolk he recognises a Bradwell Member (corresponding to unit BT2a of Knox et al., 1994) comprising up to about 4 m of glauconitic medium- to coarse-grained sand, which he infers infills an incised channel within his Pegwell Member. He points out that the same unit is present in the Dedham Mill Borehole (not registered at BGS) [TM 0568 3358] (Jolley, 1992) and that in parts of south-east Suffolk it forms the highest part of the Thanet Formation. Here it has apparently at times been misidentified as the Upnor Formation.

In the Bradwell area, the portion of King's Pegwell Member (the 'lower tongue') below the Bradwell Member comprises about 8 m of silt and very fine-grained sand. The 'upper tongue' comprises about 8 m of glauconitic silt and clayey silt.

The Pegwell Silt diminishes in thickness westwards but is recognisable in east London as a thin layer overlying the Bullhead Bed (King, in prep.).

The Stourmouth Silt and the Pegwell Silt are both early to mid-Thanetian in age (NP6 to NP8), based on microfossils (especially nannofossils) (King, in prep.) and magnetostratigraphy (Ali and Jolley, 1996).

Kentish Sands Member (KNTS)

Previously known as the ‘Kentish Sands’ (Ward, 1977), this is the typical representation of the Thanet Formation from near Chatham westwards through London, comprising mostly silty fine-grained sand, becoming more clayey downwards (Haynes, 1956) and passing transitionally into the Pegwell Silt Member. It is mainly non-calcareous.

King (in prep.) considers the unit to be of early to mid-Thanetian age, based on dinoflagellate cysts and its inferred lateral passage into the upper part of the Pegwell Silt Member.

The ‘Kentish Sands’ are incorporated in the Reculver Member by King (in prep.).

Reculver Sand Member (RCLV)

The Reculver Sand Member, formerly the Reculver Silts of Haynes (1956), typically comprises cross-bedded fine-grained sands, or bioturbated silty sands and sandy silts, some glauconitic, with scattered shells or shelly lenses. A thin calcareous sandstone is present at Herne Bay (Bed B of Ward, 1978). The mineralogy of sediments from the equivalent interval in north-east Essex indicates a component of altered volcanic ash (Ellison and Lake, 1986). The unit overlies the Pegwell Silt Member at a sharp contact, with a basal shell bed in places (King, in prep.).

This unit is re-defined by King (in prep.) and named the Reculver Member. It is mid-Thanetian in age (NP8), based on microfossils (especially nannofossils) (King, in prep.) and magnetostratigraphy (Ali and Jolley, 1996).

King (in prep.) also introduces the Faversham Member for the highest part of the Thanet Formation in east Kent (corresponding to Beds E to I of Ward, 1978), noting that previously it was regarded either as part of what is here referred to the Reculver Sand Member or of the Woolwich Formation (Haynes, 1956; Holmes, 1981). It comprises silty and clayey sand that is coarser and more poorly sorted than the underlying Reculver Member, with coarser-grained glauconite, siliceous concretions and silicified molluscs at some levels. King (in prep.) notes that ‘at outcrop the Faversham Member has in places been confused with the overlying Upnor Member, which is a superficially similar glauconitic sand. The Upnor Formation in this area [i.e. in north Kent] is, however, generally more heterogeneous, often with clay streaks and *Ophiomorpha* burrows, partly cross-bedded and with gravel at the base. None of these features is seen in the Faversham Member.’

King (in prep.) points out that a thin unit of ‘waxy’ silty clay, with glauconite at the base, has been identified only in boreholes at Bradwell (Sequence OTh4 of Knox, 1996b) but could be more widespread. It forms the top of the Thanet Formation and has been oxidised and decalcified, probably by weathering prior to the deposition of the Lambeth Group.

3.1.2 Lista Formation (LIST)

The Lista Formation was originally described from sequences in the Central and Northern North Sea (Deegan and Scull, 1977; Knox and Holloway, 1992) but Lott and Knox (1994) extended its geographical range to include the Southern North Sea. There it mostly comprises marine clays that are sandy in their lower part, commonly with a thin flint conglomerate at the base, where it overlies the Chalk Group.

King (in prep.) has pointed out that the Ormesby Clay should be assigned to the Lista Formation, so extending the latter onshore. No other components of the Lista Formation are present in southern or eastern England and its systematic description is beyond the scope of this report.

3.1.2.1 ORMESBY CLAY MEMBER (OC)

Name

This unit was defined as the Ormesby Clay Formation by Ellison et al. (1994), following the informal introduction of the 'Ormesby Clay' by Knox et al. (1990). The name is taken from the village of Ormesby St Margaret, Norfolk, which is close to the type section. It mainly comprises glauconitic marine mudstone forming the basal part of the Palaeogene succession in Norfolk and Suffolk.

Previous name

Originally known as the Ormesby Clay. The unit was considered to be part of the 'Thanet Beds' when originally described by Cox et al. (1985).

Type section

The type section is the Ormesby A Borehole (TG51SW7A) [TG 5145 1425], between 112.4 m and 139.85 m depth (Cox et al., 1985; Knox et al., 1990)

Reference sections

Reference section: Hales Borehole (TM39NE7) [TM 3671 9687], Norfolk, from 32.18 to 57.77 m depth (Jolley, 1996, fig. 9; Knox, 1996b; Knox et al., 1990)

Reference section: Sizewell C3 Borehole (TM46SE42) [TM 4735 6402], Suffolk (Ellison et al., 1994)

Formal subdivisions

None. Four informal subdivisions, designated OC1, OC2, OC3 and OC4, were recognised by Knox et al. (1990)

Lithology

Variably glauconitic, partly calcareous clay, commonly silty at the base, with a basal gravel bed. The gravelly bed is typically between 0.1 and 0.2 m thick, comprising unworn green-coated flints in a matrix of bright green, glauconite-rich sand or sandy silt. The mudstone is intensively bioturbated, blocky and poorly bedded. It is mostly pale grey to dark greenish grey but also includes a bed of red-grey mudstone and thin bands of grey-green mudstone. Sporadic, thin altered tephra layers occur in the lower part (Ellison et al., 1994). The Ormesby Clay differs from offshore portions of the Lista Formation principally in containing significant glauconite (King, in prep.)

Genetic interpretation

Marine; outer neritic to upper bathyal (King, in prep.)

Definition of upper boundary

The top of the Ormesby Clay is an erosion surface (King, in prep.). The uppermost few centimetres commonly includes burrows filled from the overlying sediment.

In Norfolk and parts of Suffolk, an upwards change from bioturbated glauconitic clay to dark grey-brown, laminated sandy clay or muddy sand of the Upnor Formation (previously the Hales Clay).

In southern Suffolk, an upwards change to interbedded medium-grained sand and laminated grey-green mudstone of the Upnor Formation.

Definition of lower boundary

Base of the basal sandy flint gravel bed, which rests unconformably on the Chalk Group.

Thickness

27.45 m in the type section, reducing to about 10 m at Sizewell, Suffolk. Assumed to thin further southwards towards the Ipswich–Felixstowe High (Boswell, 1915; Jolley, 1992).

Distribution

Onshore East Anglia in subcrop only, from the Ipswich–Felixstowe axis northwards. The upper part of the Ormesby Clay passes southwards into the Thanet Formation, a more proximal marine facies, between Ipswich and Sizewell, across the Ipswich–Felixstowe High (Ellison et al., 1994; Jolley, 1992). The lower part of the Ormesby Clay is cut out onto this structural axis and comprises a sequence not represented to the south in the Thanet Formation (Knox, 1996b; Knox et al., 1994).

The southernmost occurrence is grey mudstone found near Bramford, just north-west of Ipswich [TM 1300 4780] (Ellison et al., 1994; Jolley, 1992).

The Ormesby Clay extends eastwards into the North Sea where, together with the Thanet Formation, it is a part equivalent of the Lista Formation (King, in prep.).

Age

Late Paleocene (Ellison et al., 1994) and references therein. Late Selandian to mid-Thanetian (King, in prep.), based on dinoflagellate cysts (Zone DP10 to Subzone DP11b) (Jolley, 1992).

3.2 LAMBETH GROUP (LMBE)

Name

The Lambeth Group crops out around the periphery of the London Basin. It was defined by Ellison et al. (1994) and named after the London Borough of Lambeth, in south central London, within the area where the constituent formations overlap and where ground investigations for major civil engineering works from the 1980s onwards, such as the Jubilee Line Extension, provided an improved understanding of these strata (Ellison et al., 1994; Ellison et al., 2004; Page, 1995; Page and Skipper, 2000).

Previous names

These strata were previously known as the Woolwich and Reading Series (Prestwich, 1854), the Woolwich and Reading Beds (Hester, 1965; Hull and Whitaker, 1861; Whitaker, 1866), or separately as the Woolwich Beds or the Reading Beds, depending on the local succession.

Rock beds found either at the base of the London Clay or in the Woolwich Formation during ground investigations for the Blackwall tunnel were named the **Blackwall Rock** (Bromehead, 1925, p.17; Whitaker, 1889, pp. 274-275). This name is obsolete.

Type area

Central and south London and north Kent

Reference section

As for constituent formations

Formal subdivisions

The Lambeth Group comprises three formations: the basal **Upnor Formation**, overlain by the **Reading Formation** (in the west of the London Basin and in north-east Essex and Suffolk) and the **Woolwich Formation** (in parts of the east of the London Basin). In central and eastern London, the Reading Formation is interleaved with the Woolwich Formation (Ellison et al., 2004).

The Reading Formation and the Woolwich Formation have each been divided into a number of informal members (Ellison, 1983; Ellison et al., 1994; Ellison et al., 2004). It is possible that with further work their status could be formalised and that one of them (the Upper Shelly Clay) should become a new formation (perhaps named the Brixton Formation) within the Lambeth Group.

The Lambeth Group was deposited in four depositional sequences, separated by unconformities (Knox, 1996b). The oldest includes the lower part of the Upnor Formation; the second, the upper part of the Upnor Formation and the lower part of the Reading Formation; the third, the rest of the Reading Formation and the Woolwich Formation (excluding the Upper Shelly Clay), and the last the Upper Shelly Clay (i.e. the possible new Brixton Formation).

Lithology

Vertically and laterally variable sequences mainly of clay, some silty or sandy, with some sands and gravels, minor limestones and lignites and occasional sandstone and conglomerate.

Genetic interpretation

Deposited in fluvial, estuarine, lagoonal or proximal marine environments.

Definition of upper boundary

Eroded or interburrowed surface at base of overlying Thames Group. Uppermost part of the Lambeth Group can be the Reading Formation or the Woolwich Formation, depending on the local succession, or the Upnor Formation, depending on the depth of pre-Thames Group erosion. Overlain by sands, silts, clays or gravel beds of the Harwich Formation, depending on the local sequences, or gravelly sandy clays at the base of the London Clay Formation.

Definition of lower boundary

As for the base of the Upnor Formation. In the Hampshire Basin and the west of the London Basin, the Lambeth Group overlies the Chalk Group. In the centre and east of the London Basin it overlies the Thanet Formation, and in Suffolk the Ormesby Clay Member of the Lista Formation.

Thickness

Up to 27 m in the west of the London Basin.

Distribution

Throughout the London Basin, extending into Suffolk, but apparently absent in Norfolk (Knox et al., 1990). In parts of east London, Kent and Essex, the Lambeth Group was extensively eroded prior to deposition of the Thames Group (Hester, 1965).

The Lambeth Group also occurs within the Hampshire Basin, where it mostly comprises only the Reading Formation, although there is a thin representation of the Upnor Formation, and the Woolwich Formation forms small outliers in the most easterly parts of the onshore outcrop.

Age

Late Paleocene to Early Eocene (late Thanetian to early Ypresian). Refer to constituent formations for details.

3.2.1 Upnor Formation (UPR)

Name

The formation was defined by Ellison et al. (1994). It is named after Lower Upnor village, on the north bank of the River Medway, about 3.5 km north of Chatham, Kent, where the Lambeth Group is exposed in a large sand and gravel pit.

Previous names

'Bottom Bed' of the Woolwich and Reading Beds (Hester, 1965; Hull and Whitaker, 1861); 'Reading Formation Basement Bed (RFBB)' (Edwards and Freshney, 1987), Woolwich Bottom Bed (Kennedy and Sellwood, 1970), Reading Bottom Bed (BBD) and the like. It corresponds to the 'glauconitic sand' lithofacies described by (Ellison, 1983).

Type section

Type section: Lower Upnor Pit, north of Chatham, Kent [TQ 759 711] (Daley, 1999b; Ellison et al., 1994; Kennedy and Sellwood, 1970)

Reference sections

Reference section: Charlton Pit (or Gilbert's Pit), just south-west of Maryon Park, Charlton, London Borough of Greenwich [TQ 418 786] (Daley, 1999b; Ellison et al., 1994; Whitaker, 1889)

Reference section: Jubilee Line Extension Borehole 404T (TQ37NW2118) [TQ 33638 79604], Bermondsey, London, 35.09 to 41.1 m depth, (Ellison et al., 1994)

Reference section: BGS Crystal Palace Borehole (TQ37SW671) [TQ 3379 7082], 141.95 to 145.10 m depth (Ellison et al., 2004, p.32)

Reference section: Staines 5 Borehole (TQ07SW156) [TQ 0360 7250], 129.74 to 130.11 m depth (Ellison and Williamson, 1999, fig. 6)

Reference Section: Old Cement Works, Harefield, London Borough of Hillingdon [TQ 050 899] (Cooper, 1976b; Daley, 1999c; King, 1981, fig. 32). This locality exposes a thin development of the Upnor Formation in the west of the London Basin.

Reference section: Pincent's Kiln, Theale, Berkshire [SU 6509 7203] (Crane and Goldring, 1991; Daley, 1999c)

Formal subdivisions

None.

Knox (1996b, p.216) notes that the first depositional sequence of the four present within the Lambeth Group is represented by the lower part of the Upnor Formation, and that the second is represented by the upper part of the Upnor Formation, together with the lower part of the Reading Formation. These two depositional sequences are separated by a period of uplift, tilting and local erosion, here referred to as the mid-Upnor non-sequence.

In many parts of the outcrop, it has been found that the upper and the lower parts of the formation are of contrasting lithology, with a depositional break between them. The nature of the contrast is not consistent, however, and the overall lithological assemblage is broadly similar, so it is here proposed that the 'Upper Upnor' and the 'Lower Upnor' divisions be recognised as informal members, rather than as formations.

In the type section, the 'Lower Upnor member' corresponds to Bed 3 of Kennedy and Sellwood (1970) (named by them the 'Woolwich Bottom Bed'). The 'Upper Upnor member' corresponds to Beds 4 to 7 of Kennedy and Sellwood (1970). Bed 4, which contains scattered gravel, rests on an erosion surface, here taken to mark the mid-Upnor non-sequence.

Lithology

The Upnor Formation is typically composed of variably but commonly abundant glauconitic fine- to coarse-grained sand (which can be cross-bedded, cross-laminated, laminated or bioturbated) with variable clay and silt content, and with beds, lenses and stringers of well-rounded, black flint gravel, and minor thin clays, commonly interbedded with glauconitic sand laminae and lenses. Clay intraclasts occur in places in the sands. Shelly fossils are common in unweathered sections. Sharks' teeth and rare fragments of carbonaceous material occur also.

A basal bed of rounded flint gravel up to 1 m thick is usually present, but is impersistent. In the west of the outcrop, where the Thanet Formation is absent and the Upnor Formation rests on the Chalk Group, the basal bed may include non-rolled flint nodules. Such occurrences have, at times, apparently been assigned to the Bullhead Bed (Barrow, 1919; Curry, 1958) but this term should be reserved for the basal bed of the Thanet Formation. In some areas, the upper part of the formation also includes gravel beds, which locally predominate. These can form beds up to 5 m thick, in some places, at least, infilling channel structures. In parts of London there is a persistent gravel bed at the top.

When fresh, the sands are dark grey-brown to dark green depending on proportion of glauconite grains, which may be more than 25 per cent. The sands weather to pale shades of grey-brown or yellow-brown but the glauconite remains dark green. In the central and northern London Basin pedogenic processes prior to and during deposition of the overlying Reading Formation modified the sands, resulting in development of carbonate concretions, occasional siliceous cementation, clay enrichment and colour mottling that exceptionally extend through the entire thickness of the Upnor Formation. To the east, where the Reading Formation is absent, the higher parts of the Upnor Formation have been oxidised to brown, orange, red, and purple-brown, described as the 'ferruginous sand' lithofacies by Ellison (1983). This may be associated with localised carbonate concretions; formed during a period of tropical weathering and soil formation. As discussed in Section 3.2.2.1, these pedogenically-altered facies are assigned to the 'Lower Mottled Beds' by Page and Skipper (2000).

In central London, the lower part of the Upnor Formation varies to medium laminated clay or sandy clay. It contains moderately diverse nannofossil and palynomorph associations (Ellison et al., 1996; Knox, 1996b, see also King in prep., p.37).

By contrast, the upper part of the Upnor Formation of central London is marked partly by the deposition of gravel beds in estuarine channels. These gravel beds are typically composed of black flint gravel or sometimes cobbles in pale grey fine- to medium-grained sand to firm to very stiff green sandy clay or dense to very dense clayey sand. More generally, the ‘Upper Upnor’ in central London comprises relatively clean and less glauconitic decalcified sand with thin clay beds, with low diversity microfloras indicating marginal marine environments (Ellison et al., 1996; Knox, 1996b, see also King in prep., p.37).

In West Berkshire, the lower part of the Upnor Formation comprises a glauconitic sandy gravel bed, with some beds of glauconitic clayey sand. The ‘Upper Upnor’ is represented by ‘non-pebbly’ marine fine- to medium-grained sands and silty clays around Newbury. This facies was recognised by Crane and Goldring (1991) at Cold Ash, about 5 km north-east of Newbury, and also by Skipper (1999) and Mathers and Ellison (unpublished observations, about 1997) in excavations for the Newbury Bypass, and by Newell (unpublished observations, 2003) in excavations on the A34 at Chieveley.

In the Canterbury area of Kent, the Upnor Formation comprises cross-bedded glauconitic medium-grained sand with the trace fossil *Ophiomorpha*. King (in prep.) points out that this is quite different to the beds between the Thanet Formation and the Oldhaven Member at Herne Bay (Gurr, 1962; Beds J and K of Ward, 1978), which mainly comprises, bioturbated sparsely glauconitic very fine-grained sand and clayey sand with occasional flint gravel. This was named the ‘Woolwich Marine Bed’ (Bed K) by Ward (1978), who notes that abraded fragments of wood are common while vertebrate fossils are rare. Similar beds occur at other places from Faversham eastwards. It is above a thin basal clayey glauconitic sand with dispersed flint gravel and common fish teeth (the ‘Beltinge Fish Bed’, or Bed J, of Ward, 1978). Its fauna and microflora indicate a fully marine environment.

This facies was referred to the ‘Bishopstone Beds’ by White (1931) after the type locality at Oldhaven Gap (also known as Bishopstone Glen), east of Herne Bay, to distinguish them from typical Woolwich Formation to the west. See also Curry (1958), (Holmes, 1981) and (Daley, 1999b).

Although the position of Bed K (overlying the Thanet Formation in a part of Kent where the Woolwich Formation has generally been removed by erosion) suggests that it should be correlated with the Upnor Formation (Ellison et al., 1994), King (in prep.) points out that it has reverse magnetic polarity (Townsend and Hailwood, 1985) (whereas the ‘Lower Upnor’ has normal polarity) and its marine character differs from the ‘Upper Upnor’ (and from the occurrence of the Upnor Formation near Canterbury. On this evidence, King (in prep.) suggests that it represents a sedimentary unit not preserved elsewhere.

Emergence at the end of Upnor Formation times is suggested by local presence of silcretes and of clasts of silica-cemented conglomerate at the top of the formation, as found *in situ* at Pinner (J A Skipper, oral communication, 2010). These cemented facies are also widely represented beyond the Lambeth Group outcrop as residual fragments of ‘sarsen’ (silica-cemented sandstone) and **Hertfordshire Puddingstone** (conglomerate of very well-rounded flint gravel in a matrix of silica-cemented fine-grained sand), which is known almost entirely from loose blocks on the present-day surface or material reworked into Quaternary deposits, mainly in Hertfordshire but also in other places along the northern margin of the Palaeogene outcrop (Hepworth, 1998). Curry (1958) suggests that the Hertfordshire Puddingstone (known also by various other names such as Plum-pudding Stone) is associated with pale sands of the Reading Formation. However, sparse *in situ* occurrences (including that seen in the Pinner chalk mine) suggest that it occurs at the top of the Upnor Formation (Hepworth, 1998; Lovell and Tubb, 2006). Sarsens are of much broader occurrence, especially in areas (such as the Chalk Downs of Berkshire, Sussex and Wiltshire) where the Upnor Formation is likely to have been relatively thin, and it is likely that some represent relicts of sand deposits in the Reading Formation. The age of their silicification is uncertain.

In Kent, the same episode of emergence is represented by reddening in the upper part of the Upnor Formation, with the development at the top of purple to brown, limonitic medium- to coarse-grained sandstone, the **Winterbourne Ironstone**, which in the Winterbourne Sandpit is 4 feet [1.2 m] thick (Ellison, 1983; Gamble, 1972; Smart et al., 1966).

Genetic interpretation

The Upnor Formation represents proximal marine sedimentation in predominantly high energy, partly tidally influenced environments. In contrast to that of the Thanet Formation, the heavy mineral content of the sands suggests a provenance from the south (Morton, 1982).

Definition of upper boundary

In general, marked by an upwards change from green glauconitic sand or sandy gravel to colour-mottled clays of the Reading Formation, or dark shelly clay or lignitic sand of the Woolwich Formation. Commonly, however, the Upnor Formation has been affected by contemporary pedogenic alteration associated with the mid-Lambeth Group Hiatus. Its original character may then be obscured and the contact with the overlying Reading Formation unclear. See discussion in Section 3.2.2.1.

In north and east Kent, the Lambeth Group (including the top of the Upnor Formation) was eroded prior to deposition of the Harwich Formation (Oldhaven Member).

Definition of lower boundary

In the eastern part of the London Basin, the Upnor Formation rests on silty fine-grained sand at a burrowed contact with the Thanet Formation, with burrows extending as much as 0.5 m into the Thanet Formation, or on a channelled erosion surface (King, in prep.). The Upnor Formation is likely to be composed of medium- to coarse-grained sand that is greener and commonly more gravelly than that of the Thanet Formation but in places has a confusingly similar lithology, especially where, as in the far east of the London Basin, bioturbation has produced a gradational junction (Ellison et al., 1994). According to Morton (1982), the top of the Thanet Formation has been leached during a period of exposure, probably with some erosion, prior to deposition of the Upnor Formation.

In the west of the London Basin, to the west of the Thanet Formation outcrop and subcrop, the Upnor Formation rests on a burrowed contact with chalk and flints of the Chalk Group, commonly modified by karstic dissolution.

In East Anglia, the Upnor Formation rests on a burrowed contact with the clay of the Ormesby Clay Member.

Thickness

Up to 15 m in the east of the London Basin. Typically 5 to 8 m in central London but locally as little as 2 m, generally decreasing westwards to less than 2 m.

Distribution

Occurs throughout most of the London and Hampshire basins but thins markedly to the west of London. Also occurs in north Essex, in the Bradwell Borehole 217 (TM00NW43) [TM 01769 09156] and the Shotley Gate Borehole (TM23SW19) [TM 2439 3460], and in Suffolk, in the Sizewell C3 Borehole (TM46SE42) [TM 4735 6402] (Ellison et al., 1994; Jolley, 1992, fig. 2) although these occurrences are questioned by King (in prep.).

Age

Paleocene: Late Thanetian (NP9), based on calcareous nannofossil assemblages, dinoflagellate cysts and magnetostratigraphy (Ali and Jolley, 1996; Ellison et al., 1996; King, in prep.; Knox, 1996b)

3.2.2 Reading Formation (RB)

Name

The formation is named after Reading, Berkshire, which lies at the edge of the Palaeogene outcrop in the western part of the London Basin, where the Reading Formation comprises the greater part of the Palaeogene succession beneath the London Clay, and where it was previously widely exposed in quarries for brick and tile manufacture. The term 'Reading Formation' was introduced by Curry et al. (1978) for the 'continental facies' of the 'Woolwich and Reading Beds'. This corresponds to the 'mottled clay' lithofacies identified by Ellison (1983) and Hester (1965). It was formally defined by Edwards and Freshney (1987), based mainly on work in the Hampshire Basin, as including glauconitic sands in their 'Reading Formation Basement Bed'. This report follows Ellison et al. (1994) in accepting Curry's concept of the Reading Formation and placing the basal marine facies in the Upnor Formation. No type section was identified until Ellison et al. (1994) suggested the brick pit at Knowl Hill, near Reading.

Previous names

Reading Beds; Reading Series (e.g. Hester, 1965; Prestwich, 1854); 'continental facies' of the Woolwich and Reading Beds (Curry et al. 1978); Mottled Clay (of the Reading Formation) (MCL)

Type section

Type section: Warner's Brickworks, Knowl Hill, Reading [SU 816 797] (Ellison et al., 1994; Kennedy and Sellwood, 1970)

Reference sections

Reference section: Jubilee Line Extension Borehole 404T (TQ37NW2118) [TQ 33638 79604], Bermondsey, London, 25.05 to 29.63 m and 33.77 to 35.09 m depth (Ellison et al., 1994). This borehole passes through the two parts of the Reading Formation, here separated by the Woolwich Formation. (Front cover).

Reference section: Staines 5 Borehole (TQ07SW156) [TQ 0360 7250], 106.21 to 129.74 m depth (Ellison and Williamson, 1999, fig. 6).

Reference section: Pincent's Kiln, Theale, Berkshire [SU 6509 7203] (Crane and Goldring, 1991; Daley, 1999c)

Reference section: Bolter End, Buckinghamshire [SU 7990 1919]. This exposes cross-bedded sands with gravels and intraformational mud-breccias, representing a marginal facies of the Reading Formation (Daley, 1999c)

Reference section: Old Cement Works, Harefield, London Borough of Hillingdon [TQ 050 899] (Daley, 1999c)

Formal subdivisions

There are no formal subdivisions. The informal subdivisions described by Ellison et al. (2004), the **Lower Mottled Clay** and the **Upper Mottled Clay**, are separated by a non-sequence, the mid-Lambeth Group Hiatus (Ellison, 1983, p.316; Page, 1994; Page and

Skipper, 2000). These two units are here regarded as informal members. There is potential for confusion between the 'Lower Mottled Clay' and the 'Upper Mottled Clay' of Ellison et al. (2004), and 'Lower Mottled Beds' and 'Upper Mottled Beds', which are terms introduced by Page and Skipper (2000) for what are, at first sight, the same units. However, there is an important difference in the practical application of the two sets of terms, which is discussed in Section 3.2.2.1.

King (1981) used the term 'Twyford Member' to describe a unit of fine-grained glauconitic sand with *Ophiomorpha* burrows that is present in the Reading area (Bed 5 of Kennedy and Sellwood, 1970). He tentatively placed it at the base of his Oldhaven Formation (now part of the Harwich Formation), but later work (Goldring and Alghamdi, 1999) has put it within the Reading Formation. King (in prep.) states that it is not clear if this facies represents a unit that warrants member status.

Lithology

Dominantly clay or silty clay, colour-mottled by pedogenetic processes in a humid environment (Buurman, 1980), together with lensoid channel-fill bodies of bioturbated or cross-bedded fine- to coarse-grained sand. In the clays, red hues dominate with a more or less equal proportion of blue-grey and brown. Red to purple sediments decrease towards the east where there were shorter periods of subaerial weathering and pedogenesis, and reducing conditions in ephemeral lagoons. Beds of dark grey or black clay occur locally: these may be of significance for regional correlation at the interface between the upper and the lower parts of the Reading Formation. The proportion of sand beds varies greatly, and may constitute more than half the formation, dominantly in the basal part (e.g. Crane and Goldring, 1991; Ellison and Williamson, 1999, fig. 4). Fine-grained, bioturbated to laminated glauconitic sand with *Ophiomorpha* burrows is present in the Reading area. Gravelly sands with informational mud-flake breccias have been referred to as a marginal 'Lane End facies' by Daley (1999c). See also White (1906). In parts of London, the upper part of the Lower Mottled Clay includes calcrete as diffuse nodules or as a more continuous layer of limestone.

Ellison and Williamson (1999) recognise a series of fining-upwards cycles in the Reading Formation in the Windsor district, each cycle commencing with a bed of cross-bedded sand, grading upwards into sporadically burrowed, thinly laminated silt and sand, and culminating with mottled clays with rootlet traces and nodular calcrete.

Intervals or lenses of laminated or interbedded grey silt and clay with plant fossils, notably of leaves, have been found in the Reading Formation in various localities in the north and west of the London Basin (Blake, 1903; Curry, 1958).

Blocks of very strong, sometimes extremely strong, silica-cemented sandstone known as sarsens, greywethers or by other names (and used in a number of megalithic monuments including Stonehenge and the Avebury stone circle) are thought to represent silcretes or cemented sandstones exhumed from the Reading Formation.

Genetic interpretation

The Reading Formation is considered to have been deposited mainly in various fluvial environments within a coastal flood-plain. However, Ellison et al. (1994) point out that primary sedimentary structures in the Reading Formation clays have been largely obscured, mainly by pedogenic processes, and that it is possible that some of the Reading Formation sediments originated in estuarine or other marginal marine environments.

Definition of upper boundary

The top is generally sharply defined, at an upward change from vari-coloured mottled clay to glauconitic sands and sandy clays of the Harwich Formation, or to sandy clays of the Walton Member (London Clay Formation), or to shelly grey clays of the Upper Shelly Clay (possible Brixton Formation).

Definition of lower boundary

In the London Basin, the base is marked by the upwards change from typically green, glauconitic variably clayey gravelly sands of the Upnor Formation to vari-coloured mottled clays, locally with brownish sands of the Reading Formation. In places, the boundary has been obscured by contemporary pedogenic processes, including the downwards translocation of clay and pigmentation (Ellison et al., 1994; Page and Skipper, 2000). See also Section 3.2.2.1.

Thickness

Up to 39 m (in the Guildford district, Ellison et al., 2002), generally 12 to 20 m. Occurs in two leaves in Central London. In the Farringdon area, the Lower Mottled Clay is mostly between 2 and 4 m thick, but locally more than 5 m, whereas the Upper Mottled Clay is mostly between 4 and 8 m thick (Aldiss et al., 2009).

Distribution

The Reading Formation occurs throughout the north and west of the London Basin, possibly extending into north-east Essex and Suffolk. In central London it is divided into two at the mid-Lambeth Group Hiatus, above which the Upper Mottled Clays pass laterally south and east into the Woolwich Formation. The Reading Formation is absent from north Kent and south Essex (Ellison et al., 1994).

The Reading Formation also occurs in the eastern part of the Hampshire Basin, except in the outliers in East Sussex.

Age

Early Eocene (earliest Ypresian), possibly including the latest Paleocene (Thanetian), by reference to magnetostratigraphy and stable isotope stratigraphy. The Reading Formation in London has reverse polarity (Chron C24r) except for one sample with normal polarity (Ellison et al., 1996; Townsend and Hailwood, 1985, quoted by King, in prep.). Low $\delta^{13}C$ values in calcretes in the Lower Mottled Clay in London (BH 404T) (TQ37NW2118) [TQ 33638 79604] (Front cover illustration) have been interpreted as indicating the earliest Eocene carbon isotope excursion (Thiry et al., 1998, fig. 2). The Paleocene/Eocene boundary has been placed in the Shorne Member, above the Lower Mottled Clay of the Reading Formation (Collinson et al., 2003; Collinson et al., 2007) although King (in prep.) states that the Paleocene/Eocene boundary has not been precisely located, but probably corresponds approximately to the base of the Reading Formation.

3.2.2.1 The Upper Mottled Beds and the Lower Mottled Beds

Ellison et al. (1994) and Ellison et al. (2004) described the Upper Mottled Clay and the Lower Mottled Clay as informal subdivisions of the Reading Formation. They were named according to their major lithological component, following conventions of international stratigraphical nomenclature. Although the units do include some sand, including some clean sand bodies, they are most typically composed of 'mottled clay', particularly in the type area of the Reading Formation, in Berkshire. The Reading Formation comprises non-marine deposits; underlying marine deposits are included in the Upnor Formation.

Page and Skipper (2000), however, point out that as the Reading Formation includes a very significant component of sand, either contained in discrete bodies or dispersed within the mottled clays, the names 'Upper Mottled Clay' and 'Lower Mottled Clay' are potentially misleading to those who are not familiar with the conventions of stratigraphical nomenclature. They therefore referred to the lower part of the Reading Formation as the '**Lower Mottled Beds**', and the upper part as the '**Upper Mottled Beds**'. They identified the boundary between as the 'mid-Lambeth Group Hiatus', following Page (1994).

The 'mid-Lambeth Group Hiatus' is an omission surface marking a basin-wide event with sea-level fall and subaerial exposure of the lower part of the Reading Formation (Ellison, 1983; Page, 1994; Page and Skipper, 2000). These authors recognised that the strata beneath this surface have been extensively and significantly altered by pedogenic processes at about the time of the Paleocene-Eocene boundary (Collinson et al., 2003). The land surface exposed at the mid-Lambeth Group Hiatus was subjected to bioturbation, intense weathering and pedogenic processes under tropical or subtropical climatic conditions, probably with seasonal rainfall. These processes gave rise to a variety of phenomena, including colour-mottling and shrinkage cracks of the near-surface deposits, duricrust formation (mainly the development of calcretes) and eluviation of clays into coarser deposits beneath (Front cover illustration). The shrinkage cracks probably gave rise to much of the fissuring commonly seen in borehole core from this part of the succession.

The mid-Lambeth Group Hiatus can be recognised most readily where the Woolwich Formation was deposited on the lower part of the Reading Formation, but the non-sequence can also be recognised within the Reading Formation to the west of the Woolwich Formation subcrop, and in the topmost Upnor Formation to the east of the Reading Formation subcrop. For example, in the west of the London Basin, around Newbury and Reading, the non-sequence is overlain by an organic-rich clay.

By contrast, to the east, the Woolwich Shell bed is underlain by a thin but distinctive unit, referred to by Ellison (1983) as 'Ferruginous Sand'. It is widespread in east London, south Essex and north Kent. Brown to purplish-brown coloured ferruginous medium- to coarse-grained 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 and has yielded a mixed brackish and marine fauna. 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** (Gamble, 1972; Ward, 1972). Its occurrence at the Lower Upnor Pit, by the River Medway, is described by Daley (1999b). The ferruginous cement has been attributed to localised emergence or lowering of water table during deposition, and described by Knox (1996b, p. 216) as 'pedogenic alteration and rootlet penetration of the top of the Upnor Formation'. The ferruginous sand is apparently cut out eastwards by erosion at the base of the Harwich Formation (Ellison, 1983).

Although Ellison et al. (2004, p.29 and fig.20) recognised the Upper Mottled Clay only in a relatively narrow zone between Walthamstow and Merton, where it overlies the Woolwich Formation, the 'mid-Lambeth Group Hiatus' (and by implication the subdivision into lower and upper mottled clay units appears to extend throughout the London Basin, although the lithological characters that mark it vary.

A similar effect is seen in places where the Upper Mottled Clay is relatively thin, or absent, and sediments deposited within the upper part of the Woolwich Formation are pedogenically altered. This phenomenon is apparently less widespread than beneath the mid-Lambeth Group Hiatus, however, possibly due to less extensive or prolonged subaerial exposure at that time, and probably also to erosion prior to the deposition of the Upper Shelly Clay or of the Harwich Formation.

In addition to the lithological composition of the units, there is a further, more fundamental, difference between the concepts of the 'Mottled Clays' of Ellison et al. (2004) and the 'Mottled Beds' of Page and Skipper (2000). In some places, the pedogenic effects seen in the deposits beneath the mid-Lambeth Group Hiatus penetrated the base of the contemporary non-marine deposits (or pre-dated them) and changed the character of parts of the underlying marine deposits of the Upnor Formation. Consequently, the base of the Lower Mottled Clay is commonly gradational in nature, and it can be difficult or impossible to identify with certainty in boreholes and exposed sections. Moreover, in the context of civil engineering works, the extent of pedogenically altered deposits (commonly with duricrusts) is generally more important than the nature of the deposit prior to alteration.

Therefore, Page and Skipper (2000) defined the base of their Lower Mottled Beds as the lowest occurrence of colour-mottling at this level. This is a practical expedient which aims to ensure greater consistency in borehole and section records, and which records the composition of the material as found in the ground. It means, however, that in places some sand or gravel material that was deposited under marine conditions — and which in the Ellison scheme would be included in the Upnor Formation — is included in the Lower Mottled Beds.

In other words, the base of the Lower Mottled *Beds* is defined by the consequences of post-depositional processes, whereas the base of the Lower Mottled *Clay* is defined by the consequences of the original depositional processes. The 'Lower Mottled Clay' is a lithostratigraphical unit; the 'Lower Mottled Beds', strictly speaking, is not.

This difference is significant in the context of structural interpretation of the Lambeth Group subcrop, for example by detailed 3D geological modelling, which depends to some extent on the assumption that individual layers maintain a relatively uniform thickness. As defined, the base of the Lower Mottled *Clay* would be expected to be approximately planar, and its thickness to change gradually; whereas the base of the Lower Mottled *Beds* would be expected to be non-planar (reflecting small-scale lateral variation in the depth of penetration by contemporary pedogenic processes), and its thickness to change in a correspondingly irregular way. The differences in level can be of the same magnitude as the displacement due to faulting, so it is especially important to make this distinction when trying to demonstrate the presence and patterns of faulting in the Lambeth Group. Moreover the Lower Mottled *Beds* might extend beyond the depositional limits of the Lower Mottled *Clay*.

As both conventions have practical significance and, in their respective contexts, both are important, it is here proposed that the difference between them be made explicit through a defined change in nomenclature.

The 'Lower Mottled Beds' and the 'Upper Mottled Beds' are here recognised as informal quasi-lithostratigraphical units. The Lower Mottled Beds comprise the Lower Mottled Clay, together with pedogenically altered parts of the Upnor Formation, including the Ferruginous Sand of Ellison (1983) and the Winterbourne Ironstone of Kent. The Upper Mottled Beds comprise the Upper Mottled Clay, together with material similarly altered by Eocene pedogenesis and allied processes at the top of the Woolwich Formation.

3.2.2.2 Lower Mottled Clay (LMCL)

Name

The Lower Mottled Clay was described by Ellison et al. (1994) as the 'lower leaf' of the Reading Formation, which is characterised by mottled clay, and as defined here corresponds to the part of the Reading Formation below the mid-Lambeth Group Hiatus of Page and Skipper (2000). The unit is here regarded as an informal member.

As discussed in the previous section, the **Lower Mottled Beds** (LMBED) is a part-equivalent quasi-lithostratigraphical unit.

Type area

The type area of the Lower Mottled Clay is central, south and south-east London (Ellison et al., 2004, fig. 20). No type section has been designated.

Reference section

Reference section: BGS Crystal Palace Borehole (TQ37SW671) [TQ 3379 7082], 138.00 to 141.95 m depth (Ellison et al., 2004, p.32)

Reference section: Jubilee Line Extension Borehole 404T (TQ37NW2118) [TQ 33638 79604], Bermondsey, London, 33.77 to 35.09 m depth (Ellison et al., 1994; Ellison et al., 2004, fig. 15, p.32). This borehole passes through the two parts of the Reading Formation, here separated by the Woolwich Formation.

Formal subdivisions

None described. In places, discrete sand bodies can be identified within the Lower Mottled Clay, but none have been named, nor demonstrated to have significant lateral extent as individual bodies.

Lithology

The Lower Mottled Clay typically consists of purple, red, green, blue-grey and brown mottled or multicoloured unbedded clays, some silty or sandy, and fine- to medium-grained sands. Typically, sands in the Reading Formation are brown or grey in colour, and generally not silty. Glauconite is absent. They are either not or only weakly bioturbated, but may be cross-bedded and can form steep-sided deposits up to 5 m thick. Nodular calcrete, calcrete-cemented silt, or gravel- to cobble-sized calcareous nodules are widespread, which may coalesce to form a local limestone bed and which has been described in some borehole logs as 'chalk'. The deposits are generally not shelly, but those that are contain a low diversity non-marine (brackish) fauna.

An interval of cross-bedded glauconitic sand at Knowl Hill, near Reading, that overlies typical Reading Formation mottled clays was interpreted as a fining-upwards sequence deposited in an estuarine or deltaic distributary environment and assigned to the Twyford Member (Goldring and Alghamdi, 1999). The unit is terminated by a palaeosol horizon and so was placed in the Reading Formation. Insufficient detail of the rest of the section was provided to state whether the mid-Lambeth Group hiatus is represented at this locality.

Genetic interpretation

This unit is thought to be alluvial plain deposits, with the clays representing over-bank deposits and the sands, where present, fluvial channel deposits. The sands are thought to have been laid down in non-migrating river channels, similar to those forming at the present-day in environments such as the Okavango Delta, Botswana. The colour-mottling formed shortly after deposition in a tropical or sub-tropical climate with seasonal rainfall: it is not due to modern weathering processes (Ellison, 1983; Hooker, 1991).

Definition of upper boundary

The top of the Lower Mottled Clay is a generally clearly marked unconformity known as the mid-Lambeth Group Hiatus (Page and Skipper, 2000). Where the Woolwich Formation is present, the upper boundary of the Lower Mottled Clay is typically marked by an upwards change from vari-coloured mottled clays or, locally, brown or grey non-glauconitic sands, in places with calcrete, below the unconformity, to dark grey shelly clay or laminated clay and silt or fine- to coarse-grained sand, commonly with lignite fragments or, locally, beds, above the unconformity. Where the Woolwich Formation is absent, the nature of the boundary between the Lower Mottled Clay and the Upper Mottled Clay is not well known. It seems to be marked by a bed of grey clay, or by lignite fragments, or both, at least locally. These presumably form the basal layer of the Upper Mottled Clay.

In places there is evidence of apparent downwards penetration of the Woolwich Formation in burrows.

Definition of lower boundary

The Lower Mottled Clay rests on the marine deposits of the Upnor Formation. The boundary may be obscured by penecontemporary pedogenic alteration, but is typically marked by an upwards change from dark grey or greenish-coloured glauconitic sands to vari-coloured mottled clays or, locally, brown or grey non-glauconitic sands.

Thickness

Locally up to 5 m in central London.

Distribution

Probably present throughout the Reading Formation outcrop and subcrop. It extends eastwards beneath the Woolwich Formation, where the two units co-exist (Ellison, 1983; Hooker, 1991).

Age

Early Eocene (earliest Ypresian) or latest Paleocene (Thanetian), or both. See Reading Formation.

3.2.2.3 Upper Mottled Clay (UMCL)

Name

The Upper Mottled Clay was described by Ellison et al. (1994) as the ‘upper leaf’ of the Reading Formation, which is characterised by mottled clay, and as defined here corresponds to the part of the Reading Formation above the mid-Lambeth Group Hiatus of Page and Skipper (2000). The unit is here regarded as an informal member.

As discussed in the previous section, the **Upper Mottled Beds** (UMBED) is a part-equivalent quasi-lithostratigraphical unit.

Type area

The type area of the Upper Mottled Clay is central London (Ellison et al., 2004, fig. 20). No type section has been designated.

Reference section

Reference section: Jubilee Line Extension Borehole 404T (TQ37NW2118) [TQ 33638 79604], Bermondsey, London, 25.05 to 29.63 m depth (Ellison et al., 1994; Ellison et al., 2004, fig. 15, p.32). This borehole passes through the two parts of the Reading Formation, here separated by the Woolwich Formation.

Formal subdivisions

None described. In places, discrete sand bodies can be identified within the Upper Mottled Clay, but none have been named, nor demonstrated to have significant lateral extent as individual bodies.

Lithology

The Upper Mottled Clay typically consists mainly of clay and silt, with some sand and occasional gravel. The clay of the Upper Mottled Clay tends to be less variable in colour than that of the Lower Mottled Clay. It is typically grey mottled with brown but may also be mottled or multicoloured red or yellow. Beds of dark grey or black clay occur locally: these may be of significance for regional correlation at the interface between the upper and the lower parts of the Reading Formation where the Woolwich Formation is absent.

This unit can include channel-form bodies of cross-bedded, fine- to medium-grained sand. It is locally weakly bioturbated or with a low-diversity non-marine (brackish water) mollusc fauna.

Genetic interpretation

The Upper Mottled Clay comprises fluviatile sediments rather similar to those of the Lower Mottled Clay and is likewise thought to have been deposited under non-marine conditions, on a large coastal plain crossed by rivers. The colour-mottling formed shortly after deposition in a tropical or sub-tropical climate with seasonal rainfall: it is not due to modern weathering processes (Ellison, 1983; Hooker, 1991).

Definition of upper boundary

As for Reading Formation. The top is generally sharply defined, at an upward change from vari-coloured mottled clay to glauconitic sands and sandy clays of the Harwich Formation, or to sandy clays of the Walton Member (London Clay Formation), or to shelly grey clays of the Upper Shelly Clay (possible Brixton Formation).

Definition of lower boundary

Sharply-defined boundary at base of vari-coloured mottled clay or fine- to medium-grained sand overlying fine-grained sands, silts or clays of the Laminated Beds (Woolwich

Formation). Where the Woolwich Formation is absent, the nature of the boundary between the Lower Mottled Clay and the Upper Mottled Clay is not well known. It seems to be marked by a bed of grey clay, or by lignite fragments, or both, at least locally. These presumably form the basal layer of the Upper Mottled Clay.

Thickness

Up to 8 m

Distribution

The Upper Mottled Clay is probably present throughout the Reading Formation outcrop and subcrop. It passes eastwards into the Woolwich Formation.

Age

Early Eocene (earliest Ypresian). See Reading Formation.

3.2.3 Woolwich Formation (WL)

Name

This was defined by Ellison et al. (1994), as 'essentially equivalent to the "Woolwich Beds" of Hester (1965), following Prestwich (1854). The unit is named after Woolwich, part of the London Borough of Greenwich in south-east London and close to the type section.

Previous names

Woolwich Beds (Hester, 1965), Woolwich Series (Prestwich, 1854).

Type section

Type section: Charlton Pit (or Gilbert's Pit), just south-west of Maryon Park, Charlton, London Borough of Greenwich [TQ 418 786] (Daley, 1999b; Ellison et al., 1994; Whitaker, 1889). The Woolwich Formation comprises Units 2 to 6 of Whitaker (1889, p. 147–148*)*

Reference section(s)

Reference section: Lower Upnor Pit, north of Chatham, Kent [TQ 759 711] (Daley, 1999b; Ellison et al., 1994; Kennedy and Sellwood, 1970)

Reference section: Jubilee Line Extension Borehole 404T (TQ37NW2118) [TQ 33638 79604], Bermondsey, London, 29.63 to 33.77 m depth (Ellison et al., 1994)

Reference section: Channel Tunnel Rail Link (CTRL) Borehole A2 (TQ38SW2212) [TQ 3296 8051], London, 40.22 to 41.91 m depth (Ellison et al., 1994)

Formal subdivisions

The Woolwich Formation is here divided into five informal members: in ascending order, in London these are the **Lower Shelly Clay**, the **Laminated Beds**, the **Upper Shelly Clay** and the **Striped Loams** (Ellison, 1983; Ellison et al., 2004). The **Woolwich Sands** occurs in Kent, either overlying the Lower Shelly Clay or comprising the whole of the Woolwich Formation (King, in prep.). These units are described here in anticipation of the further work required for possible formalisation as members. Their definition as formal units requires further research on their distribution, geometry, composition and relationships.

In addition, the Cobham Lignite Bed and associated strata that overlie the mid-Lambeth Group Hiatus but underlie the Lower Shelly Clay are here assigned to a new formal basal unit, the **Shorne Member**, which is also recognised by King (in prep.).

It is possible that the Upper Shelly Clay, which is of relatively restricted distribution and which occurs above the Reading Formation in places but rests on the Lower Shelly Clay in others, will in future be separated as a new formation, for which the name 'Brixton Formation' is here suggested. The Brixton area of south London has the thickest development of this unit.

The Lower Shelly Clay and the Laminated Beds might also be formalised in future, but if so probably as members of the Woolwich Formation.

It is also possible that an eastern marine facies of the Woolwich Formation, if it can be demonstrated to exist, should also be assigned to a separate member. The Woolwich Marine Bed of the Herne Bay area (Bed K of Ward, 1978) possibly represents such a facies but is here assigned to the Upnor Formation. It is distinct from the Woolwich Sands.

Lithology

Typically either dark grey shelly clay, laminated clay and silt or fine- to coarse-grained sand. Sporadic burrows occur throughout but bioturbation is more common in the higher beds, where sparse glauconite has been recorded. Shelly beds, particularly in the basal 2 m, are dominated by brackish water shells in dark grey clay matrix. Common plant debris is concentrated locally in thin allochthonous lignites, especially near the base.

Very sparse occurrences of thin degraded ash deposits have been noted in south London and north-west Kent (King, in prep.; Knox and Morton, 1983).

Details for the individual lithofacies are given in the following sections.

Genetic interpretation

The Woolwich Formation represents a variety of marginal marine facies of the Lambeth Group, with occasional freshwater incursions.

Definition of upper boundary

Most typically, the top of the Woolwich Formation is marked by a change from fine-grained sands, silts or clays to glauconite-bearing sands, silts or clays with a basal rounded flint gravel bed and a marine fauna, or sandy flint gravels (Harwich Formation). In parts of central London, where the Upper Shelly Clay and Striped Loams are absent, the Woolwich Formation is overlain by the upper part of the Reading Formation. Here there is a change from mainly grey, thinly bedded to laminated fine-grained sands, silts and clays, to vari-coloured, mottled clays.

Definition of lower boundary

The Woolwich Formation rests either on red-brown, yellow-brown and blue-grey mottled clays (Reading Formation) or glauconitic sands (Upnor Formation). The base is sharp, with burrows extending as much as 0.5 m into the underlying beds.

Thickness

Maximum 14.5 m; generally 11 to 12 m in south-east London and north Kent; thins to the west and north as it is replaced laterally by the Reading Formation.

Distribution

Central and eastern parts of the London Basin.

Outliers occur near Newhaven in East Sussex, in the easternmost onshore extent of the Hampshire Basin (Dupuis and Gruas-Cavagnetto, 1985).

Age

Early Eocene (earliest Ypresian). Possibly includes latest Paleocene in the Shorne Member (Collinson et al., 2003). The Woolwich Formation is spanned by the *Apectodinium* (dinoflagellate) acme, which proxies the carbon isotope excursion marking the PETM (Hooker, 2010).

3.2.3.1 SHORNE MEMBER (SHOM)

Name

In some areas, the lowest part of the Woolwich Formation, beneath the dark-coloured shelly clay of the Lower Shelly Clay, comprises pale-coloured clays and sands with a lignite bed, or organic clay (or locally sand), here placed in the Shorne Member. This unit is named after the village of Shorne, north-west Kent, which is about 2 km north-east of the type area.

Previous names

The Shorne Member was treated as part of the Lower Shelly Clay by Ellison et al. (2004, p.28). Part of it was named the Cobham Lignite Bed by Collinson et al. (2003).

Type section

Temporary exposure in railway cutting at Scalers Hill, Cobham, Kent [TQ 67277 69722], exposed in 1998 to 2000 (Collinson et al., 2003; Collinson et al., 2007; Ellison et al., 2004, fig.15)

Formal subdivisions

Cobham Lignite Bed (COBL) (Collinson et al., 2003)

Lithology

In the type section, the Shorne Member comprises a 2 m thick bed of laminated or blocky, black or dark brown lignite with thin pale clays (the Cobham Lignite Bed), overlying non-marine sands and clays containing some woody debris. These were not included with the Cobham Lignite Bed by Collinson et al. (2003) but are here included in the Shorne Member. Elsewhere the member is probably represented by fine-grained sands and clays, commonly with detrital lignite, or by grey organic clay or sand.

Genetic interpretation

Non-marine, probably fluvial flood-plain. The upwards change to the dark grey shelly clays of the Lower Shelly Clay represents a transgression that introduced lagoonal conditions.

Definition of upper boundary

The top of the Shorne Member is marked by the sharply-defined planar base of the overlying dark grey shelly clay of the Lower Shelly Clay (Woolwich Formation).

Definition of lower boundary

The Shorne Member lies on an erosional surface (marking the mid-Lambeth Group Hiatus) of the Lower Mottled Clay (Reading Formation), or of the Upnor Formation. The underlying deposits are generally pale and bleached (pedogenically altered).

Thickness

Up to about 3.5 m in the type section

Distribution

The Shorne Member is known principally from the Shorne Outlier in north-west Kent but occurs more widely but discontinuously, for example in the Swanscombe Outlier (north-west Kent) and at Aveley (south-west Essex) (Collinson et al., 2009; Ellison et al., 2004, fig. 15). Lignite-bearing beds also occur at the base of the Woolwich Formation in Sussex (Dupuis and Gruas-Cavagnetto, 1985). The lignitic deposits appear to be an expression of an organic clay (or locally sand) found from Kent to West Berkshire, where it is thought to separate the Lower Mottled Clay and the Upper Mottled Clay of the Reading Formation.

Age

Latest Paleocene to earliest Eocene (latest Thanetian to earliest Ypresian), based on the occurrence of a notable negative carbon isotope excursion (CIE) identified as that marking the Paleocene/Eocene boundary (Collinson et al., 2003; Collinson et al., 2009). However, as pointed out by King (in prep.) if the CIE occurs in the Lower Mottled Clay, which pre-dates the Shorne Member (which post-dates the mid-Lambeth Group Hiatus), then the identification of the CIE in the Shorne Member needs to be reconsidered.

Cobham Lignite Bed (COBL)

The Cobham Lignite Bed comprises a 2 m thick bed of laminated or blocky, black or dark brown lignite with thin pale clays. It appears to be localised within the Shorne Outlier in north-west Kent. Page and Skipper (2000) note that detrital lignite is present at widely spaced localities in the Woolwich Formation, usually at the base, below the Lower Shelly Clay.

The Cobham Lignite Bed was exposed during construction works on the A2 road (Chandler, 1923; Martin, 1976). It was briefly mined, from 1947 to 1953, and more recently exposed during construction of the A2 main road and of the Channel Tunnel Rail Link (now known as 'High Speed 1') (Collinson et al., 2003; Collinson et al., 2009; Collinson et al., 2007; Ellison et al., 2004, fig.15).

3.2.3.2 Lower Shelly Clay (LSCL)

Name

The 'Lower Shelly Clay' of Page and Skipper (2000) is typically a conspicuously shelly clay in the lower part of the Woolwich Formation. It corresponds in part to the shelly clay lithofacies described by Ellison (1983) and Hester (1965), which also encompasses the Upper Shelly Clay. The unit is here regarded as an informal member.

Previous names

This was previously known as the Woolwich Shell Bed(s) (Curry, 1958; Stamp and Priest, 1920).

Type section

The stratotype section is in the Charlton Pit (or Gilbert's Pit), just south-west of Maryon Park, Charlton, London Borough of Greenwich [TQ 418 786] (Daley, 1999b; Ellison et al., 1994; Hooker, 2010; Whitaker, 1889).

Reference sections

Reference section: BGS Crystal Palace Borehole (TQ37SW671) [TQ 3379 7082], 136.42 to 138.00 m depth (Ellison et al., 2004, p.32)

Reference section: The Lower Upnor Pit [TQ 759 711] (Daley, 1999b; Ellison et al., 1994; Kennedy and Sellwood, 1970)

Reference section: Cliff sections west of Newhaven, East Sussex [TQ 4455 0007] (Dupuis and Gruas-Cavagnetto, 1985)

Formal subdivisions

None

Lithology

The Lower Shelly Clay consists almost entirely of a low-diversity fauna of fossil shells (of types indicating brackish water deposition) in dark grey, dark brown or black organic clay. The shell debris is concentrated into distinct beds or drifts (coquinas), which in some cases have been cemented to form limestones. The basal part is locally a shelly, clayey sand.

Genetic interpretation

Marginal marine lagoons. In the far west, this environment occurred during a very brief interval, but in the east of the London Basin lagoonal conditions persisted for longer, depositing the lower part of the Woolwich Formation. However, in the east the depositional conditions also varied in time and space, resulting in the different lithologies of the lower Woolwich Formation.

Definition of upper boundary

Generally a sharply conformable boundary with the Laminated Beds, or locally in south London with the Upper Shelly Clay.

Definition of lower boundary

Sharply-defined contact on the Lower Mottled Clay or, passing eastwards, locally on the Shorne Member or on the Upnor Formation. In the London area, the basal Woolwich Formation rests on a burrowed omission surface at the top of a pedogenically-altered interval within the Lower Mottled Clay and, in places, the Upnor Formation. This omission surface corresponds to the mid-Lambeth Group Hiatus of Page and Skipper (2000).

Thickness

Up to 6 m.

Distribution

The Lower Shelly Clay occurs in London (east of a line through Marylebone and Chelsea) eastwards to south-west Essex and north-west Kent (Ellison et al., 2004, fig. 17).

There is a small development of this facies within the Lambeth Group near Guildford, which is otherwise locally dominated by the Reading Formation (Curry, 1958, p. 78; Ellison et al., 2002) and in the outliers at Newhaven, East Sussex, in the easternmost part of the Hampshire Basin (Bone, 1976; Dupuis and Gruas-Cavagnetto, 1985; Skipper, 1999).

Age

Early Eocene (earliest Ypresian)

3.2.3.3 LAMINATED BEDS (LBED)

Name

The 'Laminated Beds' of Ellison et al. (2004), which correspond to the 'laminated sand' lithofacies described by Ellison (1983), are characterised by laminated fine-grained sediments. The unit is here regarded as an informal member.

Type area

The type area is the Stratford district of East London where numerous boreholes, especially those drilled for the Channel Tunnel Rail Link, have demonstrated a typical succession.

Reference sections

Reference section: Charlton Pit (or Gilbert's Pit), just south-west of Maryon Park, Charlton, London Borough of Greenwich [TQ 418 786] (Daley, 1999b; Ellison et al., 1994; Hooker, 2010; Whitaker, 1889)

Reference section: BGS Crystal Palace Borehole (TQ37SW671) [TQ 3379 7082], 134.65 to 136.42 m depth (Ellison et al., 2004, p.32)

Reference section: The Lower Upnor Pit [TQ 759 711] (Daley, 1999b; Ellison et al., 1994; Kennedy and Sellwood, 1970)

Formal subdivisions

None.

Lithology

The Laminated Beds typically consists of thinly to thickly laminated silts and clays, but can also include laminated fine- to medium-grained sand. Some shells can be present and the beds may contain lignite and pyritised plant material. Sporadic burrows occur throughout, and bioturbation is more common in the higher beds in which glauconite occurs sparsely. These deposits are typically pale grey but may be olive to brown; they tend to be paler than those of the Lower Shelly Clay. Beds of sand, where present, tend to form broad sheet-like deposits, in contrast to the channel-like deposits found in the Reading Formation (Aldiss et al., 2009), although some cross-bedding is present (Ellison, 1983, citing F G Berry, personal communication). Locally, the Laminated Beds can comprise the entire local representation of the Woolwich Formation.

King (in prep.) notes that un-named channel-filling sand or clay bodies occur at the top of the Laminated Beds in places. In the Farringdon area of central London one such sand body rests on a surface eroded through the underlying portions of the Woolwich Formation into the Lower Mottled Clay. At its eastern margin this body interfingers with typical Laminated Beds facies and is considered to be part of that unit (Aldiss et al., 2009).

Genetic interpretation

Estuarine and other marginal marine environments

Definition of upper boundary

Sharply-defined contact with the overlying Upper Mottled Clays or the Upper Shelly Clay.

Definition of lower boundary

Sharply-defined contact with the underlying Lower Shelly Clay or locally on the Lower Mottled Clay.

Thickness

Up to 6 m but more generally 2 to 3 m.

Distribution

Central and south-east London, extending east as far as the Swanscombe outlier (Ellison et al., 2004, fig. 18).

Age

Early Eocene (earliest Ypresian)

3.2.3.4 WOOLWICH SANDS (WLWS)

Name

This term was introduced by King (in prep.) to describe a unit of fine-grained sand and silty sand in the Woolwich Formation of Kent, whose relationship to the succession in the London area is uncertain. The unit is here regarded as an informal member.

Type section

The Lower Upnor Pit [TQ 759 711] (Daley, 1999b; Ellison et al., 1994; Kennedy and Sellwood, 1970).

Formal subdivisions

None

Lithology

Cross-bedded or bioturbated fine- to coarse-grained sand and silty sand, locally with a low-diversity fossil mollusc fauna.

Genetic interpretation

Marginal marine

Definition of upper boundary

Sharply defined erosive contact at base of overlying fine-grained glauconitic sands of the Oldhaven Member (Harwich Formation).

Definition of lower boundary

At Lower Upnor it overlies the Lower Shelly Beds, probably on an erosion surface (Kennedy and Sellwood, 1970). Further east at Canterbury it comprises the entire Woolwich Formation and rests on the Upnor Formation (Gamble, 1972) (King, in prep.).

Thickness

Up to about 6 m

Distribution

Kent, possibly extending into east London

Age

Early Eocene (earliest Ypresian)

3.2.3.5 Upper Shelly Clay (UPSCL)

Name

The Upper Shelly Clay (Ellison et al., 2004) comprises a rather varied lithological assemblage that is distinct from that of the rest of the Woolwich Formation, although some of the individual components are of very similar composition. It contains a generally greater diversity of fauna than the Lower Shelly Clay. Although in concept it occupies a position analogous to an ‘upper leaf’ of the Woolwich Formation, its more restricted occurrence, its position above the Reading Formation, and its distinctive lithological assemblage suggest that it should be treated as a separate formation of the Lambeth Group. This is consistent with its deposition following an erosive event, presumably corresponding to a regressive-transgressive cycle of sea-level change, identified as a fourth, separate depositional sequence within the Lambeth Group by Knox (1996b, p.216).

It is possible that this unit could be renamed formally as the Brixton Formation, with a type section in a cored borehole in south-east London. In view of the varied constituent lithologies, no lithological descriptor is likely to be appropriate. However, a definition of this possible formal unit requires further research on the distribution, geometry, composition and relationships of the Upper Shelly Clay.

Previous name

‘Woolwich Shell Beds’ of Curry (1958, p. 79).

Type area

South-east London, specifically in the London Boroughs of Lambeth and Southwark.

Type section

Type section to be proposed, probably from one of the Thames Water Ring Main boreholes in the vicinity of Brixton, London Borough of Lambeth.

Reference sections

Reference section: Jubilee Line Extension Borehole 404T (TQ37NW2118) [TQ 33638 79604], Bermondsey, London, 24.11 to 25.05 m depth (Ellison et al., 1994; Ellison et al., 2004, p. 32).

Reference section: BGS Crystal Palace Borehole (TQ37SW671) [TQ 3379 7082], 129.33 to 134.65 m depth (Ellison et al., 2004, p.32)

Formal subdivisions

None.

Lithology

The Upper Shelly Clay mainly comprises brown and dark grey to black shelly clay, sandy clay and muddy limestone with fossil oysters. It appears to become more sandy towards the south-east and east (Ellison et al., 2004, fig. 19) although King (in prep.) suggests that these occurrences may be partly incised channel-filling units that post-date the Upper Shelly Clay.

The Upper Shelly Clay includes a distinctive bed of grey argillaceous shelly limestone with a conchoidal fracture, typically about 0.2 m thick but locally up to 1 m (Ellison, 1983), containing the fossil shells of freshwater molluscs. This is known as the ‘Paludina Limestone’, the Paludina Bed (or Band) (Curry, 1958; Rickman, 1861) or the Woolwich Freshwater Bed (Dewey and Bromehead, 1921). An occurrence in Peckham, south London, was described by Berry and Cooper (1977). This was presumed to be part of the 'Woolwich Shell Beds' by Curry (1958, p. 79).

Shelly sands, with a mammal fauna, at Abbey Wood in the London Borough of Bexley in south-east London [TQ 4801 7864], have in the past been correlated with the Upper Shelly Clay (Hooker, 1991, 1996) or the Laminated Beds (Ellison et al., 2004, p.29). The shelly deposits were named the Lessness [sic] Shell Bed by Cooper (1976a) as an alternative to the 'Blackheath Shell Bed' (Ward, 1973). This unit is now included in the Blackheath Member (Harwich Formation) (Section 3.3.1.1).

Genetic interpretation

Marginal marine lagoons with freshwater incursions

Definition of upper boundary

The Upper Shelly Clay underlies the Harwich Formation (Thames Group) at a channelled erosion surface. This marks a change in lithology from shelly clay, sandy clay and muddy limestone of the Upper Shelly Clay to glauconite-bearing sands, silts or clays with a basal rounded flint gravel bed and a marine fauna, or sandy flint gravels of the Harwich Formation.

Definition of lower boundary

The Upper Shelly Clay rests on a burrowed erosive surface overlying either the Reading Formation or the Laminated Beds or the Lower Shelly Clay of the Woolwich Formation. The contact with the Laminated Beds may be a rapid gradation. The 'Paludina Limestone' acts as a marker horizon, which has been used to show that the Upper Shelly Clay rests directly on the Lower Shelly Clay in south-east London in the vicinity of Petts Wood and St Mary Cray [TQ 45 68] (Ellison et al., 2004, p.29 and fig.14; Whitaker, 1872, p.116).

Thickness

Up to 5 m

Distribution

The Upper Shelly Clay is of relatively restricted extent in central and south-east London but has also been recorded at Leytonstone, in north-east London. Other apparently outlying occurrences have been found in south-west Essex and north-west Kent (Ellison et al., 2004, fig. 19).

Knox (1996b, p.216) notes that a very thin representative is present at Bradwell in north Essex, where shelly gravelly clays rest on the Reading Formation.

Age

Earliest Eocene (Ypresian)

3.2.3.6 Striped Loams (SLOM)

Name

According to Ellison et al. (2004, p. 29), there is a second unit of 'Laminated Beds' locally present at the top of the Woolwich Formation, above the Upper Shelly Clay. These were originally known as the 'Striped sand and loam' by Dewey et al. (1924) and the Striped Loams by Curry (1958, p. 71). In common with King (in prep.) and Hooker (2010) the name 'Striped Loams' is preferred here. This unit is here regarded as an informal member.

Type area

The type area is taken as south-east London.

Reference section(s)

Reference section: Charlton Pit (or Gilbert's Pit), just south-west of Maryon Park, Charlton, London Borough of Greenwich [TQ 418 786] (Daley, 1999b; Ellison et al., 1994; Hooker, 2010; Whitaker, 1889).

Formal subdivisions

None.

Lithology

Laminated and thinly-bedded fine-grained sands, silts, clayey sands and clays. The occurrence at Loam Pit Hill contains fossil seeds and leaves (Curry, 1958, p. 71) in the 'Lewisham Leaf Bed' (Cooper, 1976a) and (Pitcher, 1967, fig. 3). As seen in the Charlton Pit, this comprises alternations of fine-grained sand and clay, with lignite. The name derives from sparse leaf impressions.

Genetic interpretation

Estuarine and other marginal marine environments

Definition of upper boundary

Sharply-defined contact between laminated and thinly-bedded fine-grained sands, silts, clayey sands and clays of the Woolwich Formation with glauconite-bearing sands, silts or clays with a basal rounded flint gravel bed and a marine fauna, or sandy flint gravels of the Harwich Formation

Definition of lower boundary

Sharply-defined contact that marks a change in lithology from shelly clay, sandy clay and muddy limestone of the underlying Upper Shelly Clay to laminated and thinly-bedded fine-grained sands, silts, clayey sands and clays of the Striped Loams.

Thickness

Up to about 9 m.

Distribution

South-east London

Age

Early Eocene (earliest Ypresian)

3.3 THAMES GROUP (THAM)

Name

The Thames Group forms by far the greatest part of the Palaeogene outcrop in the London Basin, where it comprises two formations. It was defined by King (1981) as comprising the **London Clay Formation** together with his Oldhaven Formation. Ellison et al. (1994) subdivided the Thames Group slightly differently, effectively by increasing the stratigraphical extent of King's Oldhaven Formation upwards and renaming it as the **Harwich Formation**, which is current practice.

The name is taken from the River Thames, whose middle and lower sections flow mainly across the outcrop of the London Clay, in the core of the London Basin. The group also occurs within the Hampshire Basin.

Previous name

London Clay Group (Cooper, 1976a).

Type area

Greater London

Reference section

Refer to constituent formations

Formal subdivisions

In the London Basin, comprises mainly the London Clay Formation, which is underlain by the Harwich Formation.

Lithology

Mainly silty clays and clays, some sandy or gravelly, with some silts, sands, gravels and calcareous mudstones

Genetic interpretation

Marine shoreface ranging out to outer marine shelf

Definition of upper boundary

As for the London Clay Formation

Definition of lower boundary

As for the Harwich Formation

Thickness

Up to about 150 m

Distribution

London Basin, East Anglia and eastern Hampshire Basin

Age

Eocene (early and middle Ypresian)

3.3.1 Harwich Formation (HWH)

Name

This unit was defined by Ellison et al. (1994) to include all the sediments between the Lambeth Group and the London Clay Formation (as redefined by them, and so reassigning basal beds previously taken as part of the London Clay). The name of this formation is taken from the port of Harwich in north-east Essex, which is close to the sites of the composite type section.

King (1981) had proposed a different subdivision of this part of the stratigraphical succession, including the proposal of his 'Harwich Member', which he included (together with the Swanscombe Member) within his definition of the London Clay. A detailed review of this part of the succession is presented by Jolley (1996), whose quantitative palynological analysis enabled detailed stratigraphical correlations to be made between occurrences of the Harwich Formation throughout the London Basin, and a detailed sea-level curve to be constructed.

Objections to the use of 'Harwich Formation' in the concept proposed by Ellison et al. 1994 were set out by Ward (1995). He observed that the fact that disparate sediments are all of about the same age is not justification for including them in the same formation. Specifically, he pointed out that in the east of the London Basin there is little lithological difference between King's (1981) 'Harwich Member' (London Clay Division A1), which Ellison et al. (1994) included in the Harwich Formation, and King's (1981) 'Walton Member' (London Clay Division A2), which Ellison et al. (1994) treated as the basal bed of the redefined London Clay. Ward (1995) felt that King's (1981) concept of the 'Oldhaven Formation' was preferable, in that it delineated the major lithological contrasts more consistently, especially if the Hales Clay (Section 3.3.1.4) were to be included in the London Clay, below Division A1. In response, Ellison et al. (1995) emphasised that in north-east Essex and Suffolk, the Harwich Formation includes ash beds and beds of fine-grained sand, and in these respects differs from the overlying basal London Clay. They maintained that their proposal was a practical solution to a problem of increasingly complex nomenclature.

Previous names

The term 'London Clay Basement Bed' was originally used by Prestwich (1850) to describe green, grey and yellow sands and sandy clays with some very well-rounded black flint gravel, and containing marine fossils including molluscs and shark's teeth, that occur at the base of the 'typical' London Clay, above the Lambeth Group (as now recognised). As noted by Curry (1958), Ward (1978), and King (1981) amongst others, Prestwich included within the 'London Clay Basement Bed' strata in the south-east of the London Basin that were later separated by Whitaker (1866) as the Oldhaven Beds (typically a sandy, more easterly facies) and the Blackheath Beds (typically a gravelly, more western facies). King (1981) separated the strata included in the Basement Bed *sensu* Whitaker into three members: his Harwich Member and Swanscombe Member which together comprise his Unit A1 of the London Clay, and his Tilehurst Member, which he included in his Oldhaven Formation, below the London Clay.

Type section

Composite type section for the 'distal' facies of the north-east London Basin and East Anglia: BGS Shotley Gate Borehole (TM23SW19) [TM 2439 3460] (Knox and Ellison, 1979); cliff and foreshore at Wrabness [TM 1726 3233] and at Walton-on-the-Naze [TM 267 244] (see also King, 1981, in prep.). See also constituent members.

Reference section(s)

This unit is discussed by Cooper (1976a), who provides information on some individual localities. See also constituent members.

Formal subdivisions

The Harwich Formation is divided into the **Blackheath, Oldhaven, Swanscombe, Orwell**, and **Wrabness members**.

Occurrences in the far north-east part of the London Basin (including parts of East Essex, Suffolk and Norfolk) are in an argillaceous 'distal' facies, which includes the Orwell and Wrabness members. Elsewhere the Harwich Formation displays a sandy or gravelly 'proximal facies', being typically composed of glauconitic silty sands, sandy silts, sandy silty clays and gravel beds. This facies is represented by the Oldhaven Member, the Blackheath Member and the Swanscombe Member in the central and western London Basin.

Previously, an argillaceous unit in East Anglia was named the **Hales Clay Member** (Knox et al., 1990) but King (in prep.) considers that the upper part of the Hales Clay Member (sequence HC2) corresponds to the Orwell Member, and places the lower part (sequence HC1) in the Upnor Formation. Although the Hales Clay Member is therefore here regarded as obsolete, a description corresponding to previous use is included in this report. King (1981, in prep.) recognises in addition the Ipswich Member, and the Tilehurst Member.

It is possible that further members, in other parts of the basin, will be formalised in future.

Lithology

The Harwich Formation varies regionally. In the south of the London Basin, it typically comprises glauconitic silty or sandy clays, silts and fine- to coarse-grained glauconitic sands, some gravelly, varying to flint gravel beds. Thin beds of grey clay occur in some parts, as do shell-rich beds and thin beds of argillaceous limestone. Volcanic ash is a significant minor component in some parts of Kent and southern Essex. The Harwich Formation commonly includes a shelly marine fauna but locally a brackish water fauna.

In East Anglia, the Harwich Formation comprises mainly bioturbated silty clays and sandy clayey silts with subordinate sandy silts and silty sands, some of which are glauconitic. There is a notable component of volcanic ash, both disseminated and in discrete beds (Knox and Ellison, 1979; Knox and Harland, 1979).

Fossils include marine invertebrates, especially molluscs, with birds and mammals (Benton and Cook, 2006; Hooker, 1991, 1996, 1998, 2010).

Genetic interpretation

The Harwich Formation is considered to have been deposited in a shallow marine shelf environment, with the 'proximal' facies closer to shore, with relatively slow and interrupted sedimentation which was at times within storm wave-base, and including shoreface deposits. The Blackheath Member is interpreted as the deposits of tidal channels and nearshore sand and gravel bars (Ellison et al., 1994). Inner to mid-shelf environments are represented in the 'distal' facies of East Anglia.

Definition of upper boundary

A discontinuity marking the upwards change from sandy sediments to silty clays and clayey silts of the transgressive marine Walton Member (London Clay Formation). In distal areas there is commonly a thin bed of silty sand at the top of the Harwich Formation, overlain by sandy clay (Ellison et al., 1994).

Definition of lower boundary

Eroded unconformity surface on underlying Reading or Woolwich Formation, or, locally south of London, the Thanet Formation or the Chalk Group. The base is sharply defined, being formed by a planar or slightly undulose discontinuity with a basal lag of very well-rounded flint gravel and fine to coarse quartz grains in a finer glauconitic matrix. Burrows commonly extend down into underlying beds.

Thickness

Up to 24 m in East Anglia. Locally up to 24 m in south-east London, more generally up to 10 m but commonly less than 2 m.

Distribution

Almost throughout the London Basin, including parts of East Anglia, but including east Norfolk. It is locally absent, for example in parts of London, where the London Clay lies directly on the Lambeth Group.

The lower tuff-bearing part of the Balder Formation (North Sea Basin) is a lateral equivalent of part of the Harwich Formation (Ellison et al., 1994). The upper part of the Sele Formation (North Sea Basin) is a lateral equivalent of part of the Harwich Formation (Ellison et al., 1994).

Age

Early Eocene (early Ypresian)

Central London Basin

3.3.1.1 Blackheath Member (BLB)

Name

This unit has been known historically as the ‘Blackheath Beds’, named after Blackheath Common in the London Boroughs of Greenwich and Lewisham. The Blackheath Member lies on an erosional surface, in part deeply channelled, cut into the Lambeth Group, and perhaps locally into the Thanet Formation and the Chalk Group. Coupled with the lateral variation and poor exposure of these units, this can give rise to uncertainty in the stratigraphical relations of some occurrences of gravels in this part of the sequence. Indeed, Ellison et al. (1994) felt that the age and stratigraphical relationships of the Blackheath Beds were not fully understood and therefore recommended that the name be used informally.

Many earlier works regarded the gravel beds that are typical of the Blackheath Beds as a unit separate from the non-glauconitic sands with which they are commonly associated, and which were then treated as part of the Woolwich Formation (e.g. Cooper, 1976a). Some exposures, however, show that there is commonly lateral change from one facies to the other, and that they are both parts of the same lithostratigraphical unit (Chandler, 1923; Dewey et al., 1924, pp. 68-70; Hooker, 2010; Tracey, 1986).

Subsequent work has confirmed the Blackheath Beds as a distinct unit worthy of formalisation. Hooker (2010) defines the unit as the ‘Blackheath Formation’ (of no specific group), observing that it is separated from both the Oldhaven Member (and other overlying units) and the Lambeth Group (and other underlying units) by erosive contacts. He points out that the Oldhaven Member characteristically contains glauconite whereas the Blackheath Beds do not.

Although Hooker (2010) asserts that his Blackheath Formation ‘is readily mappable and has been mapped’, citing the 1971 edition of BGS Geological Sheet 271 (Dartford) (British Geological Survey, 1971, cited by Hooker as Dewey et al., 1971, which is a revised version of the original 1924 map), neither the 1971 nor the current (1998) version of Sheet 271, nor Sheet 272 (Chatham), which includes the eastern part of the Shorne outlier, nor the corresponding original large-scale field maps, separate the Blackheath Beds from the Oldhaven Member. Indeed, in the corresponding memoirs Dewey et al. (1924) and Dines et al. (1954) regard these two units as lateral equivalents, according to the historical concept of

Whitaker (1872) noted by Hooker. BGS has difficulty in recognising the Blackheath Member as a formation on grounds of mappability, either at the surface or in the subsurface, except inasmuch that it largely does not coincide with other members of the Harwich Formation.

The identity of the Blackheath Beds as a formation distinct from other components of the Harwich Formation (*sensu* Ellison et al. 1994) therefore seems to rest on its lack of glauconite, its tendency to be gravelly, its distribution (associated with eroded channels rather than as a transgressive sheet) and the erosive nature of its upper bounding surface. None of these allow it to be systematically separated from the Oldhaven Member or the Swanscombe Member in unexposed ground. The Blackheath Beds are therefore here regarded as the Blackheath Member and retained in the Harwich Formation.

Previous names

Previously known as the 'Blackheath Beds' (Whitaker, 1866, 1872, 1889), which Whitaker (1889) regarded as an alternative name for the Oldhaven Beds or just for the gravelly western facies at this level. King (1981, pp.18-20), however, realised that at Swanscombe the Blackheath Member is separated from the overlying Oldhaven Member by an erosive contact.

Cooper (1976a, p.6) placed the gravel beds in his 'Blackheath Pebble Member' of his 'Oldhaven Formation', and named the sands below the gravel beds at Abbey Wood as the 'Abbey Wood Member of his 'Woolwich and Reading Formation'.

Type section

Charlton Pit (or Gilbert's Pit), just south-west of Maryon Park, Charlton, London Borough of Greenwich [TQ 418 786] to [TQ 419 785] (Daley, 1999b). Hooker (2010) designated this as the type locality for his Blackheath Formation.

Reference sections

Reference section: Elmstead Rock Pit, Chislehurst, Kent [TQ 4232 7066] (Daley, 1999b; Hooker, 2010). This section contains an unusually rich fossil fauna.

Reference section: Abbey Wood, London Borough of Bexley [TQ 480 786] (Hooker, 2010)

Reference section: A2 Well Hall Road cutting, Eltham, [TQ 426 749] (Ellison et al., 2004, fig. 24; Tracey, 1986).

Formal subdivisions

The **Lessness Shell Bed (LNSH)**

Lithology

The Blackheath Member is dominated by flint gravel, partly clast-supported, in a matrix of fine- to coarse-grained sand, with lenses of sand and thin clay layers. The gravel is almost exclusively black and well-rounded, and composed of flint, and rare siliceous sandstones and conglomerates (resembling sarsen stones and 'puddingstone' and probably representing silcretes from the Lambeth Group). The clasts are generally less than 20 mm in diameter although cobbles up to 150 mm long are known (Baker and Priest, 1919; Dewey et al., 1924; Ellison et al., 1994). The gravels are interlayered, interlensed or interdigitated with pale-coloured fine-grained non-glauconitic quartz and flint sands, locally with scattered gravel and, at Charlton, a basal bed of clay pellets. Streaks of concentrated heavy minerals occur in the sands (Dewey et al., 1924). Both gravels and sands locally include shell-rich beds (coquinas) and occasional thin beds of grey clay. Cross-bedding occurs in the gravels and ripple-bedding in the sands, with the gravel beds forming series of superimposed channel-fill deposits (Ellison et al., 2004, fig. 24; Tracey, 1986). Calcareous, siliceous or ferruginous cements occur in places, locally forming masses several metres thick (Dewey and Bromehead, 1921; Dewey et al., 1924), particularly in the extensive outcrops in south-east London. In degraded sections, the deposit can appear to consist entirely of sandy gravel. The most common fossils are of shallow marine or brackish-water molluscs, but a coral, various fish, reptiles, a bird, and a considerable terrestrial mammal fauna have also been recorded (Hooker, 1991, 2010).

Genetic interpretation

At the type locality consists of marine shoreface deposits (Hooker, 2010). Contains shelly fossil faunas indicating both marine and brackish environments.

Definition of upper boundary

The Blackheath Member is overlain at an erosive surface by the Oldhaven Member (Harwich Formation) (as at Swanscombe, King, 1981, and Cobham, Hooker, 2010, p. 4), which mainly consists of glauconitic fine-grained sand (although a basal gravel bed is present in places) or more extensively by the Walton Member (London Clay Formation), which is mainly composed of silty clay, some sandy, with a thin basal sandy and gravelly bed.

Definition of lower boundary

The Blackheath Member lies on an erosional surface, in part deeply channelled, cut into the Upper Shelly Clay or older parts of the Lambeth Group, and locally into the Thanet Formation and the Chalk Group (see also comments on distribution).

At the Charlton Pit, in some places the Blackheath Member rests on the Striped Loams of the Woolwich Formation and in others on strata as old as the Upnor Formation (Hooker, 2010; Leach and Young, 1908). At Abbey Woods, the Blackheath Member rests on strata ranging from the lower part of the Upnor Formation to the lower part of the Thanet Formation within about 300 m lateral distance. At the north-east side of Plumstead Common, the Blackheath Member rests on the Shelly Clay of the Woolwich Formation, but only about 350 m to the south it rests on the Upnor Formation (Leach and Polkinghorne, 1906).

Thickness

At the type section, the unit has recently been measured as 4.3 m thick, although an unknown part has been removed from the top by erosion, and past exposures nearby imply that at least 9 m are present (Hooker, 2010). Mapped outcrop patterns imply that the Blackheath Member is locally as much as 24 m thick (Dewey et al., 1924).

Distribution

The Blackheath Member occurs in south-east London from Croydon to Greenwich and Erith, with outliers in north-west Kent, especially around Swanscombe and Shorne. Sand-filled channels occur in subcrop to the north-west of the main outcrop, under parts of central and south-west London (King, in prep.).

The Blackheath Member rests on a significantly incised surface that has been cut through the Woolwich Formation, the Upnor Formation and, locally, the Thanet Formation and the Chalk Group. The geological maps show numerous outliers of the Harwich Formation in south-east London and north-west Kent, particularly in the Swanley area, some of which overlie the Thanet Sand and some the Chalk. The status of many of these deposits is unclear, however, and Whitaker's (1872, p.256) comment that 'even now there are sand-outliers in Kent of which the age is uncertain' remains true today. Some are very probably relicts of Palaeogene strata disturbed by dissolution of the Chalk and other near-surface processes. For example, some occurrences of sandy gravels previously regarded as part of the 'Blackheath Beds' have now been placed in the Chelsfield Gravel Formation, part of the Residual Deposits Group (McMillan et al., 2011). Borehole evidence acquired since the most recent map revision shows that the large outlier at Swanley [TQ 510 684], indicated largely by the occurrence of gravelly soils, consists of a veneer of gravelly material less than about 1.5 m thick that is less extensive than shown on the map, and which could have formed during the Quaternary. By contrast, a small pit about 1.2 km east of Crockenhill [TQ 5170 6730] was seen in 1914 to expose about 2.4 m of strongly cross-bedded sand with flint gravel (unpublished BGS field records). Although this does appear to be part of the Blackheath Member, it is possible that some other gravelly outliers are part of the Upnor Formation (King, 2006, p.409). Given the variable depth of incision at the base of the Blackheath Member, occurrences overlying the Chalk and Thanet Formation do not necessarily indicate a southwards overstep, as discussed by King (2006, p.409).

Age

Early Eocene (early Ypresian), after the Paleocene-Eocene Thermal Maximum (PETM) (Hooker, 2010). Hooker (2010) notes that there is no evidence that the *Apectodinium* (dinoflagellate) acme (that proxies the PETM) extends into the Blackheath Member. He infers that the Blackheath Member was deposited during the later part of calcareous nannoplankton zone NP9, partly by its position relative to the Woolwich Formation and to the Oldhaven Member, and partly by comparison of its mammal fossil faunas with those of the North American Big Horn Basin. He argues that it is probably about 55 Ma old.

Lessness Shell Bed (LNSH)

At the type section and at Lesnes Abbey Wood [TQ 480 786] in south-east London, the Blackheath Member comprises an upper gravel with lenses of shells, overlying a sandy bed. At Abbey Wood, the sandy facies is interlayered and interdigitated with a lenticular, sandy, gravelly shell bed, known as the Lessness Shell Bed, overlying a thin iron pan, and white sand with sparse *Ophiomorpha* burrows (Hooker, 2010). (The Ordnance Survey uses the spelling 'Lesnes Abbey', but this report follows Hooker, 2010).

The Lessness Shell Bed comprises fine- to medium-grained sand with shelly lenses and scattered very well-rounded flint gravel. The unit varies in thickness from 0 to 2 m over only a few metres lateral distance. It interfingers with non-shelly buff-coloured sand and is overlain by the same sand or by the gravels. The shell bed is underlain by bedded white sand (Hooker, 2010). The Lessness Shell Bed contains a varied fossil fauna including brackish to marine molluscs, fish teeth, birds and a significant, diverse assemblage of terrestrial mammals (Hooker, 1991, 2010; King, 1981, p.20). Further locality details are given by Hooker (2010) and in references cited therein.

Various interpretations of the stratigraphical relationships of the Lessness Shell Bed have been expressed. For example, Ellison et al. (2004, p.29) included it in the Laminated Beds although noting uncertainty in its age and stratigraphical relationships, and although on p.36 they appear to accept that it is probably equivalent to the Upper Shelly Clay.

Its position is discussed in detail by Hooker (2010), who places it within the Blackheath Member.

3.3.1.2 Oldhaven Member (OH)

Name

The ‘Oldhaven Member’ was previously known as the ‘Oldhaven Beds’ (Whitaker, 1866, 1872). It was named for a locality to the east of Herne Bay, Kent, where it is exposed in the sides of a gully cut through the cliffs, and in the adjacent parts of the cliffs. This gully was then known as 'Oldhaven Gap' but on later maps appears as 'Bishopstone Haven' (1898 to 1938), or as 'Bishopstone Glen' (current 1:10 000 scale topographical maps) or 'Bishopstone Gap'. The mouth of the 'gap' is at National Grid reference 620715, 168730. It is about 3.5 km east of the Pier at Herne Bay.

Alternative names

The Oldhaven Member was named the ‘Herne Bay Member’ by King (1981).

King (1981, in prep.) assigns the western facies of the Harwich Formation, apparently forming a separate subcrop in the west of the London Basin, to his Tilehurst Member, noting that it could be of different age to the Oldhaven Member, in spite of their similar (albeit not identical) composition and fauna, and their common stratigraphical position. While granting the hypothetical possibility that the two units are of a different age, it seems likely that if King’s Oldhaven and Tilehurst members were not geographically separated then they would have been treated as variations within a single unit. The assignment of a new name thus apparently serves only to distinguish the ‘western occurrences of the Oldhaven Member’ from the ‘eastern occurrences of the Oldhaven Member’. This is considered by BGS to be insufficient grounds for erecting a new name, so the use of ‘Tilehurst Member’ is not recommended at present. In the light of ongoing work it seems prudent not to apply any particular member name to the Harwich Formation west of London.

However, King and Curry (1992) transferred the Herne Bay Member and the Tilehurst Member to the London Clay Formation. King (1981) assigned a basal unit below the Tilehurst Member, up to 4 m thick, of very fine-grained, bioturbated and laminated, glauconitic sand, with *Ophiomorpha* burrow systems, to his Twyford Member.

Type section

Type section: Cliffs and foreshore east of Herne Bay, Kent [TR 203 687 to 215 693] (Curry, 1981; Daley, 1999b; King, 1981; Ward, 1978). It comprises beds c2 and c3 of Prestwich (1850, fig. 11) and Beds L to N of Ward (1978).

Reference section(s)

Reference section: old quarry associated with the previous Westwood brick and tile works, in the vicinity of present-day Tay Road, Tilehurst, Reading, Berkshire [SU 6830 7330] (King, 1981, fig. 32).

Reference section: Old Cement Works, Harefield, London Borough of Hillingdon [TQ 050 899] (Cooper, 1976b; Daley, 1999c; King, 1981, fig. 32).

Reference section: Warner's Brickworks, Knowl Hill, Reading [SU 816 797] (Ellison et al., 1994; Kennedy and Sellwood, 1970; Sellwood, 1974)

Formal subdivisions

None.

Lithology

The Oldhaven Member typically consists of cross-bedded, laminated or bioturbated, fine-grained glauconitic sand, some silty, sandy silts and sandy clayey silts with thin clay beds, some of which are cemented to form argillaceous limestone. There is a shelly marine fauna in shell beds or lenses, with some fish teeth. Black well-rounded flint gravel occurs at the base.

Lenses or thin beds of calcareous shelly sandstone are present locally. Occurrences in the west of the London Basin, corresponding to King's (1981) Tilehurst Member, are generally finer-grained, have more bioturbation and a more diverse fauna.

Knox (1983) reported common disseminated volcanic ash in the Oldhaven Member in north Kent and south-west Essex, from which he inferred correlation with ash-bearing deposits of the Harwich Formation in north-east Essex.

The sequence at Herne Bay is described in detail by Ward (1978) and by Daley (1999b).

Genetic interpretation

The Oldhaven Member represents a sandy, near-shore marine facies of the Harwich Formation.

Definition of upper boundary

The Oldhaven Member is overlain by the Swanscombe Member or by clayey silts and silty clays of the London Clay Formation, which include a basal gravel bed and much less glauconite. King (1981) observes that the Tilehurst Member is similar in lithology to the Swanscombe Member, but that where the units coexist there is a discontinuity between them usually marked by a gravel bed, and that the fauna differs.

Definition of lower boundary

The base of the deposit is sharp, locally erosive and generally planar. It rests on the Blackheath Member where that unit exists but more generally on the Lambeth Group.

Thickness

Up to about 10 m.

Distribution

Present throughout the London Basin except in the central part, and also occurs in the Hampshire Basin. King (in prep.) assigns occurrences to the west of London to his Tilehurst Member.

Age

Early Eocene (early Ypresian). The Oldhaven Member records the D5b dinocyst zone, the base of which coincides with the base of calcareous nannoplankton zone NP10 (Hooker, 2010, and references therein).

3.3.1.3 SWANSCOMBE MEMBER (SWCB)

Name

The Swanscombe Member was coined by King (1981) to refer to his Division A1 of the London Clay. The unit is named after Swanscombe, west Kent, where the unit forms small outliers just to the south.

Type section

Type section: disused clay pit at Bean, Swanscombe, Kent [TQ 590 717] (Durkin, 1968; Durkin and Baldwin, 1968; King, 1981, fig. 32)

Formal subdivisions

None.

Lithology

The Swanscombe Member comprises glauconitic, very silty or sandy clays, sandy silts and sandy clayey silts, which may contain dispersed shells and lignite. It is highly glauconitic and locally gravelly at the base. Ash particles occur in the Swanscombe Member in south-west Essex (Knox, 1983).

King (1981) observes that the unit is similar in lithology to the Oldhaven Member, specifically in its western facies (his Tilehurst Member), but that where the units coexist there is a discontinuity between them usually marked by a gravel bed. Also, the fauna differs.

Genetic interpretation

Marine, inner shelf.

Definition of upper boundary

Upwards change to non-glauconitic silty clay, some sandy, some gravelly, of the Walton Member (London Clay Formation).

Definition of lower boundary

Rests on the Oldhaven Member, or the Lambeth Group, on a sharp, erosive contact, commonly marked by flint gravel.

Thickness

Thin (less than 2 m) or absent in the western London Basin, north Kent and the Hampshire Basin. Elsewhere in the London Basin thickens northwards to more than 10 m (King, 1981).

Distribution

Present in much of the London Basin, but absent from the most western areas, from north-east Kent and from parts of London. According to King (1981), the Swanscombe Member passes north-east into his 'Harwich Member', which is here assigned to the Wrabness and Orwell members.

Age

Early Eocene (early Ypresian)

North-eastern London Basin

3.3.1.4 HALES CLAY MEMBER (HAC – OBSOLETE)

Name

The Hales Clay was originally described from an interval 15.6 m thick in the Hales Borehole, Norfolk, by Knox et al. (1990), who included it the London Clay Formation. Ellison et al. (1994) recognised the same interval as part of the 'distal' facies of the Harwich Formation.

The lowest 2.7 m in the Hales Borehole section was assigned to the informal division HC1; the remaining 12.9 m was assigned to HC2 (Knox et al., 1990; Jolley, 1996, fig. 9). Subsequently, it was recognised that the lower part of the Hales Clay (HC1) is separated from the upper part by an unconformity and should be correlated with the Upnor Formation (Knox 1996b; King, in prep.). However, although Knox (1996b) continued to refer the beds of HC2 to the Hales Clay, King (in prep.) considers HC2 to be laterally continuous with the Orwell Member. He therefore recommends that the designation 'Hales Clay' be abandoned, and that recommendation is adopted here.

Previous name

Originally known as the Hales Clay (Knox et al., 1990)

Alternative names

The lower part of the original 'Hales Clay' (HC1) is now considered to be part of the Upnor Formation. The upper part (HC2) is now considered to be part of the Orwell Member (Harwich Formation).

Type section

Type section: The Hales Borehole (TM39NE7) [TM 3671 9687], Norfolk, from 16.56 to 32.18 m depth as originally defined; 16.56 to 29.52 m depth as emended by Jolley (1996), Knox (1996b) and King (in prep.).

Reference section

Reference section: Ormesby A Borehole (TG51SW7A) [TG 5145 1425] (Cox et al., 1985).

Formal subdivisions

None

Lithology

Clay and silt with variable amounts of sand, and sporadic bentonitic volcanic ash layers. The lower part (HC1) comprises bioturbated silt, whereas the much thicker upper part (HC2) comprises silty clay, silt and sandy silt with thin beds of fine-grained sand.

Genetic interpretation

Marine shelf

Definition of upper boundary

The top of the silty clays, clayey silts and thin sands, giving way to the tuffaceous siltstones of the Wrabness Member at a sharply-defined discontinuity surface and with a concentration of glauconite in the overlying sediments (Jolley, 1996).

Definition of lower boundary

Originally, the base of unit HC1 overlying glauconitic mudstone of the Ormesby Clay Member (Knox et al. 1990)

As emended by Jolley (1996), the base of unit HC2 is an interburrowed omission surface overlain by a glauconitic interval (King, in prep.), overlying bioturbated silt of unit HC1, now assigned to the Upnor Formation.

Thickness

About 13 m

Distribution

Eastern Norfolk and Suffolk

Age

Early Eocene (early Ypresian)

3.3.1.5 ORWELL MEMBER (ORW)

Name

The Orwell Member was defined by Jolley (1996) to describe the lower part of the Harwich Formation in Suffolk and North Essex. The name of the unit is taken from the River Orwell, which flows through south Suffolk. It corresponds to the lower division of the 'ash-bearing' unit of Knox and Ellison (1979).

Previous name

Lower part of Harwich Member (Division A1 of the London Clay) of King (1981, p.25).

Type section

Partial type section: Low cliffs on the north bank of the River Orwell at Bridge Wood, just south of Ipswich [TM 1824 4064] to [TM 1870 4010] expose the middle and upper part of the unit (Jolley, 1996).

Reference sections

Reference section: BGS Shotley Gate Borehole (TM23SW19) [TM 2439 3460], 9.93 to 23.55 m depth (Knox and Ellison, 1979).

Reference section: Cliff and foreshore exposures at Ferry Cliff on east bank of River Deben just east of Woodbridge, Suffolk [TM 2774 4854] to [TM 2800 4867] (George and Vincent, 1976; King, 1981).

Formal subdivisions

None. The gravelly basal Unit A of Jolley (1996) was previously described as the **Suffolk Pebble Bed (SUFP)** (Boswell, 1915), which are sands and gravel beds containing vertebrate and mollusc fossils, between the London Clay and pale-coloured sands of the Reading Formation (Boswell, 1915; Boswell, 1927; Curry, 1958). King (in prep.) found that the Suffolk Pebble Bed(s) are separated from the overlying beds of the Orwell Member at a sharply defined contact and assigned them to a new 'Ipswich Member'. This unit is not adopted by the current framework.

Lithology

The Orwell Member commences in glauconitic fine-grained sands (Unit A) with well-rounded flint gravel and faunal debris at the base, conformably overlain by bioturbated silty sands and sandy clayey silts with shell fragments and discontinuous laminae of dark grey-black claystone (Unit B). The upper part of the member (Unit C) is characterised by tuffaceous sandy silt with laminae of fine-grained sand. The tephra layers are discontinuous. Microscopic tuffaceous material is disseminated through Units B and C (Jolley, 1996; King, 1981; Knox and Ellison, 1979). King (in prep.) describes more varied lithofacies from this part of the sequence.

Genetic interpretation

Marine: inner to mid shelf

Definition of upper boundary

Sharply defined disconformity at the base of the Wrabness Member.

Definition of lower boundary

Rests disconformably on sands of the Reading Formation or on the Ormesby Clay Member, on an undulating erosion surface.

Thickness

Unit A is typically up to about 1 m in thickness; Unit B up to about 1.75 m; Unit C up to about 2.5 m (Jolley, 1996). King (in prep.) suggests that channel-filling sands and gravels up to 10 m thick in the Harwich area can be correlated with his Ipswich Member.

Distribution

Eastern Norfolk and Suffolk. Onlaps to the south-west, then passing laterally into glauconitic silty sands of the Swanscombe Member. To the south, Unit C of the Orwell Member passes laterally into the Oldhaven Member of the north Kent coast (King, 1981; Jolley, 1996).

Age

Early Eocene (early Ypresian)

3.3.1.6 WRABNESS MEMBER

Name

The Wrabness Member was defined by Jolley (1996) to describe the upper part of the Harwich Formation in Suffolk and North Essex. It is named after Wrabness, on the south side of the River Stour in Essex.

Previous names

Upper part of Harwich Member (Division A1 of the London Clay) of King (1981, p.25 and fig.14).

Type section

Type section: The cliffs north of Wrabness (and about 700 m east of Wrabness Point) [TM 1726 3233], which expose the complete member from the contact with the underlying Orwell Member to that with the overlying Walton Member (London Clay Formation) (Daley, 1999b; Daniels, 1971; Jolley, 1996; King, 1981; Knox and Ellison, 1979)

Reference sections

Reference section: The upper part of the Wrabness Member is exposed in the cliffs and foreshore at The Naze, north of Walton-on-the-Naze [TM 267 244] (Jolley, 1996)

Reference section: The Harwich Stone Band is exposed on the foreshore on the eastern side of the Harwich promontory, between Beacon Cliff [TM 2629 3166] and Harwich Green [TM 2630 3233] (Daley, 1999b)

Reference section: Cliff and foreshore exposures at Ferry Cliff on east bank of River Deben just east of Woodbridge, Suffolk [TM 2774 4854] to [TM 2800 4867] (George and Vincent, 1976; King, 1981) expose the lower part of the Wrabness Member, including the Harwich Stone Band (Daley, 1999b)

Formal subdivisions

None.

Lithology

The Wrabness Member comprises tuffaceous clayey silts and silty clays, with both disseminated ash and numerous distinct tephra layers (Unit A), overlain with apparent disconformity by bioturbated fine-grained silty sand with clay interbeds (Unit B). There is a concentration of glauconite in sandy clayey silt at the base of Unit A (Jolley, 1996; King, in prep.). Layers of concretionary argillaceous limestone occur at several levels, including the tabular **Harwich Stone Band (HARS)**, which is about 0.25 m thick and which includes a central ash bed (Elliott, 1971; Jolley, 1996; King, 1981, in prep.; Knox and Ellison, 1979). The occurrence and correlation of the ash in the Wrabness Member is described by Knox (1983, 1996b) and Knox and Morton (1988).

Occurrences at Walton-on-the-Naze have yielded an extensive assemblage of fossil birds (George and Vincent, 1977; Harrison, 1983; Harrison and Walker, 1977).

Genetic interpretation

Marine: inner to mid shelf

Definition of upper boundary

The top of the unit is marked by the disconformable base of the Walton Member mudstones, which contain sporadic well-rounded flint gravel (Jolley, 1996). According to King (1981, p.25), the Walton Member has much less glauconite and much less bioturbation.

Definition of lower boundary

The base of the unit, which rests on the Orwell Member, is marked by a sharply-defined discontinuity surface and a basal concentration of glauconite.

Thickness

Up to about 24 m (King, in prep.)

Distribution

Eastern Essex and southern Suffolk. Passes south with basal onlap into the Oldhaven Member of north Kent, and west into the Swanscombe Member (King, 1981; Jolley, 1996).

Age

Early Eocene (early Ypresian)

Harwich Stone Band (HARS)

The informally described Harwich Stone Band occurs near the base of Unit A of the Wrabness Member. It is a tabular argillaceous limestone about 0.25 m thick, with a central ash bed, that appears to be a widespread, seismically-visible marker in East Anglia, north-eastern Essex and the nearby offshore (King, in prep.).

3.3.2 London Clay Formation (LC)

Name

Although the London Clay has been recognised at least as far back as the work of William Smith (Smith, p. 111 in Farey, 1811), the London Clay Formation was not formally defined until the work of King (1981), who reviewed the history of research on the unit. The definition was emended by Edwards and Freshney (1987) and by Ellison et al. (1994). The evolution of the concept is described by Curry (1958, pp.53–54).

Type area

The type area is London and Essex.

Type section

King (1981) proposed a provisional composite stratotype section based on exposures and boreholes. King (in prep.) has designated a composite type section comprising the Staines 5 Borehole (TQ07SW156) [TQ 0360 7250], 9.5 to 106.2 m (Ellison and Williamson, 1999, fig.6; Ellison et al., 2004, p.46) and the BGS Hampstead Heath Borehole

(TQ28NE198) [TQ 2646 8689], 9.5 to 66.7 m (Ellison et al., 2004, p.46). There is some overlap between these two sections.

Reference section(s)

Reference section: BGS Crystal Palace Borehole (TQ37SW671) [TQ 3379 7082], 5.16 to 128.97 m depth (Ellison et al., 2004, p.46). The BGS Crystal Palace Borehole cored most of the London Clay, from within the Claygate Member to the base.

Reference section: BGS Stanmore Common Borehole (TQ19SE102) [TQ 1611 9362] (Ellison et al., 2004, p.46)

Reference section: BGS Stock Borehole (TL70SW1) [TL 7054 0045] (Bristow, 1985; Ellison et al., 2004, p.46)

Reference section: BGS Bracknell Borehole (SU86NE42) [SU 8888 6547], 67.83 to 81.68 m depth (Ellison and Williamson, 1999, fig. 6).

Reference section in north of outcrop: BGS Dowsetts Farm Borehole (TL32SE38) [TL 3806 2079] (Hopson et al., 1996)

Reference section: Sheppey Cliffs, Isle of Sheppey, Kent, between Minster [TQ 9530 7399] and Warden [TR 0225 7201] (Daley, 1999b; King, 1984). This exposes the upper parts of the London Clay Formation and is well-known for as a fossil-collecting locality.

Other boreholes and sections are listed by Ellison et al. (2004, p.48) and by King (1981, pp.34–35)

Formal subdivisions

King (1981, 2006) identified a number of coarsening-upwards depositional sequences separated by discontinuities within the London Clay Formation, distinguished by variations in silt and sand content, the presence or not of laminations and the occurrence and nature of fossils and of cementstone concretions (King, 1981, 2006). King (1981) identified these by the letters A to E, with numbered subdivisions. This classification has found an increasing use in ground engineering, in particular.

Ellison et al. (2004) divided the London Clay into five informal lithostratigraphical divisions. The lowest four were informally denoted A to D and have not been mapped, whereas the topmost was mapped as the Claygate Member.

Although apparently based on similar criteria, the two classifications differ in their fundamental approach, and the unit boundaries in the two schemes differ. However, King (in prep.) has introduced a number of members within the London Clay, formalising the lithostratigraphical scheme introduced by Ellison et al. (2004) and corresponding in part to his own alpha-numeric divisions based on depositional sequences (King, 1981).

The Walton Member (Division A2 of King) occurs at the base of the formation and the Claygate Member at the top. King (in prep.) recognises the Ockendon, Aveley and Sheppey members in addition, and these are now included in the BGS framework. King (1981, in prep.) also recognises the Bracknell Member, which corresponds to some strata here included in the Claygate Member, and the Hadleigh Member. These units are not adopted here for reasons discussed in Section 3.3.2.5.

In the west of the London basin, distinct beds of sand or of gravel have been mapped in the Newbury district (Aldiss et al., 2006), for example, similar to those found in the London Clay in the Hampshire Basin. None has been individually named.

Lithology

The London Clay mainly comprises bioturbated or poorly laminated, blue-grey or grey-brown, slightly calcareous, silty to very silty clay, clayey silt and sometimes silt, with some layers of sandy clay. It commonly contains thin courses of carbonate concretions (‘cementstone nodules’) and disseminated pyrite. It also includes a few thin beds of shells and fine sand partings or pockets of sand, which commonly increase towards the base and towards the top of the formation. At the base, and at some other levels, thin beds of black rounded flint gravel occurs in places. Glauconite is present in some of the sands and in some clay beds, and white mica occurs at some levels. Fossils are generally sparse but locally abundant. Widespread sedimentary discontinuities are present in the London Clay, commonly marked by hardgrounds, concentrations of flint gravel or of glauconite, or by erosion.

In the west of the London Basin, the London Clay comprises mainly clayey silt, some sandy, with beds and lenses of silty sand and very fine-grained sand.

Weathered London Clay is typically brown, brownish grey or mottled brown and grey, commonly with selenite crystals, a form of gypsum.

The London Clay contains a varied marine fossil fauna, with rare occurrences of freshwater or brackish molluscs, and of other groups (King, 1981). There is also a significant macroflora, representing plant debris carried out to sea. Vertebrate fossils include the remains of fish, reptiles, and birds (Harrison and Walker, 1977).

Genetic interpretation

Marine: inner to outer shelf.

Definition of upper boundary

As for the Claygate Member, which is distinguished from the overlying Bagshot Formation by containing finer sand without cross-bedding and in the relative abundance of clay and silt in the Claygate Member.

Definition of lower boundary

Redefined by Ellison et al (1994) to correspond to the base of the Walton Member (Division A2) of King (1981). Usually marked by a thin bed of well-rounded flint gravel or a glauconitic horizon, or both, typically resting on a sharply defined planar surface, although locally uneven. It overlies the Harwich Formation or, where the Harwich Formation is absent, the Lambeth Group.

Thickness

Up to 150 m in Essex. Up to 130 m in the Guildford district (Ellison et al., 2002).

Distribution

London Basin, East Anglia and the Hampshire Basin

Age

Eocene (early and middle Ypresian), based on a variety of microfossil and macrofossil assemblages (King, 1981; Ellison et al., 2004, pp. 47-50).

3.3.2.1 WALTON MEMBER (WAM)

Name

This unit is named after Walton-on-the-Naze, north-east Essex, where coastal sections expose the lower parts of the Thames Group (King, 1981).

Previous name

Division A2 of the London Clay Formation (King, 1981) and Unit A of Ellison et al. (2004).

Type section

Partial type section: Cliff section at The Naze, Walton-on-the-Naze [TM 267 238]. This exposes the lower 15 m of the unit (Daley, 1999b; King, 1981, fig. 14).

Reference section

CTRL borehole A2 (TQ38SW 2212) [TQ 330 805] (central London), between 21.50 and 33.25 m depth.

Formal subdivisions

None.

Lithology

Partly bioturbated, silty clays and clayey silts, interbedded with some very fine-grained sandy silty clay. It is micaceous, frequently with lignitic debris and pyrite, but is generally not glauconitic nor calcareous. There is usually a thin basal glauconitic sandy and gravelly bed, or a layer of dispersed well-rounded gravel. Where the Walton Member is thin, it includes several coarse sandy and gravelly seams. It is also characterised by the occurrence of numerous whitish streaks of silt, 1–3 mm diameter and about 5 mm long, which are the remains of a type of tubular foraminiferid (King, 1981; in prep., and unpublished notes). Disseminated lignite is abundant and marine molluscs and fish teeth occur in places.

Genetic interpretation

Marine: inner to outer shelf.

Definition of upper boundary

Upwards appearance of more homogeneous strata comprising grey claystones and silty clays, in the overlying unit (Division A3 of King, 1981).

Definition of lower boundary

Rests on a discontinuity, usually marked by a flint gravel bed or a glauconitic horizon, or both. It generally overlies the Harwich Formation except where it locally overlies the Lambeth Group (King, 1981; Ellison et al., 1994).

Thickness

Thickens generally eastwards to a maximum of 17 m (King, 1981, in prep.).

Distribution

Present throughout the Hampshire and London basins, except in the west.

Age

Eocene (Ypresian)

3.3.2.2 Ockendon Member (OCKD)

Name

This unit is named after South Ockendon, south-west Essex, where the London Clay was exposed in a series of large clay pits (King, 1981, in prep.).

Previous name

The Ockendon Member corresponds to Unit B of Ellison et al. (2004) and Division A3 of King (1981).

Type section

Staines 5 Borehole (TQ07SW156) [TQ 0360 7250], from 81.0 to 97.4 m (Ellison and Williamson, 1999, fig.6; Ellison et al., 2004, p.46).

Reference section

South Ockendon clay quarry (Essex) [TQ 61 82] (cf. the nearby Aveley Quarry, King, 1981, fig. 11).

Formal subdivisions

None

Lithology

According to King (1981, 2003) this member can be divided into a lower part (A3i) that comprises silty homogeneous clay with several layers of grey claystones, and an upper part (A3ii) that comprises silty clay with many very thin layers of very fine-grained sand. This also contains claystone but in very thin layers and lenses that are commonly soft and red-brown.

Genetic interpretation

Marine: inner to outer shelf

Definition of upper boundary

Disappearance of thin layers and partings of well-sorted, fine-grained sand (beneath a thin bed of sandy silty clay at the base of the Aveley Member) and a return to mainly homogeneous clay.

Definition of lower boundary

Upwards appearance of homogeneous strata mainly comprising grey clays and claystones with calcareous fossils and calcareous concretions, with less silty clay than in the underlying unit (King, 1981, 2003, in prep.).

Thickness

Thickens generally eastwards to a maximum of 18 m (King, 1981, in prep.).

Distribution

Present throughout the Hampshire and London basins, except in the west.

Age

Eocene (Ypresian)

3.3.2.3 Aveley Member (AVLY)

Name

This unit is named after Aveley, south-west Essex, where it was once exposed in the Sandy Lane quarry [TQ 55 80] (King, 1981; Williams, 2002).

Previous name

Aveley Member corresponds to Unit C (Ellison et al. 2004), and to Division B and the lower part of Division C (King, 1981, in prep.).

Type section

Staines 5 Borehole (TQ07SW156) [TQ 0360 7250], from 40 to 81.0 m (Ellison and Williamson, 1999, fig.6; Ellison et al., 2004, p.46)

Formal subdivisions

None.

Lithology

Division B comprises mainly homogeneous silty clay, which is, however, very silty and micaceous at some levels. There are regular discontinuous layers of claystone concretions. Thin beds or partings of clayey silt, very fine-grained sand or glauconitic clay are present at some levels. The basal part is sandier and finely glauconitic (King, in prep.).

Genetic interpretation

Marine: inner to outer shelf

Definition of upper boundary

A change upwards to silty clay with common sandy clayey silt interbeds of the Sheppey Member.

Definition of lower boundary

A thin basal bed of sandy silty clay, some glauconitic, above the silty clay with thin layers and partings of well-sorted, fine-grained sand of the Ockendon Member, and a return to mainly homogeneous clay.

Thickness

About 56 m in the type area (King, in prep.)

Distribution

Occurs throughout the centre and east of the London Basin

Age

Eocene (Ypresian)

3.3.2.4 SHEPPEY MEMBER (SHEP)

Name

This unit is named after the Isle of Sheppey, north Kent, where coastal sections expose the Thames Group (King, 1981, in prep.).

Previous name

The Sheppey Member corresponds approximately to Unit D (Ellison et al. 2004), and to the upper part of Division C, Division D and most of Division E (King, 1981, in prep.).

Type section

Partial type section: Cliff section at The Naze, Walton-on-the-Naze [TM 267 238]. This exposes the lower 15 m of the unit (Daley, 1999b; King, 1981, fig. 14).

Partial type section: Cliff and foreshore sections on the north side of the Isle of Sheppey, north Kent (King, 1984, in prep.).

Formal subdivisions

None.

Lithology

Silty clay diffusely interbedded with sandy clayey silt, commonly glauconitic. There are several layers of calcareous concretions.

Genetic interpretation

Marine: inner to outer shelf

Definition of upper boundary

A change upwards to silty clay with sandy laminae, of the Claygate Member.

Definition of lower boundary

A change upwards from mainly homogeneous silty clay of the Aveley Member to silty clay with common sandy clayey silt interbeds.

Thickness

About 55 m in the type section (King, 1981, in prep.).

Distribution

Present throughout the Hampshire and London basins, except in the west.

Age

Eocene (Ypresian)

3.3.2.5 CLAYGATE MEMBER (CLGB)

Name

This division of the London Clay was initially recognised in Surrey as the 'Claygate Beds' (Dewey, 1912), named after Claygate, Surrey, where it was once exposed in clay pits. It was defined as the Claygate Member by King (1981), and by Bristow, following work in Essex (Bristow, 1982; Bristow et al., 1980). In Bristow's concept, it referred to all deposits above the base of the lowest distinct fine-grained sandy bed above the relatively homogeneous clays that make up the main part of the London Clay in that area. Correlation of transgressive cycles in the London Clay (King, 1981) suggests that the Claygate Member is diachronous, its base being older in the west (including the type area in Surrey) (Ellison et al. 2004, p.47).

Wooldridge (1924) noted that in Essex, for example around Brentwood, the strata at this level are relatively unstratified loams and suggested that they were formed under different conditions to the Claygate Beds of the type area. King (1982) considered that the definition of the Claygate Beds should be confined to the laminated and thinly bedded facies of the type area, and not be expanded to bioturbated sediments (as proposed by Bristow et al. 1980), some of which cannot be distinguished lithologically from the London Clay.

The stratigraphy of the 'Claygates' (*s.l.*) was discussed at considerable length within BGS and between BGS and King and others, both in person and in the literature, during the 1980s, when the geological maps of much of Essex were being revised.

King (in prep.) recognises a thin and discontinuous sand unit within the topmost London Clay west of London as the Bracknell Member (King, 1981). It was originally conceived as a fine- to coarse-grained sand unit above the Claygate Member and below the basal gravel bed of the Bagshot Formation (or Virginia Water Formation of King, 1981). As stated by King (in prep.) it has subsequently been found to be overlain by bioturbated sandy silts (the 'loamy facies' of the Bagshot Sands of Dewey and Bromehead, 1915), which he includes in the London Clay Formation.

However, in practice the base of the Bagshot Formation was mapped by BGS at the obvious change in lithology at the base of King's Bracknell Member (Ellison and Williamson, 1999). The Bracknell Member is therefore not recognised in the BGS lithostratigraphical scheme.

Previous names

Claygate Beds (Dewey, 1912); Passage Beds

Type area

The type area comprises the outliers north-west of Claygate, Surrey [TQ 15 64], where the unit was previously exposed in clay pits (Curry, 1958).

Reference section

No reference sections are available, according to King (1981), who recorded some ephemeral exposures in engineering excavations.

Formal subdivisions

None.

Lithology

Dark grey clays with sand laminae, passing up into thin alternations of clays, silts and fine-grained sand, with beds of bioturbated silt.

Genetic interpretation

Marine: inner to outer shelf

Definition of upper boundary

Distinguished from the Bagshot Formation by containing finer sand without cross-bedding and in the relative abundance of clay and silt in the Claygate Member.

Definition of lower boundary

Distinguished from the underlying Sheppey Member by the laminated character and relative abundance of sand in the Claygate Member. The boundary drawn at the lowest sand bed, conformable on silty clay with common sandy clayey silt interbeds.

In practical terms, it is taken at the 'lowest sandy horizon recognisable in the field' (Lake et al., 1986). In London, and further to the west, sand beds appear lower in the sequence and here the base of the Claygate Member is based on other criteria including grain size and glauconite content (Ellison et al. 2004).

Thickness

Average thickness of 16 m in London area; 17 m to 25 m in Essex.

The Albert Orphan Asylum Borehole (SU86SE52) [SU 8999 6132], drilled in about 1866 in what is now part of north-east Camberley, passed through about 30 m of 'dark sand and clay' that can be assigned to the Claygate Member, above 'blue [London] clay'.

Distribution

Axial zone of the London Basin

Age

Eocene (Ypresian)

3.4 BRACKLESHAM GROUP (BRB)

Name

The Bracklesham Group was originally defined in the Hampshire Basin (Curry et al., 1977; Edwards and Freshney, 1987), the name being derived from Bracklesham Bay, immediately west of Selsey Bill (West Sussex), where the constituent formations in the east of the Hampshire Basin are exposed on the foreshore. Its use was extended to the London Basin by King (1981).

Previous names

Curry (1992) used the term 'Bagshot Formation' to describe the London Basin equivalents of the Bracklesham Group of the Hampshire Basin. However, a three-fold subdivision of these strata has long been recognised, named the Bagshot Beds (BGB), Bracklesham Beds and Barton Beds by Dewey and Bromehead (1915) or Lower, Middle and Upper Bagshot Sands (Beds) by Prestwich (1847). The formations used in the current scheme correspond approximately to these three divisions (Table 3).

Reference sections

The type area of the Bracklesham Group is the Hampshire Basin, including the Isle of Wight.

See descriptions of constituent formations for reference sections.

Formal subdivisions

In the London Basin, the Bracklesham Group comprises three formations, in order of increasing age: the **Bagshot Formation**, the **Windlesham Formation** and the **Camberley Sand Formation**. These were defined following regional map revision by BGS in the west London and east Berkshire areas.

Lithology

Interbedded to interlaminated clays, silts and mostly fine- or medium-grained sands, locally shelly. Glauconite occurs in the mid part of the sequence. Minor coarse-grained sands, fine gravelly sand, gravel beds, sandstones or ironstone concretions occur in places.

Genetic interpretation

Marginal marine to inner shelf

Definition of upper boundary

In the London Basin, the Camberley Sand Formation is the youngest Palaeogene unit.

Definition of lower boundary

In the London Basin, the base is at the base of the Bagshot Formation, marked by an upwards change from clay, silt and fine-grained sand of the Claygate Member to thick-bedded, fine-grained sands, with a basal fine gravelly sand developed in places. Locally, erosion has removed the topmost parts of the Claygate Member.

Thickness

Up to about 140 m in the London Basin.

Distribution

In the London Basin, the main outcrop of the Bracklesham Group occurs in the central portion of the Palaeogene outcrop west of London. Small outliers of the Bagshot Formation occur in the axial part of the London Basin in north London (Hampstead Heath and Highgate), in Essex and in the Isle of Sheppey, Kent.

Age

Eocene (late Ypresian to late Lutetian)

3.4.1 Bagshot Formation (BGS)

Name

Warburton (1822) and Prestwich (1847) referred to the entire Palaeogene succession above the London Clay in the London Basin, as the Bagshot Sand or Sands, which Curry (1992) named the Bagshot Formation (Table 3). In the original sense, these deposits were the 'sands of Bagshot Heath', which now are assigned to the Camberley Sand Formation. The nearby town of Bagshot, Surrey, lies mostly on the Windlesham Formation. The restricted sense of the term Bagshot Formation recognised in this report was introduced by Ellison and Williamson (1999).

Previous names

The Bagshot Formation corresponds to the Lower Bagshot Sands of Prestwich (1847) and to the Bagshot Beds and the lower part of the Bracklesham Beds of Dewey and Bromehead (1915; Ellison and Williamson, 1999).

Alternative names

King (1981) proposed the term 'Virginia Water Formation' for most of the Lower Bagshot Sands of Prestwich (1847), in part to avoid the re-use of the term 'Bagshot', which has been used in several different stratigraphical concepts (King, 1982). He considered that the lowest part of the Lower Bagshot Sands (*sensu* Prestwich), a unit of mainly coarse-grained, cross-bedded sands with gravel stringers in the upper part, comprised his 'Bracknell Member'. He interpreted these as a deposit from a regressive phase of London Clay deposition, distinct from the coarsening-upwards sequence represented by the Bagshot Formation. He placed the base of the Virginia Water Formation at a gravel bed that he considered to be regionally extensive and environmentally significant. Bristow (1982) argued that the 'Bracknell Member' is lithologically more similar to the overlying beds of the Bagshot Formation than to the London Clay, and that the term 'Virginia Water Formation' is redundant. In practice, the base of the Bagshot Formation has been mapped by BGS at the obvious change in lithology at the base of King's Bracknell Member (Ellison and Williamson, 1999). It is considered here that the different usage of 'Bagshot Formation', 'Bagshot Sands' and 'Bagshot Beds' is unlikely to create sufficient confusion to justify the introduction of a completely new stratigraphical name.

King (in prep.) observes that the Bagshot Formation as mapped by BGS includes his Bracknell Member and an overlying interval of bioturbated sandy clay, silt and fine sand (both of which he places in the London Clay Formation), together with a unit of 'typical' fine- to coarse-grained Bagshot Sand facies that he assigns to the Virginia Water Member (emended from his previous Virginia Water Formation). He places the Virginia Water Member and the overlying Swinley Clay Member together in the Bagshot Formation. The Virginia Water Member is not currently recognised in the BGS lithostratigraphical scheme, although it should be noted for possible future use in detailed 3D geological models, should adequate borehole data enable the recognition of King's (in prep.) subdivisions.

Type section

The type section is between 32.27 and 67.83 m depth in the BGS Bracknell Borehole (SU86NE42) [SU 8888 6547] (King, in prep.; Ellison and Williamson, 1999, fig. 6). The basal contact in this section is sharp and probably erosional (King, unpublished report to BGS, 1996).

Formal subdivisions

The **St Ann's Hill Pebble Bed** was originally considered to occur locally at the base of the Windlesham Formation (Ellison and Williamson, 1999). However, King (in prep.) points out that it probably occurs below the Swinley Clay Member and so forms part of the Bagshot Formation.

The **Swinley Clay Member** occurs at the top of the formation. The underlying remainder of the formation is assigned to the Virginia Water Member by King (in prep.) but that name is not adopted in this framework.

Lithology

Most of the formation is composed of pale yellow-brown to pale grey or white, locally orange or crimson, fine- to coarse-grained sand that is frequently micaceous and locally clayey, with sparse glauconite and sparse seams of gravel. The sands are commonly cross-bedded but some are laminated. Thin beds and lenses of laminated pale grey to white sandy or silty clay or clay ('pipe-clay') occur sporadically, becoming thicker towards the top of the formation. A thick clay bed, the Swinley Clay Member, is included at the top. There are occasional seams of gravel and a basal bed of gravelly coarse-grained sand occurs in places. There is a sparse fossil fauna of mostly indeterminate marine molluscs, with some indistinct plant remains (Curry, 1958; Hawkins, 1954), but most organic material has been destroyed by oxidation or dissolution. The higher part of the interval in the Bracknell Borehole (SU86NE42) [SU 8888 6547] is predominantly bioturbated, with frequent *Ophiomorpha* burrows (King, unpublished report to BGS, 1996; (Ellison and Williamson, 1999, fig. 6).

As mapped by BGS, in places the lower part of the Bagshot Formation probably includes an interval bioturbated sandy clay, silt and fine-grained sand overlying a unit of fine- to coarse-grained sand (Bracknell Member of King, in prep.), both of which are placed in the topmost London Clay Formation by King (in prep.).

A temporary section near the M3 in Surrey, described by Goldring et al. (1978), exposed interlayered sands and muds, fine sands, channel-fill sands and intraformational (mainly mud clast) conglomerates. The facies showed rapid lateral and vertical changes in grain size and bed form and a restricted suite of trace fossils including *Ophiomorpha nodosa* and *Arenicolites* sp. The part of the formation that this section represents is not known.

Genetic interpretation

King (1981) interprets the Bagshot Formation as a basal marine transgressive unit marked by a gravel bed, overlain by an overall coarsening-upwards sand sequence. Bristow (1982) described the formation as channel-fill sands.

A temporary section near the M3 in Surrey, described by Goldring et al. (1978), was shown to have been deposited in a subtidal channel where tidal, wave and fluvial processes were dominant at different times.

Definition of upper boundary

Erosional surface at the top of the Swinley Clay Member, marking a change to the glauconitic sands of the lower part of the Windlesham Formation. In the outliers in the north of London, and to the east, the Bagshot Formation is the youngest part of the Palaeogene succession and the upper part has been eroded. In places it is overlain by deposits of Quaternary age.

Definition of lower boundary

An erosional surface marking a change from clay, silt and fine-grained sand of the Claygate Member to thick-bedded, pale-coloured, fine-grained sands, with a basal fine gravelly sand developed in places. Locally, erosion has removed the topmost parts of the Claygate Member.

Thickness

Up to about 45 m to the south-west of London, where overlain by the Windlesham Formation.

The BGS Bracknell Borehole (SU86NE42) [SU 8888 6547] passed through 39.75 m that was assigned to the Bagshot Formation, including the Swinley Clay Member (Ellison and Williamson, 1999, fig. 6).

The Albert Orphan Asylum Borehole (SU86SE52) [SU 8999 6132], drilled in about 1866 in what is now part of north-east Camberley, passed through about 30.8 m of 'light-coloured sand' and brown sand with clay beds at the top and at least one other level and including 5.8 m of 'light-coloured sand rock' at the base that can be assigned to the Bagshot Formation.

Wellington College Borehole (SU86SW89) [SU 8313 6350], sunk at Crowthorne, Berks, in about 1868, found about 34 m of strata representing the Bagshot Formation, including the Swinley Clay Member.

Distribution

Axial part of the London Basin.

Age

Eocene (Late Ypresian). Inferred from stratigraphical context by King (in prep.).

3.4.1.1 ST ANN'S HILL PEBBLE BED (SAHP)

The St Ann's Hill Pebble Bed occurs locally in Surrey, just north-west of Chertsey. It was previously exposed in an old gravel pit on the south side of St Ann's Hill [TQ 0268 6746] although showings elsewhere on the hill have been recorded. It comprises a unit of cross-bedded gravelly sand and gravel, some imbricated, up to about 3.5 m thick. The clasts are well-rounded black flint gravel and cobbles generally between 2 and 10 cm in diameter (Ellison and Williamson, 1999).

This unit was originally thought to lie at the base of the Windlesham Formation (Ellison and Williamson, 1999). However, the outcrop of this unit is very small and poorly exposed and available information suggests that there are at least two and possibly more gravel beds in this part of the succession. King (in prep.) refers to details presented by Whitaker (1872) and Dewey and Bromehead (1921, pp. 37 and 50) which suggest that it overlies typical Bagshot Sand but underlies the Swinley Clay. Specifically, the original BGS memoir for Windsor and Chertsey (Dewey and Bromehead, 1915, p.37) notes that the gravel bed is locally overlain by green and brown clays. He therefore includes it in the top of the Bagshot Formation and this interpretation is accepted here.

3.4.1.2 SWINLEY CLAY MEMBER (SWCL)

Name

This name was introduced by Ellison and Williamson (1999) for a clay unit whose existence had long been recognised. Swinley Park, Berkshire, is at the western end of the mapped outcrop. A disconformity marking a period of emergence occurs at the top of the member. This appears to have regional significance and has been taken as the top of the Bagshot Formation.

Previous names

The Swinley Clay is equivalent of the 'Lower Unit' of the Middle Bagshot Beds (King, 1981), Bed 3 of the Middle Bagshot Sands of Prestwich (1847, p. 384) and Beds 9 and 10 of Irving (1885, fig. 1). See also Dewey and Bromehead (1915, p.41). The unit varies regionally in thickness, due to its highly erosional basal contact.

Alternative names

This unit is named the Swinley Member by King (in prep.).

Type section

The type section is between 60.05 and 63.66 m deep in the BGS Mytchett (Farnborough) Borehole 2 (SU85NE185) [SU 8833 5539] (Ellison et al., 2002, fig. 6).

Reference section

Reference section: The BGS Bracknell Borehole (SU86NE42) [SU 8888 6547] between about 28.1 and 32.27 m (Ellison and Williamson, 1999, fig. 6).

Formal subdivisions

None

Lithology

This unit consists of several metres thickness of organic laminated clay, which is white, grey, pale purple, brown or yellow in colour, with flasers and laminae of fine-grained sand and silt.

In the BGS Bracknell Borehole, it comprises about 4 m of dominantly dark grey to brown organic-rich (lignitic) laminated clays with laminae of fine sand and thin beds of medium-grained sand. Plant debris, including lignite, is common and glauconite is almost absent. The top of the unit has been bleached and oxidised, with root traces. This appears to represent a soil horizon (King, unpublished report to BGS, 1996).

Genetic interpretation

Marginal marine to inner shelf, with a pedogenically altered topmost layer.

Definition of upper boundary

An interburrowed and brecciated surface with root traces, taken to represent an eroded emergent surface, overlain by the Windlesham Formation.

Definition of lower boundary

Sharply-defined, probably erosional contact with underlying non-glauconitic sands of the typical Bagshot Formation (Ellison et al., 2002).

Thickness

Up to 8 m in the Guildford district (Ellison et al., 2002).

The BGS Bracknell Borehole (SU86NE42) [SU 8888 6547] passed through 4.24 m that was assigned to the Swinley Clay Member (Ellison and Williamson, 1999, fig. 6).

The BGS Mytchett (Farnborough) Borehole 2 passed through 3.7 m that was assigned to the Swinley Clay Member.

The Albert Orphan Asylum Borehole (SU86SE52) [SU 8999 6132], drilled in about 1866 in what is now part of north-east Camberley, passed through about 5.5 m of ‘light-coloured sandy clay’ that can be assigned to the Swinley Clay Member.

Distribution

Western part of the London Basin

Age

Eocene (latest Ypresian, possibly ranging to earliest Lutetian), based on dinoflagellate cysts that suggest that the base of Zone DE10 is within the Swinley Clay Member (Islam, 1983; King, in prep.)

3.4.1.3 Bagshot Pebble Bed (BGP)

This term has been used in places to refer to a thick bed (or series of beds) of mainly well-rounded flint gravel at the top of the Bagshot Formation in parts of Essex (Bristow, 1985; Curry, 1958; Wooldridge, 1924). Ellison et al. (2004, p.51) suggest that these gravel beds belong, at least in part, with the Stanmore Gravel, which they considered to be probably of Quaternary age and which is now assigned to the Neogene to Quaternary Crag Group (McMillan et al., 2011). The term ‘Bagshot Pebble Bed’ is not formally adopted in this stratigraphical framework and its future use, if any, should be subject to critical scrutiny.

3.4.2 Windlesham Formation (WIDS)

Name

The name Windlesham Formation was introduced by Ellison and Williamson (1999) for the characteristically dark-coloured middle part of the post-London Clay succession in the London Basin. It is named after the town of Windlesham, Surrey, which lies in the broadest part of the outcrop in the axis of the London Basin.

Previous names

The Windlesham Formation comprises the Middle Bagshot Sands of Prestwich (1847), or all but the lowermost parts of the Bracklesham Beds of Dewey and Bromehead (1915) (Ellison and Williamson, 1999). It corresponds to Beds 4 to 8 of Irving (1885, fig. 1).

Alternative names

This interval is referred to units of the Hampshire Basin by King (in prep.), who observes that the strata of the Windlesham Formation/Middle Bagshot Beds comprise a lower sandy unit and an upper clay unit that respectively correlate with the Earnley and Marsh Farm formations (Edwards and Freshney, 1987). Although these divisions are recognised in cored BGS boreholes in the area, it was not possible to separate these units during revision of the corresponding geological maps.

Type section

The type section is between 16.2 and 28.9 m depth in the BGS Bracknell Borehole (SU86NE42) [SU 8888 6547] (Ellison and Williamson, 1999, fig. 6).

Reference section

BGS Farnborough (Mytchett) Borehole 1 (SU85NE184) [SU 8830 5541], 41.86 to 56.57 m, and BGS Farnborough (Mytchett) Borehole 2 (SU85NE185) [SU 8833 5539], 55.2 to 60.0 m (Ellison et al., 2002, fig. 6).

Formal subdivisions

The **Stanners Hill Pebble Bed** occurs at the top of the Windlesham Formation (Ellison and Williamson, 1999).

Lithology

The typical lithologies are bioturbated dark green to brown, fine- to medium-grained sands with sand-sized glauconite grains, silts and white, yellow or brown clay, overlain by organic dark grey clay with lenticles of fine sand, and then by glauconitic sand and sandy clayey silt. There are occasional layers of flint gravel, and a prominent gravel bed occurs at the top. Teeth and bones of marine vertebrates occur as do marine bivalve molluscs, although occurrences above the water table generally have been decalcified (Curry, 1958; Hawkins, 1954).

Three subdivisions can be recognised in the Bracknell Borehole (Ellison and Williamson, 1999, fig. 6). The lowest (equivalent to the Earnley Formation of Hampshire, and to Beds 7 and 8 of Irving, 1885), 7.5 m thick, comprises bioturbated but otherwise mainly structureless glauconitic sands, becoming less glauconitic upwards. These sands are overlain by a unit of organic-rich laminated clay (equivalent to the Marsh Farm Formation in Hampshire), 1.85 m thick, and then by glauconitic sand and sandy clayey silt with a prominent basal gravel bed and interburrowed contact on the underlying clay, altogether 2.8 m thick. This is probably equivalent to the lower part of the Selsey Formation of Hampshire, and to Beds 4 to 6 of Irving (1885) (King, unpublished report to BGS, 1996).

Genetic interpretation

Marine: inner shelf ranging up to marginal

Definition of upper boundary

Upwards change from dark-coloured sand and sandy, clayey silt to fairly homogeneous, yellow-brown silty fine-grained sands of the Camberley Sand Formation, probably at an omission surface (King, in prep.).

Definition of lower boundary

An interburrowed omission surface on the top of the Swinley Clay Member, or on sands of the Bagshot Formation, marking an upwards change from a dominantly sandy sequence without glauconite to a darker-coloured sandy sequence with glauconite.

Thickness

Up to 25 m (Ellison and Williamson, 1999).

The BGS Bracknell Borehole (SU86NE42) [SU 8888 6547] passed through an interval of 11.5 m that was assigned to the Windlesham Formation (Ellison and Williamson, 1999, fig. 6).

The BGS Mytchett (Farnborough) Borehole 1 (SU85NE184) [SU 8830 5541] passed through 17.9 m that was assigned to the Windlesham Formation, including 0.8 m of the Stanners Hill Pebble Bed.

The Albert Orphan Asylum Borehole (SU86SE52) [SU 8999 6132], drilled in about 1866 in what is now part of north-east Camberley, passed through about 12.3 m of 'dark sand' or green sand with some gravel about 3.8 m from the top that can be assigned to the Windlesham Formation.

Wellington College Borehole (SU86SW89) [SU 8313 6350], sunk at Crowthorne, Berks, in about 1868, found about 13 m of strata representing the Windlesham Formation, including the Stanners Hill Pebble Bed at the top.

Distribution

Present in the core of the western London Basin around the junction of Surrey, Berkshire and Hampshire.

Age

Eocene (early to mid Lutetian) (King, in prep.)

3.4.2.1 STANNERS HILL PEBBLE BED (STHP)

The Stanners Hill Pebble Bed was chosen by Dewey and Bromehead (1915) as the base of their 'Upper Bagshot Beds' (Camberley Sand Formation) and known by them as the Basement Pebble Bed. It consists of a unit of cross-bedded glauconitic gravelly sand and gravel up to about 4 m thick. The gravel is mainly composed of flint but some is made of quartz or of Lower Cretaceous chert (Dewey and Bromehead, 1915, p.55).

King (in prep.) interprets this deposit as a localised channel-fill between the top of the Windlesham Formation (assigned by him to the Marsh Farm Formation) and the Camberley Sand Formation (assigned by him to the Selsey Formation). It is probably confined to the Bracklesham Group outcrop in Surrey. It is represented in the Wellington College Borehole (SU86SW89) [SU 8313 6350]. An occurrence represented by two thin gravel beds in the BGS Bracknell Borehole SU86NE 42 [SU 8880 6547] noted by Ellison and Williamson (1999, fig. 6) is suggested by King (in prep.) to represent the basal gravel bed of the Camberley Sand Formation.

3.4.3 Camberley Sand Formation (CMBS)

Name

The name Camberley Sand Formation was introduced by Ellison and Williamson (1999) for the characteristically pale-coloured upper part of the post-London Clay succession in the London Basin. It is named after the town of Camberley, Surrey, which lies near the centre of the main outcrop in the axis of the London Basin.

Arguably, the strata assigned by BGS to the Camberley Sand Formation should instead have been placed in the Selsey Formation of the Hampshire succession (King, in prep.). However, the BGS framework necessarily describes what has been shown on the BGS maps and in the corresponding reports, while noting the correlation with the Hampshire unit.

Previous names

This unit is equivalent to the former Barton Beds (Dewey and Bromehead, 1915) and the former Upper Bagshot Sands (Prestwich, 1847).

Alternative names

This unit is referred to the Selsey Formation of the Hampshire Basin by King (in prep.).

Type area

The type area is around Camberley, Frimley and Farnborough in north-west Surrey. No type section has been designated.

Reference sections

Reference section: The BGS Mytchett (Farnborough) Borehole 1 (SU85NE184) [SU 8830 5541] between 6.6 and 41.86 m depth (Ellison et al., 2002, fig. 6).

Reference section: The BGS Bracknell Borehole (SU86NE42) [SU 8888 6547], between 1.77 and about 16.2 m (Ellison and Williamson, 1999, fig. 6).

Numerous occurrences of the Camberley Sand Formation, some fossiliferous, are described by Gardner et al. (1888).

Formal subdivisions

None.

Lithology

A fairly uniform sequence of homogeneous, bioturbated, yellow-brown, sparsely to moderately glauconitic silty fine-grained sand, or sandy silt, with some ironstone concretions and masses of white sandstone. Sporadic flint gravel or a gravel bed occur near the base. Thin beds of pale grey clay occur in places (Ellison and Williamson, 1999). Fossils include fish teeth and marine bivalve molluscs, although occurrences above the water table generally have been decalcified (Curry, 1958). Some beds rich in foraminifera occur in the Mytchett Borehole.

Genetic interpretation

Marine; inner shelf (King, in prep.).

Definition of upper boundary

The Camberley Sand is the youngest Palaeogene unit in the London Basin, so it is overlain, if at all, only by deposits of Quaternary age.

Definition of lower boundary

Probably an omission surface (King, in prep.) marking the upwards change from the heterolithic Windlesham Formation to the more homogeneous, paler-coloured Camberley Sand Formation.

Thickness

Up to 69 m in the Windsor district (Ellison and Williamson, 1999).

The BGS Mytchett (Farnborough) Borehole 1 (SU85NE184) [SU 8830 5541] passed through 36.36 m that was assigned to the Camberley Sand Formation.

The Albert Orphan Asylum Borehole (SU86SE52) [SU 8999 6132], drilled in about 1866 in what is now part of north-east Camberley, passed through about 70 m of ‘light green sand’ with 0.76 m of yellow sandy loam and stones at the base that can be assigned to the Camberley Sand Formation.

Distribution

Core of the western London Basin around the junction of Surrey, Berkshire and Hampshire.

Core from the BGS Mytchett (Farnborough) Borehole 1 yielded a calcareous fauna including the foraminiferid *Nummulites variolarius*, indicating correlation with the lower part of the Selsey Sand Formation of the Hampshire Basin.

Age

Eocene (late Lutetian) (King, in prep.).

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Appendix 1 Lithostratigraphical units used by BGS

These lists are in alphabetical order of unit names.

Groups

Lexicon Code	Name of unit
BRB	Bracklesham Group
LMBE	Lambeth Group
MONT	Montrose Group
THAM	Thames Group

Formations

Lexicon Code	Name of unit	Parent Unit
BGS	Bagshot Formation	Bracklesham Group
CMBS	Camberley Sand Formation	Bracklesham Group
HWH	Harwich Formation	Thames Group
LIST	Lista Formation	Montrose Group
LC	London Clay Formation	Thames Group
RB	Reading Formation	Lambeth Group
TAB	Thanet Formation	Montrose Group
UPR	Upnor Formation	Lambeth Group
WIDS	Windlesham Formation	Bracklesham Group
WL	Woolwich Formation	Lambeth Group

Members

Names in italic script are of informal units of member status.

Lexicon Code	Name of unit	Parent Unit
AVLY	Aveley Member	London Clay Formation
BSBD	Base Bed Member	Thanet Formation
BLB	Blackheath Member	Harwich Formation
CLGB	Claygate Member	London Clay Formation
KNTS	Kentish Sands Member	Thanet Formation
LBED	*Laminated Beds*	Woolwich Formation
LMCL	*Lower Mottled Clay*	Reading Formation

LSCL	*Lower Shelly Clay*	Woolwich Formation
OCKD	Ockendon Member	London Clay Formation
OH	Oldhaven Member	Harwich Formation
OC	Ormesby Clay Member	Lista Formation
ORW	Orwell Member	Harwich Formation
PGWS	Pegwell Silt Member	Thanet Formation
RCLV	Reculver Sand Member	Thanet Formation
SHEP	Sheppey Member	London Clay Formation
SHOM	Shorne Member	Woolwich Formation
STMH	Stourmouth Silt Member	Thanet Formation
SLOM	*Striped Loams*	Woolwich Formation
SWCB	Swanscombe Member	Harwich Formation
SWCL	Swinley Clay Member	Bagshot Formation
UMCL	*Upper Mottled Clay*	Reading Formation
UPSCL	*Upper Shelly Clay*	Woolwich Formation
WAM	Walton Member	London Clay Formation
WLWS	*Woolwich Sands*	Woolwich Formation
WRAB	Wrabness Member	Harwich Formation

Beds

Lexicon Code	**Name of unit**	**Parent Unit**
BGP	Bagshot Pebble Bed	Bagshot Formation
BLHB	Bullhead Bed	Base Bed Member
CEGB	Cliffs End Greensand Bed	Base Bed Member
COBL	Cobham Lignite Bed	Shorne Member
HARS	Harwich Stone Band	Wrabness Member
LNSH	Lessness Shell Bed	Blackheath Member
SAHP	St Ann's Hill Pebble Bed	Bagshot Formation
STHP	Stanners Hill Pebble Bed	Windlesham Formation
SUFP	Suffolk Pebble Bed	Orwell Member

Appendix 2 BGS Lexicon Codes

This list of the units named in Appendix 1 is in alphabetical order of Lexicon Codes (see Section 1.5). Names in italic script are of informal units of member status.

Lexicon Code	**Name of unit**
BGP	Bagshot Pebble Bed
BGS	Bagshot Formation
BLB	Blackheath Member
BRB	Bracklesham Group
CLGB	Claygate Member
CMBS	Camberley Sand Formation
HWH	Harwich Formation
LBED	*Laminated Beds*
LC	London Clay Formation
LIST	Lista Formation
LMBE	Lambeth Group
LMCL	*Lower Mottled Clay*
LSCL	*Lower Shelly Clay*
MONT	Montrose Group
OC	Ormesby Clay Member
OH	Oldhaven Member
RB	Reading Formation
SAHP	St Ann's Hill Pebble Bed
STHP	Stanners Hill Pebble Bed
SWCL	Swinley Clay Member
TAB	Thanet Formation
THAM	Thames Group
UMCL	*Upper Mottled Clay*
UPR	Upnor Formation
UPSCL	*Upper Shelly Clay*
WAM	Walton Member
WIDS	Windlesham Formation
WL	Woolwich Formation

Appendix 3 Obsolete lithostratigraphic terms and codes

This list is in alphabetical order of Lexicon Codes (see Section 1.5). It is mainly restricted to unit names used on BGS maps and in other BGS publications, with entries in the BGS Lexicon.

Extant Lexicon code	Obsolete Lexicon code	Obsolete name	Current name for equivalent or part-equivalent
	BBD	Reading Bottom Bed	Upnor Formation
	BGB	Bagshot Beds	Part of Bracklesham Group
	BGBL	Lower Bagshot Beds	Near-equivalent to Bagshot Formation
	BGBM	Middle Bagshot Beds	Near-equivalent to Windlesham Formation
	BGBR	Bagshot Beds and Bracklesham Beds (undifferentiated)	Part of Bracklesham Group
	BGBU	Upper Bagshot Beds	Camberley Sand Formation
BLB		Blackheath Beds	Blackheath Member
	HAC	Hales Clay Member	Orwell Member (Harwich Formation) and Upnor Formation
	LCBA	London Clay Basement Bed	Equivalent or part equivalent to Walton Member or Harwich Formation
	LLTE	Lower London Tertiaries	Harwich Formation, Lambeth Group and Thanet Formation, undifferentiated
	MCL	Mottled Clay (Reading Formation)	Reading Formation
OH		Oldhaven Beds	Oldhaven Member
	RFBB	Reading Formation Basement Bed	Upnor Formation
TAB		Thanet Sand Formation	Thanet Formation
	TS	Thanet Sand	Thanet Formation
	WLOH	Woolwich Beds – Oldhaven Beds	Woolwich Formation and Harwich Formation undifferentiated
	WRB	Woolwich and Reading Beds Formation	Woolwich Formation and Reading Formation undifferentiated
		Blackwall Rock	not known

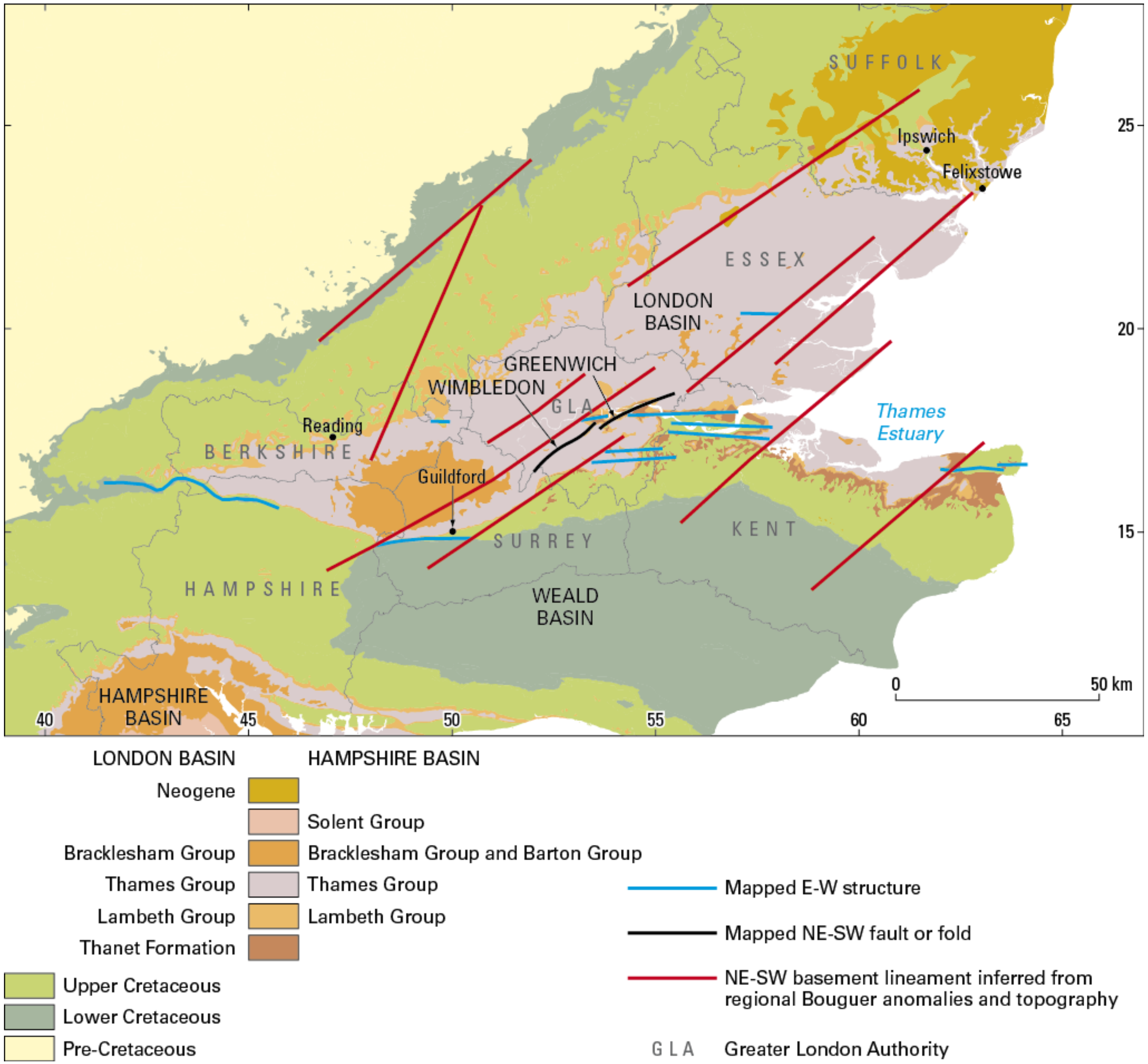

Figure 1: **Selected structures controlling the London Basin**

This map shows the areas of the traditional English counties, prior to the formation of the modern Boroughs, Districts and Unitary Authorities, although it includes the area of the Greater London Authority.

Table 1: Chronostratigraphical subdivisions of the Cenozoic Era

From Ogg et al. (2008), and from King (2006) after Berggren et al. (1995). Age/Stage names for the Neogene and Quaternary have been omitted for simplicity.

<table>
<tr><th>PERIOD</th><th colspan="2">EPOCH</th><th>AGE/STAGE</th><th>Age of base (Ma)</th></tr>
<tr><td>QUATERNARY</td><td colspan="2">Holocene
Pleistocene</td><td rowspan="3"></td><td>2.59</td></tr>
<tr><td rowspan="2">NEOGENE</td><td colspan="2">Pliocene</td><td>5.33</td></tr>
<tr><td colspan="2">Miocene</td><td>23.03</td></tr>
<tr><td rowspan="11">PALAEOGENE</td><td>Late</td><td rowspan="2">Oligocene</td><td>Chattian</td><td>28.4</td></tr>
<tr><td>Early</td><td>Rupelian</td><td>33.9</td></tr>
<tr><td>Late</td><td rowspan="4">Eocene</td><td>Priabonian</td><td>37.2</td></tr>
<tr><td rowspan="2">Mid</td><td>Bartonian</td><td>40.4</td></tr>
<tr><td>Lutetian</td><td>48.6</td></tr>
<tr><td>Early</td><td>Ypresian</td><td>55.8</td></tr>
<tr><td rowspan="2">Late</td><td rowspan="3">Paleocene</td><td>Thanetian</td><td>58.7</td></tr>
<tr><td>Selandian</td><td>61.1</td></tr>
<tr><td>Early</td><td>Danian</td><td>65.5</td></tr>
</table>

Table 2: Stratigraphical hierarchy in the Palaeogene of the London Basin

Group	Formation	Member	Bed
Bracklesham	Camberley Sand		
	Windlesham		Stanners Hill Pebble
	Bagshot	Swinley Clay	
			St Ann's Hill Pebble
Thames	London Clay	Claygate	
		Sheppey	
		Aveley	
		Ockendon	
		Walton	
	Harwich	Swanscombe	
		Oldhaven	
		Blackheath	Lessness Shell
		Wrabness	Harwich Stone Band
		Orwell	Suffolk Pebble
Lambeth	Woolwich	*Woolwich Sands*	
		Upper Shelly Clay	
		Striped Loams	
		Laminated Beds	
		Lower Shelly Clay	
		Shorne	Cobham Lignite
	Reading	*Upper Mottled Clay*	
		Lower Mottled Clay	
	Upnor		
Montrose	Thanet	Reculver Sand	
		Pegwell Silt	
		Kentish Sands	
		Stourmouth Silt	Cliffs End Greensand
		Base Bed	Bullhead
	Lista	Ormesby Clay	

Note that in normal usage, unit names are terminated by the rank term at the head of the column, other than those shown in italic script, which are informal.

Table 3: Subdivision of the Upper Palaeogene strata of the London Basin

<table>
<tr><td rowspan="2">Warburton 1822</td><td rowspan="2">Prestwich 1847</td><td rowspan="2">Dewey and Bromehead 1915</td><td rowspan="2">King 1981</td><td rowspan="2">Bristow 1982</td><td rowspan="2">Curry 1992</td><td colspan="4">Current BGS Framework</td></tr>
<tr><td colspan="2">London Basin</td><td colspan="2">Hampshire Basin</td></tr>
<tr><td colspan="8" rowspan="2">Younger beds have been removed by erosion</td><td>Barton Formation</td><td rowspan="8">Bracklesham Group</td></tr>
<tr><td rowspan="3">Selsey Sand Formation</td></tr>
<tr><td rowspan="6">Bagshot Sand</td><td>Upper Bagshot Sands</td><td>Barton Beds</td><td></td><td></td><td rowspan="6">Bagshot Formation</td><td>Camberley Sand Formation</td><td rowspan="6">Bracklesham Group</td></tr>
<tr><td rowspan="4">Middle Bagshot Sands</td><td rowspan="4">Bracklesham Beds</td><td rowspan="3">Middle Bagshot Beds
Middle unit</td><td rowspan="4"></td><td rowspan="3">Windlesham Formation</td></tr>
<tr><td>Marsh Farm Formation</td></tr>
<tr><td>Earnley Sand Formation</td></tr>
<tr><td>Lower unit</td><td>Swinley Clay Member</td><td rowspan="2">Wittering Formation</td></tr>
<tr><td>Lower Bagshot Sands</td><td>Bagshot Beds</td><td>Virginia Water Formation</td><td>Bagshot Beds</td><td>Bagshot Formation</td></tr>
<tr><td colspan="10">London Clay Formation</td></tr>
</table>

Taken from a draft document prepared by R A Ellison and I T Williamson, BGS, in 1998.