London - Palaeogene-Eocene

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LONDON CLAY FORMATION

The London Clay Formation has had an important influence on the development of London infrastructure particularly as it is a relatively homogeneous and easy tunnelling medium. It underlies most of the district and crops out extensively, except in the south-east where it has been removed by erosion. Much of it is covered by a variable thickness of superficial deposits. It gives rise to low, subdued topography in the Thames valley, for example in the area between Romford and Basildon, and rolling topography with convex slopes generally less than 4º, where dissection has been more pronounced, for example between Stanmore and Hampstead.

As its name implies, the London Clay is predominantly argillaceous, and about 60 per cent of the formation consists of thoroughly bioturbated, slightly calcareous, silty clay to very silty clay. Beds of clayey silt grading to silty fine-grained sand increase in number and thickness from east to west. The sand and silt grains are of subangular quartz, generally less than 125 microns in diameter. Glauconite grains, up to fine to medium sand grade are dispersed through most of the sandy beds. Glauconite grains are concentrated also in some of the more clayey beds, forming marker horizons.

The London Clay at outcrop is oxidised to a brown colour, and may contain secondary carbonate nodules, known as ‘race’. The thickness of the oxidised zone is generally 3 to 6 m but this depends on the lithology. The more permeable sandy beds are more deeply weathered, in places to more than 10 m. Beneath superficial deposits this oxidised zone is generally less than 1 m, but increases under successively older superficial deposits (Chandler, 1999). Below the oxidised layer the unweathered London Clay is grey to blue-grey and characteristically fissured. The top few metres of unweathered London Clay, and the bottom part of the weathered profile (see Figure 25), contains selenite (gypsum), the result of pyrite oxidation and mobilisation of carbonate, as crystals up to several centimetres in length. Pyrite is common throughout, and occurs mainly as millimetre-thick sticks (pyritised algal tubes) along with irregular millimetre-sized lumps or flakes and irregular concretions up to 50 mm in diameter. Plant fragments are generally also impregnated with pyrite. White mica flakes are most common in the coarser grained lithologies.

Carbonate concretions of varying size occur throughout the London Clay. The main horizons are shown in Figure 26. The concretions are mainly flattened spheroids of ferroan calcite (Huggett, 1994; Huggett and Gale, 1995). The larger ones, known as septarian nodules, are generally 300 to 500 mm in diameter, but are locally more than 1 m. They are characterised by radial fractures generally filled with yellow-brown ferroan calcite but more rarely also with pyrite, baryte and vivianite. Many of the concretions have burrows preserved particularly on their outer surface. Thin, impersistent tabular beds less than 50 mm thick of siderite also occur (Hewitt, 1982) principally in unit B (see below and Figure 26).

Thickness of the London Clay ranges from 90 to 130 m; the full thickness is present only in outliers where the overlying Bagshot Formation occurs, for example at Hampstead Heath and around Brentwood (Figures 26; 27).

Subdivision of the London Clay

It has long been recognised that the upper part of the London Clay is more sandy than the lower part, which consists of relatively homogeneous clay (Whittaker, 1866), but attempts to subdivide it (see King, 1981 for a review) were hampered by lack of exposure and borehole cores (for example Wrigley, 1924, 1940).

King (1981) using a combination of biostratigraphy, lithological variation and the identification of marine flooding events defined five divisions (A to E) (Figures 26; 27). A further improvement in understanding the detailed succession was made with the drilling of stratigraphical boreholes as part of the BGS mapping programme in Essex (Bristow, 1985; Lake et al., 1986). More recently, cored boreholes have been drilled by BGS at Crystal Palace, Hampstead Heath and Stanmore Common. In addition Staines No. 5 Borehole (Ellison and Williamson, 1999), drilled for Thames Water Utilities about 6 km west of this district, has provided a useful reference section (Table 7; Figures 26; 27). Samples from all these boreholes are held at BGS Keyworth.

From this extensive body of data and information from recent excavations, the main mass of the London Clay in the district is here divided into five informal units. The lowest four, informally denoted A to D (Figure 27) are not mapped, whereas the top part of the formation is mapped as the Claygate Member. The relationship of these informal units to the divisions of King (1981) is indicated in Figure 27.

The boundaries between the units are gradational with subtle changes in grain size and glauconite content; sharp boundaries are exceptional. Gamma-ray logs of the cored boreholes (Figure 26) do not clearly differentiate all the lithological changes, probably because the higher content of mica and glauconite in the coarser grained units gives a similar response to the more clayey units. Biostratigraphical assemblages provide additional evidence which helps to define the boundaries (Figure 28).

There are no significant natural exposures of London Clay in the region. Foreshore and cliff sections are accessible along the north coast of the Isle of Sheppey in north Kent [TR 02 72], 50 km east of London, and are the best places to examine the strata. The only large section that is currently exposed is at Ockendon Clay Pit [611 834] (George and Vincent, 1978; King, 1981).

Lithostratigraphy

The London Clay Formation overlies the Harwich Formation throughout most of the district, but in parts of central and south London where the Harwich Formation is absent the London Clay rests disconformably on the Reading Formation or Woolwich Formation. The base is sharp, planar or undulating and penetrated by cylindrical thalassinoid burrows that descend at least 100 mm below the contact. The top of the London Clay was defined by King (1981) at the base of the 'Bagshot sands'. The nature of the contact was then uncertain but is now thought to be erosional, and is sharply defined in places but transitional in others.

Unit A

This is a relatively sandy unit (7 to 14 m thick) at the base of the London Clay. The upper part of the unit is intermittently exposed in current workings at the Ockendon Clay Pit [611 834]. The basal bed consists of fine-grained sand with disseminated glauconite grains of fine to medium sand grade, sporadic, small, well-rounded flint pebbles and, in places, angular to rounded clay clasts derived from the Reading Formation; both clasts and pebbles are less than 10 mm across. Overlying the basal bed are alternations of rather poorly sorted silty clay, sandy silt and silty sand that is finely glauconitic and bioturbated. Disseminated pyrite, fine mica and fragments of lignite are common, and large fragments of wood occur, particularly in the lowest part. Calcareous concretions are rare, but are locally developed around logs. A characteristic of the unit, particularly in the lowest beds, is abundant clusters of horizontal, flattened white silt tubes, less than 1 mm across and up to 30 mm long. They resemble burrow fills, but are fragments of tubular agglutinating foraminiferids flattened by compaction.

Unit B

Silty clay is the dominant lithology and there are several sandy horizons. It is 7 to 18 m thick. The lower part of the unit consists of silty clay, finer grained, better sorted and containing less sand grains than the clay-dominated beds in Unit A; it includes also one or more layers of septarian calcareous concretions. This grades into bioturbated silty clay with fine sand laminae and lenses with a few interbeds of bioturbated sandy silt and silty very fine sand. The laminae are generally thicker and less disturbed by bioturbation towards the top. Many thin layers of semitabular siderite concretions less than 50 mm thick are present west of London (for example in the Staines No. 5 Borehole and in excavations at Heathrow Airport) but are absent farther east.

Unit C

This constitutes the clay-dominated middle part of the formation, about 40 to 52 m thick. A bed at the base, recorded only in the Staines No. 5 Borehole (Figures 26; 27) and probably restricted only to the westernmost part of the district, contains rounded black flint pebbles in a glauconitic sandy clay matrix. It probably passes eastwards into a thin bed of bioturbated sandy silt, locally with sporadic, relatively coarse sand grains. The bulk of the unit consists of homogenous bioturbated silty clay with layers of calcareous nodular concretions (septaria) up to 1 m in diameter and, in the east, common small phosphatic nodules, about 10 to 20 mm diameter, which are dark brown to black and rounded. In the west of the district there are beds of clayey silt with diffuse boundaries and containing fine-grained sand partings, a millimetre or so thick, and horizons with scattered glauconite pellets of fine to coarse sand grade. In north Kent and Essex, the unit is particularly strongly bioturbated, which has resulted in a uniform lithology throughout.

Unit D

This unit, 30 to 45 m thick, consists of interbedded bioturbated and glauconitic sandy clayey silt to sandy silt, in beds up to 5 m thick. Bed boundaries are mostly diffuse and transitional because of the bioturbation. Layers of septarian nodules occur at a number of levels and phosphatic concretions are present, mostly in the more clayey beds. Silt- and sand-dominated beds with a variable proportion of glauconite grains generally make up less than 10 per cent of the succession; these beds thicken westwards as the clay beds become thinner.

Claygate Member

This is shown on the 1:50 000 Series maps of the district. It was recognised initially in Surrey, around Esher [14 64] and Claygate [16 63] (Dewey, 1912), and described in the geological memoirs (Dewey and Bromehead, 1921; Dewey et al., 1924; Bromehead, 1925; Dines and Edmunds, 1925). The Claygate Member was defined by Bristow et al. (1980); it includes all the deposits above the base of the lowest fine-grained sandy bed that are thick enough to be distinguished from the underlying relatively homogeneous clays. This definition was adopted in the adjoining Southend (Lake et al., 1986), Chelmsford (Bristow, 1985) and Epping (Millward et al., 1987) districts and is also used here. Consequently, outliers of the Claygate Member in the north-east of the district in particular are now larger than shown on earlier maps. The criteria are however difficult to maintain in the mapping of outliers of Claygate Member in central London and westwards from there because of the increasing number of sand beds in the underlying Unit D of the London Clay (Figure 26).

In the central and eastern part of the district, the Claygate Member consists of alternating beds of clayey silt, very silty clay, sandy silt and glauconitic silty fine sand. Beds are generally 1 to 5 m thick, although the boundaries are generally diffuse as a result of bioturbation. Ripple laminated fine-grained sand, and flaser lamination with sand-filled burrows are common sedimentary structures in the top part of the succession. The lower part of the member is more generally bioturbated with relatively indistinct lamination and bedding; a bed of calcareous concretions is present near the base in many places. Compared to the underlying Unit D the sandy beds of the Claygate Member are slightly coarser grained and more conspicuously glauconitic. Typically, three principal beds of glauconitic sand are identified in the east (Bristow et al., 1980); some of them have been mapped around Brentwood [58 92].

In the west of the district, the Claygate Member is principally a finely interbedded and thinly laminated sequence of clay, silt and fine-grained sand with numerous interbeds of planar and lenticular bedded fine-grained, finely laminated sands up to 1 m thick.

Correlation of flooding surfaces in the London Clay Formation as a whole (King, 1981) suggests the Claygate member is diachronous and that deposits in the type area of Surrey are equivalent in age to the top part of Unit D in the east of the district.

Palaeontology

The collection of London Clay fossils was a popular pastime in the early 19th century (see for example Sowerby and Sowerby, 1812–1846), and many participants belonged to a ‘London Clay Club’. The London Clay Formation is probably even now best known to the majority of people through its fossils. Davis and Elliott (1957) briefly summarised the extensive palaeontological studies of the previous 150 years, and Curry (1965) gave additional information.

Organic-walled and phosphatic fossils (for example palynomorphs, crustacean carapaces and vertebrate skeletal debris) are preserved throughout the London Clay. Calcareous macrofossils and microfossils are also widely distributed, except in Unit A and in the higher sandier parts of the formation that are generally decalcified, probably due to the downward passage of acidic groundwater. Calcitic fossils (for example, foraminiferids, ostracods, pectinids and ostreid bivalves) are generally well preserved, although corroded at some levels. Less stable aragonite that makes up most of the mollusc fossils is commonly partially leached; the best preserved molluscs are usually those which had an early diagenetic infill of pyrite.

The distribution and relative abundance of the stratigraphically important fossils is shown on Figure 28, and a brief overview of the highly varied fauna and flora is given in the following paragraphs.

Detailed analysis carried out by Dr R. Harland (BGS, internal reports) identified dinoflagellate zones D5 (Apectodinium hyperacanthum) to D8 (Charlesdowniea coleothrypta) in core samples from the Staines No. 5, Stanmore and Hampstead Heath boreholes. Microplankton (dinoflagellates and acritarchs) of the London Basin are described by Costa and Downie (1976) and Powell et al. (1996).

Plant macrofossils were reviewed by Collinson (1983). Plant debris, mainly small fragments of plant tissue and wood, occurs throughout the formation. The wood fragments vary in size from small fragments to large logs up to several metres long. At some levels these, although relatively widely dispersed, are the most prominent macrofossils, and commonly they form the nucleus of large calcareous concretions. Most logs are intensely bored by the calcareous tubes of teredinid bivalves (shipworms) (Huggett and Gale, 1995). Well preserved fruit and seeds occur sporadically, and may have internal pyrite-fills.

Calcareous nannofossil assemblages from Zone NP11 and NP12 (Martini, 1971) have been identified, mainly in the Unit C in the Staines No. 5 Borehole (Figure 26) in which reworked Cretaceous nannofossils were also recorded at a number of levels.

Diatoms are preserved, only sporadically, as pyrite moulds as their relatively unstable siliceous (opaline) skeletons were probably dissolved during early diagenesis. They dominate the microfaunal assemblages in Unit A, characterised by the association of Coscinodiscus sp. 1, C. sp. 2 and Triceratium spp. (Figure 28). Sporadic specimens of these taxa and others occur throughout the overlying strata and there is a distinctive assemblage in the top part of the Unit D in the central and western part of the region (King, 1981).

Radiolaria, in the form of pyrite replacing the original siliceous skeletons, survive only sparsely in Unit A, but are relatively common at some levels in the top part of Unit D.

Benthic foraminiferids are common throughout. Assemblages vary laterally and vertically; King (1981) recognised a succession of assemblages in the eastern part of the London Basin and thought they werecontrolled by transgressive events (1981). These events probably also controlled the distribution of planktonic foraminiferids. These show a low diversity, and they are generally less abundant and less evenly distributed than the benthic foraminiferids. A distinct increase in their abundance in the middle part of Unit C corresponds to the 'planktonic datum' of Wright (1972); in the top part of Unit D there is the first occurrence of several taxa, including Pseudohastigerina wilcoxensis.

Molluscs dominate the macrofauna, but in general specimens are widely dispersed and imperfectly preserved. Unusually abundant and well preserved assemblages from the top part of Unit D at Highgate [282 873] were discovered in the early 19th century. Subsequently, Edwards and Wood (1849–1877) and Wrigley (1924; 1940) described numerous other taxa and lists from recent exposures in London are given, for example, in Rundle and Cooper (1970), Kirby (1974) and Tracey et al. (2002).

The most prominent molluscs are large nautiloids (chiefly Euciphoceras and Cimomia). Many of these are infilled with calcareous mudstone and their nacreous test layer is intact. They are disproportionately well represented in museum collections as they are often retrieved from excavations by construction workers. Bivalves, gastropods and scaphopods are dominant. In mudstone-dominated lithologies, molluscs are dominantly small deposit-feeding types (Nuculaceans and Thyasira). They are not evenly distributed, but occur most commonly in relatively thin units and are associated with the annelid Ditrupa. In silt and fine sand-dominated beds Striarca wrigleyi is locally common, associated with Pitar, Semimodiola and Modiolus. The gastropods (naticaceans, turrids, buccinids) are believed to have been predominantly carnivores and scavengers.

Planktonic molluscs (pteropods) occur throughout the London Clay and are abundant at some horizons (Curry, 1965). They are of considerable stratigraphical value, and four zones are differentiated (King, 1981).

Ostracods are not common but occur in relatively diverse assemblages in the lower part of the formation; they are more abundant but less diverse in the upper part, and absent in Unit A. A zonation scheme proposed by Keen (1977) has been revised by King (1981).

Crabs and lobster fossils form of the most striking part of the fauna. They occur throughout, but are most common in Unit C. They are preserved as isolated skeletal limb fragments and rarely as complete carapaces, which are usually filled by and partly enclosed in phosphatic concretions.

Isolated crinoid ossicles and parts of stems, mainly of Cainocrinus and Isselocrinus, are common in the middle of the London Clay and the restricted occurrence of I. basaltiformis in a 5 m-thick interval near the bottom of Unit C is a useful marker horizon. Sharks' teeth are sparsely distributed, fragments of teleost scales and bones are common, but entire skulls and articulated skeletons are extremely rare. Representatives of other fossils groups include pyritised sponge spicules (rare), serpulids Ditrupa and Rotularia (fairly common throughout), bryozoa (rare but generally associated with detritus drifts that accumulated around large wood fragments), and the brachiopods Lingula (throughout) and Terebratulina wardenensis (sporadic in Unit C). Environment of deposition The London Clay Formation was laid down in entirely marine conditions, either on open shelf or a more restricted lagoon or embayment. Claygate Member sediments are typical of tidal conditions, whereas the more sandy beds elsewhere in the succession are more likely to be storm-influenced but subtidal. Glauconite-rich sediments and lenticular sideritic concretions, such as those in Unit B, were formed during temporary breaks in sedimentation whereas septarian nodules are thought to have formed during periods of slow burial (Huggett, 1994).

Depositional sequences

King (1981) recognised that the London Clay was deposited during a succession of transgressive-regressive sequences. These are particularly well developed to the west of the London district and in the Hampshire Basin.The base of each is marked by an omission surface, overlain by thin poorly sorted glauconitic and locally pebbly transgressive units. These marker horizons were used to delineate King's (1981) informal divisions of the formation, but they do not in all cases correspond to the boundaries of the main lithological units described in this account. The basal omission surface is recognised as the sequence boundary, and the overlying glauconitic sediment as the transgressive systems tract; the succeeding coarsening-upwards intervals that comprise most of the formation are the highstand systems tracts. These depositional sequences are difficult to recognise in the relatively deep-water sediments of the London district, but the transgressive sequence tracts, represented by thin glauconitic units are identified. Another method of correlating the depositional sequences is the use of a combination of lithological and biostratigraphical data, for example an influx of planktonic foraminifera and planktonic gastropods (pteropods) is interpreted as indicating a major rise in sea level.

BAGSHOT FORMATION

The formation is well known from historic accounts of sections and pits given in the memoirs covering the district, and a review by Wooldridge (1924). More recently details of the succession have been obtained from cored boreholes at Hampstead Heath, Crystal Palace, Stock and Westleigh Heights (Figure 27; Table 7). The maximum thickness proved in the main outliers is: Hampstead Heath 18 m; Billericay 12 m; Brentwod 15 m; Stock 27.48 m; Westleigh Heights 17 m. The maximum estimated thickness in the Esher Common area is 10 m.

Bagshot Formation caps the highest ground in the district, mainly in the north-east and occurs as isolated outliers in central London and the south-west of the district (Figure 27); it gives rise to steep convex slopes up to 12°. It is characteristically free draining, and where undisturbed by development supports a typically heathland vegetation.

The base of the formation is well defined by a sharp lithological change, commonly marked by springs and a change of slope. Local erosion at the base has removed the top beds of the Claygate Member (Dewey and Bromehead, 1921, plate II). The basal bed in the outlier at Hampstead Heath is coarse grit with small well-rounded flint pebbles, but this is a local development. The formation comprises cross-laminated, yellow, ochreous brown and orange-brown, fine-grained quartz sand, which is silty in parts. The sand contains subordinate feldspar and white mica and grains of heavy minerals, mainly zircon and tourmaline. Laminae of pale grey clay, less than 10 mm thick, are common and there are sporadic units, generally up to 1 m thick, of thinly interbedded, flaser laminated, pale grey to greenish grey, silty clay, clayey silt and fine sand. Bioturbation is sporadic, but locally almost the entire succession is affected, as in the Hampstead Heath Borehole. The formation is oxidised throughout, and decalcified. Local iron pans, less than 50 mm thick, are developed in places.

The highest strata in the succession were proved in the Stock Borehole (Bristow, 1985) where 10.1 m of beds dominated by silt and clay occur above the typical Bagshot sand. It is overlain by 4.22 m of mainly well-rounded flint pebble beds, known as the ‘Bagshot Pebble Bed’. Similar beds are recorded around Brentwood at Langtons [578 948] and possibly also at Holden’s Wood [5910 9135] but have not been mapped in this district. The origin of these pebble beds has been a source of debate (review in Bristow, 1985) but it is possible that they belong partly with the overlying Stanmore Gravel of Quaternary age (see p.52).

The formation was deposited in a shallow marine and estuarine environment, similar to that of the top part of the London Clay Formation, but supply of sediment was greater. Similar, but better exposed, sediments of the same age in the Hampshire Basin are thought to have had a tidal influence (Plint, 1984).

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