

Lithological characteristics of the Lambeth Group

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Underlying the London Clay throughout south and south east Britain are a group of highly variable sediments belonging to the Lambeth Group (formerly called the Woolwich and Reading Beds). The Lambeth Group comprises a mixture of stiff and hard clays, silts, sands and gravel which vary tremendously both laterally and vertically. Locally, these sediments are cemented with calcium carbonate, iron oxides and silica to form materials with relatively high strength. It is the variable lithology and strength, combined with the general poor understanding of the group within the industry, that has made these sediments probably the most difficult to engineer in the UK.

The lithologies within the Lambeth Group are highly diverse – there is probably no other group of sediments within the UK that displays such a range of textures and fabrics within such a small stratigraphical thickness (generally between 15m and 40m). The origin and characteristics of these lithologies are the key to understanding the engineering behaviour and properties of the Lambeth Group.

This paper describes the main divisions of the Lambeth Group in terms of the component formations and informally recognised members. For each, the lithologies are described, together with the sedimentary structures that typify them and influence the measured

geotechnical properties. This is set in the context of the environment of deposition and also the post-depositional changes that altered these sediments, both of which are necessary to explain the observed diversity.

The measured geotechnical properties of the Lambeth Group are highly diverse, often too diverse to draw other than very conservative assumptions on engineering behaviour. This paper sets out to explain why and how the sediments were formed and some of the complex processes that affected them. With this in mind, the measured values often obtained from a ground investigation can be appreciated and understood in a broader sense. Some brief recommendations are made for the treatment of sites where the Lambeth Group is encountered.

The group has been increasingly encountered in major civil engineering schemes, for example, in the expansion of the east Thames corridor, the Jubilee Line Extension, the Docklands Light Railway Extension to Lewisham, the planned East London Line, CrossRail and the Channel Tunnel Rail Link. However, there have been few geological or integrated engineering geological studies of the Lambeth Group.

The paper forms a reference work for the forthcoming CIRIA report on Engineering Properties of UK Soils and Rocks: RP576 for the Lambeth Group co-authored by Darren Page with contributions by Jackie Skipper.

Stratigraphical framework

Ellison et al (1994) have devised a new stratigraphical scheme for the Palaeogene of the UK. In it, the term Woolwich and Reading Beds has been discarded in favour of a term that can encompass the three main formations (Table 1).

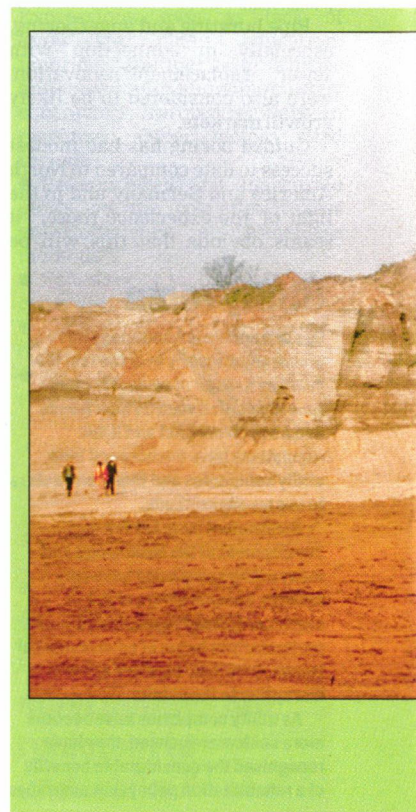
The diversity within the Lambeth Group has been recognised for a long time and accurate descriptions were made as long ago as the early 19th century during the expansion of the railway network (Prestwich, 1854 and Whitaker, 1872). The group was brought together for mapping by Hester (1965) and a "lithofacies" approach has only more recently been adopted for London (Ellison, 1983 and 1991). This approach has allowed these sediments to be more readily recognised across the whole of southern Britain (Skipper and Page, in preparation).

The Upnor Formation, which comprises the stratigraphically lowest and geographically most widespread formation, unconformably overlies and oversteps the Thanet Sand Formation in the London area. Elsewhere the Upnor Formation lies directly on the Chalk. The Thames Group, which comprises the Harwich or London Clay Formations (Ellison et al 1994), overlies the Lambeth Group.

Table 1: Lambeth Group: Stratigraphical framework

	Formation (Ellison et al 1994)	Informal lithostratigraphical member (based on Ellison, 1991 and work by King)	Dominant sediment type(s)	Environment of Deposition
Lambeth Group sediments	Reading Formation	"Upper Mottled Beds"	Pedogenically altered sediments. Typically mottled clay, silt and sand	Alluvial plain (overbank deposits plus channel sand)
		"Lower Mottled Beds"		
	Woolwich Formation	"Upper Shelly Beds"	Laminated shelly clay, silt and fine sand	Brackish, shallow water, restricted marine, tidal estuary (estuarine)
		"Lower Shelly Beds"	Laminated shelly clays	plus channel sands)
		"Laminated Beds"	Laminated silts, clays and fine sands	
	Upnor Formation	"Pebble Bed"	Locally significant gravel component	Shallow marine – high energy
		"Glaucinitic Beds"	Heterolithic clays, silts and sands containing the green clay glauconite	Shallow marine – shoreface

Note: This is not a stratigraphical column; it merely tabulates the formations and their constitutive informal members. The Upnor Formation can be contemporaneous with the Reading Formation and the Woolwich Formation contemporaneous with the Reading Formation. The Woolwich Formation lies stratigraphically above the Upnor Formation and is not contemporaneous (see Figure 1). Channel sand bodies occur throughout the group.



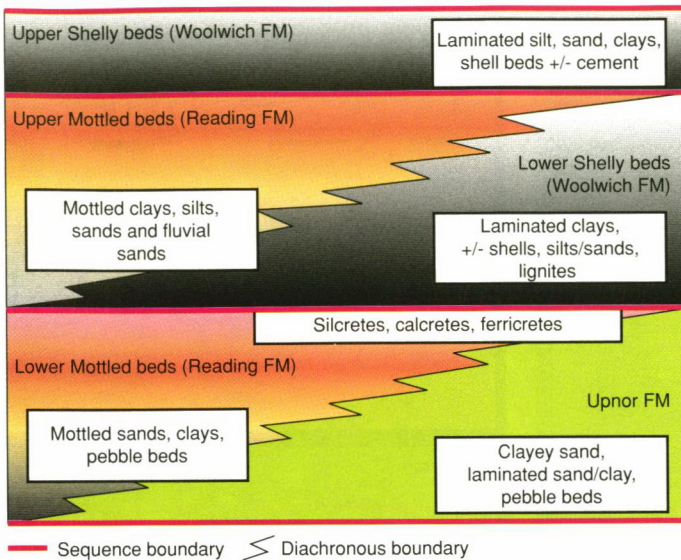


Figure 1: Schematic sequence stratigraphical relationship for the Lambeth Group. The diagram represents a west to east section across the Hampshire and London Basin.

Palaeoenvironmental model

During the deposition of the Lambeth Group, the London/Hampshire Basin lay to the south east of uplands within a broad, topographically low lying, alluvial and coastal plain area. To the east lay the North Sea occupying a major fault bound, rapidly subsiding, depositional basin. In this type of situation relative changes in sea level are more pronounced and a slight change in sea level can dramatically alter the environment and therefore the sediment type produced. Sea level fall caused a shift in the alluvial sediments seawards and a rise led to the landward shift in marine sediments (**Figure 1**). Exposure of the sediments as a result of sea level fall created "palaeo-landsurfaces", subsequently colonised by vegetation and within which soils (in the non-engineering sense) developed. The events that resulted in their formation were widespread across the basin so that these periods of relative sea level fall are well recorded. A number of these events occurred during the deposition of the Lambeth Group, the most notable of which is represented by the weathered top of the Upnor Formation and the "Lower Mottled Beds",

which were then later overlain by the base of the Woolwich Formation. This palaeo-landsurface has been termed the "mid Lambeth Group hiatus" (Page, 1994) and is often easily recognisable in borehole logs by a sharp change in lithology, downwards from the reduced grey or black sediments of the Woolwich Formation (Lower Shelly Beds) to the reddish, oxidised or colour mottled sediments of the Reading Formation (Lower Mottled Beds).

Another occurs above the Reading Formation ("Upper Mottled Beds") at the base of Woolwich Formation ("Upper Shelly Beds") in central and south eastern London (**Figure 1**). These two surfaces represent sequence boundaries (a point at which there has been the most rapid rate in fall of sea level which results in downcutting/planation of the landsurface (Van Wagoner et al, 1990). They are important in correlating the Lambeth Group.

The climatic conditions during the deposition of the Lambeth Group were sub-tropical with a distinct seasonality, similar to climates associated with parts of South East Asia today.

Contemporaneous volcanic activity was occurring in western Scotland and northern Ireland (as a consequence of the opening of the north Atlantic Ocean) and periodic ash falls were widespread (Knox, 1996). Clays, chiefly illite, kaolinite and smectite, (derived from volcanic ash), form a significant component of the fine grained sediments within the Lambeth Group (eg Ellison and Lake, 1986).

Upnor Formation

The Upnor Formation is characterised by predominantly sand lithologies with a variable clay and/or silt content. It varies from fine to medium grained clean sands to sandy clays and can be well graded. Well rounded flint gravel is present, as beds from one clast thick to beds up to about 5m thick and as large channel fill structures – ribbon shaped bodies of impersistent lateral extent (Skipper, 1999). The green clay mineral glauconite is present throughout the formation although where exposed it weathers to iron oxides. Two subdivisions of this unit have been recognised on palaeomagnetic evidence (Ali and Jolley 1996 and Ellison et al 1996). In central London these subdivisions each coarsen upward from a sand to a coarse gravel representing a fall in sea level.

The surface at the base of the formation is usually burrowed either into the underlying Thanet Sand Formation (Page, in preparation) or Chalk (Bromley & Goldring, 1992), with material from the overlying sediment penetrating into that underneath. The Upnor Formation can be cross-bedded, laminated, cross-laminated and bioturbated at various scales. Some typical sedimentary structures are shown in **Figure 2**. Ash fall layers of volcanic origin have been recognised in boreholes in Suffolk and Essex.

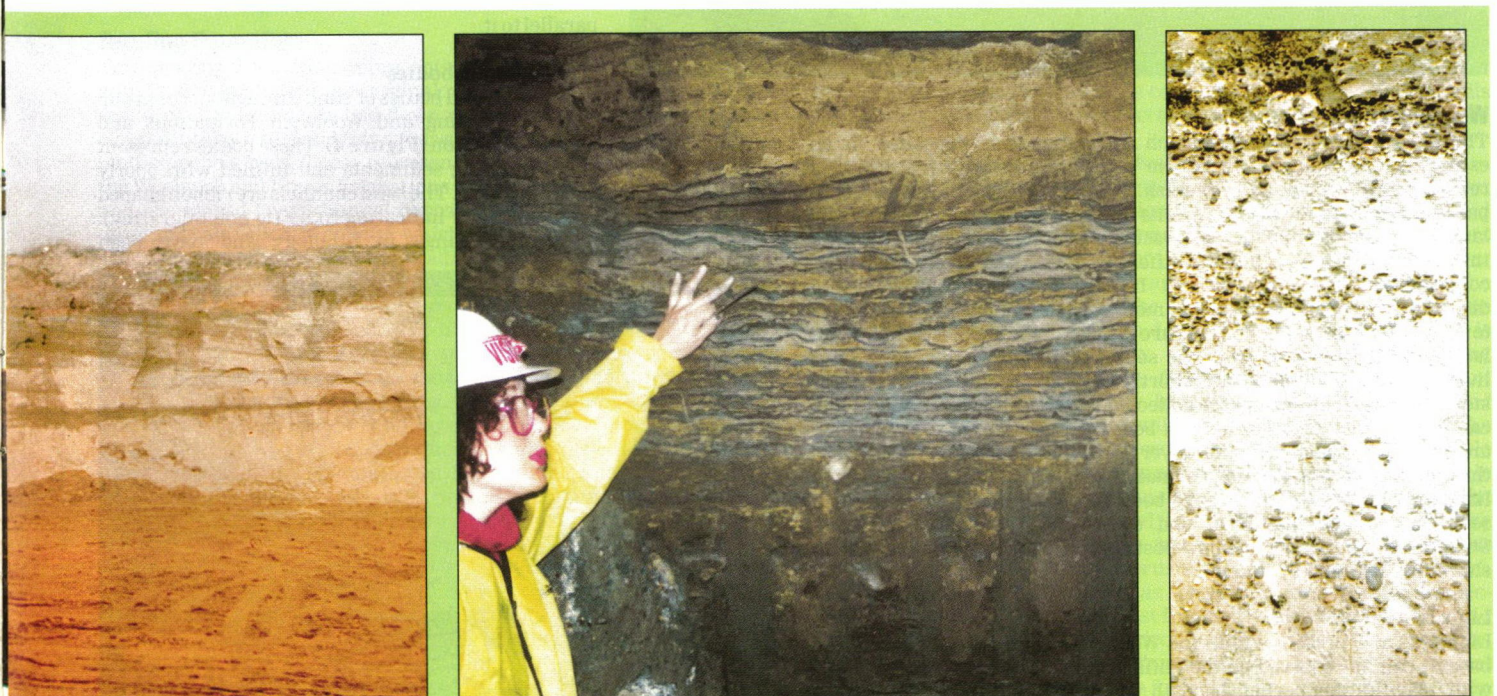


Figure 2: Typical sedimentary structures of the Upnor Formation. ABOVE LEFT: Large scale cross bedding (5m high) at Orsett, Essex (Photo: Jerry Hooker). ABOVE: Laminated and cross-bedded sand and clay at Canada Water Station, Rotherhithe. ABOVE RIGHT: Gravel bed forms Orsett, Essex (Photo: Jerry Hooker). Lens cap 50mm in diameter.

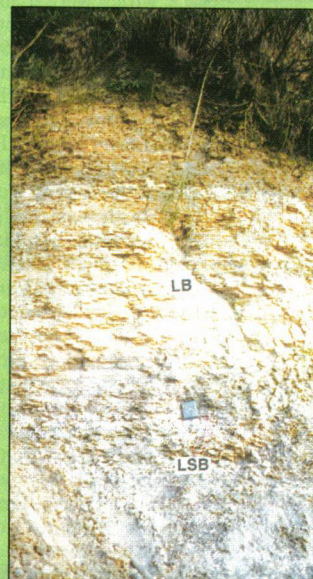
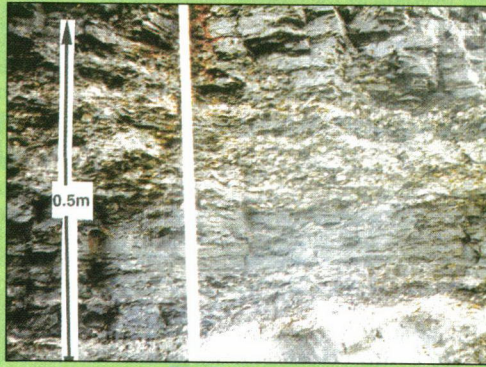


Figure 3: Typical sedimentary structures of the Woolwich Formation. ABOVE: "Lower Shelly Beds" Canada Water Station. RIGHT: Transition from 'Lower Shelly Beds' to 'Laminated Beds', Charlton. Compass 80mm high. BELOW: "Lower Shelly Beds" overlying Upnor Formation A2 road cutting, Swanscombe Kent. "Mid Lambeth Group hiatus" (MLGH) indicated.



Woolwich Formation

The lowest part of the Woolwich Formation was deposited in an estuarine environment where the water was relatively shallow, of restricted circulation and brackish. In central London, the sequence passes from clays to silty clays, silts and fine grained interbedded and laminated sands up the succession. Laminations and the thin interbedding of materials of different grain size typify this unit, consequently the formation is highly anisotropic. Broken and disarticulated shell debris is common, especially near the base of the formation in central London (Figure 3). The shells are mostly not in situ having been winnowed from the sediment in which they were once living and rapidly redeposited shortly after, as a result of tidal and/or storm activity. The shells have collected together to form coquinas and can be cemented together to form beds of limestone. In south London and around Croydon, a further layer of "Upper Shelly Beds" lies above the upper part of the Reading Formation (Figure 1). In this area, beds of limestone up to 1.8m thick have been recorded. The coarser grained sediment can be laminated and cross-bedded or cross-laminated. Structures indicating immediate post depositional deformation, such as slumping, can also be present.

Lignite

Lignite is also present within the Woolwich Formation, usually at the base. It can be observed on the cliffs at Newhaven and is interbedded with clay in the outlier beneath Shoreham where it has proved problematic in works undertaken with the harbour (eg shaft sinking, piling, slope stability and dewatering). It is also recognisable in central London and is best developed at Shorne near Gravesend in Kent. This woody organic material remains preserved due to the ponding of surface water and rapid burial (thereby inhibiting oxidation). Lignite is

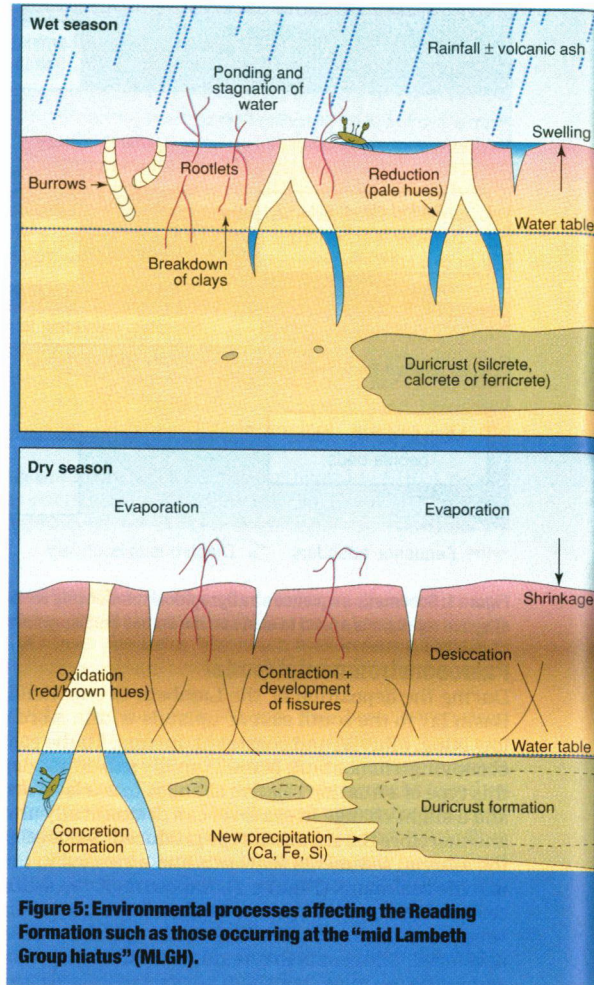


Figure 5: Environmental processes affecting the Reading Formation such as those occurring at the "mid Lambeth Group hiatus" (MLGH).

extremely anisotropic as a consequence of the alignment of wood fibres. High strengths occur across the fibres and extremely low strengths parallel to it.

Channel sand bodies

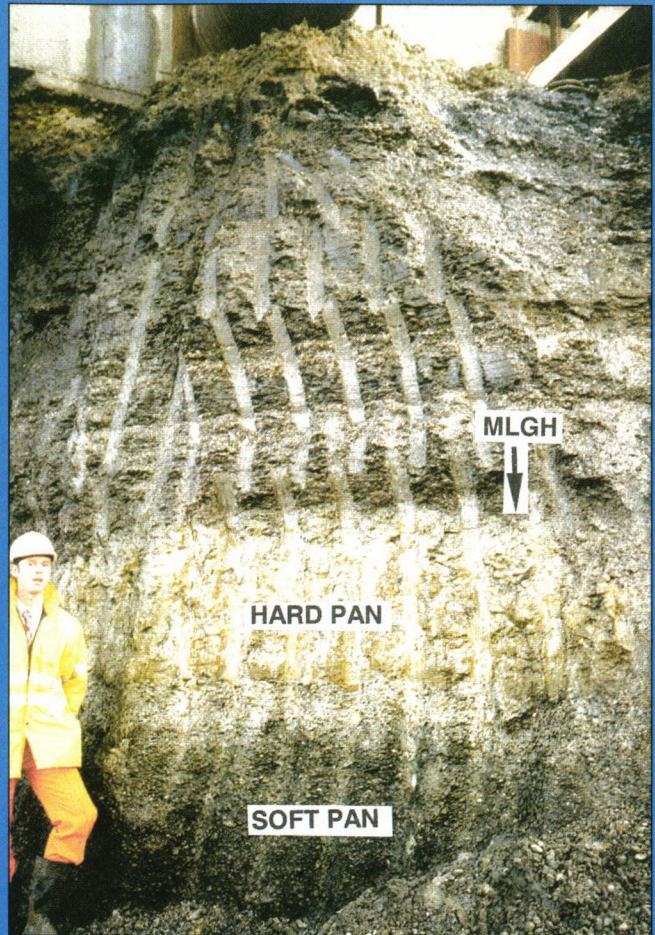
Channel shaped bodies of sand throughout the group are most common in the Reading and Woolwich Formations and particularly in the west of the region (Figure 4). These bodies represent channels cut into the underlying sediments and infilled with poorly graded fine to coarse grained sand. The sand channels are ribbon shaped in plan and laterally impersistent indicating fixity (ie non-migrating). They represent an abrupt change in lithology and have been



Figure 4: Large sand channel structures at the base of the Lambeth Group at Studland Bay, Dorset.



Figure 6: Duricrusts of the Lambeth Group. ABOVE: Silcrete – “Hertfordshire Puddingstone” (Photo: John Hepworth). RIGHT: Calcrete – lying below the “mid Lambeth Group hiatus”, Canada Water Station. The “mid Lambeth Group hiatus” (MLGH) is indicated. The calcrete has developed into a “hardpan” and underlying “softpan”, typical of this form of duricrust. These conditions are identical to those encountered by Brunel during construction of the Thames Tunnel.



encountered on a variety of tunnelling projects in London where they can be water bearing. The channels can be up to about 4m to 5m in depth and up to a couple of hundred metres wide.

Reading Formation

The Reading Formation represents sediments laid down within an alluvial floodplain and in marginal marine areas during a time of low sea level. The sediments laid down comprise in decreasing frequency clays, silty clays, silts and clay sands and there are also occasional colour mottled pebble beds. These represent soils formed in the sediments of the Woolwich and Upnor Formations as well as in river flood (overbank) and abandoned river channel deposits. Cleaner, coarse to fine sands (grey and pale yellow in colour), which appear to represent fixed channel sands are also found within the Reading Formation. With the exception of the channel sands, all Reading Formation sediments are recognisable by an almost complete lack of any sedimentary structures such as bedding, or shells, having instead a high degree of clay enrichment and marked colour mottling. Colours generally range from strong reds and oranges to browns, greens, blues and purples – some horizons displaying all of these colours together. These unusual features formed in soils which alternated between waterlogged and drier conditions, perhaps seasonally. During wet periods reducing conditions prevailed, in which grey and blue colours predominated. During drier periods, cracks, roots and burrowing animals (eg crabs, worms and insects – see **Figure 5**) permitted oxygen into the soils creating red, purple, brown and yellow hues.

Simple pedogenic model

Soil forming processes (pedogenesis) are the key to explaining the extremes in measured properties of the Reading Formation (**Figure 5**). The nature of any soil is dependent on the prevailing climatic conditions. In modern soils the organic content is near the surface but in ancient soils the organic component is frequently not preserved. The quantity of organic matter is controlled by its production and the water level. Both are ultimately controlled by the climate. However, the organic component plays an important geochemical role in the soil formation. Plant roots may extend down through the soil causing

physical disturbance and removing nutrients from lower levels. Percolating water can break down silicate minerals (ie clays) and remove alkali ions. These products may be transferred to other levels in the soil where they are reprecipitated. The mottled clays owe their high strength partly to the fact that the original detrital clay particles have been weathered and/or recrystallised and reorientated and new authigenic minerals have partially cemented these materials. The soils produced could be classified as relict tropical residual soils.

Calcretes, silcretes and ferricretes

The soils of the Reading Formation generally have a low organic content and high pH, due to the combination of carbonate rich sediments and periodically waterlogged environments. During wet seasons rivers overflowed providing new sediment and saturating existing soil, but during drier seasons (**Figure 5**) evaporation and desiccation were the primary processes resulting in the precipitation of minerals in the upper part of the soil profile. The depth of the mineral precipitate is dependent on the permeability of the sediment (ie grading characteristics) and the climate. Carbonate is the most common precipitate and this forms calcrete. Iron rich soils form ferricretes and the presence of secondary silica will form silcretes. The form of the precipitate varies with the host sediment and the available soluble compounds. In clay rich soils of low permeability pore fluids are unable to migrate and the calcretes are fine grained or nodular. In sands, the nodules can grow to coarse gravel size and may coalesce. Pervasive cementation can occur forming hard pan calcretes, silcretes or ferricretes (pedocretes or duricrusts). The distribution of these different types of duricrust was probably governed by palaeotopography and duricrusts are most frequently encountered at the Mid Lambeth hiatus (see Palaeoenvironmental model). The calcrete-cemented sediments are most frequently encountered in central London, while evidence of silcrete formation is prevalent in the basin margin areas (eg the Chilterns, Salisbury Plain and South Downs). Ferricretes are generally present in the south and east of the area (eg Canterbury).

Where the host lithology is gravel then conglomerates can form, such as the silica cemented Hertfordshire Puddingstone and the carbonate



Figure 7: Typical features of the Reading Formation. LEFT: Prismatic blocks of clay defined by fractures, Bermondsey Station. Clutch pencil for scale. BELOW: Mottled clay exposed in Chichester Harbour.

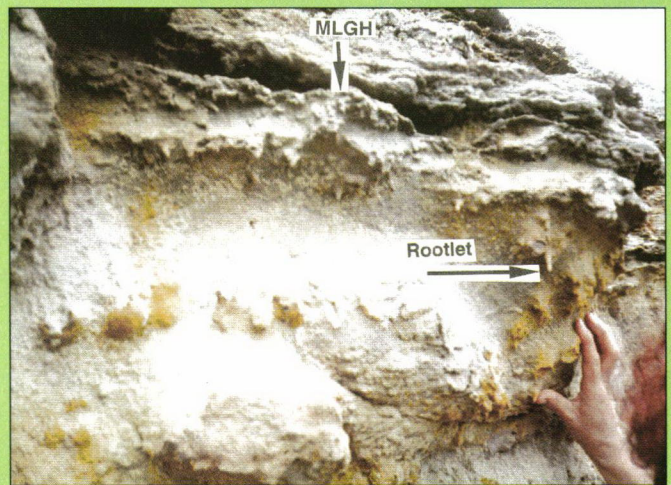


Figure 8: TOP: The "mid Lambeth Group hiatus" (MLGH) palaeosurface at Newhaven. Vertical rootlets (indicated) penetrate into the underlying Upnor Formation. ABOVE: Burrow at the top of the Upnor Formation formed at the "mid Lambeth Group hiatus", A2 road cutting Swanscombe Hill, Kent.

cemented conglomerates exposed in the excavations for the Jubilee Line Extension (**Figure 6**). These materials are vastly different to the temperate soils usually found in the UK; tropical residual soil classifications can be used to describe these soils (Geological Society Working Party report on Tropical Soils, 1990). Duricrusts form significant problems in the drilling of boreholes, excavations, dredging (in the 19th century, dynamite was used to dredge these materials from the bed of the River Thames), diaphragm wall excavation, bored piling and sheet piling. It should be noted that silcrete, calcretes and ferricretes form significant geological hazards in parts of the world where they are now forming or have formed in the recent past (for examples, see Netterberg, 1994). A number of piled structures in London, particularly on the Isle of Dogs, are founded on a duricrust.

Mottled sediments

Periodic drying out/drainage of the soil leads to the development of negative pore water pressures, which result in the relatively even distribution of points of suction through the sediment and large volumetric changes. The increase in effective stress led to the premature

consolidation of the sediment and the development of polygonal shaped peds bound by fractures (this can lead to the development of peds of high strength although the overall soil may lose its primary cohesion and be relatively weak). Periodic volumetric expansion and contraction of the soil led to the polishing of the fracture surfaces and contributed to the loss of the primary sedimentary structures. This texture is evident as the extremely closely spaced fissuring seen in samples.

Larger scale fissures, which occur at the decimetre and metre scale, are also probably of pedogenic origin (**Figure 7**). Desiccation led to the development of an open network of fissures penetrable by water and sediment. During flooding, surface ponding may have led to stagnation and the development of anaerobic conditions within the near surface sediment and water which penetrated these fissures. This is responsible for the blue grey hues often seen on the fissure surfaces (pseudogleying).

Colour mottling also occurs due to uneven oxidation of the sediment, some areas remaining unoxidised. The percentage of colour mottling tends to increase upwards through each ancient soil horizon, often being greatest within a few centimetres of what would have been the soil surface.

Bioturbation and Rhizoliths

Biogenic activity within the sediment immediately after it was deposited is noticeable as burrows, borings and the traces of rootlets (rhizoliths) (Figure 8). Biogenic activity may lead to the introduction of the overlying sediment into the void created by the organism below. Where intense it may lead to the complete mixing of the sediment. Unique geochemical conditions caused by the organic material contained in a burrow or rootlet may lead to precipitation of minerals around the burrow forming concretions. Burrows take various forms and can be large, up to 150mm in diameter and 2m in length. Biogenic activity is preserved within all formations and can significantly influence the measured strength of samples tested, indicating the importance of carefully splitting and logging the sample upon completion. The most intense biogenic activity occurs at palaeosurfaces.

Some recommendations

Borehole descriptions and samples retrieved from an investigation should, ideally, be placed into one of the formations defined by Ellison et al (1994). Depending on the intraformational variation, scale and importance of the project it may be unnecessary to assign the materials further, provided that the environment of deposition is recognised and the inherent variations anticipated. The informal lithostratigraphical terms may be important should the project be sufficiently large for there to be enough test results with which to fully characterise it. Classification should ensure that materials, the product of a particular facies, are compared, thus improving the selection of geotechnical design parameters. Discontinuous sampling methods such as light cable percussion boring are strongly discouraged in these materials in preference of continuous methods (ie coring) due to the high variability of the strata (important layers may be missed) and sensitivity of bonded/cemented materials to sampling strains. Engineering geology is key to understanding the Lambeth Group and careful attention should be paid to their engineering geological description.

The results of insitu and laboratory testing should be closely scrutinised against the material tested to fully appreciate what is being measured. Table 2 provides a simple aide-memoire for this process. It is important to understand which category is dominant in influencing the measured material response. Sampling and testing methods should be selected accordingly.

It is important to recognise that the formations are contemporaneous (Figure 1) and the boundaries between them diachronous (ie they cut across time planes). This may not be a problem on a small site but on a large linear scheme such as for a road or railway this may be important. For correlation, reliance should not be placed on gross lithology but on the recognition of key palaeosurfaces (sequence boundaries) that occur at the top of the Reading and Upnor Formations, such as the "mid Lambeth Group hiatus" and the base of the London Clay or Harwich Formation. The base of the Reading Formation is not a reliable stratigraphical horizon. The engineering properties of the Lambeth Group materials can be more influenced by their stratigraphical position within the sequence than by their depth below the surface and consequently the results of tests should be presented in relation to the palaeosurfaces. This emphasises the importance of good sampling and logging and the necessity to continue boreholes until such a surface is recognised.

Conclusions

Like all sedimentary materials, the environment of deposition is important in controlling the nature of the sediment laid down – it influences the composition of the sediment, the distribution of grain size and its arrangement (ie sedimentary structures such as bedding) ("first effect", Table 2). Of great importance for the Lambeth Group were the immediate post depositional changes that occurred that led to the premature ageing of the sediment – including bonding, cementation, fissuring and biogenic activity ("second effect"). These effects can have a far greater influence over the behaviour of the material than do those changes due to burial and loading. Weathering, reductions in effective stress due to removal of overburden and periglacial effects ("third effect") have led to the reduction in the influence in some cases of these secondary effects where the sediments are close to the surface. At depth, these tertiary effects may not be so pronounced. The importance of the correct selection of sampling method, insitu testing and laboratory procedure cannot be overemphasised ("fourth effect").

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Table 2: Evolution of any sediment or sedimentary rock and its measured properties

Sedimentation	Immediate post depositional	Burial	Uplift, weathering and periglacialation	Sampling and testing
First effect	Second effect	Third effect	Fourth effect	
Primary structures due to deposition of particles	Changes due to the alteration by processes such as pedogenesis, biogenic activity etc	Changes due to burial at depth as a result of overburden	Changes due to reduction in overburden and exposure to surface effects	Dependent on the choice of the most suitable methods for the materials
eg cross bedding, laminations, shell debris, coquinas, burrowing	eg cementation (formation of calcretes, fissuring, bonding, 'premature ageing' of sediment, recrystallisation colour mottling boring, rootlets/rhizoliths	eg where $\sigma_v > \sigma_h$ 'quasi'p, continued reduction in void ratio, cementation, 'natural ageing' of the sediment	eg alteration of existing fabrics, softening, weathering, faulting	eg sample disturbance, discontinuous sampling, change in moisture content, SPT refusal

Acknowledgements

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