The relevance of lithostratigraphy in the assessment and investigation of engineering ground conditions in UK mudstones

La pertinence du lithostratigraphy dans l'évaluation et la recherche sur les conditions au sol de technologie en argilite UK

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ABSTRACT

Stratigraphy is the study of layered rock sequences, particularly in terms of their age and correlation with equivalent rocks elsewhere. It has many different branches of which some of the most fundamental are lithostratigraphy, concerning the subdivision of rock succession into units on the basis of their lithology and physical characteristics; biostratigraphy, involving the subdivision and correlation of the rock succession based on its contained fossils; and chronostratigraphy concerned with the subdivision and classification of rock successions according to their age.

Lithostratigraphic subdivisions are those normally depicted on geological maps and sections and most commonly encountered in the ground engineering industry. However, because of local (site scale) lithological and property variations it is arguable that lithostratigraphic classifications are of only limited use for site-specific engineering, given that subdivisions are based on generally broad physical characteristics aimed at wider regional correlations. Practical use of stratigraphic subdivisions in ground engineering is further hindered by periodic changes to their nomenclature that has caused confusion to non-specialist users not fully aware of the reasons for making such changes.

Despite these apparent limitations, recent research into the geotechnical characteristics of the Lias Group and Lambeth Group deposits in the UK has shown how lithostratigraphy can aid in anticipating regional trends in their characterisitics, properties and behaviour. The studies have also demonstrated how understanding regional geological controls can enhance site specific knowledge, leading to more focussed and cost effective ground investigation planning.

Keywords: lithostratigraphy, Lias Group, Lambeth Group, clay minerals, mudstones, depositional environments, engineering ground conditions, ground hazards, shrink swell

1 INTRODUCTION

Stratigraphy is the study of stratified rocks, especially their sequences in time, their character and the correlation of beds in different localities. It has many different branches of which some of the most fundamental are lithostratigraphy, biostratigraphy, and chronostratigraphy. Lithostratigraphy is, perhaps, the most familiar and is concerned with subdividing rock successions into units based on changes in lithology or physical characteristics, both vertically and laterally, that reflect changing environments of deposition. It involves the differentiation, delineation, and classification of such units into ‘Groups’, ‘Formations’, ‘Members’ and ‘Beds’[1]. Biostratigraphy is based on fossil evidence in rock layers, employing the principle that strata from wide-

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spread locations containing the same fossil flora and fauna are correlatable in time. Thus strata are divided into units based on their fossil content, of which the fundamental unit is the 'biozone'. Chronostratigraphy is concerned with the relative time relations and ages of rock strata, and deals with the organization of rock into units on the basis of their age or interval of time during which they were deposited. Chronostratigraphical units are ranked according to the length of time they record, i.e. 'Erathem' (longest), 'System, 'Series', 'Stages', and 'Zones' [1].

The emphasis of this paper is concerned with the lithostratigraphic classification of rocks into 'Groups', 'Formations', 'Members' and 'Beds, as it is these divisions that are normally depicted on geological maps and sections and are hence most commonly encountered in the ground engineering industry.

Of necessity, lithostratigraphic subdivisions as displayed on geological maps generally reflect broad physical characteristics aimed at wider regional correlations. However, because of local (site scale) lithological and property variations, necessitating site-specific investigations to enable an adequate ground model to be developed, it is arguable that lithostratigraphic information is of only limited use for site-specific engineering projects. Why not simply undertake a 'standard' ground investigation (GI) to obtain field sample descriptions and depths, acquire samples for testing and base engineering design on the test results? Pre-ground investigation desk studies usually include reference to a geological map to ascertain what the surface geological conditions of the site are in general terms (e.g. Mercia Mudstone, Lias Clay, etc) – why bother with any further consideration of stratigraphy other than to identify the name of the geological materials that the site is located on? The above simplistic approach may be acceptable for small, localized developments and infrastructure installations (e.g. small housing developments, local drainage works, etc.), but for larger developments a more comprehensive appreciation of stratigraphical information in the context of depositional environments is required to enhance the prediction of anticipated ground conditions and significantly aid cost-effective GI planning.

2 LITHOSTRATIGRAPHY AS AN AID TO GROUND ENGINEERING

At its most basic level, lithostratigraphical nomenclature can aid ground engineering projects by providing a consistent geological ground model (framework), by which to identify the rock units to be intersected by the planned engineering works; providing the range of physical properties is fully understood. Appropriate identification and naming of particular strata can ensure accurate communication between engineers and contractors and enable site scale and regional identification and correlation of rock sequences with similar physical characteristics to be more readily understood. Understandably, the plethora of lithostratigraphic terms that have arisen over the years has caused confusion to non-geological specialists and generally hindered the adoption of lithostratigraphic information as a standard ground investigation tool. This has been exacerbated by frequent re-naming of specific beds as detailed information is acquired from successive geological mapping and academic investigations. However, in the UK, a more consistent and rational approach to lithostratigraphic nomenclature and classification is now steadily being applied to the major rock 'groups' [2]. In addition, an excellent guide to British stratigraphical nomenclature [3] directed to engineers, geotechnical engineers and geologists engaged in the construction industry, and other professionals, now provides a significant clarification of stratigraphical terms and their application to UK rock units.

Being intimately linked to the environment of deposition, lithostratigraphic information also provides critical input to constructing the geological ground model during the desk study and site reconnaissance phase of ground engineering project. The power of the geological ground model is in its ability to anticipate ranges of ground conditions rather than to predict them precisely. Anticipation is turned into reality by the ground investigation. As stated by Fookes [4], successful design and cost effective completion of engineering projects relies on "getting both the geological and companion geotechnical models of the site right, in order to outline objectives and questions to be answered and to determine activities to achieve this." The more realistic the geological ground model, the better the realization of anticipated ground conditions. This is particularly important where planned engineering works are likely to encounter highly variable geology, or are of regional extent, e.g. road and pipeline routes. Lithostratigraphic information can indicate potential variations in lithology and associated physical properties and, importantly, potential ground hazards, e.g. shrink swell, sulphate attack. This can lead to improved and better focused GI planning. In turn, greater optimisation of GI and testing programmes can preempt the likelihood of 'problem' or 'unforeseen' ground conditions, and result in significant time and cost savings during the whole life time of an engineering project. Using two examples, from recent research into the geotechnical characteristics of UK mudstone sequences (the Lias Group & Lambeth Group – Fig 1), evidence is presented to demonstrate how lithostratigraphy can aid in assessing regional trends in lithological characteristics and properties and thus help to anticipate ground conditions, both regionally and at a site scale.

2.1 The Lias Group

The Lias Group sediments consist predominantly of shallow marine, grey, fissured and variably pyritic mudstones with intercalated limestones, deposited at the end of the Triassic and Early Jurassic Periods during a world-wide marine transgression. In the UK they form a nearly continuous northeast-southwest trending outcrop extending from the Cleveland coast in Yorkshire to the Dorset coast in the south, with outlying areas in Somerset and South Wales (Fig. 1). The thick mudstone sequences that dominate the Lias succession were deposited in four basins – the Cleveland Basin, East Midlands Shelf, Worcester Basin and the Wessex Basin - while thin calcareous and sandy deposits were formed in shallow shoals or emergent ridges. Three structural 'highs' in the Mendips, Moreton-in-the-Marsh and Market Weighton separated these areas of substantial subsidence. Because subsidence was less rapid on these inter-basin 'highs', the successions there are substantially thinner and less complete than in the adjoining basins. As a result, the Lias is characterised by considerable lateral thickness variations (Fig. 2).

Figure 1. Map showing the distribution of Lias Group and Lambeth Group deposits in the UK (BGS © NERC. OS topography © Crown copyright. All rights reserved. License number 100017897/2011)

During deposition, clay minerals formed by surface weathering and pedogenic processes accumulated in the basin depressions; in some cases forming up to 65-70% of the sediments [6 & 7]. During sedimentary burial a progressive series of diagenetic changes (clay mineral dehydration reactions) converted soft mud to weak or moderately strong mudstone. This transformation was a result of smectite converting to illite as the burial depth of the rock increased. In the northernmost Cleveland Basin the proportion of illite to smectite (I-S) is 90% illite suggesting a maximum depth of burial of 4 km, whilst in the East Midlands Shelf I-S is 80% illite suggesting a burial depth of perhaps 3 km. In the southernmost Worcester and Wessex basins the presence of discrete smectite minerals indicates a burial depth of no more than 2 km. The increased depth of burial, as indicated by different I-S percentages, results in an increase in density and strength in the Lias. The change in clay mineralogy from smectite to illite indicates a decrease in plasticity. Thus a general south to north trend of increasing density and stiffness, and decreasing water content and plasticity can be recognized between the southern (Wessex and Worcester) basins and the more northerly (East Midlands Shelf and Cleveland) basins (Fig.2). In addition, being south of the maximum limit of glaciations, weathered Lias material in the Wessex Basin and large parts of the Worcester Basin have not been removed by glacial erosion. Thus weathering depths are greater here than the northern basins and have resulted in a greater variation in engineering properties at shallow depths.

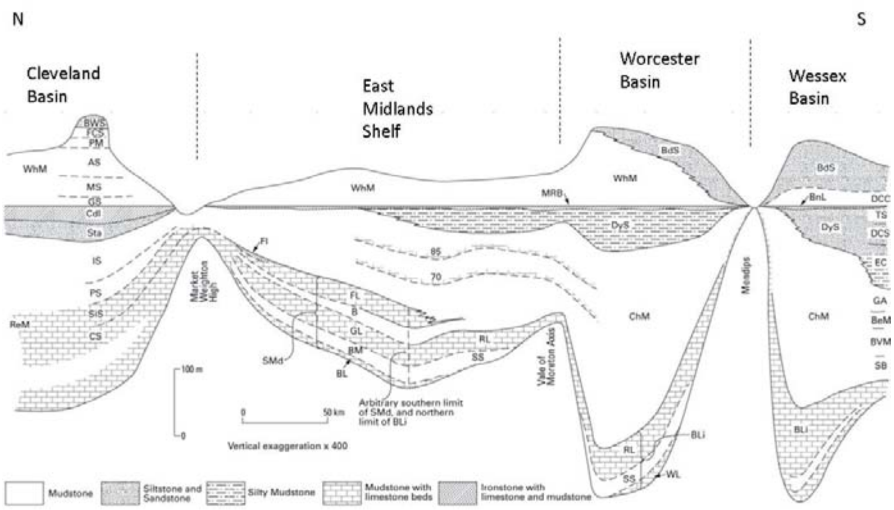

Figure 2. Section showing Lias Group lithostratigraphy and depositional basins. [BnL-Beacon Limestone Formation; BWS-Blea Wyke Sandstone Formation; BLi-Blue Lias Formation; BdS-Bridport Sand Formation; ChM-Charmouth Mudstone Formation; Cdi Cleveland Ironstone Formation; DyS-Dyrham Formation; MRB-Marlstone Rock Formation; ReM-Redcar Mudstone Formation; SMd-Scunthorpe Mudstone Formation; Sa-Staithes Sandstone Formation; WhM-Whitby Mudstone Formation. Other members not identified]

Discrete smectite found in the southern basins is an important potential ground hazard, as smectite is an active clay mineral and if present in high proportions could cause a serious shrink-swell hazard. A further hazard to consider is the potential for sulphate attack of buried concrete. All Liassic mudstones, contain relatively high pyrite contents. Pyrite when oxidized, by weathering or when disturbed by man, forms sulphuric acid that reacts with calcium carbonate in the rock to form calcium sulphate (i.e. gypsum). Typically, sulphate contents vary with depth and weathering state but recent research [5 & 6] has shown that particularly high sulphate concentrations are present in the Charmouth and Scunthorpe Mudstone Formations (Fig. 2). A particular form of sulphate attack resulting in the formation of thaumasite, caused by the reaction of sulphate and cement in concrete, is most notably associated with the Charmouth Mudstones of the Worcester Basin. This has caused severe deterioration of buried concrete bridge abutments on the M5 motorway in Gloucestershire.

Another important ground hazard in the Lias Group mudstones are landslides, the occurrence and distribution of which are linked by both lithostratigraphy and topography [5]. Of particular note, are major slope displacements associated with the cambering of jointed competent limestones overlying weaker Lias Group mudstones. In the Cotswolds area of the Worcester Basin lithostratigraphic knowledge has proved essential to understanding the complex topography and geological sequences resulting from large-scale multiple cambering of the Middle Jurassic limestone caprocks that overlie the Lias Charmouth and Whitby Mudstone formations. The development of a cambered terrain geological model has proved critical to the optimal planning and investigation of road and pipeline routes.

Lithostratigraphic information, confirmed and supplemented by mineralogical studies, has enabled construction of a regional geological model of the Lias depositional basins. The model is essential in explaining inter-basinal differences with regards to the thickness of the Lias mudstone sequences, their differing clay mineral assemblages and anticipated ground properties and behaviour (notably shrink-swell potential, high sulphate-bearing formations and landslides).

2.2 The Lambeth Group

The Lambeth Group was deposited in embayments on the western margin of the North Sea basin in the Paleogene; in depositional environments that include: coastal, estuarine, lagoonal and alluvial (Fig. 3). These marginal deposits were very sensitive to minor changes in sea level and hence resulted in alternating migration of the depositional and erosional environments (Fig. 3 & 4). Although the Lambeth Group is rarely more than 30 m thick, it is well known for its lateral and vertical lithological variation, unpredictability and complex and variable hydrogeology.

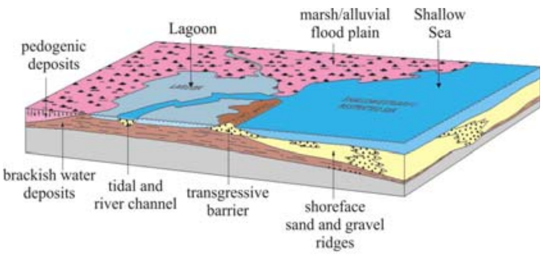

Fig. 3. Schematic block diagram to illustrate the environment of deposition of the Lambeth Group.

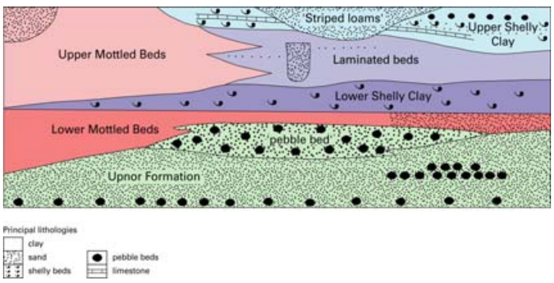

Fig 4. Schematic diagram showing the relationship the relationship of lithological units of the Lambeth Group in central London. Left - west, Right – east.

Five lithostratigraphical units are identified during four depositional sequences within the Lambeth Group (Table 1). Fig 4 gives a schematic summary of the sequence beneath London.

As a result of the Lambeth Group's variable environments of erosion and deposition, which gives rise to high lateral and vertical lithological variability, there are a number of potential ground hazards [8] that are associated with different units of the Group, such as:

- *'Hard Beds'* – top Upnor Formation, Lower Mottled Beds & shelly limestone in Lower/Upper Shelly Beds
- *Flint gravel* – Mostly upper part of the Upnor Formation
- *Fissuring* – Lower/Upper Mottled Beds & Lower/Upper Shelly Beds
- *Unpredictable groundwater conditions (Sand filled channels)* - primarily in the Lower & Upper Mottled Beds
- *Variable groundwater conditions* – Upnor Formation, Lower/Upper Shelly Beds & Laminated Beds
- *Gypsum formation* – Lower/Upper Shelly Beds

These hazards are all related to the geological environment and history of deposition and erosion that has occurred within the Lambeth Group. It is therefore vital when undertaking a ground engineering project that a good understanding of the lithological variability (lateral & vertical) of the lithostratigraphy of the Lambeth Group is known (Fig. 3 & 4). From this understanding it is then possible to develop a ground model for a site and hence anticipate what ground conditions and ground hazards are likely to be encountered. Documented information of this kind can significantly assist in developing a good geological ground model [9] for both regional and site-specific ground investigation planning across the Lambeth Group's outcrop and sub-crop

Table 1. Lambeth Group lithostratigraphy, lithologies & geological history [8].

Lithostratigraphy & geological events (in grey)	Description & environment of deposition
Upper Shelly Beds	Grey shelly clay, thinly laminated silt & fine sand & grey fossiliferous limestone. Deposited in brackish lagoon & estuary.
Upper Mottled Clay	Stiff to very stiff, fissured, multicoloured clay & dense multicoloured or mottled sand. Deposited in non-marine, alluvial & fluvial environments. Changes in edge of lagoon resulted in oscillation of deposition of Lower Shelly Beds & Laminated Beds, as shown in Fig. 3 by deposits inter-digitating
Lower Shelly Beds & Laminated Beds	Stiff to very stiff, dark grey to grey, shelly or very shelly clay or sand. Laminated Beds are firm to stiff grey laminated or thinly bedded clay, silt and sand were deposited. Lignite occurs in parts. Deposited in a Lagoon environment.
Mid Lambeth Hiatus	Soil forming processes (subtropical climate) resulted in formation of calcium carbonate, iron oxide & silica deposits/cements. Coherent beds of strong or very strong rock occur in some places known as 'hard beds'.
Lower Mottled Beds	Stiff to very stiff, fissured, multicoloured clay & dense multicoloured or mottled sand. Non-marine, alluvial and fluvial deposits. Clays are overbank deposits formed during seasonal flood events. Sands are infilled river channels. Some weathering occurred during dry season resulting in colour variation.
Upnor & Pebble Beds	Dense to very dense fine to medium sand, clayey sand with thin firm to stiff clay beds. Beds of rounded flint gravel up to several metres thick present near the top of the formation. Thin bed of rounded flint gravel often occurs at the base.

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3 CONCLUSION

Based on environments of deposition, and hence variations in lithological and physical properties, lithostratigraphic information can play a significant role in constructing geological ground models during the desk study and site reconnaissance phase of ground engineering project. Examples from the contrasting Lias Group and Lambeth Group deposits in the UK rock have demonstrated how such information can be utilized to aid in the assessment of anticipated ground conditions and hence ensure a more focused and cost-effective ground investigation strategy.

Misunderstanding arising from incorrect identification and classification of rock strata can lead to costly design and construction errors and to poor communication between engineers and geotechnical specialists [3]. A good working knowledge of stratigraphical nomenclature helps to avoid mistakes in naming and describing rock units in site investigation and project reports, understanding old maps and memoirs, and promote consistency of communication regarding geological information. To assist in this aim, a more consistent and rational approach to lithostratigraphic classification is now being applied to the major rock 'groups' in the UK, with published guides to help in the application of appropriate lithostratigraphic nomenclature. This, of course, does not supplant the need for high quality description of rocks and engineering soils, which are covered in other standard guides and codes of practice, but contributes to best practice throughout a ground engineering project.

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