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The Engineering Geology of the A74M and M6 in the Solway area

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The Engineering Geology of the A74M and M6 in the Solway area

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Foreword

This report publishes the results of research undertaken by the British Geological Survey (BGS) as part of the study of the Quaternary deposits in the Solway area (Eastern Dumfries & Galloway and Northern Cumbria). It is based on data from the ground investigation of the M6-M74 extension and the new interpretation of the Quaternary geology. The ground investigation data aided the interpretation of the Quaternary Geology. The linear route covered is between M6 junction 66, north of Carlisle to M74 junction 21 at Kirkpatrick-Fleming. The area is included in 1:50000 geological sheet Solway East Special Sheet and parts of the following 1:50 000 geological sheets: Annan 6E and Ecclefechan (Scotland) and Carlisle 17 (England and Wales.

The work was requested by the manager of the BGS Quaternary of Southern Scotland Project, A A McMillan.

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Acknowledgements

Draft chapters of the report were reviewed by Jon Merritt and Andrew MacMillan.

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Summary

This report is an assessment of the geotechnical data and engineering geology characteristics of the Quaternary deposits identified from ground investigations for the M6 and M74 extension corridor from Carlisle to Kirkpatrick-Fleming, connecting the motorway network between Scotland and England. The work was carried out under the

Quaternary of the South of Scotland Project (BGS Integrated Geoscience Surveys (North) Programme). The ground investigations for the road extension are from M74 Beattock to M6 Ecclechan to Carlisle (1988), A74M Glasgow to Carlisle Trunk Road (M74 Gretna to Kirkpatrick-Fleming) (1989) and M6 Extension to Scottish Border). The data from the ground investigations were added to the National Geotechnical Properties Database with a lithostratigraphical code using information supplied by A A McMillan and J W Merritt based on the findings of a new survey of the Quaternary geology of the Solway. Assessment of geotechnical data was used to describe the engineering geological characteristics of the deposits encountered and specifically it provided guidance on the origin of some problematical deposits, which could be either weathered bedrock or Quaternary glaciolacustrine deposits.

1 Introduction

This report accesses the geotechnical data and engineering geological characteristics of the Bedrock and Quaternary deposits found during the M6-A74M extension between Carlisle and Kirkpatrick-Fleming. Completion of the Quaternary mapping of the Solway area (BGS, 2006) and the availability of the ground investigations along the proposed motorway corridor provided an opportunity for a geotechnical and engineering geological assessment. Also, the origin of one of the deposits could not decided from borehole description as the whether it is weathered bedrock or A Quaternary deposit. It was hoped that analysis of the geotechnical data would enable this deposit to be assigned to a geological formation.

1.1 SCOPE OF THE REPORT

The geotechnical and engineering geological assessment is limited to the *deposits encountered by three ground investigations provided by the Highways Agency and Scottish Office. The ground investigations were carried out during the late 1980's and mid 1990's as part of the engineering and environmental assessment for the extension of the M6/A74M between M6 junction 44, north of Carlisle, and M74 junction 21, to the east to Kirkpatrick- Fleming. This is a predominantly rural area straddling eastern Dumfries & Galloway and northern Cumbria, comprises low-lying ground and includes the floodplain of the River Esk and the River Sark.*

1.2 OUTLINE

The area covered by the study falls in 1:50 000 Special Sheet Solway East (Superficial) (British Geological Survey, 2006) which includes parts of the following 1:50,000 geological sheets: Annan 6E (Scotland), Ecclefechan 10E (Scotland), Langholm 11 (Scotland), Longtown 11 (England) and Carlisle 17 (England).

The lithostratigraphy is shown in Table 1. A map of the area with the site investigation area discussed in this study is in Figure 1. The data from the ground investigations was added to the National Geotechnical Properties Database, either by hand, from paper records, or directly from Association of Geotechnical and Geoenvironmental Specialists (AGS) digital data. Coding of the lithology based on the description and lithostratigraphy, based on information provided from the BGS Solway Quaternary mapping project by J W Merritt and A A McMillan and from the Lex-rock codes form for the 1:50 000 special sheet Solway East special sheet (BGS, 2006).

The depth of boreholes from the ground investigation limits the information, mostly to the top 25 m. As a thick layer of Quaternary deposits usually covers the area there is little data on the bedrock, although there is some information on the rocks of the Mercia Mudstone, and Sherwood Sandstone groups

1.3 GROUND INVESTIGATION

A mix of pitting, cable percussion and rotary drilling provided material for description and laboratory testing as well as in situ testing. Rotary drilling was used for most of the sandstones of the Sherwood Sandstone Group and some of the deeper mudstones of the Mercia Mudstone Group, and cable percussion for the Quaternary deposits, the upper part of the Mercia Mudstone Group and Sherwood Sandstone Group to a little below bedrock. The ground investigations reported on a wide range of field and laboratory tests, but a more limited suite are used here because there were few data for many of the tests. The ground investigations were carried out in accordance with BSI (1999) and the laboratory testing to BSI (1990).

2 Data

2.1 DATABASING AND DATA ANALYSIS

The data for this desk study are from three site investigations as listed in Table 1. The data were added to the British Geological Survey's National Geotechnical Properties Database, which is a relational database based in the Association of Geotechnical and Geoenvironmental Specialists (AGS) data tables. The database contains fields for lithological codes, which are used in 2D and 3D modelling, and lithostratigraphy, including Group, Formation, Member and Bed. The database interface is through Microsoft Access© and stored in Oracle©. Data that are provided in AGS digital format are added directly to the relevant table and those received as paper records were added manually. AGS data are preferred for addition to the database. All the geotechnical data and descriptions are added.

Analysis of the data requires it to be related to specific lithostratigraphical units and this is done for each unit identified in the borehole logs and in the database. This assessment is based on description, 1:50000 scale digital maps from the Geoscience Data Index (GDI), Lexicon rock codes (Lex-rock) for the relevant area and a geological cross-section along the M74/M6 road drawn by J W Merritt. The lithostratigraphy was tested by using the data to produce three new cross-sections using GSI3D© software. Once the lithostratigraphy had been validated the data were analysed.

Analysis of the data was carried out in Microsoft Excel© initially by splitting the data into lithostratigraphical units and drawing profile graphs, that is parameter versus depth plots, and other cross plots. In some the data were classified by their lithological code. Atypical data points were then identified and investigated to find out if the lithological code or lithostratigraphical attribution was correct. If this was the case then the value was compared to the description. Where necessary the data were checked against the original record, however, this was only possible for paper records as the AGS data is added directly to the database and the original data could not be checked. Occasionally some values appeared to be unusual, such a high moisture contents in a glacial till described as stiff or very stiff. Where it was considered that the data did not represent the sample as described, possible due to drilling disturbance, the value was rejected.

The data in the report is presented in a series of cross plots including profiles showing the changes in the parameter with depth. Other data is provided in the description of the lithostratigraphical unit. The engineering geological classification is based on the interpretation of the descriptions and the in situ and laboratory tests.

3 Bedrock

The bedrock along the section is from the Permo-Triassic and the lithostratigraphy is summarized in Table 1. The northern part, M74 Junction 21 [NY 328, 706] to Rockcliffe Moss [NY 373 326] comprises the sandstones of the Sherwood Sandstone Group, and the Mercia Mudstone Group in the south, from Rockcliffe Moss to Kingmoor Park [NY 389 602]. It is often difficult to identify the position of the base of granular Quaternary and the top of the Sherwood Sandstone Group as both may be recovered as sand and gravel or cobbles. This may be made more difficult by the use of cable percussion drilling in the upper part of the sandstone. In general, differentiating the top of the mudstones of the Mercia Mudstone Group from the base of the Quaternary deposits is easier as they have different lithologies. However, it may be confused with glaciolacustrine clays (see 5.1).

3.1 SHERWOOD SANDSTONE GROUP

The Sherwood Sandstone Group in this area comprises the St Bees Sandstone and the Kirklinton Sandstone formations.

3.1.1 St Bees Sandstone Formation

The Sherwood Sandstone Formation is limited to a 1.3 km stretch of the ground investigations. It was present in five boreholes, of which penetrated less than 2 m into the sandstone, whilst the other four penetrated over 10 m. The boreholes showed that the sandstone is covered by more than 7 m of mostly Quaternary deposits. Much of the core was extracted using rotary drilling.

The Sherwood Sandstone Formation is a red-brown, fine- to medium-grained, commonly micaceous sandstone, which is generally cross bedded with some parallel lamination. Mudstone clasts are locally common and there are some thin beds of greenish grey sandstone.

The St Bees Sandstone is slightly weathered at depth and highly weathered at or near rockhead. At depth it is a moderately weak to moderately strong, closely to very thinly bedded light reddish brown or reddish brown fine SANDSTONE with occasional bands of silty fine sand. Very closely spaced to closely spaced sub-horizontal fractures are probably formed as a result of drilling disturbance along bedding planes. RQD values indicate that the slightly weathered rock is poor to fair. However, this may underestimate the true quality of the rock as drilling induced fractures along bedding planes reduce the RQD values. Solid core recovery is generally greater than 80%.

Within 6 to 8 m of rockhead the St Bees Sandstone is generally very weak to moderately weak, often with very closely spaced subhorizontal fractures. Within a metre or so of rockhead it may be as above or recovered as sandy, very dense, angular to sub rounded GRAVEL with many cobbles and occasionally dense fine to medium gravelly SAND.

3.1.2 Kirklinton Sandstone Formation

The Kirklinton Sandstone Formation is mapped conjecturally between about 0.7 km south of Guard's Farm [NY 337 664] to Rockcliffe Moss [NY 727 326]. However, the boreholes indicates that a highly weathered sandstone, recovered as very dense silty fine sand with much fine to coarse very weak sandstone gravel, extends south to east of Heathlands Farm [NY 380 613]. The Kirklinton Sandstone Formation is generally thinly to very thinly, occasionally thickly bedded, locally cross-laminated, red-brown, slightly silty or silty fine to medium SANDSTONE with some coarser rounded sand-sized grains, (so called millet seed grains). Rockhead tends to be within 2 to 4 m of ground surface, which is nearer the surface than the other sandstone formations. Some of the boreholes penetrate over 10 m into the formation.

It is generally weaker than the St. Bees Sandstone and weathered to a greater depth. In its least weathered form it is moderately weak to moderately strong and generally described as slightly to moderately weathered. Within a half to two metre of rock head it is often recovered as moderately weak, tabular to angular, to coarse sandstone GRAVEL. Nearer rockhead it is often very dense silty SAND with some sub-angular to sub-rounded fine to medium gravel and classified as highly to completely weathered. Uniaxial compressive strength test on moderately weathered material vary 10 and 34 MPa, that is moderately weak to moderately strong, whereas those on highly weathered rock is weak having uniaxial compressive strength of less than 5 MPa.

Solid core recovery is often more than 75%, even in moderate to highly weathered rock, but may be as low as 10% in some cases. Although there is generally an increase in solid core recovery and RQD with increasing depth, this in not always the case.

3.2 MERCIA MUDSTONE GROUP

The Mercia Mudstone Group is represented by the Stanwix Shales Formation, which is red and green, sometimes dolomitic, micaceous and sandy MUDSTONE with gypsum veins, bands and beds at some levels. Halite is also found in this formation but will have been removed by dissolution at the depths covered by the ground investigation.

3.2.1 Stanwix Shales Formation

The Stanwix Shales Formation is mapped conjecturally to south of Rockcliffe Moss [NY 373 326], but the boreholes indicate that it is present to the south of Harker Moss [NY 380 613] (see Kirklinton Formation above). It is described in 20 boreholes and one deep trial pit. In the boreholes rockhead is generally within 5 to 9 m of ground surface and covered by Till. At depth the shales are very weak to weak, closely to medium bedded, purple brown or red brown, occasionally mottled with grey green spots, silty to very silty MUDSTONE sometimes with very closely to medium spaced thin gypsum veins. Above is about 3 to 6 m of very weak MUDSTONE sometimes in a very stiff clay matrix. Within 2 to 4 metres of rockhead it is a stiff to very stiff red-brown CLAY usually with some to much angular, fine to coarse gravel-sized mudstones clasts.

The least weathered material is sometimes good quality rock but the propensity to fail along 'incipient fracture' often reduces the RQD and indicates that this is usually very poor to poor quality rock.

The limited moisture content data vary between 10% and 14%.

4 Quaternary deposits

4.1 INTRODUCTION

The Quaternary deposits of this area comprise glacial, glaciofluvial, lacustrine, and recent alluvium, raised tidal flat, peat and warp deposits and their distribution is shown in BGS (2006) and described in detail in McMillan et al. (in preparation). A lithostratigraphical summary is in Table 1.

The oldest named Quaternary deposits were considered to be the Chapelknowne Till Formation, the Plumpe Sand and Gravel Formation and the Gretna Till Formation. The two till formations may be separated by the Plumpe Sand and Gravel Formation, which includes the Loganhouse Gravel Member and Plumpe Farm Sand Member. Where the Plumpe Sand and Gravel Formation is absent the two till members may be distinguished by their clast content. However, the lithology of the coarse material is generally not described in ground investigation boreholes and the tills are classified at their formation level as indicated in BGS (2006). A localised lacustrine laminated silt and clay, the Great Easby Clay Formation, lies above the Chapelknowne Till to the south of the River Esk.

Above the lower formations is a sequence glaciofluvial sand and gravel deposits of the Kilblane Sand and Gravel Formation and the Cullivait Silts Formation. The Kilblane Sand and Gravel Formation comprises the glaciofluvial sheet and glaciofluvial ice-contact deposits both of coarse grained materials whereas the Cullivait Silts Formation is commonly a laminated clay, silt and sand with gravel dropstones.

The youngest deposits are river terrace gravels, raised tidal flat deposits, salt marsh, alluvium and peat in low lying and poorly drained area.

4.2 CHAPELKNOWNE AND GRETNA TILL FORMATIONS

4.2.1 Description

The Chapelknowne and Gretna Till formations are generally firm to very stiff, occasionally laminated, sometimes fissured near surface, red or reddish brown sandy CLAY or sometimes compact SILT with little to much fine to coarse angular to rounded gravel sometimes with cobbles. Near surface it may be soft or sometimes very soft and occasionally soft 20 m below ground level. The tills may be red-brown, orange brown, grey brown, light brown and occasionally mottled grey.

4.2.2 Material characteristics

The near surface moisture content varies widely, between about 5 and 28%, reflecting the seasonal changes and perhaps lithological differences. The maximum moisture content tends to decrease with depth and all values are between 5 and 20% below 5 m.b.g.l.

The tills are low to intermediate plasticity clay (Figure 2). Particle size distribution graph (Figure 3) shows that the tills are variable, but generally poorly sorted.

4.3 PLUMPE SAND AND GRAVEL FORMATION

The Plumpe Sand and Gravel Formation is composed of the Loganhouse Gravel Member, the Plumpe Farm Sand Member and undifferentiated Plumpe Sand and Gravel Formation. It is found between the Chapelknowne Till Formation and the Gretna Till Formation. The two members have been identified in the Gretna Green area and north to just north west of the Gretna Services [NY 307 688]. Along this section the undifferentiated Plumpe Sand and Gravel Formation occurs beneath the Gretna Till Formation in the Gearshill area [NY 385 605], Grahamshill [NY 284 700] and south of Kirkpatrick-Fleming. [NY 278 709].

4.3.1 Plumpe Sand and Gravel (undifferentiated)

The Plumpe Sand and Gravel Formation described here is mostly a coarse grained deposit present in the h of Gretna above the predominantly gravel Loganhouse Gravel Member. It is highly variable and usually mixed deposit but is sand or sand with other components and can be gravel-dominated or very occasionally, silt or predominantly cobbles.

The sand may be medium dense to very dense reddish brown fine or fine to medium sometimes fine to coarse SAND or silty fine SAND.

Mixed sand deposits include medium dense to dense red brown, brown, orange brown or orange, slightly to very clayey, fine or fine to medium or coarse SAND with some to much subangular to subrounded or rounded fine to coarse, the gravel and sometimes cobbles, which are generally sandstone. Sometimes the sand and gravel is of equal importance.

4.3.2 Loganhouse Gravel Member

The Loganhouse Gravel Member is generally a dense to very dense, reddish brown, silty, angular to rounded, fine to coarse GRAVEL with some to much fine to coarse sand and cobbles. Alternatively, it can be a dense to very dense, reddish brown, fine to coarse SAND and fine to coarse, angular to rounded GRAVEL with cobbles, or dense to very dense reddish brown, fine to coarse SAND with some to much fine to coarse angular to rounded gravel and cobbles. The gravel is generally sandstone, clayey sandstone and siltstone.

4.3.3 Plumpe Farm Sand Member

The Plumpe Farm Sand Member is a medium dense to very dense, reddish brown or brown, occasionally gravelly, sometimes silty or clayey, fine to medium SAND, sometimes with layers or bands of silt and clay. The gravel is angular to rounded, fine and medium gravel. There are also beds of very dense, angular to rounded, fine to coarse GRAVEL.

4.4 KILBLANE SAND AND GRAVEL FORMATION

The Kilblane Sand and Gravel Formation in this area comprises ice-contact deposits and sheet deposits. They are generally a coarse grained deposits. The gravel and coarser particles (cobbles and boulders) are composed of a mixture of pre-Permo-Triassic rocks, comprising Ordovician, Silurian, Devonian and Carboniferous rocks.

4.4.1 Ice contact deposits

The ice contact deposits along the line of the road scheme are found near Gretna and form the high ground just to the north of the River Sark. They form mounds and ridges. They are described as:

Medium dense to very dense reddish brown clayey or silty fine to coarse SAND and fine to coarse angular to rounded GRAVEL, sometimes with some to many cobbles.

Dense reddish brown slightly silty fine to medium SAND.

Very dense fine to coarse angular to rounded GRAVEL with some fine to coarse sand and cobbles.

Density, indicated by standard penetration testing, varies between medium dense and very dense in the top three metres but becomes medium dense to dense below, indicating a reduction in density with depth.

4.4.2 Sheet deposits

The sheet deposits form flat-topped sand and gravel deposits and are generally thought to be better sorted than the ice-contact deposits. They are generally less than 10 m thick and usually less than 7 m thick in the study area. North of the River Esk they a concealed by tidal flat deposits and terrace gravel deposits from a little north of the River Esk [NY 335 648] to Rosetrees Moss [338, 662], and have been described beneath the Cullivait Silts Formation (BGS, 2006) north to about 250 m south east of Guards Farm [NY 340 665]. South of the River Esk it is present beneath alluvium and peat in the Hespin Wood area south of Floriston Bridge [NY 362 638] to near Todhils Farm [NY 367 631]. The Kirklinton Sandstone Formation lies beneath the southern half of the sheet deposits north to the Mossband Viaduct [NY 347 654]. Laminated silts, clays and sand underlie most of these deposits to the north.

They vary between silty sand, sand, gravelly sand, sand and gravel, sandy gravel and silty sandy gravel and are generally red-brown, light brown, orange brown and brown. The particle size distribution graph is shown in (Figure 4).

4.4.2.1 DETAILED DESCRIPTION

SAND

Very loose to medium dense red, silty fine CLAY sometimes with a little angular or subangular gravel.

Loose to dense clayey or silty fine or fine to medium or medium to coarse SAND sometimes with a little to much angular to subrounded fine to fine to coarse or fine to medium gravel, occasionally with cobbles.

GRAVEL

Loose to dense slightly silty, sandy or sandy, sub-angular to subrounded fine to coarse GRAVEL sometimes with occasional to some cobbles.

4.5 CULLIVAIT SILTS FORMATION

The Cullivait Silts Formation is present between just north of Rosetrees Moss [NY 338 662] to the River Sark [NY 328 673] beneath the Terrace gravels and the Alluvium and above the Kirklinton Sandstone Formation in the south, and the St. Bees Sandstone Formation or Chapelknowne Till Member in the north. It usually red brown, but may be mottled grey.

It comprises clay, silt or sand, which may be thinly or thickly laminated or interlaminated with occasional sub-angular and subrounded fine and medium, rarely coarse, gravel.

4.5.1 Detailed description

Very soft to very stiff often thickly or thinly laminated, sometimes slightly sandy CLAY with silt partings or interlaminations of silt.

Uncompact to compact, sometimes fine sandy SILT sometimes with thin interlaminations of clay.

Very loose to medium dense silty fine, occasionally coarse SAND sometimes interlaminated with sandy SILT.

Occasionally clay, silt and sand will be interlaminated.

4.5.2 Geotechnical assessment

The strength or compactness does not necessarily increase with depth, indeed firm layers are found above soft or very soft. This is confirmed by the moisture content profile, which does not decrease with increasing depth (Figure 5).

It is of low to intermediate plasticity.

4.6 RIVER TERRACE DEPOSITS (ESK)

The terrace gravel deposits are found between the River Sark and River Esk as flat topped areas of raised ground above tidal flat deposits and alluvium. Three different terrace gravel deposits have been identified. They lie on the Kilblane Sand and Gravel Formation sheet deposits in the south and on the Cullivait Silts Formation in the north.

4.6.1 Third River Terrace (River Esk)

The third terrace forms the higher ground from Guards Farm northwards to the River Sark and lies on the Cullivait Silts Formation. It is generally between 2 and 10 m thick. It usually red-brown or red, but also orange, orange brown or pale orange and comprises mixed lithologies, predominantly gravel and sand, but also silt and occasionally clays.

4.6.1.1 DETAILED DESCRIPTION

The sands are normally loose to medium dense, but may be dense or occasionally very dense, sometimes silty or clayey, occasionally very silty, sometimes fine, but generally fine to coarse SAND with some to much fine medium and/or coarse gravel, which may be rounded or sub-angular to sub-rounded with occasion cobbles.

The gravel-dominated beds are medium dense to very dense sometimes slightly silty, sandy or very sandy, sub-rounded, or angular to sub-rounded fine to coarse GRAVEL.

Locally, this terrace deposit is a compact slightly sandy SILT with a little sub-angular to sub-rounded, fine to medium, sometimes coarse, gravel.

The particle size distribution graph (Figure 6) shows seven examples.

4.6.2 Second River Terrace (River Esk)

The Second River Terrace occurs above the Cullivait Silts Formation, and forms a small flat-topped in the Guards Farm area [NY 330 567]. It is encountered in only a few boreholes and is typically red brown or grey and a mixed deposit generally of sand, gravelly sand or sandy gravel with silt. The sand and gravel is medium dense to dense.

4.6.2.1 Detailed description

Red-brown very clayey silty fine to coarse SAND.

Very dense grey mottled red-brown slightly clayey very silty fine SAND and angular to sub-rounded fine to coarse GRAVEL.

Dense grey slightly silty sandy sub-angular and sub-rounded fine to coarse GRAVEL with occasional cobbles.

Occasionally there is thin (to half a metre thick) compact red-brown fine sandy SILT.

4.6.3 First River Terrace (River Esk)

The First River Terrace occurs as relatively flat-topped land above the tidal flats. Three sub terraces have been identified named 1a, 1b and 1c. The base of River Terrace 1c can be identified from the underlying laminated clay, silt and sand of the Cullivait Silts Formation. The bases of River Terraces 1a and 1b are more difficult to identify above the Kilblane Sand and Gravel Formation sheet deposits as they have similar lithologies. All the First Terrace Deposits are predominantly sand and/or gravel, but may also contain beds of silt and clay generally between 0.3 and 2 m thick, which occasionally contain organic material. They occasionally contain cobbles.

4.6.3.1 Detailed description

The sand and gravels are generally medium dense to dense grey, brown or light brown, occasionally mottled. The sands may be silty sometimes clayey or silty, fine to medium, occasionally coarse. Sand and gravel mixes are usually silty fine to coarse sand and fine to coarse gravel, which may be angular to subrounded or sometimes just rounded.

4.6.3.2 Geotechnical data

The limited number of particle size distribution data are presented in Figure 7.

4.7 RAISED TIDAL FLAT DEPOSITS

The Raised Tidal Flat Deposits cover most of the lowest-lying area between the Mossband viaduct [MY 339 660] and the saltmarsh to the north of the River Esk [NY 354 650]. In some places these deposits may have been impounded by man to provide grazing land and may accordingly be classified as warp. The Raised Tidal Flat deposits generally comprise very soft to soft, clay and uncompact silt, which may be slightly sandy or sandy. They commonly contain include roots, rootlets, other fibrous plant remains and occasionally peat or wood. Loose silty fine sand beds up to 2 m thick occur in some places. Gravel is a minor component and is generally fine and sub-angular and sub-rounded. The colour is either light grey, grey, light brown or brown and sometimes mottled grey and brown. Near surface the clay may be stiff, a result of desiccation.

4.7.1.1 Geotechnical data

The moisture content generally deceases with depth, however, some of the variation is controlled by lithology, and near surface, by seasonal changes. High moisture content is generally associated with higher organic content and lower values are probably due to greater sand content.

Plasticity is also very variable due to the lithological variation, clay or silt, and organic content. The clays vary between low and high plasticity and the silts between intermediate and high plasticity. Very high and extremely high plasticity samples plot beneath the A-line are typically organic (Figure 8).

Particle size determinations were carried out on silt samples and one sand sample and this is reflected in the particle size distribution graph (Figure 9).

4.8 ALLUVIUM

Alluvium forms the lowest lying ground along rivers. It is a mixed deposit, generally fine grained, but there are also beds of sand and, less commonly, gravel at all levels. The basal part of the alluvium is often sand and gravel, so-called ‘lag’ deposits. It is also found beneath peat at Hespin Wood [NY 364 635] and Rockcliffe Moss [NY 373 624].

The fine grain deposits are generally very soft to firm, but stiff near surface, grey or brown or red brown, occasionally gravelly, often sandy, CLAY or uncompact SILT, sometimes organic or with plant remains. The Clay and Silt may be interlaminated. The coarse deposits vary from loose to dense light brown, red brown or grey silty fine or fine to coarse SAND sometimes with fine to coarse gravel, to loose to medium dense silty, sandy angular to rounded fine to coarse GRAVEL. More organic beds occur within Alluvium and sometimes form peat layers.

4.8.1 Geotechnical data

Moisture content generally varies between 10 and 38%, higher values, which are associated with more organic clay samples. A moisture content profile of the Alluvium is presented in Figure 10.

The plasticity chart (Figure 11) shows the fine-grained Alluvium to be a generally low plasticity, sometimes intermediate and high samples clay.

Particle size analyses of the Alluvium were carried out on silty or clay sands and two silty gravelly sands as reflected in Figure 12. This figure is, therefore, not representative of the particle size distribution of the Alluvium.

4.9 PEAT

Peat is present in areas of poor drainage and where the water table is high. Harker Moss [NY 379 616] and Rockcliffe Moss [NY 373 624] are in shallow wide hollows above the Gretna Till Formation. Hespin Wood [NY 364 635] is in a low-lying hollow above alluvium and Kilblane Sand and Gravel Formation sheet deposits. Peat also occurs on Terrace Gravel Deposits near the Mossbank Viaduct [NY 346 655] to Rosetree Moss [340 660] and sporadically just to the north of Gretna Green on a hollow in the Gretna Till Formation. Some of the Tidal Flat Deposits are very organic or peaty and a peat sometimes occurs at the base.

Most of the peat is fibrous and spongy, but may also be amorphous. It is typically black or dark brown and may be clayey or occasionally sandy.

4.9.1 Geotechnical Data

Peat is typically high moisture content, extremely high plasticity and highly compressible. Low moisture content peat, (<50%) are generally sandy and those between 50% and 100% have a greater clay or silt content than those samples that are described as PEAT. The moisture content does not tend to decrease with depth (Figure 12) indicating that the structure of the peat is not compressing much under the small overburden pressure of the peat, maintaining an open structure, therefore, remaining highly compressible even at depth.

5 A problematic glaciolacustrine or weathered mudstone deposit

5.1 INTRODUCTION

A problematic unit of laminated clay and silt, sometimes with sand occurs beneath the peat, terrace sand and gravel, Cullivait Silts Formation and the Kilblane Sand and Gravel Formation sheet. The deposit runs for about 1.2 km along the line of the A74M from west of the Rosetree Moss [NY 338 662] to a about 300 m south of the Mossband Viaduct/A74M crossing [NY 347 654]. This deposit is found between about 1 mOD and -20 mOD with a fairly flat top and very undulating base.

In drawing a cross-section across the Solway Lowlands, J W Merritt experienced difficulty in interpreting whether the unit was weathered mudstone in the Kirklinton Sandstone Formation, or, a laminated glaciolacustrine silt and clay infilling a buried valley. If glaciolacustrine in origin, it predates the Cullivait Silts Formation.

It was anticipated that the ground investigation description and laboratory results would provide a good indicator of the likely origin of this unit. If it is a weathered mudstone, then it is likely to be similar to the weathered Stanwix Shales Formation, however, if it is a glaciolacustrine in origin it is likely to be similar to the Cullivait Silts Formation.

5.1.1 Description

This unit comprises very soft to stiff or uncompact, often thinly to thickly laminated, red brown or brown slightly sandy CLAY or SILT. A little angular to rounded fine to coarse gravel may be present. Sometimes within the fine-grained deposit there are beds of very loose to loose red brown very silty SAND. The base of the deposit may be silt or silty fine sand, or sand and gravel, which may be weathered Kirklinton Sandstone Formation. Importantly, there appears to be no unweathered mudstone beneath the clay, silt and sand.

In general, there is a decrease in strength with depth. The top is often firm to stiff, and may be very stiff locally. Soft to firm clay is found at depths of 15 m; 8 m below the top of this deposit. As the stiffer layer occurs beneath 11 m of Raised Tidal Flat and Kilblane Sand and Gravel Formation, it cannot be due to modern climatic desiccation.

5.1.2 Geotechnical Assessment

Moisture content should be a good indicator of whether this unit is a weathered mudstone or a lacustrine deposit. It is assumed that if the moisture content profile is similar moisture to that of the Cullivait Silts Formation then it is likely to be a glaciolacustrine deposit, and if it is similar to the weathered Stanwix Shales Formation, it is likely to be weathered Permo-Tirassic mudstone. Figure 13 shows the moisture content depth profile of this deposit, the Cullivait Silts Formation and the Stanwix Shale Formation. The data show that a majority of samples have similar moisture contents to the Cullivait Silts Formation, there also tends to be an increase in moisture content with depth similar to the Cullivait Silts Formation.

5.1.3 Discussion

The descriptions and geotechnical data indicate that this unit is most likely to be a glaciolacuastrine deposit. It is often markedly thinly to thickly laminated, which is common in glaciolacustrine deposits and occurs in some parts of Permo-Triassic mudstones. A little angular to rounded gravel is sometimes present. Unfortunately, the gravel lithology is not described as it would provide important information as to the origin of this unit. Both glaciolacustrine deposits and Permo-Triassic mudstones sometimes contain gravel. Glaciolacustrine deposits, for instance the Cullivait Formation, may contain occasional to some subangular to subrounded gravel. Gravel in Permo-Triassic mudstones occurs in weathered horizons as mudstone lithorelicts or angular fine-grained sandstone or siltstone, derived from siltstone and sandstone beds. Lithorelicts and sandstone layers are not described in this unit, but lithorelicts are described in the weathered Stanwix Formation in the southern end of the site investigation. It is, therefore, assumed that similar features would be described elsewhere in the site investigation if they were present, and that the gravel in this unit is not mudstone lithorelicts. Beds of very loose to loose sand occur in glaciolacustrine deposits but are very unusual in Permo-Triassic mudstones, perhaps in highly weathered material.

High values of moisture content and their increase with depth, and the inverse relationship with strength, would be very unusual for a weathered Permo-Triassic mudstone sequence particularly to such a depth and thickness of the unit. Also, moisture content values of the Permo-Triassic mudstones (Mercia Mudstone Group) (Hobbs et al., 2001) show that values above 30% are very unusual and are sometimes associated with gypsum dissolution or disturbed weathered material near surface. Whereas, this unit has a significant number of samples above this value.

The descriptions and geotechnical data both show this unit to be similar to the Cullivait Silts Formation than weathered mudstones of the Stanwix Shales Formation, or what is likely in weathered mudstones from the Kirklinton Sandstone Formation.

This unit is probably the Great Easby Clay Formation (J W Merritt, personal communication 2006), which is found in the Solway Lowlands. It is described as generally very thinly to thinly laminated, dark reddish brown, clay silt and very fine sand with occasion gravel dropstones.

Table 1 Lithostratigraphy of the area.

Period or sub Period	Group	Subgroup	Lithostratigraphical unit	Members or sub units	Lithological description
Quaternary	British Coastal Deposits Group		Raised Tidal Flat deposits		Mainly clay, silt and sand. May be organic sometimes contains peat. Forms low relief areas in the tidal zone.
	Britannia Catchments Group	Solway Catchment Subgroup	Peat		Fibrous and amorphous peat. Mainly basin peat and raised bogs.
			Alluvium		Mainly clay, silt and sand. May be organic, sometimes contains peat. Forms floodplains and infills basins.
			River Terrace Deposit 1a		Sand and gravel or gravelly sand with silty sand, silt and sand, especially at base. Contains organic layers. Dissected remnants of former floodplains.
			River Terrace Deposit 1b		Sand and gravel or gravelly sand with silty sand, silt and sand, especially at base. Contains organic layers. Dissected remnants of former floodplains.
			River Terrace Deposit 1c		Sand and gravel or gravelly sand with silty sand, silt and sand, especially at base. Contains organic layers. Dissected remnants of former floodplains.
			River Terrace Deposit 2		Sand and gravel or gravelly sand with silty sand, silt and sand, especially at base. Contains organic layers. Dissected remnants of former floodplains.
			River Terrace Deposit 3		Sand and gravel or gravelly sand with silty sand, silt and sand, especially at base. Contains organic layers. Dissected remnants of former floodplains.
	Caledonic Glacigenic Group	Irish Sea Coast Glacigenic Subgroup	Kilblane Sand and Gravel Formation	Glaciofluvial Ice-contact Deposits	Sand and Gravel, cobbles, sometimes silt and clay. Mounds and ridges.
				Glaciofluvial Sheet Deposits	Sand and gravel. Flat-topped spreads.
			Plumpe Sand and Gravel Formation		Sand, gravel and silt. Coarse-grained deposit between Gretna and Chapelknowe Till Formations.
				Plumpe Farm Sand Member	Silty sand with laminated clay and gravel.
				Loganhouse Gravel Member	Silty gravel.
			Cullivait Silts Formation		Laminated silt and clay sometimes with gravel.
			Gretna Till Formation		Gravelly, sandy clay or silt.
			Chapelknowe Till Formation		Gravelly, sandy clay or silt.
			Great Easby Clay Formation		Laminated silt and clay sometimes with gravel.
Triassic	Mercia Mudstone Group		Stanwix Shales Formation		Mudstone with some gypsum and sandstone.
	Sherwood Sandstone Group		Kirklinton Sandstone Formation		Cross-bedded fine to medium sandstone.
			St. Bees Sandstone Formation		Generally cross-bedded, some parallel lamination Red-brown, micaceous, fine to medium sandstones with mudstone clasts.

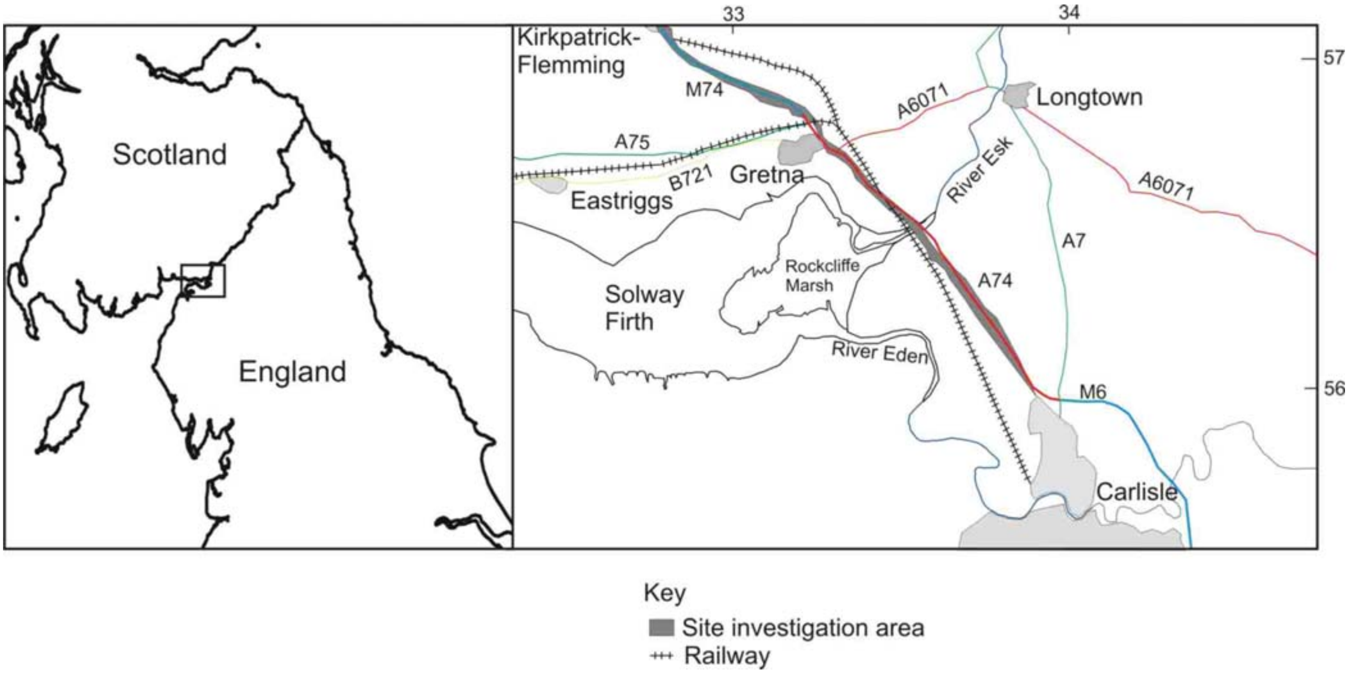

Figure 1. Location map of the A74M/M6 with the site investigation area.

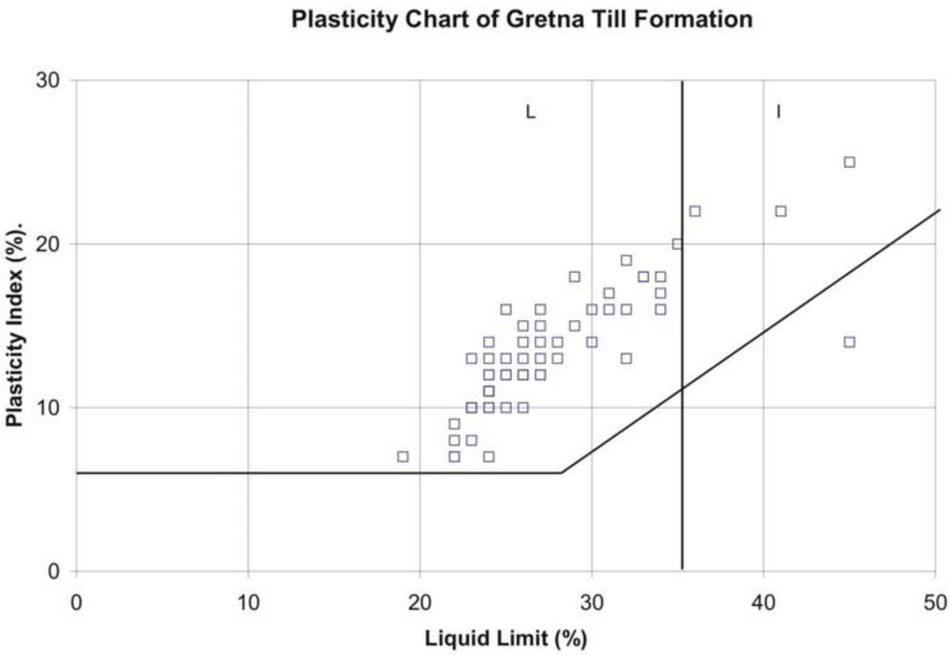

Figure 2. Plasticity chart of the Gretna Till Formation.

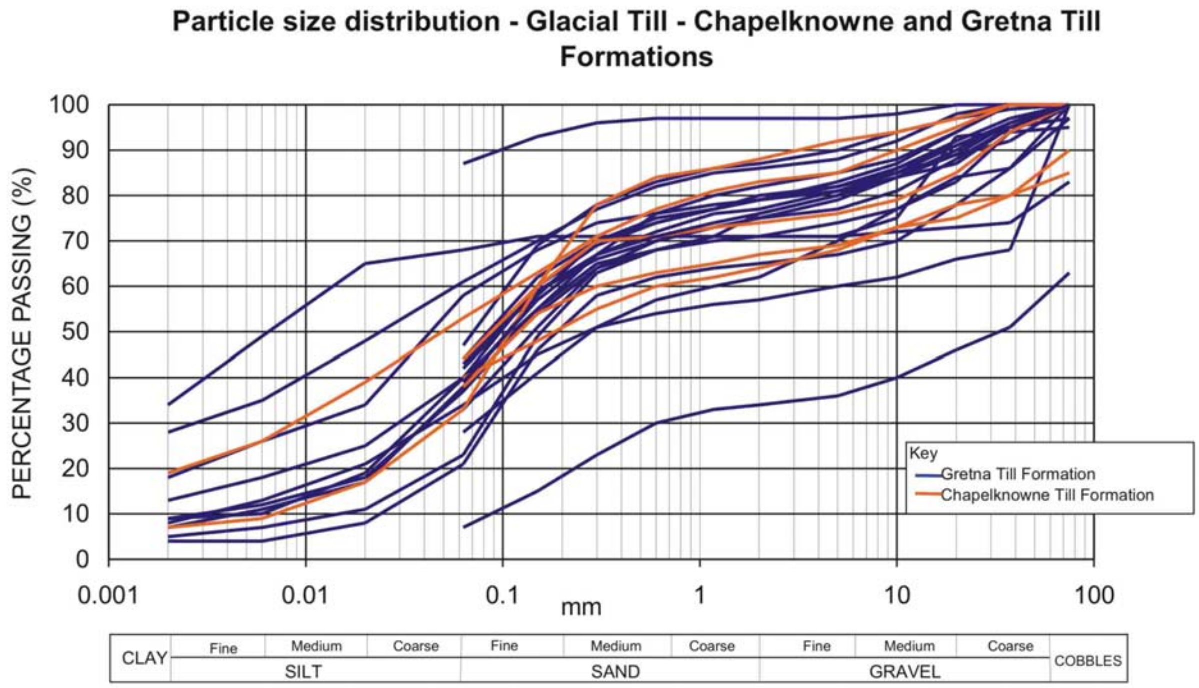

Figure 3. Particle size distribution of the Gretna Till Formation.

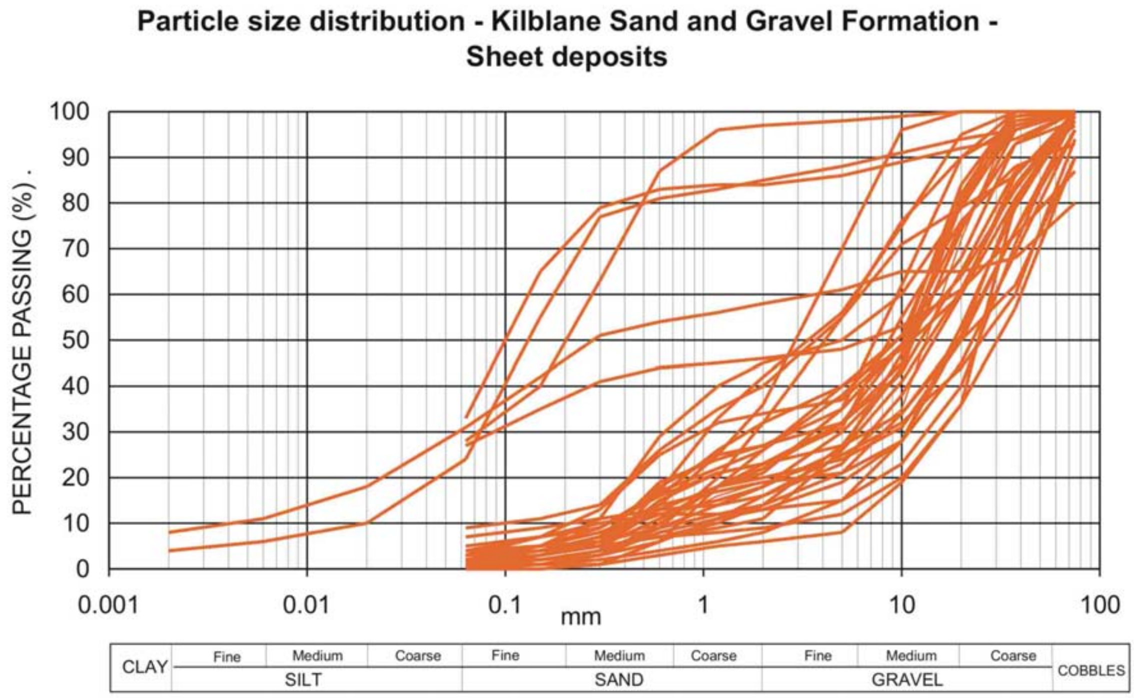

Figure 4. Particle size analysis of the Kilblane Sand and Gravel Formation sheet deposits.

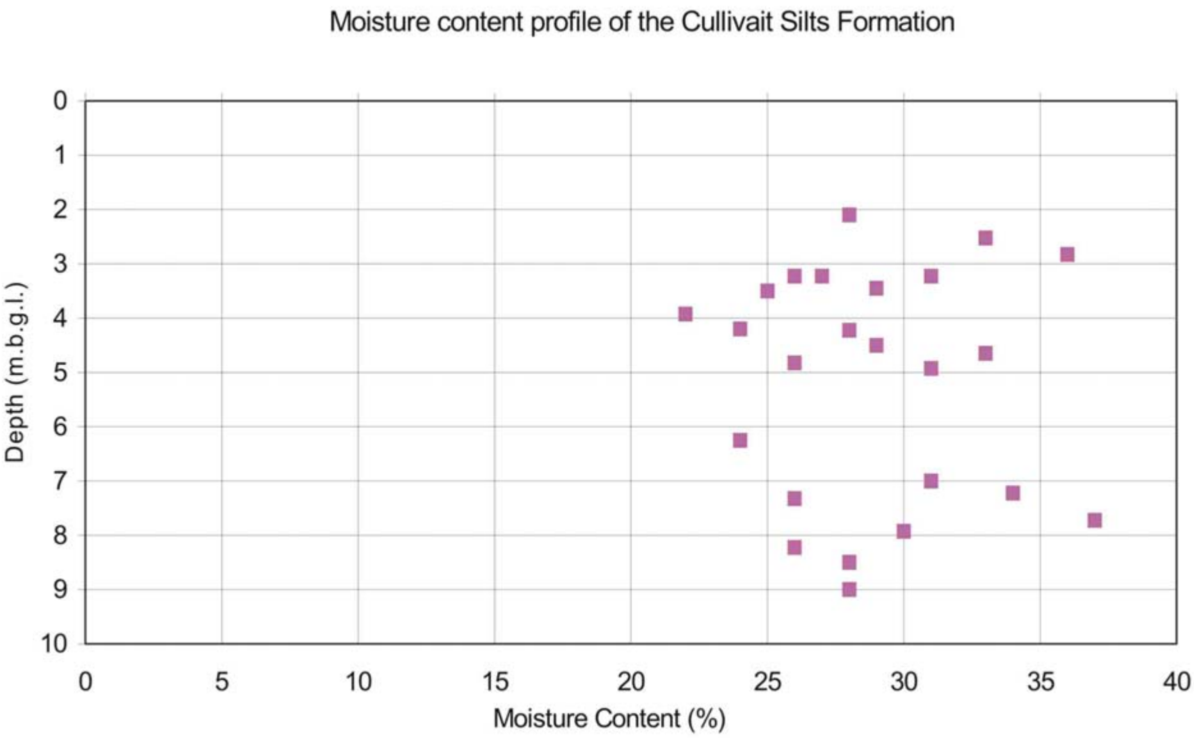

Figure 5. Water content profile of the Cullivait Silts Formation.

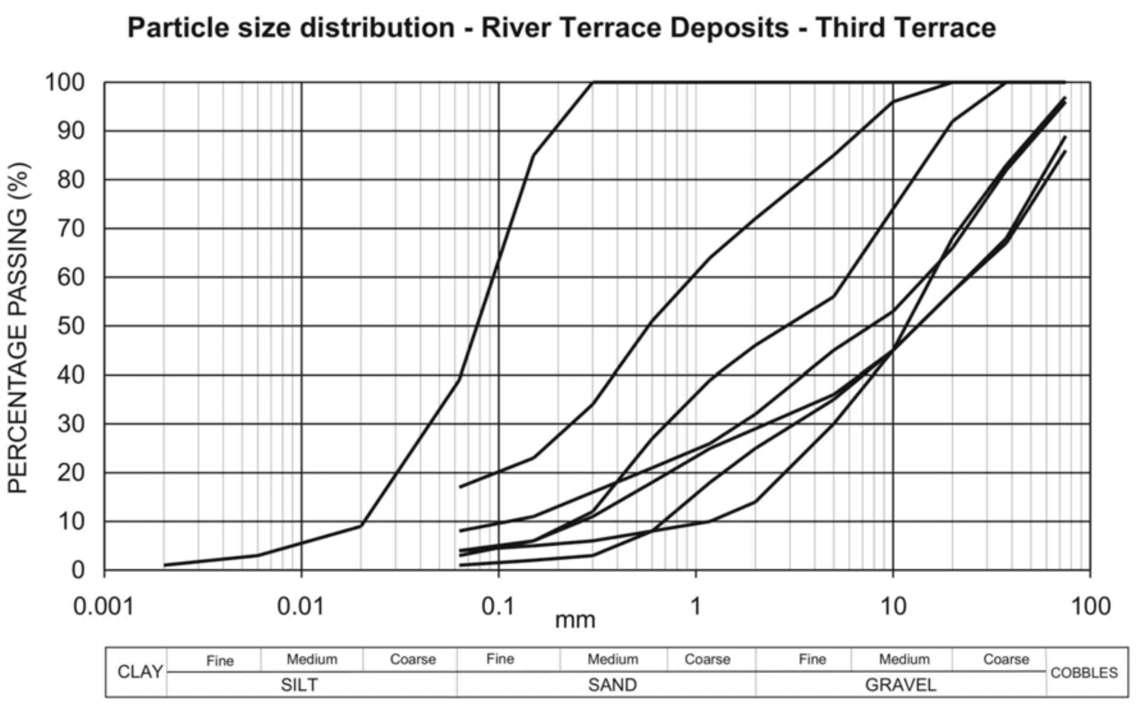

Figure 6. Particle Size distribution of the Third River Terrace Deposits, River Esk.

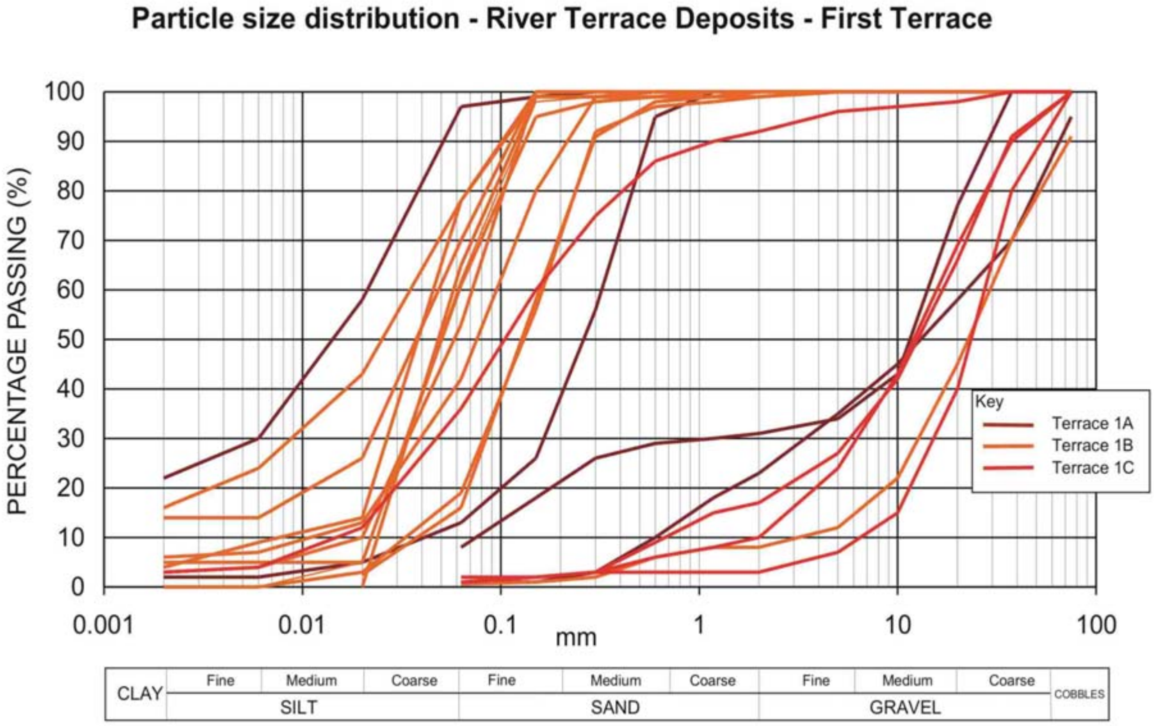

Figure 7. Particle size distribution of the First River Terrace Deposits, River Esk.

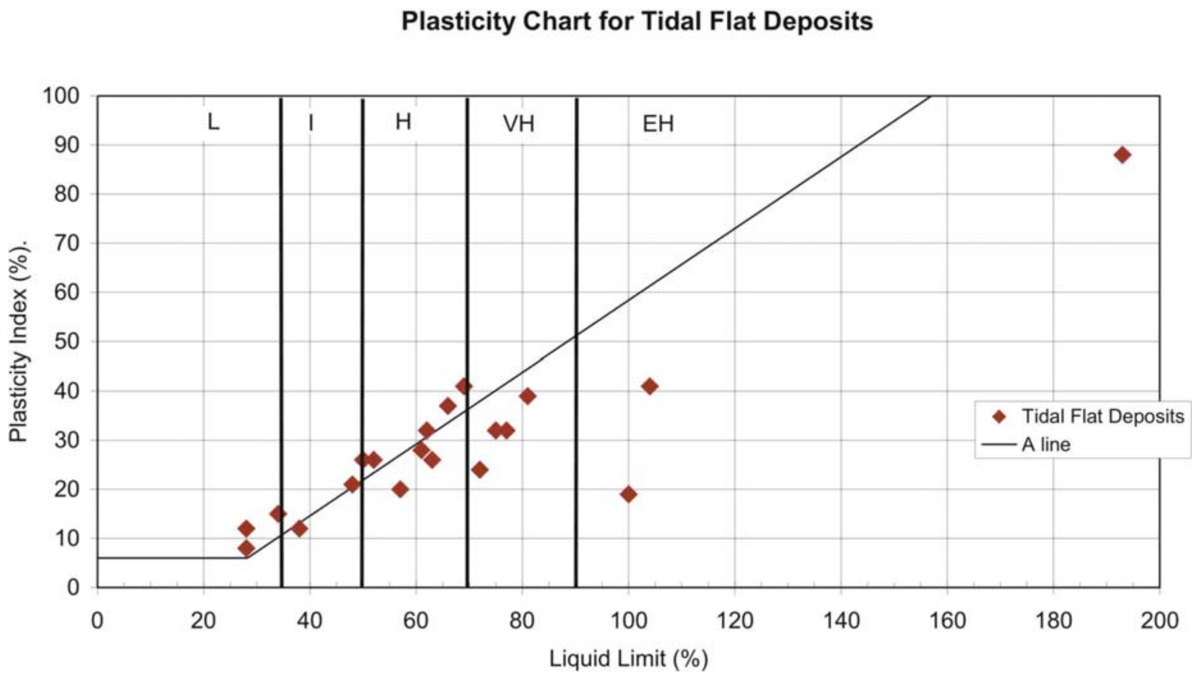

Figure 8. Plasticity chart of the Raised Tidal Flat Deposits.

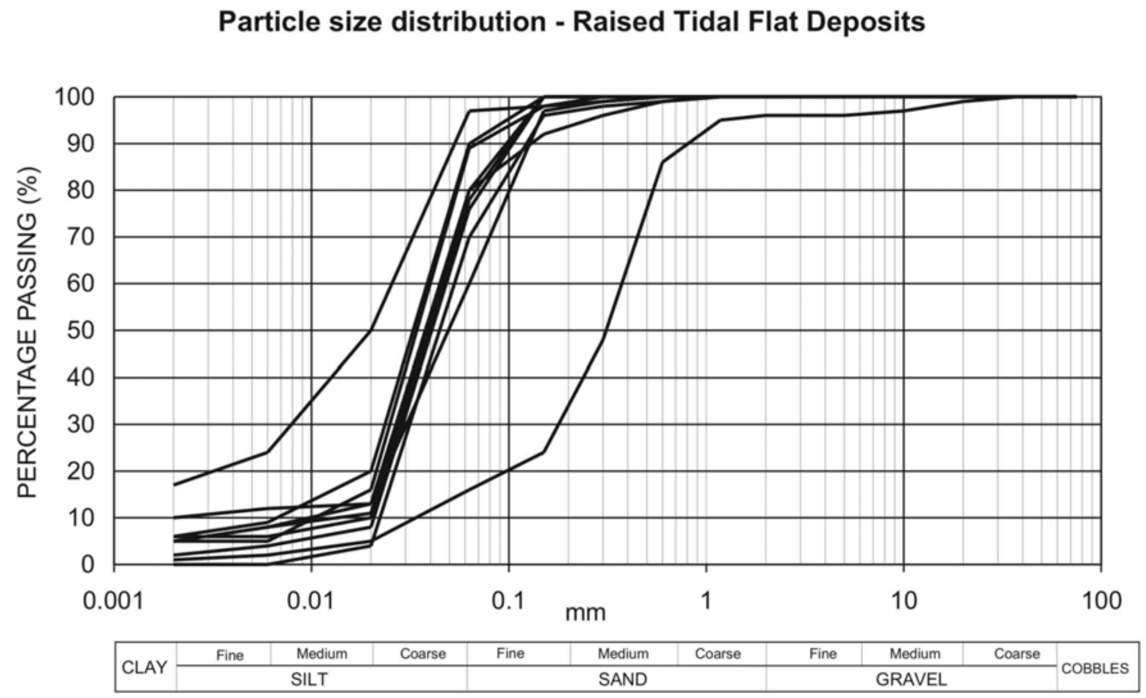

Figure 9. Particle size distribution of mostly silt and sand Raised Tidal Flat Deposits.

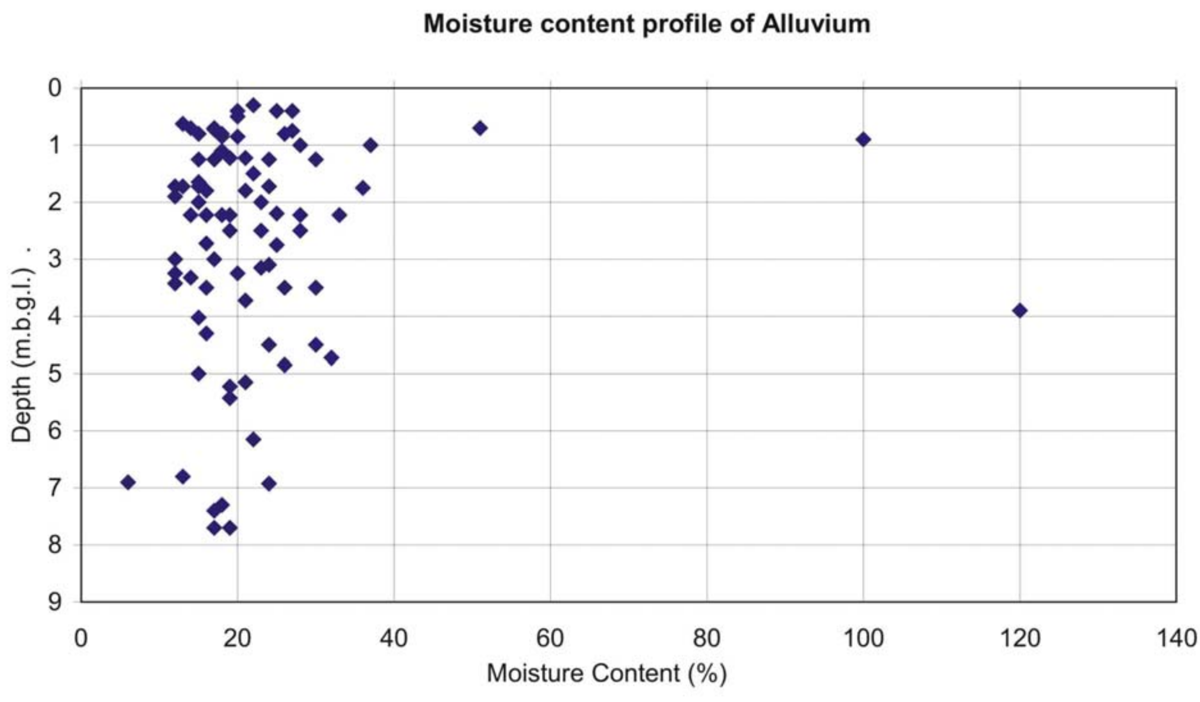

Figure 10. Moisture content profile of Alluvium.

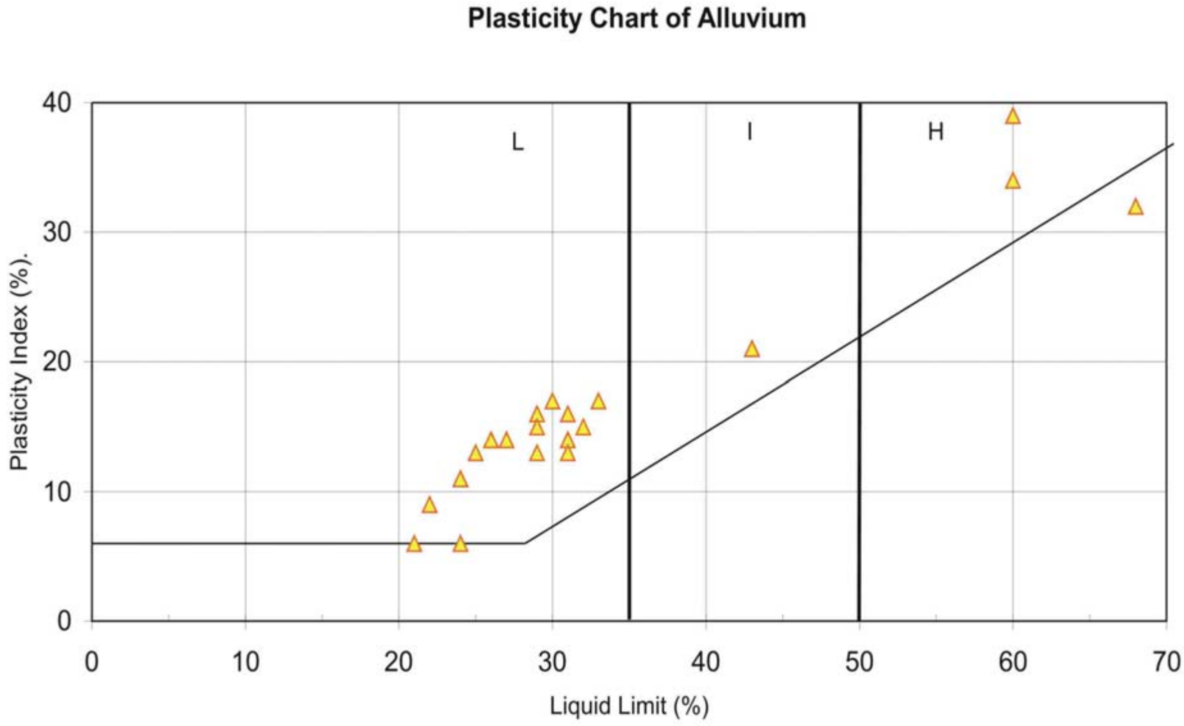

Figure 11. Plasticity chart of Alluvium.

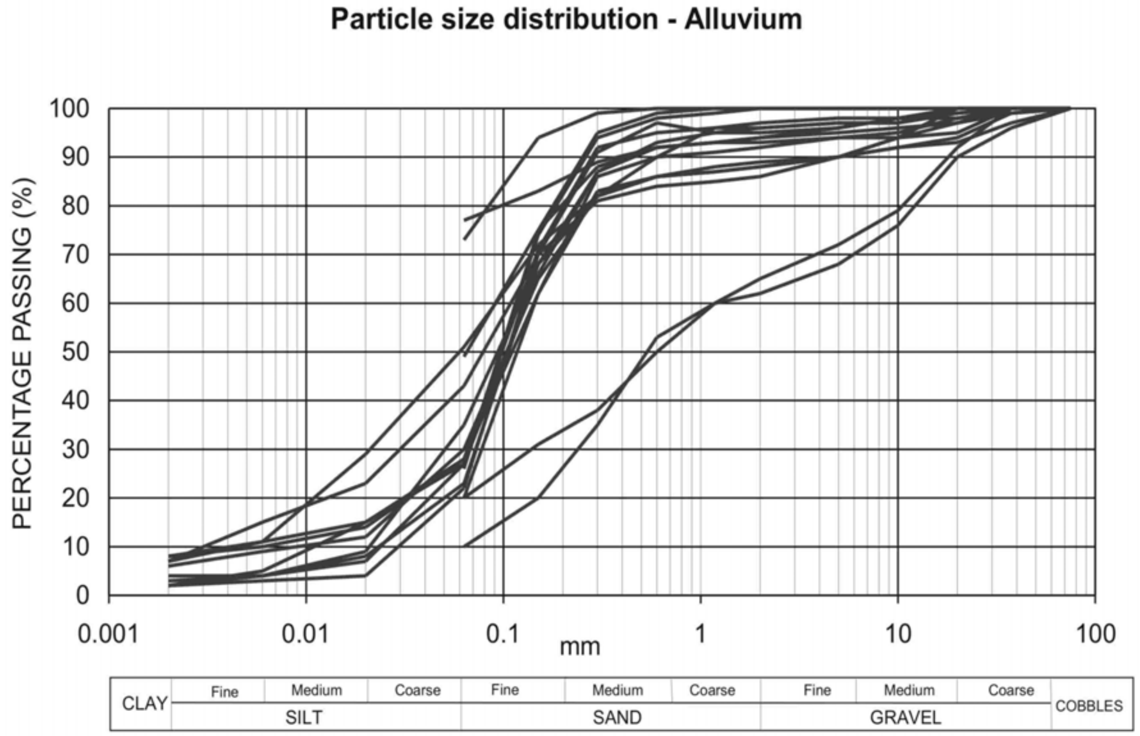

Figure 12. Particle size distribution of Alluvium, mostly sand samples.

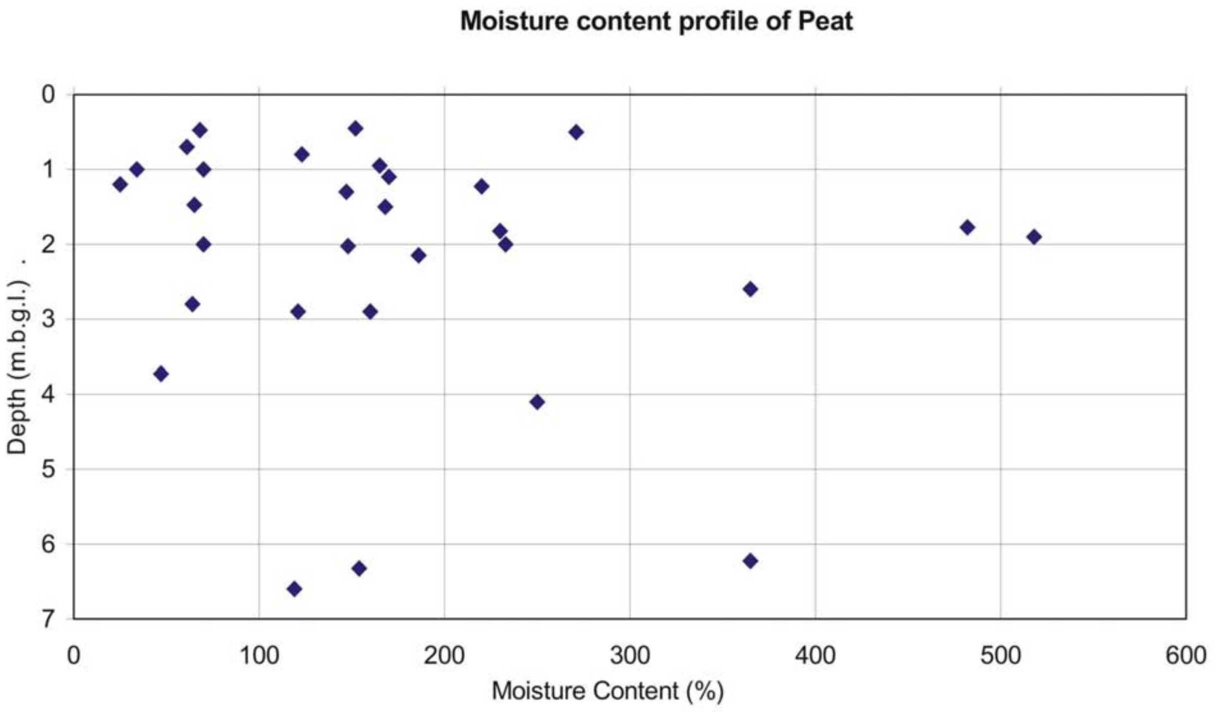

Figure 13. Moistrue content profile Peat.

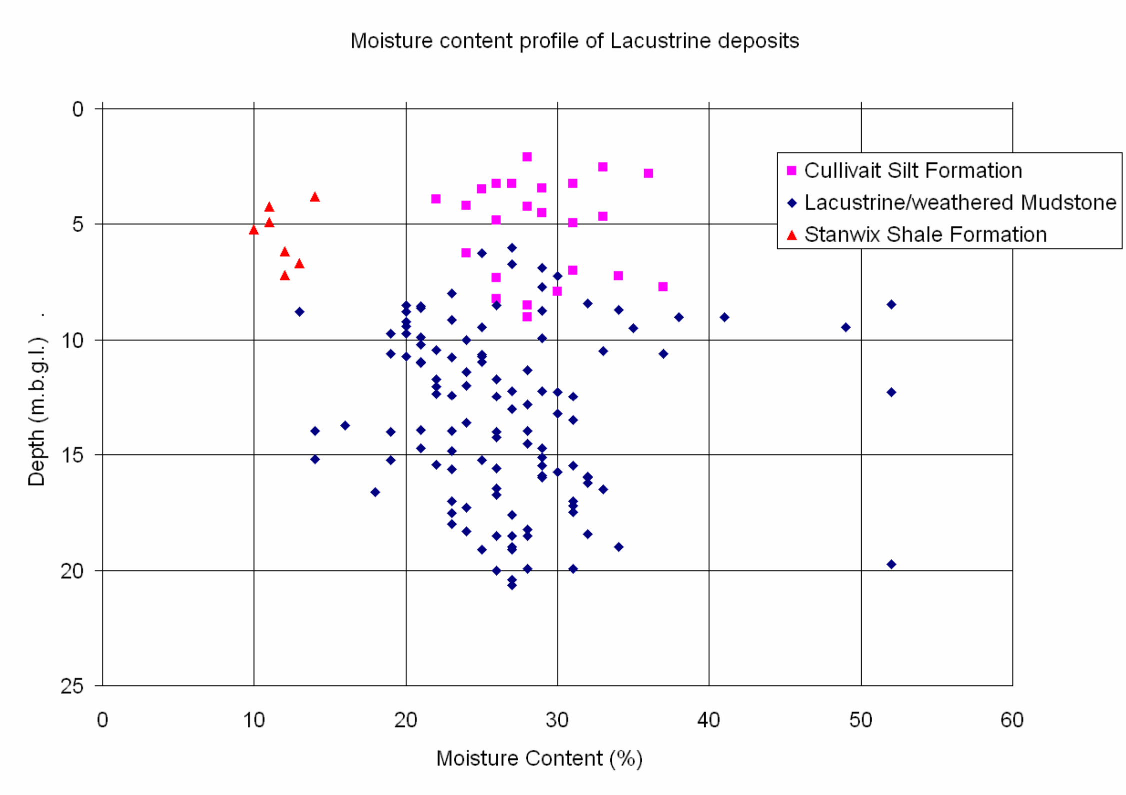

Figure 14. Moisture content profile of Cullivait Silts Formation, problematical glaciolacustrine/ weathered mudstone and Stanwix Shale Formation.

Table 2. Engineering properties of the Quaternary deposits beneath the area.

Engineering geological units		Geological units	Description/ characteristics	Engineering considerations			
				Foundations	Excavation	Engineering Fill	Site investigation
MIXED LITHOLOGY FINE/COARSE	Stiff/dense	Gretna Till Formation Chapelknowe Till Formation	Firm to very stiff, occasionally laminated, sometimes fissured near surface, red or reddish brown sandy CLAY or sometimes compact SILT with fine to coarse angular to rounded gravel sometimes with cobbles.	Generally good, but may be impaired if soft at surface or if there are water bearing lenses or layers. Possible uneven settlement if variable.	Diggable. Ponding of water. Short-term stability may be good but poor where highly fissure or in saturated silt and sand.	Generally suitable if moisture content is controlled. Cobbles and boulders will generally be screened out.	Determine depth, presence of sand and silt layers. Drilling difficult where cobbles and boulders are present
FINE	Soft/ Firm loose	Cullivait Silts Great Easby Clay Formation	Soft-firm, laminated CLAY and uncompact SILT, with some loose-dense SAND laminae, occasional gravel.	Poor where soft.	Diggable. Poor stability. Running conditions in silt and sand below water table.	Generally unsuitable	Determine depth and extent of soft, compressible zones.
	Soft/firm Loose	Alluvium Raised Tidal Flat Deposits Warp	(Very) soft to firm CLAY, uncompact SILT and loose to moderately dense SAND, occasional to some Gravel. Often organic, sometimes contains peat lenses or beds.	Generally poor especially where soft, organic or peat.	Diggable. Poor stability. Running conditions in silt and sand below water table. Where desiccated clay (top metre or so) may be more stable.	Generally unsuitable, especially when organic. Some sand or gravels may be suitable if in large enough volume.	Determine extent and depth especially of soft, compressible zones.
COARSE	Loose/dense	River Terrace deposits Kilblane Sand and Gravel Formation Plumpe Sand and Gravel Formation	Generally medium dense to dense sand and gravel with occasional silt or clay layers and cobbles	Generally good.	Diggable. Poor stability. High rate of water inflow below water table. De-watering maybe required.	Sand and gravel suitable.	Determine depth, extent and nature of the deposit including density and particle size distribution..
ORGANIC		PEAT	Fibrous and spongy sometimes amorphous may be clayey or occasionally sandy.	Highly compressible. Very poor.	Diggable. Generally poor stability especially below water table.	Not suitable	Determine the depth and extent.

References

One of the references listed below is held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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