Deeside (North Wales) thematic geological mapping

Technical Report WA/88/2

Onshore Geology Series

British Geological Survey

TECHNICAL REPORT WA/88/2

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S D G Campbell and B A Hains

Contributors M G Culshaw, J A Crummy and M A Lewis

BRITISH GEOLOGICAL SURVEY

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M G Culshaw and J A Crummy *engineering geology*

M A Lewis *hydrogeology*

Keyworth, Nottingham British Geological Survey 1988

Cover photographs

Front cover Well-bedded limestone of the Cefn Mawr Limestone is exposed in Waen Brodlas quarry, now disused. The main face [SJ 1875 7315] is here seen from the south-west. The unusual nature of the bedding at this stratigraphic horizon is particularly well displayed, with several prominent low-angle discordant bedding-plane contacts.

Back cover 1 To the south of Waen Brodlas quarry [SJ 186 732] the moundy topography comprises deposits of made ground associated with the numerous shafts and trial pits that characterise much of Halkyn Mountain. Most were sunk during the nineteenth century in the search for lead and copper veins.

2 Beautifully preserved fossil crinoids are exposed in a disused quarry [SJ 188 725] on Halkyn Mountain. The rock-type was mainly used for ornamental purposes.

3 A spectacularly well-preserved trace-fossil burrow system (*Zoophycos*) exposed in Pant Quarry [SJ 201 702], in which limestone is worked.

4 Sand and gravel is worked in the Rhosemor pit [SJ 216 670], here seen from the north.

5 The Loggerheads Country Park is a Site of Special Scientific Interest. Large-scale bedding typical of the Loggerheads Limestone dips gently to the east in the west-facing scarp.

6 Well-bedded and finely laminated cherts are exposed in the disused Pen yr Henblas quarries [SJ 191 727].

Geographic index

United Kingdom, North Wales, Clwyd

Subject index

Thematic maps, resources, geotechnics, hydrogeology, minerals, coal, aggregate, ground stability

This report was produced under contract to the Department of the Environment on behalf of the Welsh Office, but the views expressed in it are not necessarily those of the Department nor of the Office.

Bibliographic reference

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BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available through the Sales Desks at Keyworth and Murchison House, Edinburgh. Selected items can be bought at the BGS London Information Office, and orders are accepted here for all publications. The adjacent Geological Museum bookshop stocks the more popular books for sale over the counter. Most BGS books and reports are listed in HMSO's Sectional List 45, and can be bought from HMSO and through HMSO agents and retailers. Maps are listed in the BGS Map Catalogue and the Ordnance Survey's Trade Catalogue, and can be bought from Ordnance Survey agents as well as from BGS.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as its basic research projects. It also undertakes programmes of British technical aid in geology in developing countries as arranged by the Overseas Development Administration.

The British Geological Survey is a component body of the Natural Environment Research Council.

Maps and diagrams in this book use topography based on Ordnance Survey mapping

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CONTENTS

Tables

Accompanying documents

The accompanying maps at 1:25 000 scale and printed on amended Ordnance Survey topographic bases, are available separately. The full set is part of BGS Research Report WA/88/2 comprising the following volumes:

Deeside (North Wales) Thematic Geological Mapping - Report
Map 1 of Bedrock Geology
Map 2 of Superficial (Unconsolidated) deposits
Map 3 of Boreholes, Rockhead and thickness of Superficial deposits
Map 4 of Mining activities; Coal/Metalliferous
Map 5 of Resources (Bedrock) - except Coal/Metalliferous
Map 6 of Resources - Sand and Gravel
Map 7 of Hydrogeology and Water Supply

Note: it is emphasised that the maps associated with this report should be used for preliminary studies only and are not to be used as a substitute for on-site investigations

PREFACE

This account describes the geology of the Deeside area, encompassing approximately 265 km^2. It covers the Ordnance Survey 1:10 000 Sheets SJ 26 NW, NE, SW, SE; SJ 27 SW; parts of SJ 17 NE; SJ 27 NW, NE, SE; SJ 36 NW, SW; SJ 37 SW; and parts of the 1:10 560 Sheets SJ 17 SE and SJ 16 NE, SE. The area lies within the 1:50 000 Geological Sheets 96 (Liverpool) and 108 (Flint).

The district was first surveyed at the six-inch scale by A Strahan and C E De Rance between 1879-85 with an accompanying descriptive memoir by A Strahan published in 1890. A resurvey of the Coal Measure sequences was undertaken by C B Wedd, W B R King, H H Thomas and G W Lamplugh in 1910-13. An accompanying memoir by C B Wedd and W B R King was published in 1924. A memoir by B Smith describing aspects of the metalliferous mining and mineral resources of the region was published in 1921.

The present study was commissioned by the Department of the Environment on behalf of the Welsh Office. Funding was provided jointly by the Department of the Environment and the British Geological Survey. Its objectives were to produce new geological maps at 1:10 000/10 560 scale, and together with other available surface and subsurface data, to present the geological information relevant to land use planning, development and redevelopment in the form of a set of thematic geological maps at 1:25 000 scale with an accompanying explanatory report. Particular emphasis has been placed on superficial deposits, underground workings and mineral resources. A limited shallow borehole programme was carried out to prove sand and gravel deposits. Further syntheses were undertaken by M G Culshaw, J A Crummy and J R Hallam of the engineering properties of both the bedrock and superficial deposits of the area, and of its hydrogeology by M A Lewis. The mapping was undertaken by Drs S D G Campbell, J R Davies, B A Hains and D Wilson. Dr N J Riley provided palaeontological support. The text was word-processed by Mrs L M Ellis. The Project Leader was Dr Hains. Dr R A B Bazley, Regional Geologist for Wales, was the Nominated Officer for the British Geological Survey, and Mr D B Courtier, Welsh Office, was the Nominated Officer for the Secretary of State.

The ready cooperation of landowners, tenants, and quarry companies during this survey and of local and regional authorities, and other holders of data is gratefully acknowledged. In particular we thank Clwyd County Council, Alyn and Deeside District Council, Delyn District Council, Glyndŵr District Council, British Coal, the Welsh Development Agency, Wimpey P.L.C., Alfred McAlpine Quarries Ltd., Tilcon Ltd., North West Aggregates Ltd., Castle Cement Ltd., Welsh Aggregates Ltd., Pioneer Aggregates (U.K.)Ltd., Thomas Dodd and Son Ltd., and Butterley Brick Ltd. We also acknowledge many geological and geotechnical consultants and in particular Wardell Armstrong and Partners.

EXECUTIVE SUMMARY

This study was commissioned by the Department of the Environment on behalf of the Welsh Office and was funded jointly by the Department of the Environment and the British Geological Survey. Its principal aim was to produce a synthesis of geological information relevant to the planning of land-use and development in the Deeside area of Clwyd (North Wales). The intention is that this report presents that information in a style comprehensible to those involved in planning and development and little geological knowledge is required to be able to use it. Much of the information is provided on a series of seven thematic maps, each of which concentrates on a specific aspect of the geology. In addition to the information contained in the report, sources of other more detailed data are indicated.

The study area is approximately 265 km^2 in size. It lies within the area covered by the British Geological Survey 1:50 000 geological sheets 96 (Liverpool) and 108 (Flint). It includes the major towns of Flint, Connah's Quay, Mold, Buckley and Holywell. The area stretches from the eastern margin of the Clwydian Hills in the southwest, to the Dee Estuary and the boundary with England in the northeast. The highest point (441 m) is in the Clwydian Hills and there is a gradual reduction in the height of the topography, moving from west to east. The drainage patterns are influenced by the disposition of scarp features related to the outcrop of bedrock. The main rivers of the area are the Alyn and the Dee.

The economy of the area is mixed, with agriculture predominating in the central and western parts, whereas industry is concentrated around the larger towns and particularly along the coastal strip bordering the Dee Estuary. The Shotton steelworks and neighbouring modern industrial estates occupy large sites in the northeast. Mineral extractive industries have been important in the past and, though more limited in their range today, they continue to play a very important rôle in the local economy.

The main objective of the report is to provide geological information which is of direct concern to planners and developers and it concentrates on four main aspects: the nature and extent of mineral resources; geological constraints, including both natural hazards (e.g. landslips) and those related to former mining and quarrying activity (e.g. subsidence and collapse related to shafts and mine workings); engineering characteristics of the various deposits at or near surface and related engineering problems of the deposits; and hydrogeological characteristics of the area, its water resources and problems of aquifer protection with respect, for example, to waste disposal.

The information used in the report was acquired essentially in two ways. Firstly, a revision geological survey of the entire area was undertaken at a scale of 1:10 000/10 560 between 1985 and 1987. Information from previous surveys, in the archives of the British Geological Survey, was also used and a set of maps and related descriptive reports were produced (these are listed in Appendix A). Secondly, data was sought and compiled from various sources, most notably from central government and local authorities, British Coal, the Welsh Development Agency, Welsh Water, the Central Electricity Generating Board and several geological and geotechnical consultants. This data was mainly in the form of site-investigation reports, borehole logs and the results of geotechnical tests. Much of it, and in particular that related to opencast coal site-investigation (provided by the Opencast Executive of British Coal), is confidential. However, information has been derived from these confidential boreholes and used, for example, in the construction of rockhead contours presented on the thematic maps. A comprehensive list of boreholes consulted is given in Appendix C. Other sources of data used included: the results of a limited test-drilling programme (see Appendix F) carried out as part of the study to prove and quantitatively assess sand and gravel deposits; and published scientific literature and other unpublished reports.

Seven thematic geological maps, at a scale of 1:25 000, are provided and described. In addition, a report of the engineering characteristics of bedrock and superficial deposits, based on available geotechnical data, is given. The geology of the area is also described in detail, including general features of the formations and members, interpretations of the modes and environments in which strata were deposited, the regional structure and the nature of mineralisation.

The relevance to planners and developers of the various types of geological information presented is outlined. The most significant mineral resources of the area are limestone, sand and gravel, and coal. The former two are currently the basis of major extractive industries. Coal mining was formerly important but no mining or opencasting is active at present. There are also

several lesser resources, including sandstone, chert, metalliferous ores, brickclay and refractory clay, moulding sand and calcspar. Of these, only brickclay and moulding sand are currently extracted. Knowledge of the areal extent, and qualitative and quantitative assessments of the resources establishes a basis for their efficient and rational exploitation. Sterilisation of valuable resources can be avoided, and alternative sites of extraction identified. Detailed subdivision and mapping of the strata (e.g. the limestones) constrain the distribution of specific resource types with distinct characteristics.

As important as the mineral resources themselves are the consequences of their earlier extraction, and in particular the effects of coal and metalliferous mining. Thus, shaft sites present common hazards, while constraints on areas known to have been undermined are also important. Planners and engineers are inevitably concerned with the foundation properties and stability of sites. Analysis of available geotechnical data indicates the ranges of engineering properties of surface and near surface deposits, such as their compressibility, the likelihood of differential subsidence problems, and their likely behaviour if excavated. The bedrock and superficial deposits can be categorised in terms of their general cohesion, consolidation and heterogeneity. The relative importance of the aquifers in the area highlights those most needful of protection when, for example, planning sites for waste disposal.

The seven thematic maps contain generalised and selective, rather than fully comprehensive, information regarding specific themes. They are presented at 1:25 000 scale, whereas they are largely based on 1:10 000/10 560 and yet more detailed maps. Consequently, there is inevitably a significant information loss associated with the reduction in scale. As with all of the information presented in the report, they should *not* be regarded as a substitute for specific site-investigations.

The thematic maps concentrate on seven specific themes: bedrock geology; superficial (unconsolidated) deposits; non-confidential borehole sites, rockhead and drift thickness information; mining information (related to coal and metalliferous ores); bedrock resources; sand and gravel resources; hydrogeological features.

The map of bedrock geology indicates the surface extent of the various formations (bedrock units) both as exposed and as interpreted beneath a varying thickness of superficial deposits. Limited structural data are given, including the more important faults and the orientation and relative dip of strata.

The superficial deposits map indicates their distribution at surface, where they exceed 1 metre in thickness. It does not display their variation with depth. Information on the form of rockhead (the interface between bedrock and superficial deposits) is given in the form of rockhead contours.

The map of boreholes shows the sites only of non-confidential boreholes for which the British Geological Survey holds information. Those for which geotechnical test data are also available are highlighted. Where known, the thickness of the superficial deposits and the level of rockhead are shown. From these data and, in addition, using data from confidential sources, rockhead contours have been constructed. A full list of non-confidential boreholes with further details is included in Appendix C.

The thematic element of mining information concentrates on features associated with coal and metalliferous mining, and a small area of cementstone mining. Thus, the loci of shafts and adits (those capped being differentiated) and the distribution of related made ground and backfilled opencast sites are shown. In areas of metalliferous mining, the position at surface of the principal worked veins are indicated. In areas of coal mining, the extent of underground workings for which records exist are shown, and areas undermined by workings in more than one seam are distinguished. This aspect is particularly problematic since much of the mining preceded the age of statutory regulations on recording mine workings. Consequently, the workings shown represent only a proportion of those likely to have taken place. In areas of especially intense mine workings (e.g. Halkyn Mountain), shafts were categorised qualitatively according to their relative hazard potential, and detailed figures showing these shafts are included within the report. Some of the inadequately treated or untreated shafts which are open at surface are listed in Appendix E. Appendix D gives a comprehensive list with further details of all known shafts and adits related to coal mining. The nature and depth of coal mining has not been constrained. More recent workings are likely to have used longwall methods but earlier (and often unrecorded) workings would have been likely to use pillar and stall techniques. Active subsidence was observed during the field survey and has been recorded in recent times in relation to collapse of shafts rather than to underground workings. The courses of the drainage tunnels of the Halkyn-Holywell mine drainage scheme are also shown on this map.

Data on bedrock resources and sand and gravel resources are shown on separate maps. That of bedrock resources indicates those areas where resources (excluding coal and metalliferous ores) are available at surface or with only limited superficial overburden. The sand and gravel resource map similarly defines the distribution of the resource where it occurs at or near surface. Some information on the thickness of the deposits and its variability are provided on the map face. Test results of a limited drilling programme undertaken to prove these deposits in the north of the area are in Appendix F. Crude estimates of the tonnage of potential resources were made.

The hydrogeology map shows the outcrops of the principal aquifers and the locations of springs, wells and boreholes licensed to abstract groundwater. Groundwater level contours are represented in the Kinnerton Sandstone. Waste disposal sites are also shown since these represent potential risks to groundwater quality. However, most of the water used in the area comes from surface and groundwater sources outside the area.

As the coverage of available geotechnical data is very patchy, no maps of engineering geology were considered worthwhile. However, the ranges of geotechnical properties of the various bedrock formations and superficial deposits are discussed within the report. Hence the suitability for foundations, potential backfill materials, behaviour of excavations and stability of each of the deposits are discussed and potential problems highlighted. Much of the information is tabulated and/or presented in figures within the report. Descriptions of the geotechnical tests used to provide the data considered in the report are given in Appendix B.

The possibility of landslip and the occurence of previous landslips are considered both within the section on Engineering Geology and that on Summary of Geology. Active landslip has been identified at some sites and many apparently inactive landslips were also mapped. Of the bedrock formations, those containing weathered shale (e.g. the Halkyn Formation) are the most susceptible to landslipping and of the superficial deposits, head is particularly prone.

The bedrock geology and its superficial overburden are described more rigorously in geological terms in the Summary of Geology. This section describes the variations in thickness and internal characteristics of the constituent formations of the area. In addition, interpretations of the mode and environment of deposition of the sediments are made. Patterns of regular vertical repetitions of rock types (cyclicity) and the recognition of temporally equivalent sedimentary rocks (correlation) are discussed. The sequence ranges in age from Silurian to Permo-Triassic (and locally Tertiary), while the superficial deposits are of Quaternary to Recent age. The area is dominated by sedimentary rocks of Carboniferous age, which lie unconformably on Silurian strata, and are themselves overlain unconformably by Permo-Triassic strata. The Carboniferous sequence includes approximately 650 m of Dinantian limestones which are in part cyclic. They are overlain by up to 350 m of Namurian sandstones, chert, siltstones and mudstones. These are in turn succeeded by the Westphalian Productive Coal Measures (up to 450 m) which are characterised by cyclic repetition of mudstone, siltstone, sandstone, seatearth and coal. Coals in excess of 4 m in thickness occur within the area. The Buckley Formation and Ruabon Marl, both of which lack significant coal seams, overlie and are in part laterally equivalent to the Productive Coal Measures. In general, coal seams are more laterally continuous within the lower part (Westphalian A) of the Productive Coal Measures than within the overlying Westphalian B, though the latter includes the Main and Hollin Coals, two of the thickest and most extensively worked seams in the area.

The report concludes with a list of specific problems and factors to be considered in planning and development. It also includes a reference list, and a glossary of terms used. Copies of this report and its accompanying maps can be obtained from the British Geological Survey, National Geosciences Data Centre, Keyworth, Nottingham, NG12 5GG. The archival data are held at the Aberystwyth Office of the British Geological Survey and enquiries should be directed to The Regional Geologist for Wales, British Geological Survey, Bryn Eithyn Hall, Llanfarian, Aberystwyth, Dyfed SY23 4BY.

NOTES TO THE USER AND LIMITATIONS

Notes to the user

All National Grid references in this report lie within the 100 km square SJ. Grid references are given to either eight figures (accurate to within 10 m), or six figures (accurate to within 100 m) for more extensive locations.

Data used in preparing this report and associated maps are lodged at the Aberystwyth office of the British Geological Survey. Any enquiries concerning these documents should be directed to the Regional Geologist for Wales at that office.

Boreholes and shafts registered with BGS are identified by a four element code (e.g. SJ 26 NE 112). The first two elements refer to the relevant 10 km National Grid square, the third element to the quadrant of that square and the fourth to the accession number. In this report boreholes and shafts are generally referred to only by the last three elements (e.g. 26 NE 112).

Limitations

This report and its constituent maps have been produced by collation and interpretation of, and interpolation from geological, geotechnical and related data from a wide variety of sources. Details of the various sources of the data together with an evaluation of their reliability are contained in the report.

The maps provide only a general description of the nature and extent of factors relevant to the planning of land use and development. The data on which they are based are not comprehensive and their quality is variable, and the maps reflect the limitations of that data. Localised or anomalous features and conditions may not be represented, and any boundaries shown are only approximate. No information made available after 31st December 1987 has been taken into account. For these reasons:

This report and its constituent maps provide only general indications of ground conditions and must not be relied upon as a source of detailed information about specific areas, or as a substitute for site-investigations or ground surveys. Users must satisfy themselves, by seeking appropriate professional advice and carrying out ground surveys and site-investigations if necessary, that ground conditions are suitable for any particular land use or development.

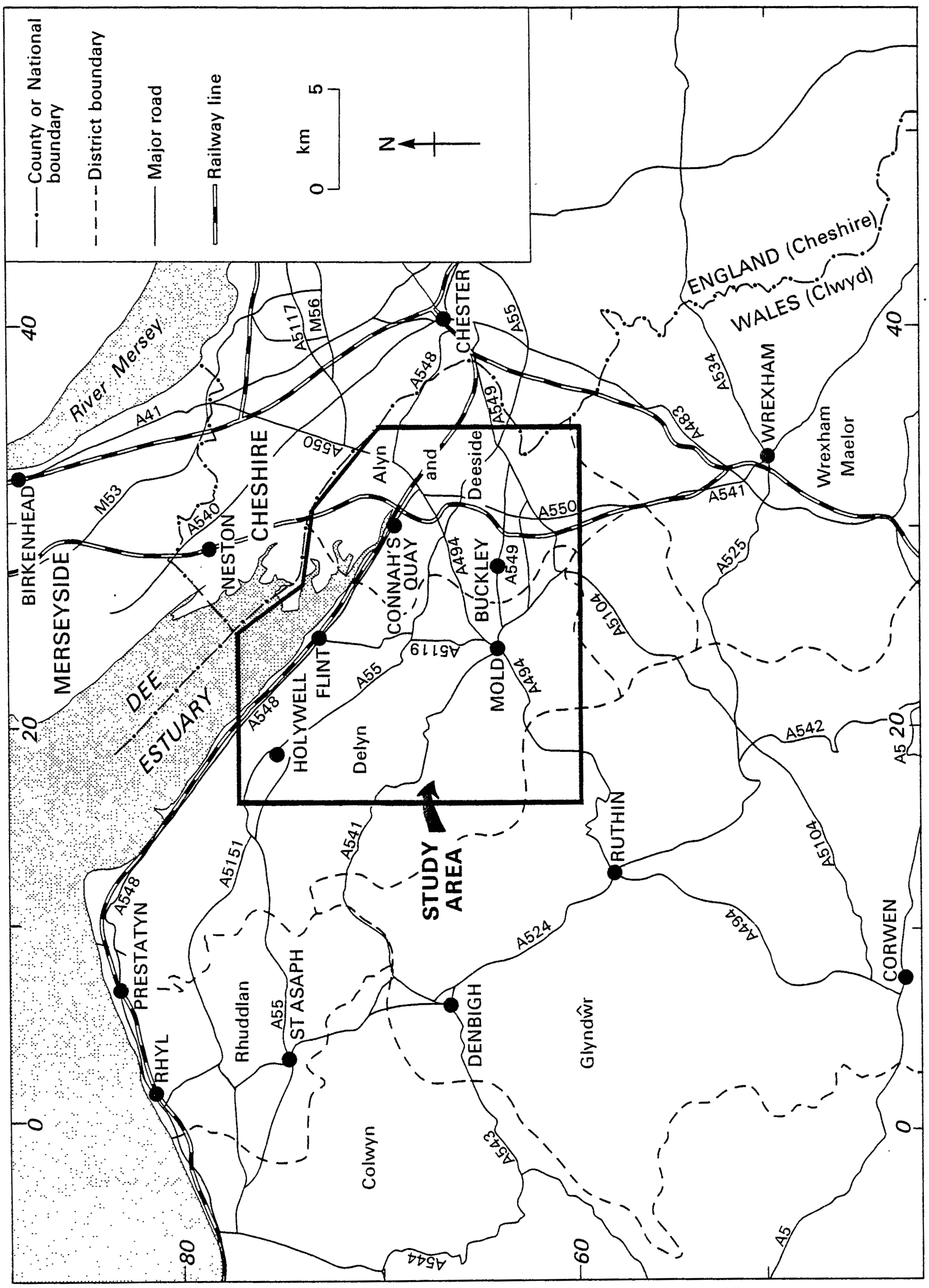
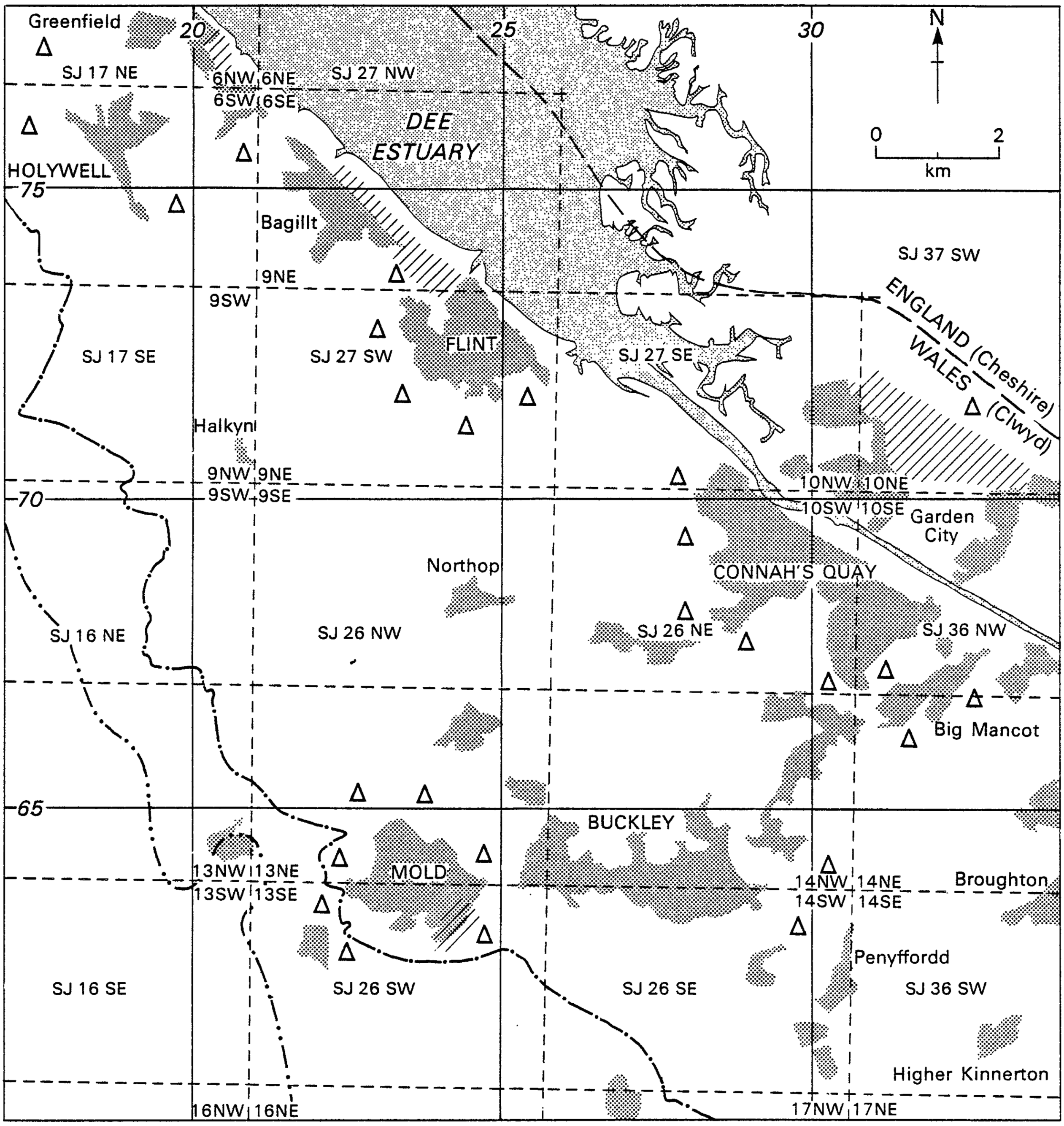


Figure 1 Sketch-map of the study area showing its regional setting



Boundary of component National Grid 1:10 000/1:10 560 Sheet identified thus: eg SJ 27 NW	Approximate eastern limit of area of outstanding natural beauty
Boundary of component County grid 1:10 560 Sheet (Flintshire) identified thus : eg: 6NW	Existing built-up areas
North-eastern limit of study area	Generalised position of 'Green Barriers' (Clwyd Structure Plan)
Eastern limit of special landscape area	Major industrial estates

Figure 2 Sketch-map showing the component 1:10 000/10 560 sheets of the study area, the outlines of the earlier County Sheet Grid, and selected planning features

INTRODUCTION

The data summarised in this report were obtained during a three year contract, commissioned in 1985 by the Department of the Environment on behalf of the Welsh Office. Funding for the work was shared jointly by the Department of the Environment and the British Geological Survey. The study area (Figure 1), which is referred to in this report as the Deeside area, is defined by the following Ordnance Survey (OS) National Gridlines, and the border between Wales and England;

Eastern boundary	SJ 3400
Western boundary	SJ 1700
Southern boundary	SJ 6000
Northern boundary	SJ 7800, but excluding the area south of this boundary which lies within England.

The component 1:10 000 and 1:10 560 maps are shown in Figure 2.

The area occurs within that covered by Sheets 96 (Liverpool) and 108 (Flint) of the British Geological Survey. It lies entirely within the county of Clwyd and includes several large towns, including Flint, Connah's Quay, Mold, Buckley and Holywell.

Objectives

The report provides updated geological information which is needed for planning and development purposes in the Deeside area, for example in helping to rationalise between development needs and preventing the potential sterilisation of valuable mineral resources which are identified. Other important factors include information relevant to ground stability, geological hazards such as subsidence and landslips, geotechnical characteristics and groundwater.

The ethos of the report is to provide the geological information in a readily comprehensible form and assumes the reader may have little geological or geotechnical background knowledge. Hence technical jargon is kept to the minimum. Since, however, some technical language is necessary, a glossary of terms is included to assist the reader. The form of presentation adopted is in line with the recent emphasis placed by the Department of the Environment on producing applied geological maps as a way of better communicating results than traditional reports constrained by a more geologically based framework.

The aims of the project were essentially twofold.

1. To produce a new set of geological maps at 1:10 000/10 560 scale of the entire area, based on a systematic field survey and incorporating borehole and subsurface data where available.

2. To produce a set of thematic element maps at 1:25 000 scale and to collate various geotechnical and other available information in a report intended for use principally by planners and developers. The thematic maps delimit areas and sites of specific geological characteristics. The information contained on these maps is highly selective as it is not possible to reproduce all of the information present on the new 1:10 000/10 560 geological standards at the reduced scale of 1:25 000. Furthermore, the quality of data on some of the thematic element maps is very variable. For example, the available information for the extent of underground coal seams was recorded over a period stretching from the middle of the nineteenth century to recent times and in some parts of the area, no information is extant.

The use of this report

It must be stressed that the information provided on the thematic maps and in the report is interpretive, of variable quality, and is distributed unevenly. Consequently, the maps and report should only be used in preliminary investigations. They cannot be considered as a substitute for on-site investigation. Rather, they should be used as a reference source providing a regional and background context to assist in the interpretation of detailed on-site observations. Furthermore, the report should act as a guide to other more detailed sources, e.g. the British Geological Survey archives of non-confidential boreholes and other data, including, most importantly, the 1:10 000/10 560 geological standards, open-file reports, and the original field-slips and annotated air photographs which are the fundamental sources on which much of the report is based. It is strongly recommended that the maps and report should not be used in isolation of one another. Each map has only a limited descriptive key and a fuller detailed description with relevant provisos is contained in the report.

In areas of particularly detailed information, e.g. the distribution of shafts on Halkyn Mountain in the northwest of the area, some text figures at a larger scale are included in the report. Some information, most notably with respect to geotechnical data, was found to be distributed too unevenly to warrant producing a thematic map. Such information has been incorporated in the report in tabulated and graphical form.

Data sources used in the report

1. British Geological Survey (BGS) archival maps and data. Two previous surveys of the area had been carried out at 1:10 560 scale, a primary survey by Strahan and De Rance (1879-85) and a revision of the Coal Measures by Wedd, King, Thomas and Lamplugh (1910-13). The field-slips relating to these two surveys are held at the Aberystwyth Office of BGS. Descriptive memoirs of both surveys were produced (Strahan, 1890; Wedd and King, 1924) and maps published at 1:63 360 scale. In addition, maps of the coal measure sequences were published at 1:10 560 scale as a result of the revision survey. The metalliferous deposits of the area were described in a '*Mineral Resources Memoir*' by Smith (1921). Extensive non-confidential and confidential borehole records were held prior to the present project at the Aberystwyth Office of BGS, as were some geotechnical reports, and plans and cross-sections relating to metalliferous mining.

2. Information from the new geological field survey of the entire contract area, carried out between June 1985 and August 1987. The observations made during the survey were recorded directly on to 1:10 000/10 560 field-slips but in areas particularly of intensive mining activity, information was recorded initially on black and white air photographs (scale approximately 1:10 000) and was transferred subsequently to the base maps. The air photographs were obtained from Clwyd County Council, who hold a set of photographs providing complete stereoscopic coverage of the area. Standard BGS mapping techniques were used during the field survey. These include systematic examination of all exposures of rock. Detailed descriptions and measured sections were recorded where appropriate. The larger working and disused quarries in limestone provided the most detailed sections, allowing close correlation to be performed. Most topographic features greater than approximately 1 metre in elevation were systematically recorded to assist interpretation in areas of limited rock exposures. In mapping the superficial deposits, hand augers (1.4 m length) were used to prove the nature of subsoil. Identifications both of fossils recognised in the field and of microfossils, visible only in thin sections of rock examined under the high-power microscope, were carried out by Dr. N J Riley of the Keyworth Office of BGS. The identified fossils were used in correlating between exposures. A complete set of 'geological standards' was then produced. These are fair copies of the base maps at 1:10 000/10 560 scale.

Each map delineates both lithological and structural variations in the bedrock geology and the nature and distribution of superficial deposits (drift). In addition, details relating to mining and quarrying activities are recorded and the sites of selected non-confidential boreholes plotted. Each base map (see Appendix A for details) has a generalised vertical section with general descriptions of the constitutent geological formations. To accompany each base map, an open-file report has been produced. These reports give details of all significant exposures of bedrock and superficial deposits including measured thicknesses and descriptions of the various lithologies. They also give details of selected non-confidential boreholes and shaft sections.

3. Information was sought from a large number of holders of geological data. The largest single source of information obtained was the database held by British Coal. Borehole data obtained from the Opencast Executive was used to derive information but the primary data remains confidential. Seam plan information was collated from the Coal Commission plans, and other plans held by British Coal, Staffordshire House, Berry Hill Road, Stoke-on-Trent, ST4 2NH. A synthesis of this data is held on maps at 1:10 560 scale at Aberystwyth Office of BGS. Opencast abandonment plans were also obtained.

Site-investigation information for civil engineering projects comprising borehole data and trial pits, with in many cases details of engineering properties, and in some instances full geotechnical and other reports were obtained from many bodies, including the Welsh Office, Clwyd County Council, Alyn and Deeside District Council, Delyn District Council, Glyndwr District Council, the Welsh Development Agency and a number of geotechnical consultants. Most of these boreholes were carried out using shell and auger methods and are less than 25 m in depth, and many are restricted to the unconsolidated deposits. The distribution of borehole sites is very uneven, with particular concentrations along the A55 and other road improvement schemes. Access to borehole core was provided by Wimpey

P.L.C.

4. During 1986, 12 boreholes were drilled, as part of the project, by the shell and auger method in order to prove sand and gravel resources in the north of the area. The logs of the boreholes, associated geotechnical data and particle size data of the deposits are contained in Appendix F. Together with other non-confidential and confidential boreholes, records from approximately 4,500 boreholes were considered during the project.

5. Various publications relevant to the area are available in the scientific literature. These deal particularly with aspects of the stratigraphy of the Carboniferous Limestone sequence and with the nature and interpretation of superficial deposits within the area. These are referred to where appropriate within the report and full details are given in the reference list. These references are available in the libraries of the British Geological Survey at Aberystwyth and Keyworth. Other useful reference centres are: the London Information Office, British Geological Survey, Geological Museum, Exhibition Road, London SW7 2DE; the Department of Geology, Jane Herdman Laboratories, University of Liverpool, P.O. Box 47, Liverpool; and for historical information with reference to mining and quarrying, the Clwyd Records Office, Clwyd County Council, Hawarden.

Constituent parts of the results

Seven thematic element maps are included with the report. These are:

1. Bedrock Geology
2. Superficial (Unconsolidated) deposits
3. Boreholes, Rockhead and thickness of Superficial deposits
4. Mining activities; Coal/Metalliferous
5. Resources (Bedrock) - except Coal/Metalliferous
6. Resources - Sand and Gravel
7. Hydrogeology and Water Supply

Full descriptions of each of the thematic maps are contained in the report, and an outline of the geological history is given. A section is devoted to engineering geology. It deals with the geotechnical characteristics of the bedrock formations and superficial deposits and highlights associated problems. Representative data are presented in tabulated and graphical form.

Six appendices are presented. These are:

A. A list of BGS geological standards, open-file and palaeontological reports produced for the area.
B. Geotechnical tests quoted in the database, and their applications.
C. A list of boreholes held in the BGS archives. Where confidential, only the BGS reference number and the source of the borehole are provided. Where non-confidential, the BGS reference number, its National Grid Reference and, where known, date of sinking, surface level, drift (superficial deposits) thickness, borehole depth and availability of geotechnical data are given.
D. A list of shafts sunk for coal with the BGS archival reference number, the British Coal reference number, its National Grid Reference (6 or 8 figure) and, where known, the thickness of drift (superficial deposits) and its depth.
E. A selective list of shafts and adits identified as being open at surface, at the time of survey.
F. Borehole logs and particle size data are given for those boreholes carried out as part of the project.

GEOGRAPHICAL AND PLANNING BACKGROUND

Geographical background

The study area (approximately 265 km^2) lies entirely within the county of Clwyd. Its regional context is demonstrated by Figure 1. The component OS 1:10 000/10 560 sheets of the study area are shown in Figure 2, together with the outlines of the former 1:10 560 County Sheet grid which was used as the topographical base for previous geological surveys of the area. Much of the archival material used in the report is also recorded on the County Sheet base. The generalised topography, drainage pattern, and major towns are shown in Figure 3.

The economy of the area is mixed, combining agriculture in rural districts with industry principally around the larger towns. Mineral extractive industries are a major component of the local economy, providing aggregate both for local needs and for the major conurbations of Merseyside, Greater Manchester and elsewhere (see 'Mineral Working in Clwyd', 1982). There has been a rapid evolution in recent years from traditional heavy industry towards those of the

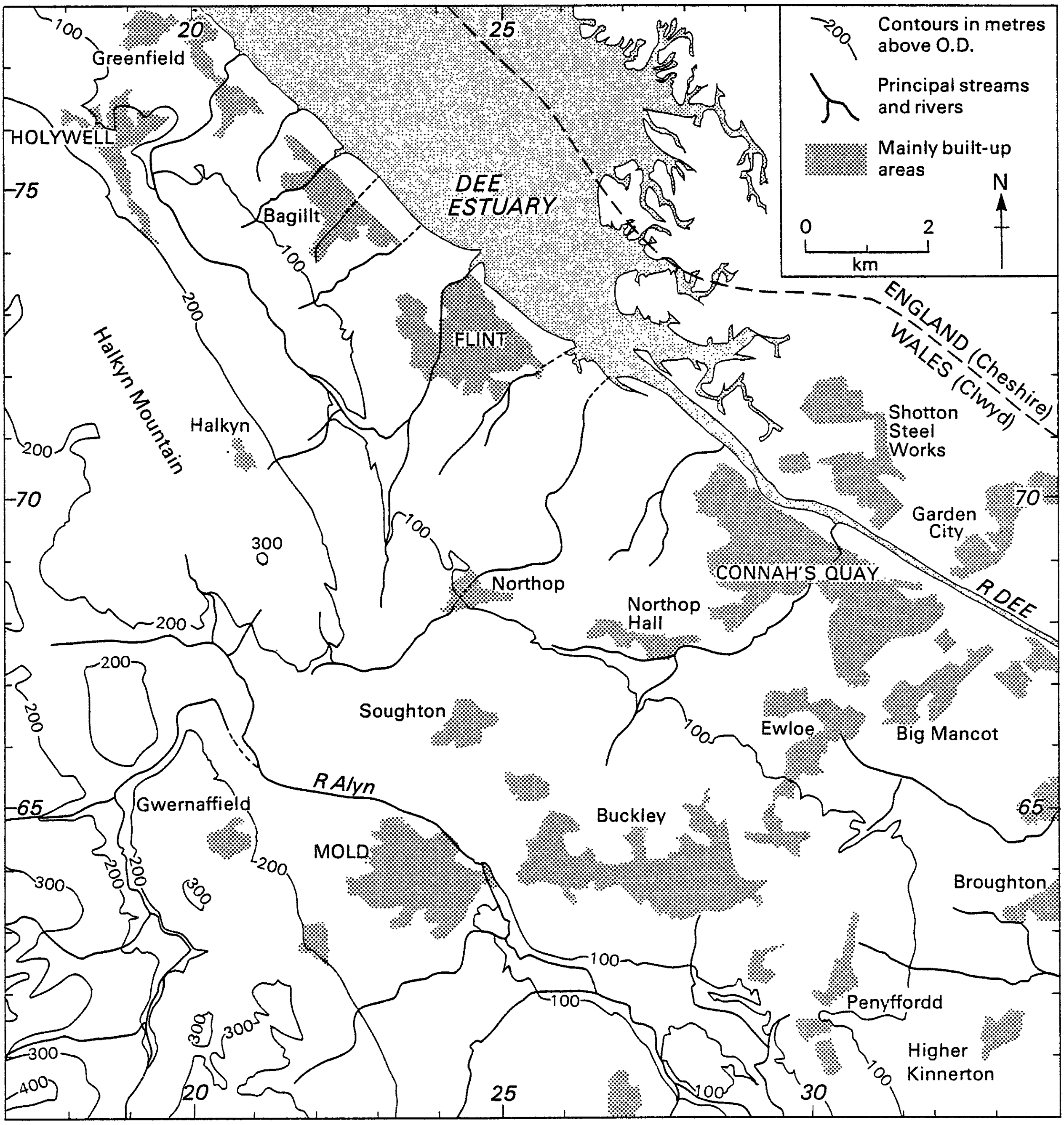


Figure 3 Topography, drainage and chief towns of the study area

new technologies, and urban development and redevelopment reflect these and related demographic changes.

The area reaches its highest point (441 m) in the southwest, on the steep flanks of Moel Famau in the Clwydian Hills. These hills are separated from the north-northeast trending escarpment of the Carboniferous Limestone by the valleys of the Alyn and Wheeler rivers. The rough pasture of the Clwydian Hills contrasts markedly with the rural aspect of the more fertile limestone terrain. The Alyn River breaches the limestone escarpment west of Rhydymwyn [SJ 203 668]. There is a similar east-west breach at Hendre [SJ 195 677]. From Rhydymwyn, the Alyn trends generally southwards, past Mold, eventually to join the River Dee southeast of the study area. The Dee itself flows to the northwest, across the northeast part of the area, its wide flood-plain east of Connah's Quay giving way to the broad Dee Estuary northwest of Connah's Quay.

The limestone escarpment, with west-facing crags and more gentle slopes to the east, extends the length of the study area from south of Cadole [SJ 205 628] towards Holywell in the north. Considerable exposure of bedrock on the westerly aspect of the escarpment contrasts with the typically sloping grassland to the east. Cattle and sheep farming predominate in this part of the area. The limestone terrain includes the common land area of Halkyn Mountain which rises to a maximum height of 294 m. This rough pastureland has been extensively mined for lead and the resulting minetips have disrupted local drainage and sterilised the soil.

North to northwest trending escarpment features of progressively diminished elevation occur towards the east of the limestone escarpment. This pattern of features exerts the main control on the drainage system in the north, with streams hugging the bases of the westerly to south-westerly facing escarpments. Other streams drain the gentle back-slopes of the escarpment.

Much of the eastern part of the area, including the exposed and concealed coalfield, is of low elevation (<150 m) with minor undulations, but is deeply dissected by streams. Clayey soils are typical and the agriculture is mixed dairy and cereal production. Near the Dee Estuary, the ground falls away rapidly and many deep north-east trending river dissections occur. A flat estuarine alluvial strip extends along the coastal margin. Moundy topography characteristic of sand and gravel deposits, with small peat and clay-filled hollows occurs, particularly along the Alyn River and to the southwest of Northop [SJ 245 685].

The main towns of the area are Connah's Quay, Flint, Holywell, Mold and Buckley, with most industry concentrated around these centres. New industrial parks at Greenfield, Flint, Shotton and Mold are the focal points of new, high-technology industries. The main extractive industry is limestone quarrying, mainly for aggregate but with some production for cement, industrial and agricultural use. Production is currently from seven sites. Sand and gravel is also extracted at two sites, for aggregate purposes; moulding sand for the steel industry and other purposes is produced in small quantities at one site. Following the closure of the last colliery in the area in the 1930's, no coal extraction is extant, but opencast production remains a possibility for the future. Fireclay quarrying for the brickclay industry is now limited to one site at Buckley. Chert and calcspar have been worked in the recent past.

Public water supply is provided from several abstractions within the study area, but most of the water used comes from surface and groundwater sources outside the area. The Halkyn-Holywell mine drainage scheme has provided an important source of water for industrial use.

Planning background

The Deeside area is typical of many areas in Britain experiencing the uneasy economic transition associated with the decline in traditional heavy industries and their replacement by an expanding service sector and new light and high-technology industries. Unemployment higher than the national average has been the consequence of this change and the importance of redevelopment is clear. However, two significant parts of the local economy, namely agriculture and the mineral extractive industry (limestone, sand and gravel, and opencasted coal) are likely to continue to play an important rôle. This fact was clearly recognised in the 'Clwyd County Structure Plan' (1982), with policy statements recognising the importance of rational equilibrium between development pressures, conserving agricultural productivity, environmental protection and the efficient use of available mineral resources. Thus it is stated that '... there will be a strong presumption against the use of agricultural land of grades I, II and III for non-agricultural purposes.' With regard to the development and control of mineral working, the relevant policy indicates that '... close regard will be had to the economic need for the mineral and to the significance of the proposal for local employment. All proposals for mineral working will be considered in the light of: a. the demand for and the quality of the product; b. the availability of alternatives; c. local, regional and national needs and reserves; d. their likely effect on any town or village.'

Criteria for the consideration of mineral working proposals include agricultural land quality, nature conservation interests (e.g. Sites of Special Scientific Interest), the impact on the landscape, land drainage and water supply, highways and transportation, and the scope for restoration and rehabilitation. It is further intended that, to prevent the sterilisation of mineral resources, 'mineral reserves of special economic value regionally or nationally will be safeguarded from other development, either on site or nearby.' The Clwyd County Planning Authority are currently preparing an alteration to the structure plan including an expanded set of policy guidelines for the extraction of mineral resources. The Local District Councils also define policies for development control through local plans, while further constraints apply under the Control of Pollution Act, 1974, and the Health and Safety at Work Act, 1974.

Within the Deeside area, the Clwyd County Structure Plan cites several areas around and separating settlements, known as 'Green Barriers' (see Figure 2), for which there would be a strong presumption against development that would affect their open character. The structure plan defines an extensive Special Landscape Area for the protection of those parts of the county possessing the 'highest landscape quality'. The eastern part of this falls within the study area. Also, a smaller tract of country was designated by the Secretary of State in 1985 as the Clwydian Hills Area of Outstanding Natural Beauty. In addition the Loggerheads Country Park [SJ 199 628] is designated as a Site of Special Scientific Interest (SSSI) (Figure 6), as are the Alyn Gorge [SJ 195 657] north of Pantymwyn and part of the Dee Estuary.

With respect to water resources, the Control of Pollution Act 1974 legislates that groundwater be protected from pollution. Hence, protection of the major aquifers of the area from, for example, industrial and toxic waste disposal is a high priority in terms of planning and development. Consideration also has to be given to factors affecting development costs, project duration, and (under the provisions of the Health and Safety at Work Act, 1974) the safety of schemes. Hence, the geotechnical characteristics of deposits likely to be encountered during developments must be reviewed, and the impact of geologically related problems minimised.

GEOLOGICAL INFORMATION RELEVANT TO PLANNING

The main areas in which geological conditions affect land use planning are:

Mineral extraction and resources
Engineering geology
Water resources

Mineral extraction and resources

Given the fact that large quantities of aggregate (limestone, and sand and gravel) are 'exported' from the region (see North Wales Working Party on Aggregates, Report 1981; Mineral Working in Clwyd, 1982) particularly to northwest England, pressures for increasing development of the extractive industries arise from external as well as local demands. The provision of thematic maps provides an important data source with regard to mineral working. They delimit the various finite bedrock and superficial resources and provide information on the thickness variations and quality of the deposits. Such information also assists in the efficient siting of plant in order to avoid sterilising valuable resources as has been the case in the area in previous years (e.g. at the Brookhill Brickworks Fireclay pits [SJ 279 656]).

The following comments relate to specific resources:

Limestone

The extensive limestone outcrop in the west of the area is a valuable resource for aggregate, cement and for industrial and agricultural purposes. The outcrop has been subdivided into several formations (units) with distinct resource characteristics (e.g. purity, limestone to shale ratio). Limestone extraction is currently the most important extractive industry in the area. Aggregate is produced at six sites and one other quarry produces limestone for cement making. Limestone has been extracted from numerous other smaller sites in the past (see Thematic Element, Map 5). The presence of the limestone resource is a significant factor in planning, and while scope exists for deepening existing quarries without major drainage problems, future demand may well give rise to calls for expanding existing quarries or for developing new ones. Consequently, planners and developers (quarry companies) will need an information base from which to identify potentially suitable areas for future extraction. The limestone is a significant source of groundwater, having provided water for industrial use via the Halkyn-Holywell Drainage Tunnel Scheme and, as such, requires planning protection.

Sand and Gravel

Significant sand and gravel deposits occur in several parts of the area. Currently, two sites are exploited for aggregate production, and deposits have been worked at several smaller sites in the past. There is increasing demand for sand and gravel nationally (Mineral Working in Clwyd, 1982) and this is likely to persist. As the sand and gravel deposits are relatively thin (<40 m), their extraction in significant volume necessitates pits of large areal dimensions which are relatively ephemeral compared to those associated with bedrock quarrying. The deposits tend to occur in areas of higher grades of agricultural land and substantial sites may need to be identified for future extraction. Additionally, planners will have to ensure that sterilisation by development of this comparatively limited and valuable resource (see Thematic Element, Map 6) is avoided where possible. It should be noted that sand and gravel deposits often occur as moundy topographic features and their removal alters the landscape in a way which is hard to restore to the original form. Potential resources, including concealed deposits, were identified in the southeast of the area by the Industrial Minerals Assessment Unit of the British Geological Survey (Ball and Adlam, 1982) and further information is given in this report (see also Appendix F). The deposits are very heterogeneous and vary greatly in thickness. Consequently the quality of the resource can only be proved by site-specific investigations.

Coal

Coal mining by shallow and deep methods (pillar and stall or longwall) and more recently by opencasting has been a major industry over much of the central and eastern parts of the area in past years. No mining or opencasting is extant, though opencasting may occur in the future. Economic considerations suggest that future extraction is likely to be from limited opencast sites only. As exposure of the coal measure sequence is very limited and superficial overburden often substantial, specific areas of opencast potential are not readily predicted, and strategic planning is hampered. The impact of former coal mining activity (see Thematic Element, Map 4) is of more practical concern, e.g. in knowing areas of underground workings, indicating whether more than one seam has been worked at a site and thus compounding possible subsidence problems, the position of shafts and the distribution of waste tips and backfilled opencast sites.

Fireclay

Extraction of fireclay for the brick industry was formerly important in the Buckley area but is extant at only one site. Resource protection and future extraction are not likely to be of immediate concern but future demands for fireclay cannot be predicted. Information regarding former quarries, and related backfill deposits (see Thematic Element, Map 5) will however be of value in assessing other developments in their vicinity.

Chert

Chert was formerly quarried for aggregate and for use in the glassmaking and silica brick industry. Extraction was locally considerable, but none is extant. As with fireclay deposits, the consequences of extraction are of more obvious concern to the planner than is resource conservation. However, possible future uses of this resource, which it should be stressed is relatively uncommon nationally, should not be ignored.

Sandstone

Numerous small quarries in sandstone occur but there is active extraction at only one site. Sandstones of differing resource characters are identified in the report (see Thematic Element, Map 5). These resources are scattered widely across the area and most are of little economic importance. Thus, resource sterilisation of sandstone is unlikely to be a major planning consideration. The sole site of extraction is for sand from the Kinnerton Sandstone of Triassic age. Its outcrop is limited by thick superficial deposits and is unlikely to be a significant factor in planning decisions.

Lead, zinc and copper ores

Considerable mining of lead, zinc and copper ore took place largely in the second half of the nineteenth century but none is extant. Although resources still exist, particularly at depth, their extraction is uneconomic in present or foreseeable terms due to drainage problems and the unpredictable nature and quality of the resource. This aspect is therefore of little concern to planners. As with coal mining, the results of this intensive mining, which is restricted to the west of the area, provide the most important considerations. Most of the multitudinous shafts have not been capped and many present danger to members of the public as well as potential problems to development schemes. As increasing leisure use is made of the limestone terrains (e.g. the common land of Halkyn Mountain and Loggerheads Country Park) consideration must be given to reducing these hazards. It was noticed that it is commonly the practice for farmers to attempt to reclaim land affected by trial pits and shafts by bulldozing the areas flat. This technique serves only as a temporary, cosmetic treatment of the problem and arguably may increase potential hazards in the long term. The distribution of shafts, to which particular attention was given during the field survey, is given on Thematic Element, Map 4; more detailed maps of shafts and trial pits on Halkyn Mountain and at Loggerheads are given within the report (Figures 5a, 5b, and 6).

Peat

Minor extraction is in progress at one site. Deposits are very localised, scattered and small-scale and as such, do not constitute an important resource.

Calcspar

Small-scale extraction has until recently been in progress at one site. Although relatively common, this resource is rarely sufficient to warrant its economic extraction and is not a significant planning consideration.

Engineering Geology

The report synthesises and presents available geotechnical data relevant to planning and development. These include foundation characteristics, ground stability including landslip, the ease of and durability of excavations, the suitability of available deposits as a fill material and groundwater problems.

For planning and development purposes, the deposits of the study area can be divided into five principal engineering groups:

1. Rock
2. Overconsolidated cohesive soils (clays and silts)
3. Dense non-cohesive soils (sands and gravels)
4. Heterogeneous deposits (mainly head)
5. Normally consolidated cohesive soils (clays and silts) and non-cohesive soils (sands and gravels)

Rock

Whilst the rock (bedrock), as a whole, often provides a suitable foundation for most light-weight structures, this is not always the case. The mudstones and shales in particular, are weathered to varying degrees and depths. This weathering to a clay soil is likely to reduce allowable bearing pressures. Weathering is greater where drift cover is less. As a general rule, piles need to be taken through the worst of the weathered zone into fresh or slightly weathered rock. Landslips occur within the weathered mudstone and shale and, consequently, careful investigation of sites on weathered mudstone and shale slopes, and especially those steeper than about 7°, must be made to confirm their long-term stability. The weathered mudstones and shales are generally unsuitable as fill and care is needed when constructing cuttings to reduce their exposure to wetting.

The other rock types, limestones, sandstones and cherts generally provide good foundations for most light-weight structures. However, potential hazards are present and need to be considered in any investigation. These include infilled or open cavities in the limestones, uneven rockhead surface with open and infilled joints and sandstone weathered to a dense sand. The limestones are generally strong but this strength may be reduced *en masse* by interbedded mudstone or shale bands. Ease of excavation in the rock will also vary with the degree of weathering.

Overconsolidated Cohesive Soils

The tills that make up the overconsolidated soils are widespread. They vary vertically from soft, weak materials at the top of the weathered zone, to stiff to hard materials at depth. They are very variable in their foundation conditions. They generally provide a satisfactory foundation for light-weight structures though lateral variation on a site-scale may make differential settlements a possibility.

Granular materials in the till are prone to running or piping conditions or high water flows and hence cuttings may need good drainage. Clays in the till may soften rapidly on wetting leading to boggy conditions and unstable pit or trench walls. The till is generally suitable as a fill material. As a whole, it needs careful site-specific investigation to determine its geotechnical variability in three dimensions.

Dense Non-Cohesive Soils

These include the widespread glacial sands and gravels and some of the deeper and coarser estuarine alluvium. The glacial deposits are more variable, often containing clayey and silty horizons. Where dense or very dense, the deposits provide an adequate foundation for most purposes. For the estuarine alluvial sands, however, piling to some depth may be necessary to find a suitable bearing horizon.

Excavations need support and running conditions are likely, particularly in the estuarine alluvial sands, so that de-watering may be required. Cuttings through these deposits need adequate drainage and high water pressures may be found in sands or gravels overlain by less permeable clays, leading to possible heaving or sagging on excavation.

Heterogeneous Deposits (mainly Head)

This deposit is very heterogeneous in composition and is found in variable thicknesses (frequently less than 1 m) on hillslopes and in valleys. Shear planes within it are a possibility and consequently there is a risk of landslip. Thus, where slopes are steeper than about 7°, careful site assessment must be made.

Where head is thin, it is likely to be stripped off the site prior to construction. In other areas however piled foundations *may* be necessary with piles founded beneath the head. The heterogeneity of the deposit makes generalisation difficult.

Normally Consolidated Cohesive and Loose Non-Cohesive Soils

The cohesive soils are usually unsuitable as a foundation for even light-weight, single-storey structures, with large settlements possible even at low loads. The deposits can be variable in composition leading to possible differential settlement. Accordingly, foundations or piles may need to be taken through the deposit. Occasional gravel layers may provide better foundation conditions (though the nature of the deposits underlying the gravel must be determined). Conversely, peat horizons in the alluvium or organic clays in the estuarine alluvium may also be found, both of which are unsuitable for any foundation.

Hydrostatic pressures in the estuarine alluvium may fluctuate because of the tides and this will affect bearing capacities. Groundwater control for excavations, together with shoring are essential. In the estuary, piles founded in denser, coarser deposits at depth will usually be required, though skin friction values in the near surface deposits will be low.

The non-cohesive loose deposits have higher bearing capacities than the cohesive soils in this group but they are often variable lithologically leading to possible differential settlements. Perched water-tables and high permeabilities in these deposits mean that groundwater control for excavations and cuttings will be necessary. They can be used as a fill material only where clay is absent. Lithological and geotechnical variation on a site scale will need careful investigation.

Groundwater

Few geotechnical problems are anticipated from groundwater sulphate contents or pH values for any deposit except where the groundwater has been contaminated by water draining through mine waste tips. For sites in the vicinity of such tips groundwater quality should be carefully monitored to determine whether higher quality concrete is required and whether steelwork needs protection.

Water Resources

Groundwater is generally less vulnerable to pollution than surface sources because of the filtering and attenuating effects of the unsaturated zone above the aquifer. Consequently it commonly receives little treatment before being pumped into supply. This means that it is important that aquifers are protected from potential pollutants. There are two main sources of pollution, point and diffuse. Point sources include landfills and other waste disposal sites such as sewage treatment works, and storage tanks for silage, fuels, industrial solvents and other chemicals. There are several landfill sites that have in the past or currently accept household and industrial waste. However, generally they represent little risk to groundwater quality because of the presence of impermeable drift deposits. Storage tanks, particularly where poorly constructed or in bad repair, can represent a serious risk to groundwater quality.

Diffuse sources of pollution are nitrates, applied to the ground in the form of fertiliser, and biocides (particularly herbicides); both are widely used in agriculture. As much of the area under consideration is agricultural these are a risk to groundwater quality. However, the risk is low with respect to the major aquifer in the area, the Kinnerton Sandstone Formation, because it is overlain by considerable thicknesses of unconsolidated deposits of low permeability. The Carboniferous Limestone which occurs at the surface over large areas is at greater risk.

GEOLOGICAL SEQUENCE

The bedrock formations, in stratigraphic (age) order, and superficial deposits recognised in the area are:

SUPERFICIAL (UNCONSOLIDATED) DEPOSITS

Recent
- Backfill
- Made ground
- Alluvium
- Estuarine Alluvium
- Alluvial Terrace
- Alluvial Fan
- Landslip

Quaternary
- Landslip
- Peat
- Head
- Sand and Gravel
- Till (Boulder Clay)

BEDROCK	Thickness (m)
?Tertiary	
(Solution-pipe infills).	
Permo-Triassic	
Kinnerton Sandstone Formation	up to 300
Carboniferous	
(Westphalian)	
Ruabon Marl	up to 120
Buckley Formation	up to 250
Productive Coal Measures	
(Westphalian C)	0 - 150
Hollin Rock	10 - 70
(Westphalian B)	100 - 150
Drowsell (or Massy) coal	0 - 1.21
Powell (or Bind) coal	0 - 1.07
Hollin coal	0.7 - 2.75
Crank coal	0 - 0.96
Quaker (or Brassey) coal	0 - 1.19
Black Bed (or Rough) coal	0 - 1.11
Main coal	1.8 - 4.5
Lower Bench coal	0 - 0.76
Crown (or Diamond) coal	0 - 1.83
(Westphalian A)	160 - 230
Upper Red (or King) coal	0.35 - 1.8
Lower Red (or Cannel) coal	0.3 - 1.0
Stone (or Wall and Bench) coal	0.15 - 4.14
Nine Foot Rider coal	0 - 3.0
Nine Foot coal	0 - 2.87
Nant coal	0.48 - 1.93
Ruabon Yard (or Yard) coal	0 - 1.68
Premier coal	0.45 - 2.13
Llwyneinion Half Yard (or Half Yard) coal	0.4 - 1.3
Chwarelau (or Little) coal	0 - 0.88
(Namurian) (=Millstone Grit Series)	
Halkyn Formation	250 - 350
Gwespyr Sandstone	0 - 150
'Cefn-y-Fedw' Sandstone	0 - 80
'Pentre' Cherts	0 - 150
Carboniferous Limestone (Dinantian)	
Minera Formation	0 - 170
Cefn Mawr Limestone	50 - 120
'Main' Shale	0 - 4
'Thick' Shale	0 - 3.5
Loggerheads Limestone	c 170
Leete Limestone	75
Llanarmon Limestone	c 150
Llwyn-y-fran Sandstone	0 - 20
Foel Formation	c 20
'Basement beds'	0 - 5(?)
Silurian (Ludlow)	
Elwy Group	up to 350

DESCRIPTION OF THEMATIC GEOLOGICAL MAPS

Notes about the topographic base

The topographic base used (scale 1:25 000) was compiled by the Welsh Office, Cardiff. As the constituent Ordnance Survey (OS) 1:25 000 base maps are of differing ages, changes in topographic detail (e.g. housing, quarry outlines) occur across some grid boundaries. In compilation, some imprecision of the grid alignment has occurred across these same grid boundaries.

Several amendments have been made to the OS base. To aid inspection of the geological information added, many of the field boundaries were removed. Furthermore, topographic contours are not represented, although spot heights (in feet N of Grid Line 70 and W of Grid Line 20, in metres elsewhere) are given.

The proposed lines of the A55 road improvements were added by the Welsh Office. The routes shown vary slightly from those recently constructed, particularly in the vicinity of Holywell [SJ 1840 7478]. This is of importance where embankment (made ground) has been mapped, and in this area it is shown in its accurate position and is thus slightly offset from the route of the A55 as shown.

List of Thematic Elements

Map 1.Bedrock Geology
Map 2.Superficial (Unconsolidated) deposits
Map 3.Boreholes, Rockhead and thickness of Superficial deposits
Map 4.Mining activities; Coal/Metalliferous
Map 5.Resources (Bedrock) - except Coal/Metalliferous
Map 6.Resources - Sand and Gravel
Map 7.Hydrogeology and Water Supply

Thematic Element, Map 1 - Bedrock Geology

The map depicts the distribution at the surface of all of the major bedrock formations, with important subdivisions where identified. It makes no attempt to portray the vertical variations of bedrock, other than in the generalised vertical section, and the cross-section appended to the map face. A simplified geological map is presented in Figure 4.

The 'formation' is the fundamental level of subdivision of a sequence of rocks and refers to a body of strata which is recognisable and mappable over large areas. The formation comprises strata of distinctive geological characteristics (e.g. similar composition, grain-size, sedimentary structures, persistent association of beds of different rocktype). Specific lithologies can be recognised within a formation (e.g. sandstones, coal seams) and named accordingly as a 'member'. These need only be of local distribution. Where several formations have a general relationship, they can be amalgamated to form a 'group'.

The linework shown on the map is based on that produced during the recent 1:10 000/10 560 field survey. Some simplification has proved necessary in reducing to 1:25 000 scale. In particular, the density of faults (e.g. in the vicinity of Halkyn Mountain in the NW) has been greatly reduced, and in some formations, most notably the Minera Formation, the closely-spaced individual sandstones have been generalised as single packets, whereas in other instances, minor sandstones have been removed altogether where geologically reasonable to do so. For more detailed information, planners and developers must consult the available British Geological Survey (BGS) geological maps and open-file reports (see Appendix A) and BGS archival maps, field-slips and annotated aerial photographs held in the Aberystwyth Office of the BGS.

The bedrock succession of the area is given in the form of a generalised vertical section. This shows the stratigraphic order of the formations, their thickness variations (approximately to scale) across the area and general relationships with underlying and overlying formations (i.e. normal contact, lateral equivalence or unconformity). Brief descriptions of each formation and member, including age, rocktype, lateral and vertical variations, and interpretation of mode and environment of deposition are given in the Summary of Geology (see below). The cross-section (with vertical exaggeration relative to horizontal scale of x 2) is an interpretation, based on available surface information and relevant borehole data, of the nature of bedrock at depth along the line of section shown on the map. The line of cross-section was chosen to best illustrate the overall structure of the area.

This map should be used in conjunction with Thematic Element, Map 2 - Superficial (Unconsolidated) deposits, as the accuracy and certainty of the linework depends to a large degree on the availability of information from exposures of bedrock, and the thickness of the superficial deposits (drift). Thus in areas of little or no drift, a lesser degree of interpretation is

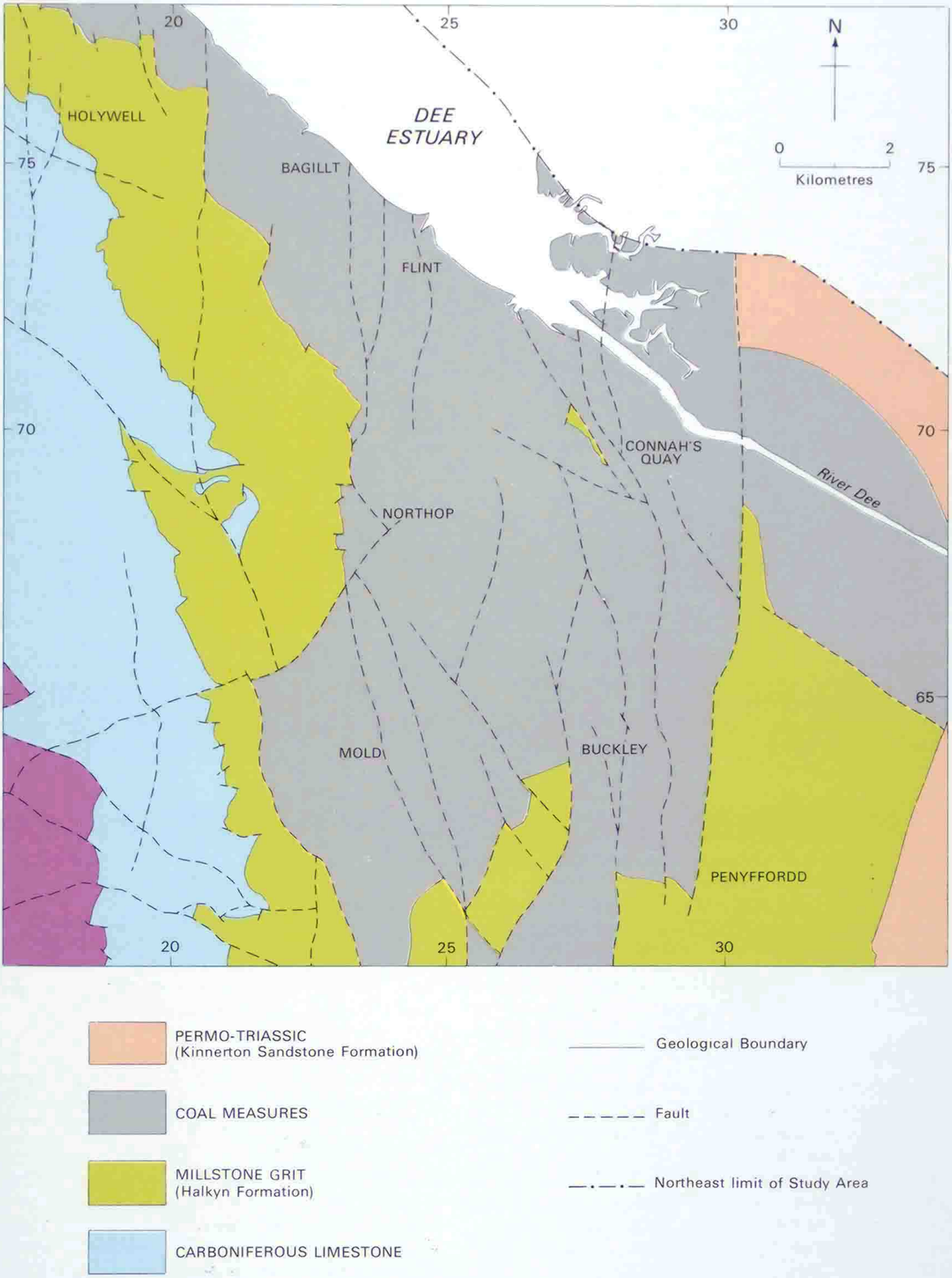


Figure 4 Simplified geological map of the study area

necessary. However, in mapping the coalfield, considerable information is available, despite thick drift cover, from boreholes, previous mining and opencasting. Therefore, in some areas, the position of coal seams and faults is well constrained.

Selected data on the orientation of strata (direction and amount of dip from the horizontal) are given. Faults are discontinuities in the bedrock and may in addition to offsetting geological boundaries, coincide with changes within the formations. Most faults in the area are steep (within 20° of vertical). No attempt is made however to indicate the variation of steepness (other than in the cross-section). Few faults are ever seen in exposure other than in the mines and quarries and most, therefore, are inferred, and their position subject to inaccuracy. The relative downthrow of faults is shown, but not the amount.

Thematic Element, Map 2 - Superficial (Unconsolidated) deposits

This map shows the distribution at surface of all superficial (unconsolidated) deposits. The general term drift is applied to the unconsolidated, superficial deposits of Quaternary age, and these are largely glacial in origin or are related in some way to glaciation. Localised peat and clay-filled depressions related to the deglaciation, and known as kettle-holes, are symbolised. Deposits which have formed recently, or are actively forming by natural processes are also shown, together with man-made deposits (made ground and backfill). The map displays landslip of various ages (Quaternary to Recent), and foundered ground and swallow holes (symbolised individually) in the Carboniferous Limestone terrain, which may contain clays and silts as old as Tertiary. The swallow holes are dissolution pipes in the limestone; they may be vertical or inclined.

The maps have been simplified from the 1:10 000/10 560 geological maps produced during the recent survey (1985-87). Borehole information was used to aid interpretation.

The superficial and other unconsolidated deposits are categorised according to two factors, a) the process by which they were formed, and b) the composition of the deposit. The former includes landslip, made ground, backfill, foundered ground and the various forms of alluvium. The latter includes till (boulder clay), sand and gravel and peat. Blown sand involves both factors. Those categorised solely according to process are therefore very variable in grain-size, clast content and fabric.

The map shows only the variation of surface deposits (i.e. within 1 metre of surface) and makes no attempt to show variations with depth. Although the deposit indicated on the map may be considerably thicker than 1 metre and perhaps the only deposit overlying bedrock at a given site, it is equally likely that there may be many different types of deposits. Therefore, borehole data must be consulted (see Thematic Element, Map 3 and Appendix C). Limited information regarding thickness variations, mainly of sand and gravel deposits, is given on Thematic Element, Map 6 and in Appendix F, and further information in the Summary of Geology.

Deposits generally less than 1 metre thick are not shown. Areas shown as bedrock, especially the limestone terrain, may have extensive veneers of drift (usually head). It may locally exceed 1 metre in thickness, but such areas are too patchy to show. Thin drift veneers may, however, be a very important factor when considering local ground stability (see section on Engineering Geology).

In addition to the distribution of the deposits, rockhead contours are shown. For a description of these, see the description of Thematic Element, Map 3, where the rockhead contours are repeated.

The categories of superficial (unconsolidated) deposits are briefly reviewed below.

Made Ground

Areas of made ground are related to mining (metalliferous and coal), quarrying [e.g. SJ 198 703, SJ 188 724], land development and road and railway embankments. The largest areas of made ground are those along the northeast coast, related to industrial development (especially on the site of the Shotton Steelworks [SJ 31 70], at Flint [SJ 245 735], Connah's Quay [SJ 28 71], Bagillt [SJ 215 760], and Greenfield [SJ 198 777]). The various forms of made ground are not distinguished, but for further information see Thematic Element, Map 4 (Mining activities; Coal/Metalliferous), Map 5 (Resources (Bedrock) - except Coal/Metalliferous) and Map 6 (Resources - Sand and Gravel).

Mining waste tips related to metalliferous mining generally comprise calcite vein material and the local country rock, principally limestone and some chert. Coal tips usually comprise mudstone, siltstone and sandstone debris. Made ground related to limestone quarrying generally comprises calareous mudstone and muddy limestone, while that related to sand and gravel extraction usually consists of fine-grained sand, silt and mud.

Backfill

Backfill of quarries and opencast coal sites often comprises the waste products of the quarrying [e.g. SJ 195 679] and sand and gravel [e.g. SJ 179 681] extraction, and coal extraction [e.g. SJ 290 660, SJ 268 682] (as given for made ground above). It may also include, however, household rubbish [e.g. SJ 1890 7246, SJ 264 660, and SJ 2862 6500], and industrial waste at approved sites [e.g. SJ 1935 6928, SJ 2778 6600, and SJ 2155 6230].

Foundered Ground

Some areas of foundered ground are shown [e.g. SJ 209 604, SJ 2056 6010, SJ 2035 6054, SJ 2066 6290, SJ 1890 6264, SJ 1900 6305 and SJ 1890 6250]. These are sites where dissolution of the Carboniferous Limestone has induced collapse or foundering of the superficial overburden. They sometimes contain lacustrine alluvium deposits (see below).

Landslip

Landslip affects both bedrock and superficial deposits. Some landslip is active [SJ 2065 6790, SJ 290 678] or has recently been so [e.g. SJ 1978 7376, SJ 3128 6506]. Most landslip recognised is probably of immediate post-glacial age and may not have been active for thousands of years. It must be stressed, however, that excavation of recorded landslips and particularly of the fronts of landslips is likely to reactivate them. Most landslip occurs along steep-sided valleys, and is particularly common where the Halkyn Formation or Coal Measures are the bedrock. For example, there is extensive landslipping along the valley of the Wepre Brook [SJ 278 671 - 295 681], some of which is still active [e.g. SJ 290 678], and along the valley of the Nant-y-Flint [SJ 194 750 - 223 716].

Alluvium

Alluvium (floodplain deposits) occurs along most of the more important streams and rivers. It occupies considerable tracts of land along the courses of the Alyn and Dee rivers, and can be considered as actively forming. It consists mainly of fine sands, silts and clays, with local gravels.

Estuarine Alluvium

Areas of alluvial sediment are currently being deposited in the Dee Estuary. Large areas of the recently reclaimed flat terrain northeast of Queensferry and of the northeast coastal strip are occupied by estuarine alluvium.

Alluvial Fan

This category is morphological and the sediments even within one deposit may be very variable. They form where constricted streams and rivers flow into a less constrained area (e.g. the alluvial floodplain of a large river) and the sediment carried by the stream is laid down in a deposit which increases areally downstream. There may be a pronounced grain-size decrease downstream on the fan (e.g. gravel varying downstream to fine sand and silt).

Alluvial Terrace

These deposits are only very localised and small-scale. They usually comprise similar material to other alluvium and represent flooding during formerly higher levels of the stream or river.

Lacustrine Alluvium

These are small deposits generally, often occurring at the sites of temporary lakes which existed in areas of sand and gravel during and immediately after the Quaternary glaciation. An unusually large area of this type occurs at [SJ 1785 7500]. Other areas are sometimes associated with foundered ground [e.g. SJ 2100 6044, SJ 2052 6010].

Head

Head deposits are very variable in character and represent downslope solifluction and redeposition of glacial and other unconsolidated deposits, particularly during conditions of freeze and thaw. They are more extensive than shown on the map, but veneers of head are often less than 1 metre thick and on this criterion are not depicted. Head often accumulates in the bottom of valleys as areas of low relief.

Till (Boulder Clay)

Boulder clay is very widespread, particularly in the centre, east and northeast of the area. It is extremely variable and was the product of direct deposition from melting glaciers. Clasts of varying size up to several metres are suspended in a clay matrix. There is usually no order or bedding though occasional beds of sand, gravel and silt may be intercalated.

In the area, there were two different sources of boulder clay, with quite different suites of clasts, clay matrices and grain-size characteristics (see Summary of Geology for further details).

Sand and Gravel

These deposits are extensive along the Alyn and Wheeler rivers, north of Mold and immediately southwest of the Dee Estuary. They were deposited by fluvio-glacial processes beneath and in front of the glacial ice-sheets. They are generally well-bedded and cross-bedded. The coarser gravels often occur in lenses and channels. The deposits often form moundy topography. In between the mounds, small depressions (kettle holes) sometimes occur in which silts, clays and peat accumulated in swampy and lacustrine conditions (see Summary of Geology for further details).

Peat

Some thin hill-peat occurs on the Clwydian Hills in the southwest of the area, but it is too thin to be shown. Small peat deposits occur in some kettle holes (see Sand and Gravel above).

Thematic Element, Map 3 - Boreholes, Rockhead and thickness of Superficial deposits

This map shows the distribution of sites of non-confidential boreholes registered in the BGS 1:10 000/10 560 borehole system. Logs of these boreholes are available for inspection at (or copies can be obtained from) the Aberystwyth Office of the BGS.

In areas where the density of boreholes is great, some boreholes have been omitted. The criterion for omission was that adjacent boreholes provided substantially the same information as those omitted.

Shell and auger techniques were used for a large majority of the boreholes shown. These have a maximum depth of 30 m. Some boreholes, particularly for testing water supply, are considerably deeper. A full list of the boreholes is given in Appendix C, indicating surface level and depth, detailed grid reference and other information. Boreholes drilled as part of the study are listed in Appendix F (see also Thematic Element, Map 6).

The boreholes are symbolised according to whether or not they provide geotechnical information. Although the geotechnical data may only be Standard Penetration Test data, a wide range of test data and some interpretive geotechnical reports are available (see Engineering Geology) for some boreholes.

For most of the boreholes, information on the total thickness of the superficial deposits and the height of rockhead above Ordnance Datum (mean sea-level) is given. Rockhead is the base of the weathering profile in bedrock. Where surface level of the borehole was not recorded, only the thickness of the superficial deposits is given. Where the borehole failed to reach rockhead, the minimum thickness of superficial deposits is recorded, while rockhead is shown as being less than (<), i.e. lower than the specified height above Ordnance Datum. The density of available boreholes is very patchy. Concentrations occur along the routes of road-schemes, most notably the A55, and at specific development sites.

Rockhead contours have been derived from the borehole data in areas where sufficient data are available to constrain them. In addition to non-confidential boreholes, an even larger number of confidential boreholes (mainly relating to British Coal opencast site investigations) have been used. The varying height of solid/drift boundaries (see Thematic Element, Map 2) also provide constraint on the calculation of rockhead contours. In areas free of superficial deposits, the topographic contours are essentially rockhead contours also, although the extent of the weathering profile must also be taken into account. Rockhead contours have only been shown on the map for these areas where they assist in constraining the form of rockhead contours under adjacent drift-covered areas. In areas covered by superficial deposits, the rockhead contours depart increasingly from the topographic contours with increasing thickness of the deposits. The form of rockhead contours particularly indicates the form of buried channels related to the major river systems. Both the Alyn and Dee have deep, buried channel systems. The migration and abandonment of channels is apparent along the Alyn River southeast of Mold.

The River Dee has a buried U-shaped channel in the northeast of the area, whose base reaches substantial depths (at least -54 m) below Ordnance Datum, suggesting it was probably excavated during the Quaternary glaciation, when sea-level was much lower than at present. The channel was infilled initially by glacial deposits and latterly, with the post-glacial rise in sea-level drowning the valley northeast and east of Connah's Quay, estuarine alluvium accumulated. An asymmetric partially buried channel extends from south to north, approximately between Mold and Flint. Glacial and glacially-related deposits largely infill most of the buried channels.

Thematic Element, Map 4 - Mining activities; Coal/Metalliferous

This map shows the areas mined for coal and metalliferous ore, and aspects related to that mining. A small area was mined for 'cementstone' (calcareous siltstone). The information on coal mining is derived to a large extent from that of the British Coal database (Opencast Executive, Coal Commission and other abandoned mine plans) and BGS archival data supplemented by the recent survey. The information on metalliferous mining is derived from the recent survey with supplementary BGS archival plans and maps. In the case of specific site investigations, the documents held by British Coal and at the Aberystwyth Office of the BGS must be consulted.

Coal Mining

Coal has been mined in the area at least since the Middle Ages and possibly earlier. Earliest workings were likely to have been of coal at outcrop, gradually developing into shallow workings by adits and bell pits. With the advent of greater demand for coal during the industrial revolution, deeper mining became prevalent.

The map delimits the areas of underground workings for which plans are available. Prior to 1872, there was no statutory obligation to record plans of underground workings. The only information relating to very early mining derives from surface expressions (e.g. shafts, depressions, waste tips) where recognisable. Even after 1872, the plans lodged with the Mines Record Office (copies of which are held by British Coal) were of very variable quality and accuracy. Few of the plans record details of depth of workings and many show little surface detail by which they can be positioned. On some plans, for example, it is clear that the direction of north shown is inaccurate, to the extent in one instance of nearly 45°. Plotting such information is therefore liable to considerable error.

The areas of underground workings shown are differentiated into areas where only one coal seam has been worked and those where more than one seam has been worked. Approximately 20 km^2 of the area is known to be undermined. No attempt is made to indicate the depths of workings since insufficient information is available. It is certain that the records of underground workings are incomplete. Thus, known mine-shafts, adits and coal waste tips are shown in areas without any mine plans. The possibility exists, therefore, of shallow workings anywhere in the area where the coal measures are present and particularly so where the thicker seams (e.g. the Main and Hollin coals) occur at outcrop or shallow depth. The likelihood of shallow workings will decrease with increased superficial overburden.

Many of the mine-shafts and adits shown were recorded during the field survey. Additional sites have been transferred from British Coal plans (which indicate the validation of the data). Unrecorded shafts are likely to exist. A register of all known shafts, totalling over 1000, with grid references and depth, are listed in Appendix D. Those shafts which have been capped are differentiated on the map. Capping does not imply that the shaft has been filled. Uncapped shafts may be wholly or partly filled.

Backfilled opencast sites are shown, as are areas of made ground (waste tips) related to coal mining. No opencast sites are active at present, but recent opencasting at Ashfield House Farm [SJ 313 674] was completed in 1987 and is now being backfilled and restored. British Coal have applied for permission to develop an opencast site at Pont Einion [SJ 260 686] near Northop.

It cannot be stressed too strongly that shallow workings, shafts and underground workings may exist in addition to those shown on the map, and that the limits of underground workings are only approximate. Unrecorded shafts, in particular, are a hazard and there have been a number of cases of such shafts collapsing in recent years, as for example in Flint [SJ 2424 7227] and Hawarden [SJ 3167 6636].

Little information exists as to the methods of underground working used at specific sites. However, it is known that two general methods were employed. The earliest technique of large-scale extraction was the 'pillar and stall' method. This involved the selective extraction of coal, leaving up to 60% in position to support the roof of the seam. Subsequent improvements in technique increased the efficiency of recovery. Thus panel working and longwall methods were used from the latter part of the 19th Century onwards (and probably applied in some cases to seams already mined by pillar and stall). Many of the available mine plans suggest longwall extraction was used. This involved the complete removal of coal from certain areas resulting in the controlled collapse of the unsupported seam roof. On the map, no attempt is made to show areas of potential subsidence due to mining. This would relate to the age and depth of workings, the number of worked seams and the thickness of superficial deposits.

Of the two main methods of mining, areas of pillar and stall provide the greater potential hazard to development. As a large proportion of the seam was left as roof support, a borehole is highly likely to pass through the pillars (i.e. the preserved seam) rather than adjacent voids. Furthermore, downward bowing of the seam roof between pillars may suggest in a borehole that only a thin seam is present, whereas voids close to the pillars may still exist. Collapse of the pillars themselves can result in cavities, breccia pipes and voids in overlying strata. In most parts of the coalfield any voids are now likely to be filled with water.

Longwall extraction, used generally for the deeper seams, typically results in the collapse of the unsupported seam roof during or soon after mining and further collapse is unlikely. Only the connecting 'roads' which were permanently supported for access are likely to cause later subsidence problems and problems with voids. As a large majority of these workings on-shore are related to mines abandoned by the late 19th and early 20th Centuries, little subsidence due to collapse is likely. The considerable thickness of superficial deposits over much of the coalfield also serves to mask and diffuse any collapse in the underlying Coal Measures. No deep mining has taken place recently. The only deep mine in the area to continue production until the 1930's was Bettisfield colliery (Bagillt) [SJ 215 760] whose workings were predominantly beneath the Dee estuary, thus posing no land subsidence problems.

The most extensively worked seams are the Main and Hollin coals (see Summary of Geology below). Considering the area as a whole, approximately 132 km^2 is underlain by strata with coal seams of Westphalian A age, and 65 km^2 by strata with coal seams of Westphalian B age (and including the Main and Hollin coals; see Thematic Element, Map 1 and Summary of Geology). The cumulative average thickness of all coal seams in Westphalian A is approximately 10 m while that in Westphalian B is approximately 9 m. The original resources of the area were approximately 300 million tonnes (with approximately 200 million tonnes in Westphalian A and 100 million tonnes in Westphalian B). Of this total, the extent of recorded workings suggests that approximately 15% of Westphalian A resources and 30% of Westphalian B resources have been substantially extracted. The remaining 'resources' are not necessarily readily available (e.g. due to unrecorded mine workings, substantial overburden, local thinning and washouts of coal seams), or amenable to modern extraction methods, due mainly to the intense faulting and other structural complexities of the coalfield. Furthermore, no attempt can be made to assess the quality of individual seams. As coal seam nomenclature varies across the area, a 'correlation' of the local seam names with the name used by British Coal for the whole of the North Wales Coalfields is given in Table 1.

Metalliferous Mining

Metalliferous mining was restricted to the west of the area and largely concentrated on the upper geological formations of the Carboniferous Limestone (see Summary of Geology - Mineralisation). The lead ore galena was the main economic basis for the industry with peaks in production around 1850 and 1895 (Smith, 1921). Silver extracted from the galena was a valuable by-product. Although mining on a small scale persisted until the 1960's, very little extraction has post-dated 1920. As little of this mining was recorded, no attempt is made to show areas of underground working. Unlike coal mining, however, the areas of mining were mostly restricted to narrow, relatively thin veins and joints which tend to occur in conjugate sets. As these veins can, in many instances, be well defined by the linear chains of shafts and shallow trial pits, displaying the veins themselves provides a good guide to the undermined areas. However, in the case of the deeper, usually more scattered shafts, these were not necessarily sited directly on the vein trends, and hence the positioning of the veins is subject to inaccuracy. A further problem is that many of the veins depart significantly from vertical, increasing the area of potential undermining.

The map shows selected shafts only and the real number of shafts (of very variable depths) runs into several thousand. The archival field-slips and annotated photographs held by BGS must be consulted for the complete distribution.

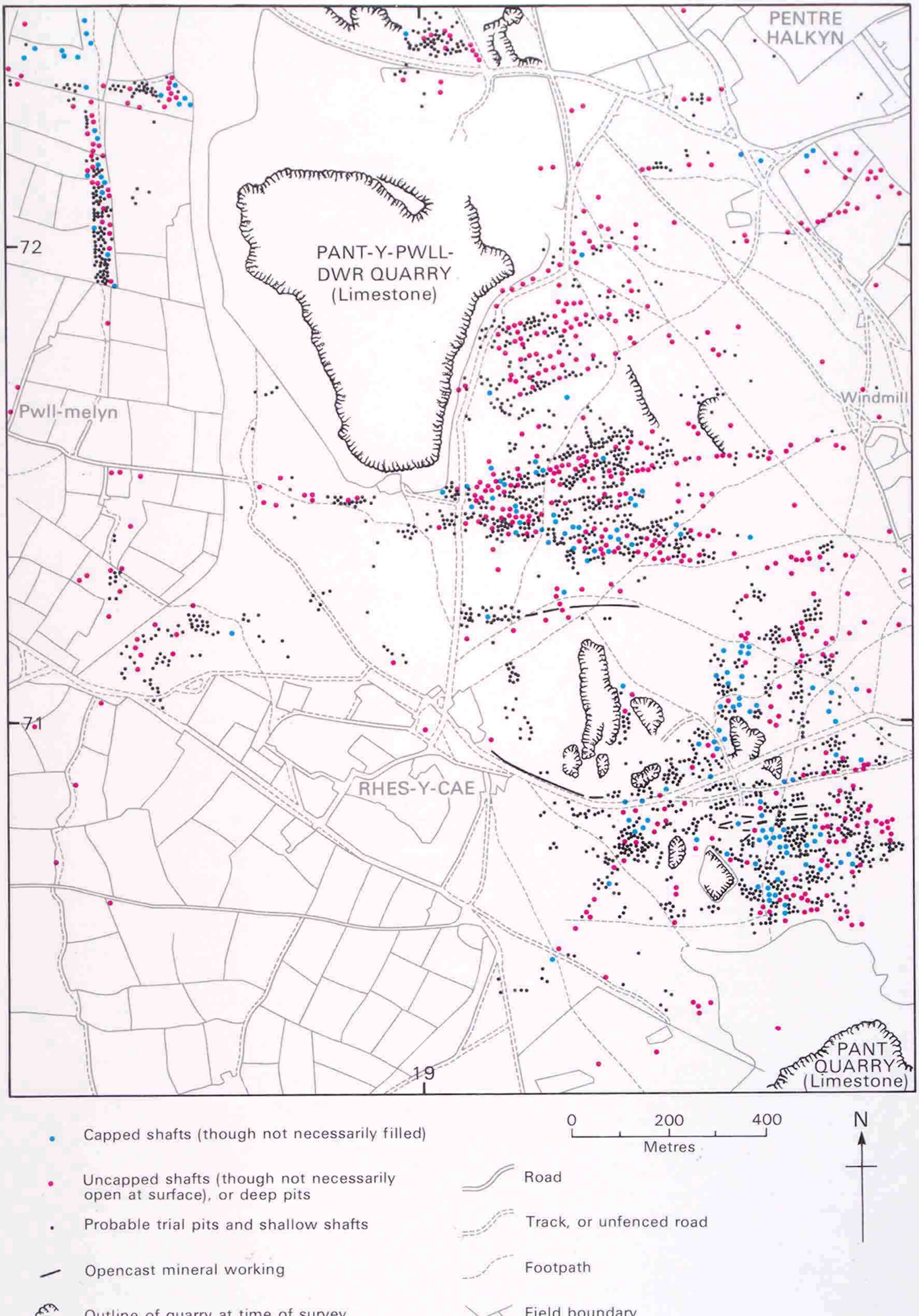
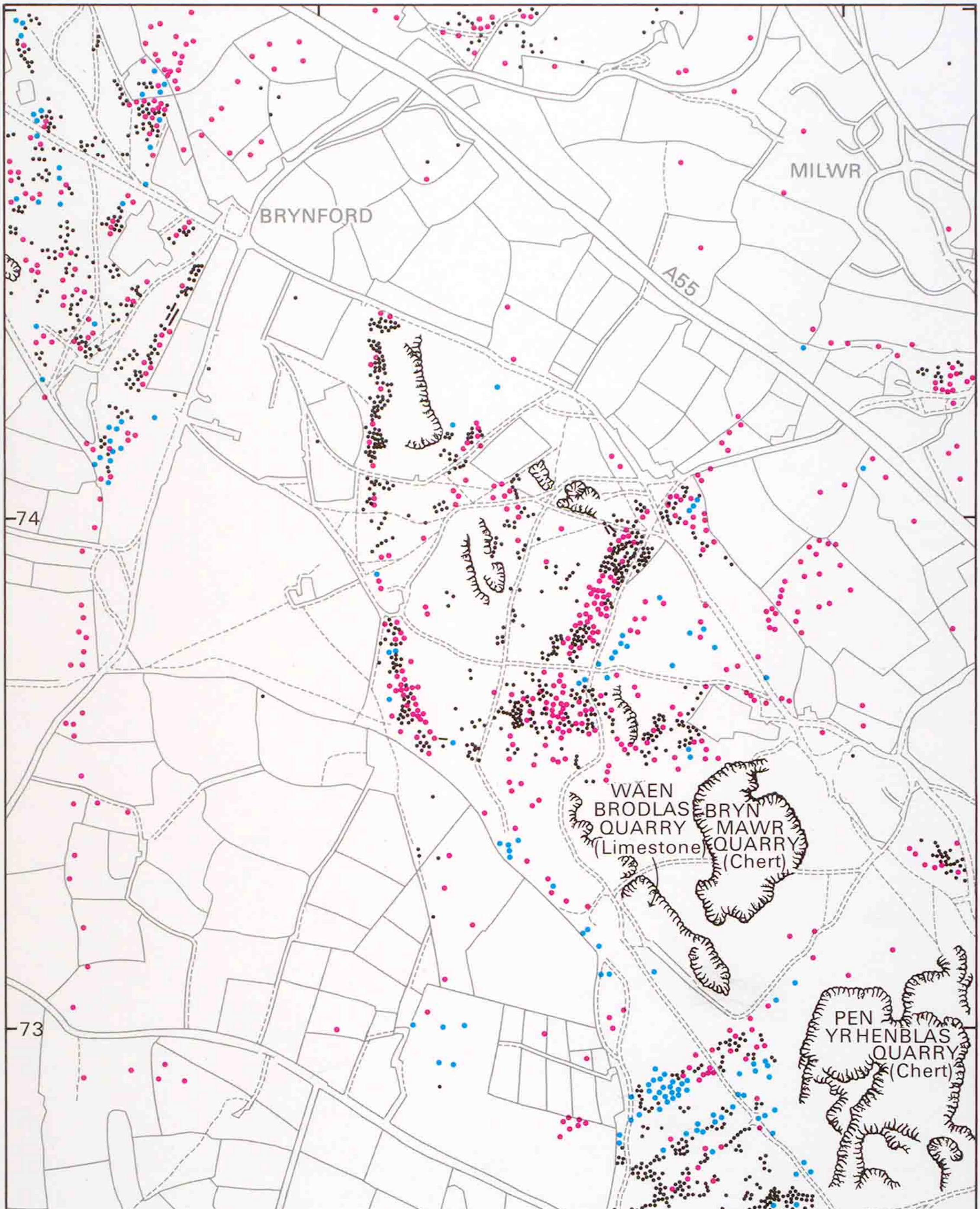


Figure 5a Detailed map (Scale 1:10 560) of the distribution of shafts and trial pits on Halkyn Mountain. The area between Pant and Pant-y-pwll-dwr



For key see figure 5a.

Figure 5b Detailed map (scale 1:10 560) of the distribution of shafts and trial pits on Halkyn Mountain. The area between Pen yr Henblas and Brynford. For key see Figure 11a

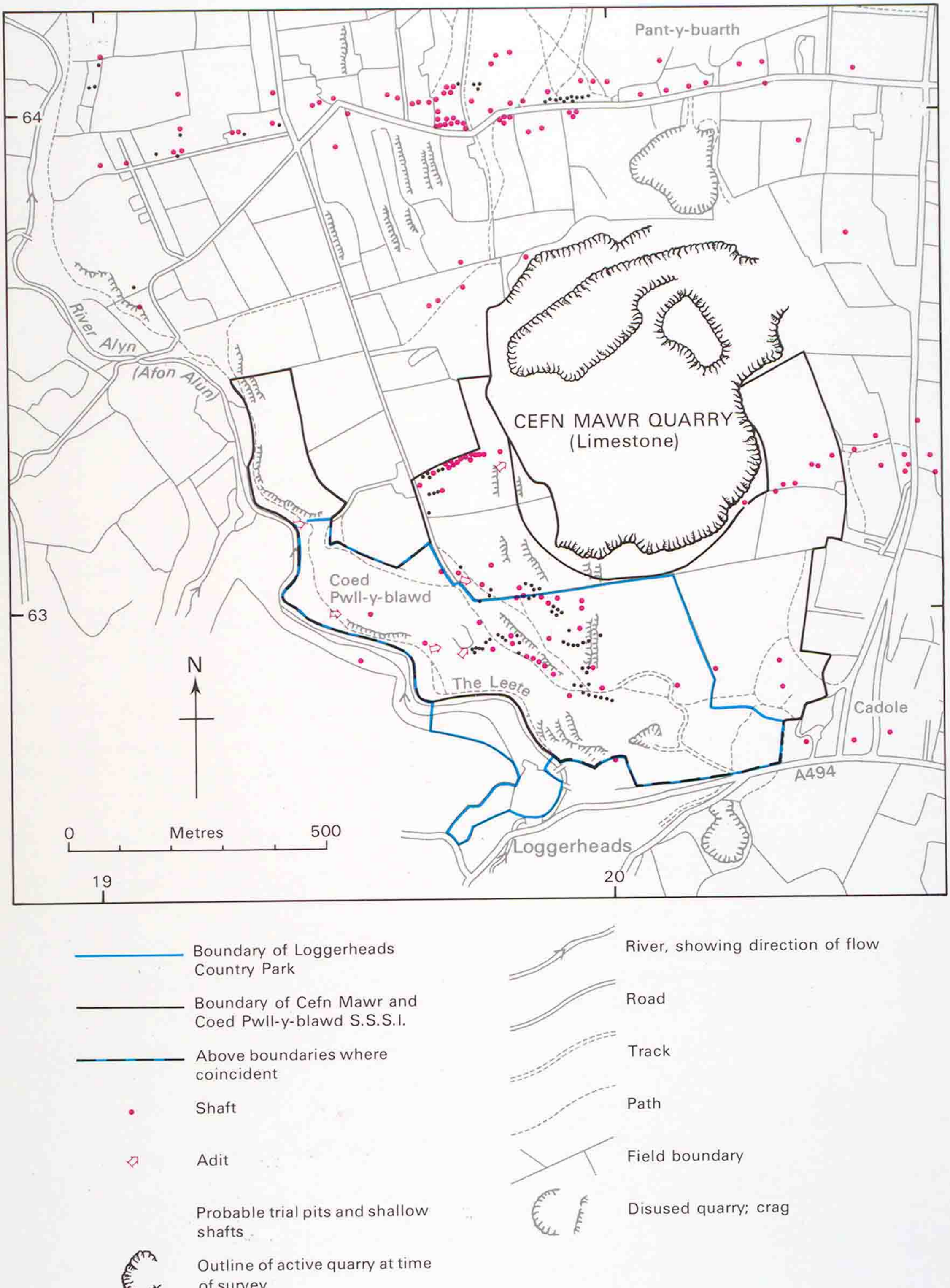


Figure 6 Detailed map (Scale 1:10 560) of the Loggerheads Country Park and Cefn-Mawr/Coed Pwll-y blawd Site of Special Scientific Interest

Table 1. 'Correlation' of Coal Seam nomenclature for the northern 'Flintshire Coalfield' after British Coal

Whole Coalfield name	Local names: Flint, Bettisfield, Englefield and area	Local names: Northop Hall, Queensferry, Ewloe, Buckley and area
Upper Stinking		Upper Main
Drowsell	Unnamed	Massy, Small and Massy, Four Foot or Bind
Powell	Bind, Upper Two Yard, or King	Bind or Powell
Hollin	Cannel, Upper Main, Bind, Bagillt Two Yard or Yard	Hollin or Two Yard. (Bottom leaf only, Hollin Bench, Little or Cannel)
Crank	Little	Crank, Little or Thin
Quaker		Brassey or Yard
Black Bed		Rough or Black Stone
Main Bind		Main Bind, Half Yard, Foul, Rough or Brick
Main	Five Yard or Three Yard	Main
Lower Bench	Three Yard or Brassy	Lower Bench, Little, Two Foot, Finger or Half Yard
Crown	Double, Upper Double or Double Roll	Diamond, Five Foot, Two Foot, Four Foot or Jubilee
Upper Red	Durbog or Lower Double	King
Lower Red	Yard, One Yard or Two Foot	Cannel, Red, Two Foot or Three Foot
Stone	Double, Cannel or Four Foot	Wall and Bench, Stone, Wood Pit, Mount Pleasant, Yard, New, Five Foot or Four Foot
Nine Foot Rider	Unnamed	Nine Foot Rider or Wall
Nine Foot	Hard Five Quarter, Three Yard, Main, New Three Yard, Two Yard, Thicker Six Foot	Nine Foot, Dirty or Upper Four Foot
Nant	Brassy, Best, Hard, Dirty, Double, Middle or Five Foot	Nant, Upper Four Foot, Upper Latchcroft, Four Foot, Dirty or Yard
Ruabon Yard	Soft Five Quarter or Four Foot	Yard, Arley, or Cannel
Premier	Four Foot, Bottom or New	Premier, Lower Four Foot, Lower Five Foot, Five Quarters, Latchcroft, Four Foot, Wall and Bench or King
Llwyneinion Half Yard	Queen, Yard or Small	Half Yard or Queen
Chwarelau	Little or Lower Yard	Little

An attempt was made during the field survey to categorise shafts in the northern half of the mining district into three types, reflecting their hazard potential:

1. Capped shafts (though not necessarily filled)
2. Uncapped shafts (though not necessarily open at surface) and deep pits
3. Probable trial pits and shallow shafts.

These were coded by colour on the air photos and field slips, but only those in categories 1 and 2 were transferred to the 1:10 000/10 560 'geological standards' and are thus selectively represented here. Figures 5a and 5b reproduce the original categorisation for the main area of mining on Halkyn Mountain where the number of shafts and trials is at its greatest. The categorisation of types 2 and 3 was highly subjective. Some deep shafts which are open at the surface are readily assigned, but the majority are closed, at least at surface (due to collapse), though they may be open at depth. Therefore the assignment was mainly influenced by the volume of spoil material surrounding the shaft site. These areas of spoil form ring-like ramparts around the shafts, which are themselves usually preserved as depressions. The larger the volume of spoil relative to the diameter of the shaft-site, the greater is the likelihood of it having been a deep shaft, rather than an ephemeral trial pit. Only the more extensive areas of made ground are shown on the map. However, the close spacing of the shafts results in many areas, along veins, in chains of mounds of made ground (see Thematic Element, Map 2 and rear cover photograph 1).

Figure 6 is a detailed map of the distribution of shafts in the Loggerheads Country Park, and the Cefn Mawr and Coed Pwll-y-blawd Site of Special Scientific Interest.

It is increasingly common practice to attempt land restoration in areas of previous lead mining by bulldozing flat the made ground. Consequently in some areas, the number and density of shafts will remain unknown.

Ores are principally restricted to veins, joints, pipes and some bedding planes (see Summary of Geology - Mineralisation). They occur as discontinuous deposits whose distribution and concentration are unpredictable. As modern large-scale base metal extraction tends to rely on prospects of predictable, albeit often relatively low, concentrations, the ore deposits in the area would seem not to be a viable prospect under present or foreseeable economic conditions. Furthermore, the extensive shallow-level removal of ores during the past would necessitate that future mining would have to exploit resources at some depth and this would pose problems of mine drainage (see Drainage Tunnels below).

Cementstone

This was extracted from a number of adits in one small area near Holywell [SJ 193 754]. The adits are confined to the Halkyn Formation.

Drainage Tunnels

As metalliferous mining reached deeper levels, drainage became the principal limiting factor of development of the mines. Consequently lengthy drainage tunnels were constructed, connecting several of the more important mines. Of these, the two main tunnel schemes were the Halkyn or Deep Level Tunnel and the Milwr Sea Level Tunnel. Gradients of approximately 1 in 1000 carried water northwards. The Milwr Tunnel has provided water for industrial use recently, and the tunnel is maintained with access using the winding gear at 'Hendre Mine' [SJ 2015 6777]. Other drainage tunnels, including branches on the main tunnels, are also shown.

Thematic Element, Map 5 - Resources (Bedrock) - except Coal/Metalliferous

This map shows the distribution of areas within which bedrock resources, apart from coal and metalliferous deposits, are or have been extracted and where potential may exist for further exploitation. It has been compiled from the 1:10 000 and 1:10 560 geological maps. Where applicable, the resource areas are shown as being limited by superficial deposits more than 10 m thick since it is considered that most bedrock resources are unlikely to be exploited beneath an overburden which exceeds that thickness. It must be emphasized that this 10 m limit is only approximate as there are many parts of the study area in which there is insufficient borehole information or field evidence to permit the drawing of an accurate 10 m isopachyte of superficial deposits.

Active quarries and pits and the larger disused quarries and pits are shown; sites of completely backfilled quarries and pits (where known) are also shown since these could represent a possible hazard for developers. Each quarry or pit, whether active or disused, is annotated to indicate the type of resource which was obtained from it; the same annotation is given with each heading in this description. A few of the disused quarries and pits lie outside indicated resource areas. These either lie within resource areas which are too small to show on the map or were for clay, a resource which is not shown in detail on the map (see under Clay).

Limestone (L)

The Carboniferous Limestone has a broad north-south outcrop covering some 39 sq km in the western part of the study area, extending from Holywell in the north, through Halkyn Mountain, Cilcain and Loggerheads to Big Covert [SJ 200 600] in the south. Most of this outcrop is free from thick superficial deposits. On previous geological maps the limestone has been shown as one unit; in the recent survey six divisions (formations) have been recognised within the limestone and their areas of outcrop are now known in detail. The sequence of formations and their thickness variation is given in the Geological Sequence and a detailed description of the rock types in each formation in the Summary of Geology. Physical properties of the limestones and estimates of their purity, derived from Harrison and others (1983) and related to the new stratigraphy, are given in Table 3. The high purity reef limestones mentioned in that report (p. 75) as occurring between Prestatyn and Mold are not present within the study area.

The limestones of the Cefn Mawr Limestone and Minera Formation have been grouped together on the resource map since they have similar characteristics. The significant difference between the formations is that the Minera Formation, which is only present from Moel-y-Crio southwards, includes interbedded quartzitic sandstones which are not present in the Cefn Mawr Limestone. The limestones of the Cefn Mawr Limestone are interbedded with mudstones, with the proportion of mudstone increasing towards the top of the formation. The Minera Formation has been worked in the past for limestone, sandstone and silica sand; the Cefn Mawr Limestone is worked in all the active quarries (see Table 2 below) within the study area.

The Loggerheads Limestone, in contrast to the Cefn Mawr, is of very high purity and has a very low mudstone content. On the resource map it is grouped with the Llanarmon Limestone which has similar characteristics. It is worked in the northern five of the active quarries. The Llanarmon Limestone is not at present worked in the study area; it is quarried further south, near Llanarmon.

The Leete Limestone, which separates the Loggerheads and Llanarmon Limestones in the vertical succession, comprises interbedded porcellanous and fine-grained limestones of moderate purity and lithologies similar to the Llanarmon Limestone. It has been worked on a small scale in the past.

The Foel Formation, the thin basal division of the Carboniferous Limestone, is largely composed of dark impure limestone and has not been included on the resource map.

Limestone is without doubt the single most important resource within the study area. It is present in enormous quantity; the total amount of theoretically workable limestone, taking Ordnance Datum as a base level and an average surface level of the terrain as +250 m OD, is approximately 2.75×10^{10} tonnes. Obviously only a fraction of this amount is likely to be worked, at least in the foreseeable future, and many factors effectively reduce the amount of the resource actually available. These include geological factors such as the presence of shale and sandstone units in the upper part of the sequence and past mining for metalliferous deposits, areas sterilised by housing, and environmental factors such as the effect on topography and the presence of SSSI's. Nevertheless, less than 1% of the total volume has so far been extracted and one of the most important results of this study is that the new detailed geological maps will enable the future exploitation of the resource to be carried out more effectively now that the areal extent and thickness of the various limestone types is more closely defined. Deepening of some of the quarries can be considered, rather than further lateral expansion, particularly if the drainage of the northern part of the outcrop via the Milwr tunnel is maintained.

The Loggerheads and Llanarmon limestones are formations of predictable and constant nature; they are of high purity and good aggregate quality and can generally be expected to be of sufficient strength and durability to be used as a roadstone (base and sub-base) and concrete aggregate (Harrison and others, 1983). The Cefn Mawr Limestone and Minera Formation contain limestones of similar aggregate quality but they also contain a high proportion of mudstone/shale waste; however, the association of limestone and shale is particularly useful for cement production. The Minera Formation, however, has the additional problem that sandstone bodies within it

Table 2 Active limestone quarries at the time of survey

Quarry name	Operator	Grid Reference	Formation worked
Pant-y-pwll-dwr	North West Aggregates Ltd	SJ 190 720	Cefn Mawr, Loggerheads
Pant	Wimpey plc	SJ 199 702	Cefn Mawr, Loggerheads
Hendre	Alfred McAlpine Quarries Ltd	SJ 193 681	Cefn Mawr, Loggerheads
Trimm Rock	Tilcon Ltd	SJ 191 660	Cefn Mawr, Loggerheads
Cefn Mawr	Castle Cement Ltd	SJ 200 634	Cefn Mawr, Loggerheads
Aberduna	Pioneer Aggregates (UK) Ltd	SJ 204 618	Cefn Mawr
Burley Hill (partly on study area)	Welsh Aggregates Ltd	SJ 203 600	Cefn Mawr

detract from its value as a primary resource for the cement industry. The Leete Limestone and Foel Formation are more variable in character and their resource potential is therefore less predictable and harder to generalise; however, the combined thickness of these two formations represents only a small proportion of the limestone sequence as a whole.

Sandstone (S and Sf)

Two types of sandstone are shown on the map. These have been denoted as a) quartzitic sandstone (S) and b) feldspathic sandstone (Sf).

The quartzitic sandstones are the Kinnerton Sandstone Formation (described separately under Moulding Sand) and sandstone beds within the Halkyn and Minera formations. They are sandstones with a very high quartz (silica) content and a low content of feldspar. In the lower part of the stratigraphical sequence these sandstones contain an appreciable proportion of calcium carbonate either as included fossil (shell) debris or as an intergranular cement. Normally the quartzitic sandstones are hard, but locally and unpredictably the more carbonate-rich types may weather to a disaggregated and very pure silica sand.

The feldspathic sandstones include the Gwespyr Sandstone at the top of the Halkyn Formation and all the sandstones within the Coal Measures. They contain a higher content of feldspar than the quartzitic types and may also have an appreciable content of iron oxides. In general they are softer than the quartzitic sandstones and are more liable to weather along bedding planes or other planes of weakness in the rock.

Both types of sandstone have been widely exploited in the past, mainly in small quarries, for building and walling stone. None is now used for that purpose. Some of the softer sandstones within the Buckley Formation have been used in conjunction with the fireclays (see under Clay). The aggregate quality of the sandstones is not known in detail though their mineral composition and weathering characteristics suggest that the feldspathic sandstones are likely to be of poor to moderate quality while the quartzitic sandstones may locally be of good quality. However, there are a number of factors which militate against their exploitation for this purpose. Firstly, most of the sandstone beds, particularly within the Coal Measures, are relatively thin and often change rapidly in thickness, and thus are not amenable to large-scale quarrying operations; secondly, the

Table 3 Summary of mechanical and chemical property data from limestones. (Adapted from Harrison and others, 1983)

Formation	Rock type (generalized)	Purity		Mechanical properties			
		Purity	Insoluble residue	Flakiness Index	AIV	ACV	AAV
Cefn Mawr	Dark argillaceous limestone with shales	Generally low purity	1.2 - 31.9	27 - 51	20 - 24	23 - 25	5.0 - 9.1
Loggerheads	Massive pale grey limestone	Very high purity	0.2 - 1.5	14 - 31	20 - 25	25	10.2 - 11.8
Leete	Dark grey fine-grained limestone and massive pale grey limestone	Medium purity	No data available				
Llanarmon	Massive pale grey limestone	Very high purity	0.1 - 3.6	24 - 35	21 - 25	25	8.6 - 10.7

weathering characteristics of the sandstones are very variable and unpredictable, especially the quartzitic type where a hard sandstone can change laterally to a disaggregated sand within a few metres; thirdly, they are closely adjacent to very large resources of limestone of consistent and proven aggregate quality.

The disaggregated quartzitic sandstones (silica sand) have, in the past, been worked south [SJ 209 605] of Moel Findeg. There are probably appreciable resources of this material, but the apparently completely unpredictable nature of its occurrence makes it impossible to comment on its potential. It can only be assessed locally by detailed investigation on a site-specific basis.

Moulding Sand (MS)

Moulding sand is obtained from the Triassic Kinnerton Sandstone Formation at Kinnerton Bank Quarry [SJ 330 604] owned by Thos Dodd & Son Ltd. At this locality the sandstone has weathered to a disaggregated soft sand which is easily won. It has a large areal extent in the eastern part of the study area (see Thematic Element, Map 1 - Bedrock Geology), but only around Kinnerton is it covered by less than 10 m of superficial deposits. Since the decline in the steel industry, particularly at Shotton, the demand for moulding sand has fallen considerably and most of the output is now used for general purposes.

Clay (C)

The most important clay resources are those within the Buckley Formation, but clay has been worked at various locations at other horizons within the Coal Measures and in the Halkyn Formation. Additionally there have been very small local workings in Till (Boulder Clay). Only the Buckley Formation clays are indicated as a resource on the map. The only working pit is in the Buckley Formation, at Lane End, Buckley [SJ 288 639] operated by Butterley Brick Ltd. The main products from the Buckley Formation have been firebricks, acid-resistant bricks and housebricks.

The Buckley Formation has an estimated maximum thickness of 250 m but only the lowest beds have been exploited. In general terms these comprise about 15 m of fireclay overlain by 15 m of sandstone (GSGB 1920b, pp. 167-82); at some pits the lower part of the sandstone, which is the most siliceous and least feldspathic part, has been utilised as well as the fireclay. The worked area lies in two eastward-dipping fault-bounded north-south strips from Lane End to the Etna Brickworks [SJ 286 652] and from Hawkesbury [SJ 279 645] to the Castle Brickworks [SJ 277 661]. In the eastern strip the workings are limited by faulting, while in the western strip the worked clays dip under an increasing thickness of sandstone overburden and thus become less economical to work. Additionally, the siting of many of the brickworks on the eastern parts of the outcrops has resulted in partial sterilization of the resource.

There are three other areas in which the Buckley Formation is present (see Thematic Element, Map 1 - Bedrock Geology). In the first of these, between Tirlasgoch and Wared Wood, there is some evidence, along the Alltami Brook, that the lower, workable, part of the formation is present. However, most of the area is covered in thick superficial deposits (see map). The other two areas are between Nercwys and Gwysaney Hall [SJ 228 665] and along the margin of the Dee Estuary at Bagillt. Both areas are largely covered with thick superficial deposits and have not been included as a resource.

Thinner fireclays occur at various levels throughout the Coal Measures and the Halkyn Formation. These, together with other soft mudstones, have been dug for brickmaking and other products in various locations, for example Ruby Brickpits [SJ 206 678] in the Halkyn Formation and the Standard Brickpits [SJ 290 650] in the Coal Measures. They are not now utilised and since such clays and mudstones occur so commonly within the Coal Measures and Halkyn Formation it is not feasible to categorize them as a resource on the map.

Many of the old clay pits have been or are being used as disposal sites for industrial or household waste (see Thematic Element, Map 7 - Hydrogeology and Water Supply).

Chert (Ch)

The thickest development of chert is at the base of the Halkyn Formation, particularly along the eastern side of Halkyn Mountain (up to 150 m thick). Thinner beds are present at a similar horizon towards the southern part of the study area around Moel Findeg. On Halkyn Mountain the purest chert is found in the middle part of its development. The deposits have been worked in the past for silica for glass making and silica bricks, and more recently for aggregate. Although not utilised at present within the study area, it should be emphasized that chert is a very pure form of silica and that workable deposits are comparatively rare nationally.

Clay and Sand in pipes (CS)

These deposits are found in large solution hollows and steep-sided pipes in the Carboniferous limestones. They comprise soft clays and sands, probably of Tertiary age, and have been worked in the past for pipe-clay and porcelain manufacture near Rhes-y-Cae [SJ 190 710], Colomendy [SJ 203 620] and elsewhere (Maw, 1867; Strahan, 1890; Walsh and Brown, 1971). The deposits are too small in area to show on the Thematic Element Map and are unlikely to be of economic value in the future.

Calcspar (Ca)

Calcspar (crystalline calcium carbonate) occurs in varying quantity along most of the mineralized veins within the Carboniferous limestones. It has been worked until recently along a N-S vein [SJ 186 676 - 187 662] south of Hendre. Although it is a common mineral it rarely occurs in sufficient quantity to be worthwhile exploiting.

Thematic Element, Map 6 - Resources - Sand and Gravel

This map shows the known distribution of sand and gravel within 1 metre of the surface. Deposits less than 1 metre in thickness have been omitted. The deposits are almost entirely classified as Glacial Sand and Gravel on the Thematic Element, Map 2 - Superficial (Unconsolidated) deposits; one small area [SJ 239 718] of Alluvial (River) Terrace south of Flint is also included. Areas of potentially workable sand and gravel (see below) beneath overburden are also shown with the thickness of the deposits as proved in selected boreholes. Sites of active and former workings for sand and gravel are shown; grading diagrams are given for deposits proved both in shallow boreholes sunk as part of the present contract (see Appendix F) and in those put down earlier by the Industrial Minerals Assessment Unit (IMAU) of BGS. At present there are two active pits within the study area, at Rhosesmor [SJ 216 670] operated by Welsh Aggregates Ltd and at Star Crossing [SJ 175 680] operated by Tilcon Ltd.

The area covered by sheets SJ 16 and SJ 26 has previously been assessed by the IMAU, and the results published (Ball and Adlam, 1982). For consistency, the criteria used to describe the parameters of the deposits over the whole of the contract area are those used by the IMAU. Thus a deposit stated to be 'potentially workable' must satisfy the following criteria:

1. The deposit should average at least 1 metre in thickness.
2. The ratio of overburden to sand and gravel should be no more than 3:1.
3. The proportion of fines (particles passing an 0.625 mm BS sieve) should not exceed 40 per cent.
4. The deposit should lie within 25 m of the surface.

For particle size analyses a grain size definition based on the geometric scale 1/16 mm, 1/4 mm, 1 mm, 4 mm, 16 mm, and 64 mm has been adopted. The boundaries between fines (that is the clay and silt fractions) and sand, and between sand and gravel are placed at 1/16 mm and 4 mm respectively. The area previously assessed by the IMAU (Sheets SJ 16 and 26) has been resurveyed, and consequently the boundaries of the sand and gravel deposits on the published map (Ball and Adlam, 1982) have been amended. Additionally the areas indicated on that map as being "potentially workable" beneath superficial deposits have also been amended in the light of evidence from recent boreholes. No additional particle size analyses of deposits within this area have been carried out and the grading diagrams on that part of the Thematic Map are taken from the IMAU Report. A number of shallow boreholes were put down on sheets SJ 17 NE, 17 SE, 27 NW, 27 SW, and 27 SE as part of the present contract. The logs of these boreholes and the results of particle size analyses of the sand and gravel deposits proved in them are detailed in Appendix F; grading diagrams derived from these results are shown on the Thematic Map.

The main potential resource outside the area already covered by the IMAU Report lies along the slopes above the Dee Estuary between Greenfield and the Lead Brook [SJ 259 703]. The deposits are patchy and some areas, notably at Greenfield, Bagillt and in the southwestern outskirts of Flint, have been obscured by urban development. A second resource area lies between Hawarden and Warren Mountain [SJ 320 630]; the thickest deposits are around Hawarden but these are now largely built over. The limited number of boreholes in both areas precludes a detailed estimate of the value or quantity of the potential resource.

A number of factors affect the ease of working of the sand and gravel deposits; these include their topographic form and the degree of lateral variation within them. In some areas, as around Padeswood [SJ 275 620], the deposits have a marked moundy topography with a number of enclosed hollows (kettle holes) which may be filled with peat and/or clay to a considerable depth. One such hollow [SJ 237 710] north of Flint Mountain was proved to a depth of 17.4 m. The variable thickness of the sand and gravel in such moundy areas, together with the infilled hollows, renders such deposits more difficult to work on a large scale than flat-topped spreads of sand and gravel as at Rhosesmor. All the sand and gravel deposits show rapid lateral changes of lithology. In particular the coarser gravels are often confined to irregular channels within a deposit of generally finer grade. The proportions of the various types of clast within the gravels also vary considerably. In the south-western part of the study area, between Cilcain and Llanferres, the main clasts are siltstones and feldspathic sandstones, whereas in the remainder of the area limestone, quartzite and igneous rocks are predominant.

Approximately 43 sq km of the study area has sand and gravel either at the surface or concealed beneath overburden. Extrapolation from the results obtained by Ball and Adlam (1982) for the Mold area, with additional information obtained during the present study, indicates a total volume of deposit of between 3×10^9 and $4 \times 10^9 m^3$ (approximately 7.5×10^8 million tonnes). Of this at least 10% has already been sterilized by the urban areas of Mold, Bagillt, Flint, Greenfield and Hawarden. The areas of greatest potential resource lie along and adjacent to the valleys of the Alyn and Wheeler rivers, and between Mold and Flint.

Thematic Element, Map 7 - Hydrogeology and Water Supply

The map indicates the outcrops of the Cartboniferous Limestone, the sandstones within the Namurian and Westphalian and the Kinnerton Sandstone Formation. The superficial deposits have been omitted from this map for clarity; they are shown on Thematic Element, Map 2. It shows the locations of the springs, wells and boreholes that are licensed to abstract groundwater, and the positions of the main tunnels. Groundwater level contours are indicated in the Kinnerton Sandstone. In addition the positions of past and present landfill waste disposal sites and storage lagoons, for non-inert wastes, are marked. These have been subdivided by both waste type and period of tipping as both of these affect the quality of the leachate produced. They represent potential risks to groundwater quality.

The average annual precipitation for the study area varies from 700 mm in the Dee Valley to over 900 mm around Halkyn and Llanferres. Annual evapotranspiration is about 450 mm.

Within the area there are several groundwater abstractions for both public and industrial purposes, although most of the water used comes from surface and groundwater sources outside the area.

Silurian

The indurated mudstones and subordinate sandstones of the Elwy Group are relatively impermeable. However, small domestic supplies of soft water are locally obtained from springs.

Carboniferous

The Carboniferous Limestone is the second most important aquifer in the district in terms of water usage. However, drilling for water is highly speculative as the limestones have minimal primary porosities and permeabilities, and groundwater movement is restricted to fissures enlarged by solution. Few boreholes have been drilled in the area as, although the fissures are commonly fault-controlled, they are neither regularly spaced nor extensively interconnected; failure to intersect a fissure generally results in a dry hole. Although fissures are relatively sparse, where they do occur they tend to be large and, therefore, groundwater movement can be rapid. Flows from fissure systems issue from a limited number of springs whose flow rates vary considerably with time, and can decrease by an order of magnitude in dry weather. Tunnels through the limestone, associated with old mineral workings in the lead and zinc veins, intersect the fissure systems and have had a significant effect on the hydrogeology of the area. Two of these, the Milwr Sea Level Tunnel and the Halkyn Deep Level Tunnel, are now used for water supply. Where the limestone outcrop is free of superficial deposits, recharge is equal to effective precipitation.

Under low-flow conditions, water from the limestones is generally hard, but of good quality; the concentration of metal ions may be high. However, after heavy rain, supplies from both boreholes and springs may become turbid and polluted with high concentrations of suspended solids, organic matter, bacteria and nitrates.

Water from the Namurian strata is used from springs which occur at the junctions of the jointed sandstones with underlying less permeable mudstones. Boreholes that fail to intersect water-bearing joints and fissures are generally dry, and only one low-yielding borehole is recorded from the area. However, tunnels and adits associated with old lead and zinc workings have been used for water supply. The water is of good quality, but hard. Iron may be a problem, and other metals are present where the water has been in contact with mineral workings.

The mudstones and well-cemented sandstones of the Westphalian have low primary permeabilities. However, water occurs in the sandstones to depths of a few hundred metres within joints and fractures caused by mining subsidence. The yields of boreholes depend on the number of joints intersected but 5 l/s (litres per second) is not uncommon and a 123 m deep, 200 mm diameter borehole at Mold [SJ 2418 6348] yielded 16.1 l/s from beneath 13.4 m of superficial deposits. Despite the fact that disused colliery workings contain considerable storage, yields are rarely sustained in the long-term. This is because recharge is limited by the separation of the aquifer into isolated fault-blocks and by an extensive cover of low permeability drift of considerable thickness. Springs occur where the more permeable horizons crop out. Locally, beneath drift, overflowing conditions exist. The quality of the water is variable, but usually non-potable. Total dissolved solids are in the range 500-2000 mg/l (milligrammes per litre) and iron concentrations are often high. The water tends to be polluted by coal-mining activities. A borehole, 76 m deep, at Ferry Bank Farm [SJ 3280 6870], which had a yield of 4.4 l/s when initially completed, is used for spray irrigation.

Kinnerton Sandstone Formation

The Kinnerton Sandstone Formation is the major aquifer in the district despite its small outcrop area. The porosity of the weakly-cemented sandstones ranges from 20% to 30%. Intrinsic permeabilities vary but even the higher values are significantly less than the hydraulic conductivities encountered in the field. This is because water movement is controlled by fissures which provide nearly all the permeability and are encountered to depths of at least 100 metres. Transmissivities and yields vary considerably depending on the development of fissures but boreholes are rarely failures. Water in the fissures is supplied by inflow from pores in the matrix of the rock. Over 50 l/s have been obtained from the 760 mm diameter boreholes at Shotton [SJ 3380 7110 and SJ 3197 7256), but yields of 30 l/s are more common. Apart from a few very small areas in the south , where the aquifer is recharged by the Brad Brook, the entire sandstone outcrop is overlain by boulder clay or estuarine alluvium. Consequently the northern part of the aquifer, where abstractions occur, is being recharged from areas further to the east.

The quality of water is good, but hard; bicarbonate concentrations in excess of 360 mg/l have been recorded. Chloride concentrations are generally less than 100 mg/l, but higher values occur locally.

Superficial deposits

Most of the district is overlain by superficial deposits. These vary from impermeable boulder clay, estuarine alluvium and lacustrine deposits to permeable fluvial and glacial sands and gravels. They often exceed 20 metres in thickness (see Summary of Geology) and may exceed 90 metres locally. Yields of about 12 l/s have been obtained from a 4.1 m thick gravel horizon at the base of a 9.3 m deep borehole at Hendre [SJ 1828 6766] and from an 8 m thick sand and gravel deposit in a 55 m borehole at Sandicroft [SJ 3377 6742]. However, elsewhere recorded yields are generally about 5 l/s. Sand and gravel overlying an aquifer is an important factor allowing recharge, both directly and also indirectly, where there is hydraulic continuity between the aquifer and a river.

The quality of water from these deposits is variable. Unpolluted sources will be chemically similar to, but harder than, any surface water with which they are in continuity. However, the water is susceptible to contamination from agriculture, waste disposal sites, septic tanks and leaky sewers, except where the permeable glacial deposits are protected by overlying till. Near the coast, the water is liable to saline intrusion.

ENGINEERING GEOLOGY

The Geotechnical Database

Classification of the geological formations into groupings with similar engineering properties was carried out using geotechnical data extracted from site-investigation reports on sites within the study area. As much of the area is rural, coverage of these reports is restricted. In general, the reports are of two types in terms of their areal coverage; firstly, they relate to development and other sites in and around current urban areas (for example, Mold, Connah's Quay, Flint, Bagillt and Holywell); and secondly, they relate to road developments (particularly the A55, but including the A550/491 from Shotwick to Ewloe and bypasses to Mold and Penyffordd). The distribution of boreholes for which geotechnical data are available is shown on Thematic Element, Map 3. This information is supplemented by limited information from publications.

The geotechnical information used here to classify geological formations in engineering terms is not necessarily representative or comprehensive. For some formations (for example, the mudstones of the Elwy Group) no geotechnical data are available. For others (for example, the Kinnerton Sandstone Formation) data are limited to those from a handful of boreholes. For most of the formations, geotechnical information is only available for part of their outcrop. Consequently, summary values of geotechnical parameters given for the various formations should be considered as a general guide only and should not be used in detailed foundation design calculations.

Geotechnical test data were obtained for 4273 individual samples (a single Standard Penetration Test [S.P.T] counting as one sample) and these data were contained in 68 individual reports. Whilst this geotechnical data set may be relatively small compared with some other areas of similar size, considerable time was required to extract and analyse the data. To determine whether it was necessary to extract all geotechnical data to understand the properties of a formation, site-investigation reports were divided into four groups based on the extent of the factual information and accompanying interpretive reports. Subjective assessment of the quality of data was also attempted. The nature of reports ranged from those containing a wealth of geotechnical data, apparently of good quality, with detailed engineering geological logs and accompanying interpretive reports (Category One), to those that contained no geotechnical data, logs of low quality (often by drillers only, or worse), poorly located boreholes, and no interpretation (Category Four).

Of the 68 reports, 15 fell in Category One (the best), 24 in Category Two, 25 in Category Three and 4 in Category Four. A limited comparison was made of data from the different categories of report. One particular deposit (Till) was selected and a simple statistical analysis of some of the geotechnical data carried out for selected Category One test samples alone (322 samples), and for all test samples (1645 samples). The geotechnical classification test parameters chosen were moisture content, liquid limit, plastic limit, plasticity index, bulk density, clay, silt, sand and gravel contents, and the N value (the number of blows) from the S.P.T. In addition, data from consolidation, strength, compaction and chemical tests were compared visually. The comparison of the summary is shown in Tables 21 and 22.

The analysis carried out measured whether the two sets of data differ significantly, in statistical terms, for each parameter. For all parameters, the two sets of data were identical within 90% confidence limits (two-tailed Z-test). Visual inspection of consolidation, compaction and chemical test data showed the results from the two sets of test samples were very similar. Only in the case of results from the quick undrained triaxial test was there any divergence. The reason for this is not known but it may be related to the way results are quoted in the reports. Sometimes only undrained shear strength is quoted. In this case the undrained angle of friction is assumed to be zero and the undrained cohesion equals the undrained shear strength. In other reports, both undrained cohesion and angle of friction are given. Consequently, cohesion will be less than the shear strength. Other factors, such as the sampling method used, may have contributed to the disparity but analysis of this is beyond the scope of this report.

From this limited statistical analysis it may be concluded that for Till, at least, there is no significant difference in the summary geotechnical values obtained from a small (20%) sub-set of the test samples compared with the complete set. This implies that considerable time can be saved in handling and analysis of the geotechnical data by careful selection of limited "good quality" data only. However, further work is required to confirm that this conclusion applies generally.

Results of the following geotechnical tests and measurements (laboratory and in-situ) were abstracted from all categories of site investigation report and entered into the database.

1. Standard Penetration Test (S.P.T.)
2. Rock Quality Designation (R.Q.D.)
3. Moisture content
4. Liquid limit
5. Plastic limit
6. Bulk density
7. Dry density
8. Triaxial (drained and undrained)
9. Consolidation
10. Permeability
11. Particle size analysis (P.S.A.)
12. Compaction
13. California bearing ratio (C.B.R.)
14. pH
15. Sulphate content
16. Specific gravity

For most samples, only a few of these tests had been carried out, and rarely was a full range of test results available for a particular lithological/geotechnical unit within one borehole. Descriptions of the tests are provided in Appendix B.

The classification of rock (bedrock) and soils (superficial deposits) in terms of their engineering characteristics was aided by analysis of results from the more commonly performed tests:

1. Standard Penetration Test (S.P.T.)
2. Moisture content
3. Liquid limit
4. Plastic limit
5. Bulk density
6. Undrained triaxial
7. Consolidation
8. Particle size analysis

Results of this analysis (tables 4-22) give summary values of the geotechnical properties for the different soil units (superficial deposits). Insufficient data are available to produce a summary table of geotechnical properties of rock units (bedrock formations) other than the mudstones of the Buckley Formation, the Productive Coal Measures and the Halkyn Formation (Tables 4-10).

The summarised geotechnical properties given in tables 4-22 are intended as a general guide to engineering properties of the materials and their variation. In most cases, differences between maximum and minimum values are high. The classification should only be used, therefore, as a guide when planning a site-investigation and not as a substitute for a sampling and testing programme.

It should also be noted that no account is taken here of problems relating to past mining. These are described in the section relating to Thematic Element, Map 4 - Mining activities; Coal/Metalliferous. The suitability of any site will be dependent, therefore, not only on the engineering characteristics of the near-surface deposits but also on the likely effect that mining may have (in terms of collapse, old shaft location etc.) upon the integrity of the proposed structure.

Engineering Classification of the Rocks and Soils

The division of the rocks and soils of the Deeside area into groupings of materials of like engineering properties is based, in part, on the engineering properties themselves, as determined in the various tests, and partly on geological grounds. For example, whilst on the basis of their engineering properties there is little reason to differentiate estuarine alluvial sands from sands of other forms of alluvium, they can be clearly separated geologically (see Thematic Element, Map 2). Hence, they have been classified separately for engineering geological purposes.

In engineering terms, the rocks and soils of the area can be divided into eight broad groupings:

1. Rock
2. Fill, made ground
3. Peat
4. Normally consolidated cohesive soils
5. Loose non-cohesive soils
6. Heterogeneous soils (cohesive/non-cohesive soil mixes in varying proportions)
7. Overconsolidated cohesive soils
8. Dense non-cohesive soils

In general, group 1 materials are shown on Thematic Element, Map 1 - Bedrock Geology, and groups 2-8 on the Thematic Element, Map 2 - Superficial (Unconsolidated) deposits. It should be noted, however, that the simple division of rock and soils is complicated by gradation across the weathering profile of bedrock. Geotechnical data for weathered deposits are not usually available, except for the Buckley Formation, the Productive Coal Measures and the Halkyn Formation (see Tables 4-10).

Engineering Geology of the Bedrock Formations (Rock)

As indicated above, geotechnical data available from site-investigation reports for many formations are limited. This is particularly true of the solid formations. In many cases no test results are available and consequently there is only brief descriptive information.

The bedrock formations of the area are defined on the basis of internal lithological characteristics. They each comprise rocks of broadly similar engineering characteristics, as these are broadly related to lithology. It should be noted however, that the formations take no account of the degree and nature of fracturing which can greatly influence engineering behaviour. The broad lithological divisions used below are set out in terms of decreasing strength but, again, this is a generalisation. The divisions almost equate to those shown on Thematic Element, Map 1 - Bedrock Geology, except that the Ruabon Marl has been divided into sandstones and siltstones on the one hand and mudstones and shales on the other; feldspathic sandstones of the Productive Coal Measures and the Halkyn Formation have been grouped with the quartzitic sandstones of the Halkyn and Minera formations. This has been done because only limited data are available for these rocks.

The groupings are:

1. Limestones
   i) Dark grey, thinly bedded, argillaceous limestones with mudstones and interbedded, pale grey, massive, shelly limestones of the Cefn Mawr Limestone and Minera Formation.
   ii) Pale grey, coarse-grained, rubbly, shelly limestones of the Loggerheads Limestone and the Llanarmon Limestone.
   iii) Dark, brownish grey, porcellanous limestones with subordinate fine- to coarse-grained, shelly limestones of the Leete Limestone.
2. Chert
   Grey and white, laminated and glassy cherts and siliceous mudstones of the Halkyn Formation.
3. Sandstones
   i) Brownish red and yellow, fine- to medium-grained sandstones of the Kinnerton Sandstone Formation.
   ii) Purplish grey sandstones, weathering to a dense or very dense sand, and siltstones of the Ruabon Marl.
   iii) Yellowish brown to grey and white, fine- to coarse-grained feldspathic, quartzitic (variably calcareous lower in the sequence) sandstones of the Productive Coal Measures, Halkyn Formation and Minera Formation.
4. Mixed Limestone/Sandstone/Siltstone
   Dolomitic and argillaceous limestone and calcareous sandstones and siltstones of the Minera and Foel formations.
5. Mudstones/Shales
   i) Purplish grey and reddish brown mudstones of the Ruabon Marl.
   ii) Purple, reddish brown, yellow and grey, mottled, silty mudstones and seatearths of the Buckley Formation.
   iii) Grey mudstones/shales and silty mudstones of the Productive Coal Measures and the Halkyn Formation.
   iv) Grey, laminated, often cleaved, silty mudstones of the Elwy Group.

Geotechnical data for these rock formations are so sparse that a summary table of properties cannot be presented, However, where appropriate, such summary data as are available are given. For fuller descriptions of the formations, see Summary of Geology.

1. Limestones

The various limestone formations of the Carboniferous occur on the sparsely populated western side of the study area. Little geotechnical data are available, and there is only one site-investigation report which attempts to describe the limestones.

Limestones 1 (i) (Cefn Mawr Limestone and Minera Formation) and
Limestones 1 (ii) (Loggerheads Limestone and Llanarmon Limestone)
For engineering purposes no differentiation between these two groups has been made because of lack of data.

The limestones are strong but mass strength will be dependent on the presence of mudstone/shale layers, their thickness and separation, and jointing. The degree of jointing is variable. Open or infilled cavities and swallow holes (see Description of Thematic Element, Maps 2 and 5 for descriptions of infilling deposits) clearly present an engineering hazard. In the study area such features as have been observed are generally of small size though some substantial areas of foundered ground occur (see Thematic Element, Map 2). Larger cave systems are known elsewhere in the Carboniferous limestones of the Vale of Clwyd.

The limestone rockhead is very irregular with weathering opening up joints into which overlying superficial deposits are washed down. Because of the greater openness of near surface fractures and their greater frequency it is possible that limestones within about 5 m of rockhead can be ripped without blasting. In the more massive limestone however, blasting will be necessary. Cuttings in shaly limestones with mudstone layers should not be steeper than 1:1 as weathering of shaly layers may lead to their erosion and subsequent loss of support to limestone blocks.

The limestone would be suitable for use as a fill material after breaking up and can be classified as a rock for compaction purposes. The proportion of mudstone/shale is probably insufficient to affect the quality of the limestone fill.

Limestone 1 (iii) (Leete Formation)
No engineering information is available.

2. Chert

The cherts are variously described as strong, massive, very brittle, highly jointed rock with near surface joints that are open and clay infilled. Laminae of fine-grained, cherty sandstone or mudstone have also been noted. There are no geotechnical data available for the cherts.

3. Sandstones

Sandstones 3 (i) (Kinnerton Sandstone Formation)
Geotechnical data for this sandstone are only available from beneath the alluvial deposits of the Dee Estuary, where a maximum of 9.5 m has been penetrated. The sandstone is generally highly to moderately weathered (the weathering classification is that described by Anon (1972)) in the 2 to 3 m below rockhead, becoming slightly weathered below that depth. Fractures (from R.Q.D. and fracture space index records) range from a very low spacing (6-20 mm) within 2 to 3 m of rockhead to a high (200-1000 mm) spacing at greater depths.

Sandstones 3 (ii) (Ruabon Marl)
Values of uniaxial compressive strength are very variable ranging from around 10 MPa to about 81 MPa with a mean of 51 MPa (16 tests). For siltstones, in the same sequence, the mean strength is 50 MPa with a range from about 16.5 to 95 MPa (17 tests). Initial tangent modulus of elasticity values have also been determined. These are very variable ranging from 1.4 to 8.3 GPa for the sandstones and from 0.7 to 7 GPa for the siltstones.

Maximum nett safe bearing pressures for moderately strong sandstone ranging from 500 kPa for shallow foundations to 1500 kPa for pile foundations have been quoted for sandstones in the Flint area, whilst values of around 2000 kPa for piled foundations have been suggested between Flint and Connah's Quay. If this sandstone is used as a pile foundation in the vicinity of the Dee Estuary, any concrete for cast *in situ* piles will have to be placed beneath water which, in some instances, may be saline. Care should be taken to determine the nature of the strata below the pile founding depth to avoid the possibility of over-stressing any underlying weaker mudstones or shales.

The sandstone will be difficult to excavate by digging and will probably, therefore, require ripping.

Sandstones 3 (iii) (in the Productive Coal Measures, the Halkyn Formation and the Minera Formation)
These sandstones include the Hollin Rock and Gwespyr Sandstone (see Summary of Geology). They are variable but are generally moderately strong to strong and slightly to moderately weathered; however, near rockhead, they may be weathered to a weak rock and heavily fissured with clay infilling the fissures.

There is little geotechnical data available for this grouping. Maximum nett safe bearing pressures for footings on moderately strong sandstone beneath the weathering zone have been estimated at between 1000 and 3000 kPa. S.P.T. results for the sandstones gave N values in excess of 50 for a full 450 mm test drive for slightly to moderately weathered rock and between 25 and 47 for completely weathered rock.

For the more massive, strong sandstones in this group, explosives will be required to break up the rock to facilitate excavation. Weathered sandstone near to rockhead may be ripped or dug.

4. Mixed Limestone/Sandstone/Mudstone (Minera Formation and Foel Formation)

No site-investigation encountered rocks of these formations, and hence no geotechnical data are available.

5. Mudstones/Shales

Mudstones 5 (i) (Ruabon Marl)
These mudstones are difficult to distinguish from

the mudstones of the Buckley Formation (see Summary of Geology). Little geotechnical data are available but it is anticipated that their geotechnical properties and engineering behaviour will be similar to those of the mudstones of the Buckley Formation. Unconfined compression tests in slightly weathered mudstone and shale samples have indicated strengths in the range 16.5 to 18.6 MPa (14 samples), whilst initial tangent elastic moduli are in the range 0.7 to 2.3 GPa. Maximum nett safe bearing pressures for large spread footings have been estimated at 650 kPa. Strength may be expected to increase with depth, depending upon the degree of fracturing.

Mudstones 5 (ii) (Buckley Formation)
These mudstones have been described as ranging from a blocky, fractured shale with traces of clay weathering to a stiff to very stiff silty clay with frequent litho-relicts in the top metre.

Geotechnical data for the mudstones are limited, but are summarised in Table 4 for the highly to completely weathered mudstones upon which tests have been carried out. This weathered zone varies in thickness, and up to 6 m have been recorded, though this should not be considered as a maximum. The weathered rock can be classified as a clay of low to intermediate plasticity (CL to CI) (Figure 7) and low compressibility with a medium to high rate of consolidation. Strength determinations indicate that the clay is firm to stiff but, because of the fractured nature of the material it has been difficult to sample and, therefore, the clay is probably very stiff *en masse* with shear strengths probably greater than 500 kPa.

For pile foundations which may be considered for sites along the Dee Estuary, allowable end bearing pressure of about 200 kPa may be assumed with allowable shaft resistance in the mudstones of around 150 kPa. Piles should be taken 3 m into the rock through the weathered zone. N values from the S.P.T. are in excess of 50, even in the weathered zone.

Mudstones 5 (iii) (Productive Coal Measures and Halkyn Formation)
Geotechnically these mudstones are very similar (Tables 5-10), though data for those of the Productive Coal Measures are more limited. Consequently, the mudstones/shales are considered as one unit geotechnically. They are weak or very weak to moderately strong or strong, jointed shales and mudstones. Strength decreases with increased weathering. The internal laminae generally dip at low angles, from sub-horizontal up to 20°. A number of joint sets have been observed, the principal one being sub-vertical with generally clean joints and occasional calcite infilling. Subsidiary sets at about 70° to the horizontal and 45° have been noted.

The mudstones weather to a residual soil or completely weathered rock which is a firm to stiff, brown and grey, laminated, fissured, silty clay with litho-relicts of shale. The weathering zone has been observed up to about 4 m thick for completely weathered rock, but the degree of weathering will decrease beneath this depth. Weathering is greater where drift cover is thin.

The slightly weathered to highly weathered mudstone can be classified as a clay of intermediate plasticity (CI) (Figure 7) and low compressibility. The completely weathered rock is a clay of intermediate to high plasticity (CI to CH) (Figure 7). Shear strengths for the highly to completely weathered mudstones range from around 50 to about 200 kPa, but increase with depth and decreased weathering. Chemical tests indicate that pH ranges from 7.4 to 8.0 and that, with the exception of one sample, sulphate determinations place the materials in class 1 of the BRE classificiation (Building Research Establishment 1975) so that no special precautions need to be taken over the concrete used (but see the comment under Fill and Made Ground below). For all degrees of weathering, N values from the S.P.T. are generally greater than 50, though occasional lower values have been obtained indicating local softening of the weathered clays.

The mudstones/shales have not been considered suitable as fill materials unless there is no alternative; then they should only be used for low embankments. The weathered clay tends to be too wet and the mudstones/shales have a tendency to weather rapidly, swell and settle. However, their swelling has not been quantified.

Side slopes for cuts have been recommended at 1V:4H with drainage, particularly where the groundwater table is high. As observed above, precautions may have to be taken to prevent weathering and swelling.

Landslips have been observed at a few locations, particularly around Holywell (see Thematic Element, Map 2 - Superficial (Unconsolidated) deposits and its description). The failure planes for these slips appear to be located in weathered mudstone/shale. For stability analysis at one site the following parameters were selected: peak effective strength parameters - c' = 15 kPa,

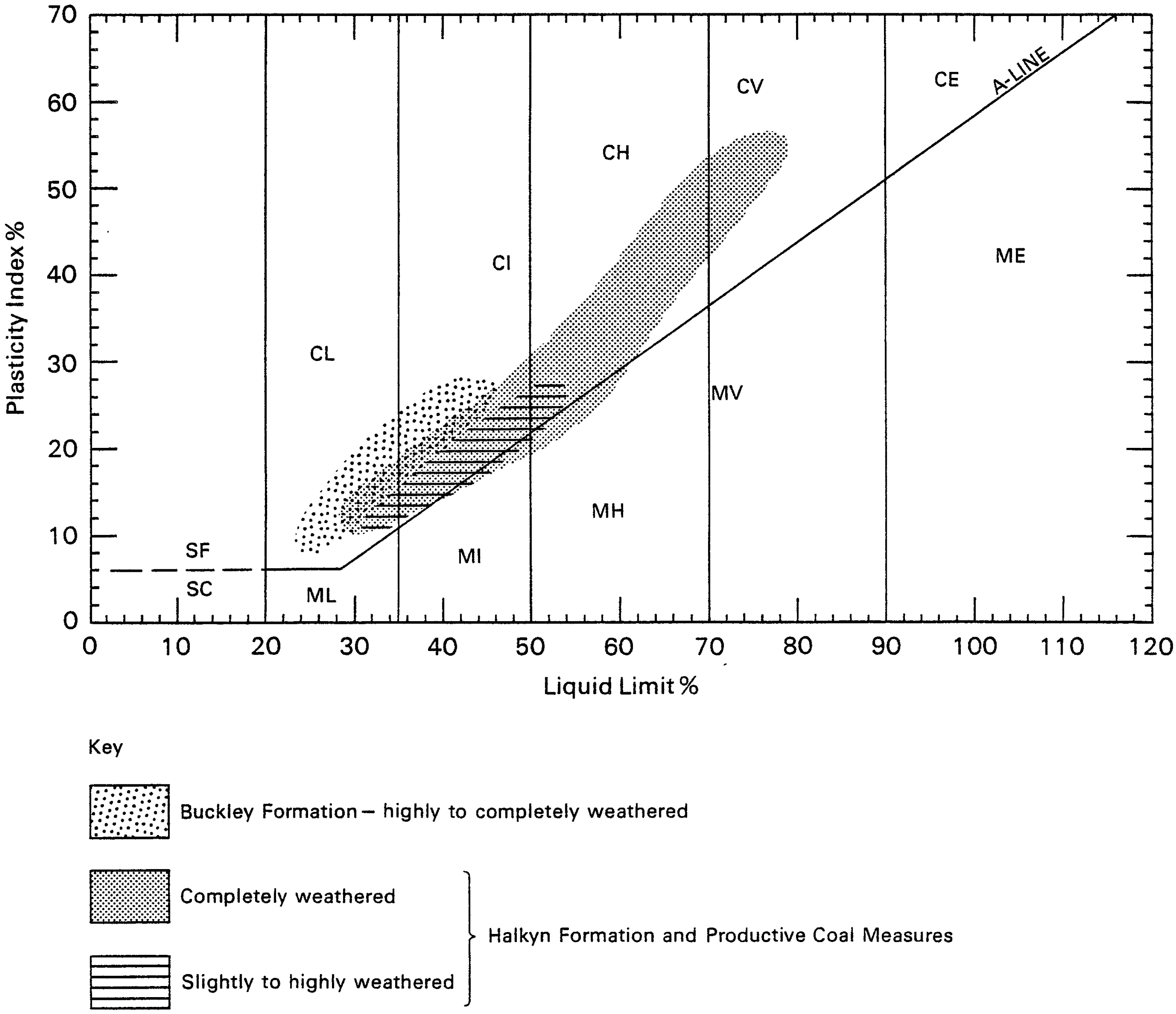


Figure 7 Plasticity Diagram for Weathered Mudstones and Shales

Table 4 Summary geotechnical data for Mudstones of Buckley Formation (Highly to Completely Weathered)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Mudstones of Buckley Formation – highly to completely weathered.	10 All ≥ 50	14 10(2.8) 5–16	11 37(7.4) 24–47	11 18(2.5) 15–22	11 19(5.8) 9–25	15 2.28(0.07) 2.20–2.43						

FILE FORMAT

No. of samples Average (Standard Deviation)* Range	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv+ m^2/MN	Cv+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3+	CBR %	Comments
* quoted where no. of samples ≥ 10 + class values see relevant tables below	6 16–90	6 0–28	3 2,3	3 3,4							**Weathered zone observed up to 6m thick. Low compressibility, medium to high rate of consolidation. Firm to stiff or very stiff. Piles require 3m penetration into rock, through weathered zone.**

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 – 0.3	Fluvio-glacial clays Late clays
2	Low	0.05– 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
1	<0.1	Greater than	CLAYS Montmorillonite
2	0.1 – 1	25	High plasticity
3	1 – 10	25 – 5	Medium plasticity
4	10 – 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 – 120 parts in 100 000
3	0.5–1.0%	1.9 – 3.1 grams/litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 – 5.6 grams/litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 5 Summary geotechnical data for Shales/Mudstones of Productive Coal Measures (Fresh to Slightly Weathered)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Shales/Mudstones of Productive Coal Measures; fresh to slightly weathered.	**5** **All ≥ 50**	**4** **2-8**					**1** **2.29**					

FILE FORMAT

No. of samples Average (Standard Deviation)* Range	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv+ m^2/MN	Cv+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3+	CBR %	Comments
* quoted where no. of samples ≥ 10 + class values see relevant tables below	**1** **100**	**1** **20**						**9** **7.4-8.0**	**9** **1**		**Shear strength increases with depth and decreasing weathering. Unsuitable as fill material. Side slopes 1:4 with drainage. Landslipping possible, slopes > 7° at particular risk. Piles require to be taken through weathered zone.**

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 - 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 - 0.3	Fluvio-glacial clays Late clays
2	Low	0.05- 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
1	<0.1	Greater than	CLAYS Montmorillonite
2	0.1 - 1	25	High plasticity
3	1 - 10	25 - 5	Medium plasticity
4	10 - 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2-0.5%		30 - 120 parts in 100 000
3	0.5-1.0%	1.9 - 3.1 grams/litre	120-150 parts in 100 000
4	1.0-2.0%	3.1 - 5.6 grams/litre	250-500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 6 Summary geotechnical data for Shales/Mudstones of Productive Coal Measures (Moderately to Highly Weathered)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Shales/Mudstones of productive Coal Measures; moderately to highly weathered.	27 23 values > 50 34-> 50	18 9(3.1) 4-16				2 2.13-2.26						

FILE FORMAT

No. of samples / Average (Standard Deviation)* / Range	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv^+ m^2/MN	Cv^+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3^+	CBR %	Comments
* quoted where no. of samples ≥ 10 + class values see relevant tables below	1 359	1 0									Shear strength increases with depth and decreasing weathering. Unsuitable as fill material. Side slopes 1:4 with drainage. Landslipping possible, slopes >7° at particular risk. Piles require to be taken through weathered zone.

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 - 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 - 0.3	Fluvio-glacial clays Late clays
2	Low	0.05- 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
1	<0.1	Greater than	CLAYS Montmorillonite
2	0.1 - 1	25	High plasticity
3	1 - 10	25 - 5	Medium plasticity
4	10 - 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2-0.5%		30 - 120 parts in 100 000
3	0.5-1.0%	1.9 - 3.1 grams/ litre	120-150 parts in 100 000
4	1.0-2.0%	3.1 - 5.6 grams/ litre	250-500 parts in 100 000
5	>2.0%	5.6 grams/ litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 7 Summary geotechnical data for Shales/Mudstones of Productive Coal Measures (Completely Weathered to Residual Soil)

Geotechnical Group		N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Shales/Mudstones of Productive Coal Measures completely weathered to residual soil.	No. of samples	5	40	3	3	3	5						
	Average (Standard Deviation)*	All 50	18(5.6)										
	Range		10–34	30–47	16–23	14–24	2.00–2.16						

FILE FORMAT

	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv⁺ m^2/MN	Cv⁺ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3⁺	CBR %	Comments
No. of samples	9	9						1	1		Completely weathered zone observed to 4m. Shear strengths increase with depth and decreasing weathering. Unsuitable as fill material. Landslipping possible. Slopes >7° at particular risk. Piles need to be taken through weathered zone. Slopes 1:4 with drainage.
Average (Standard Deviation)*									1		
Range	72–170	0						8.0			

* quoted where no. of samples ≥ 10
\+ class values see relevant tables below

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 – 0.3	Fluvio-glacial clays Late clays
2	Low	0.05– 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
1	<0.1	Greater than	CLAYS Montmorillonite
2	0.1 – 1	25	High plasticity
3	1 – 10	25 – 5	Medium plasticity
4	10 – 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 – 120 parts in 100 000
3	0.5–1.0%	1.9 – 3.1 grams/litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 – 5.6 grams/litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 8 Summary geotechnical data for Shales of Halkyn Formation (Fresh to Slightly Weathered)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Shales of Halkyn Formation (Holywell Shales) fresh to slightly weathered.	20 All ⩾ 50	5 8–18	4 38–44	4 19–24	4 17–23							

FILE FORMAT

No. of samples Average (Standard Deviation)* Range	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv+ m^2/MN	Cv+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3+	CBR %	Comments
* quoted where no. of samples ⩾ 10 + class values see relevant tables below											Shear strength increases with depth and decreasing weathering. Unsuitable as fill material. Side slopes 1:4 with drainage. Landslipping possible, slopes >7° at particular risk. Piles require to be taken through weathered zone.

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 – 0.3	Fluvio-glacial clays Late clays
2	Low	0.05– 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
1	<0.1	Greater than	CLAYS Montmorillonite
2	0.1 – 1	25	High plasticity
3	1 – 10	25 – 5	Medium plasticity
4	10 – 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 – 120 parts in 100 000
3	0.5–1.0%	1.9 – 3.1 grams/ litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 – 5.6 grams/ litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/ litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 9 Summary geotechnical data for Shales of Halkyn Formation (Moderately to Highly Weathered)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Shales of Halkyn Formation (Holywell Shales) moderately weathered to highly weathered.	17	14	7	7	7	3	1					
	9 values ⩾ 50	17(5.6)										
	21–⩾ 50	10–26	32–51	21–26	11–25	1.90–2.22	1.55					

FILE FORMAT

No. of samples
Average (Standard Deviation)*
Range
* quoted where no. of samples ⩾10 + class values see relevant tables below

Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv^+ m^2/MN	Cv^+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3^+	CBR %	Comments
2	2						1	1		**Shear strength increases with depth and decreasing weathering. Unsuitable as fill material. Side slopes 1:4 with drainage. Landslipping possible, slopes >7° at particular risk. Piles require to be taken through weathered zone.**
								2		
124–154	0						7.4			

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 – 0.3	Fluvio-glacial clays Late clays
2	Low	0.05– 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
			CLAYS
1	<0.1	Greater than	Montmorillonite
2	0.1 – 1	25	High plasticity
3	1 – 10	25 – 5	Medium plasticity
4	10 – 100	15 or less	Low plasticity
			SILTS
5	>100		

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 – 120 parts in 100 000
3	0.5–1.0%	1.9 – 3.1 grams/litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 – 5.6 grams/litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 10 Summary geotechnical data for Shales of Halkyn Formation (Completely Weathered to Residual Soil)

Geotechnical Group		N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Shales of Halkyn Formation (Holywell Shales); completely weathered to residual soil.	No. of samples	30	24	15	15	15	12	1					
	Average (Standard Deviation)*	23 values 50	26(11.0)	49(12.4)	23(4.0)	27(11.2)	1.96(0.08)						
	Range	8– 50	7–49	32–77	17–32	12–53	1.84–2.11	1.47					

FILE FORMAT

	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv+ m^2/MN	Cv+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3+	CBR %	Comments
No. of samples	12	12						3	3		Completely weathered zone observed to 4m. Strength increases with depth and decreasing weathering. Unsuitable as fill Landslipping possible particularly for slopes >7°. Piles need to be taken through weathered zone. Cut slopes 1:4 with drainage.
Average (Standard Deviation)*	92(53)								1		
Range	23–198	0						7.6–7.7			

* quoted where no. of samples ⩾ 10
\+ class values see relevant tables below

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 - 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 - 0.3	Fluvio-glacial clays Late clays
2	Low	0.05- 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
			CLAYS
1	<0.1	Greater than	Montmorillonite
2	0.1 - 1	25	High plasticity
3	1 - 10	25 - 5	Medium plasticity
4	10 - 100	15 or less	Low plasticity
			SILTS
5	>100		

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2-0.5%		30 - 120 parts in 100 000
3	0.5-1.0%	1.9 - 3.1 grams/litre	120-150 parts in 100 000
4	1.0-2.0%	3.1 - 5.6 grams/litre	250-500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

ϕ' = 21°; residual effective strength parameters - c' = 0 kPa, ϕ' = 14°; bulk density 2.00 Mg/m^3. Where slopes steeper than about 7° are present on these mudstones/shales, careful investigation should be made to try to determine if any slope movement has taken place and to check the effect of any proposed structure upon slope stability.

Limited information is available on bearing pressures for the mudstones/shales. For the completely weathered rock, maximum nett safe bearing pressures of 120 kPa for strip footings and 145 kPa for square footings have been suggested. For moderately weathered mudstones/shales, values in the range 300 to 600 kPa are proposed; for slightly weathered mudstones/shales, 1200 to 1600 kPa. For end bearing piles, end bearing pressures between 1000 and 1500 kPa are suggested, and usually towards the higher end of the range. The piles should be taken through the weathered zone (at least 2.0 m, but dependent on the site) into the hard mudstone/shale beneath, if possible. Confirmation should be obtained that weathered mudstone/shale horizons are not present within the stressed zone beneath the piles.

As these mudstones/shales soften on contact with water, excavations should be protected as far as is possible against wetting, and they will need support. The weathered mudstones/shales are diggable but may need ripping when fresh.

Mudstones 5 (iv) (Elwy Group)
No geotechnical data are available for the mudstones of this group. They are often cleaved (see Summary of Geology).

Engineering Geology of the Superficial (Unconsolidated) Deposits (Soils)

The superficial (unconsolidated) deposits have been subdivided both on the basis of their lithology (which can be directly related to their engineering characteristics) and the environment in which they were deposited. The following categories of deposit are described in terms of their engineering characteristics.

1. Backfill and Made Ground
2. Peat
3. Wind-blown Sand
4. Alluvium
5. Estuarine Alluvium
6. Lacustrine Alluvium
7. Heterogeneous deposits (Head)
8. Glacial Sand and Gravel
9. Till (Boulder Clay)

The engineering problems associated with each of these deposits are reviewed following their descriptions. Their distribution is shown on Thematic Element, Map 2 - Superficial (Unconsolidated) deposits.

1. Backfill and Made Ground

This category is very variable in composition, thickness and geotechnical properties. In general, it is loose, weak, and highly compressible. The most common materials involved are chemical waste, domestic refuse, mining waste and quarrying waste.

2. Peat

Geotechnical data (Table 11) on peat are only available for three samples, though it was encountered in several boreholes (around Penyffordd, Northop, Holywell and Flint). These occurrences of peat were at, or near, the ground surface (except in one case where it was buried beneath 6.5 m of fill) and it was recorded as varying in thickness from about 1 m up to almost 3 m. It is usually associated with very soft, grey, organic, alluvial clays and is, itself, usually very soft to soft, dark brown to black and fibrous, though often it has a significant clay content. Occasionally, sandy bands are found in it.

The peat is highly compressible with high moisture contents and Atterberg limits, and low density. It will not necessarily be present at the surface but may be thinly covered by alluvial sands or clays.

3. Wind-blown Sand

As this deposit was not recorded in any site-investigation report, no geotechnical data are available. The sand is generally fine-grained.

4. Alluvium

Mainly restricted to the floor of the valley of the River Alyn and several smaller river valleys in the area, the alluvium varies from a soft, compressible, silty clay or clayey silt of low to intermediate plasticity (CL to CI) (Figure 8) to a clayey, silty, fine-grained sand, with occasional gravel. The geotechnical properties of the alluvium are summarised in Tables 12 and 13. In most respects it resembles estuarine alluvium (see below) but with a greater abundance of gravel, and greater heterogeneity produced by the more energetic depositional environment. Generally low maximum nett bearing pressures have been

Table 11 Summary geotechnical data for Peat

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Peat; dark brown, fibrous, with occasional sand or clay.	1 4	3 59-364	1 370	1 137	1 233	2 1.00-1.60		1 2.19				

FILE FORMAT

No. of samples Average (Standard Deviation)* Range
* quoted where no. of samples ≥ 10 + class values see relevant tables below

Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv^+ m^2/MN	Cv^+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3^+	CBR %	Comments
2 9-32	2 0						1 5.0	1 1		**Very soft, highly compressible 1to 3m thickness recorded. Limited extent in area. Remove or avoid.**

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 - 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 - 0.3	Fluvio-glacial clays Late clays
2	Low	0.05- 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
1	<0.1	Greater than	CLAYS Montmorillonite
2	0.1 - 1	25	High plasticity
3	1 - 10	25 - 5	Medium plasticity
4	10 - 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2-0.5%		30 - 120 parts in 100 000
3	0.5-1.0%	1.9 - 3.1 grams/ litre	120-150 parts in 100 000
4	1.0-2.0%	3.1 - 5.6 grams/ litre	250-500 parts in 100 000
5	>2.0%	5.6 grams/ litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

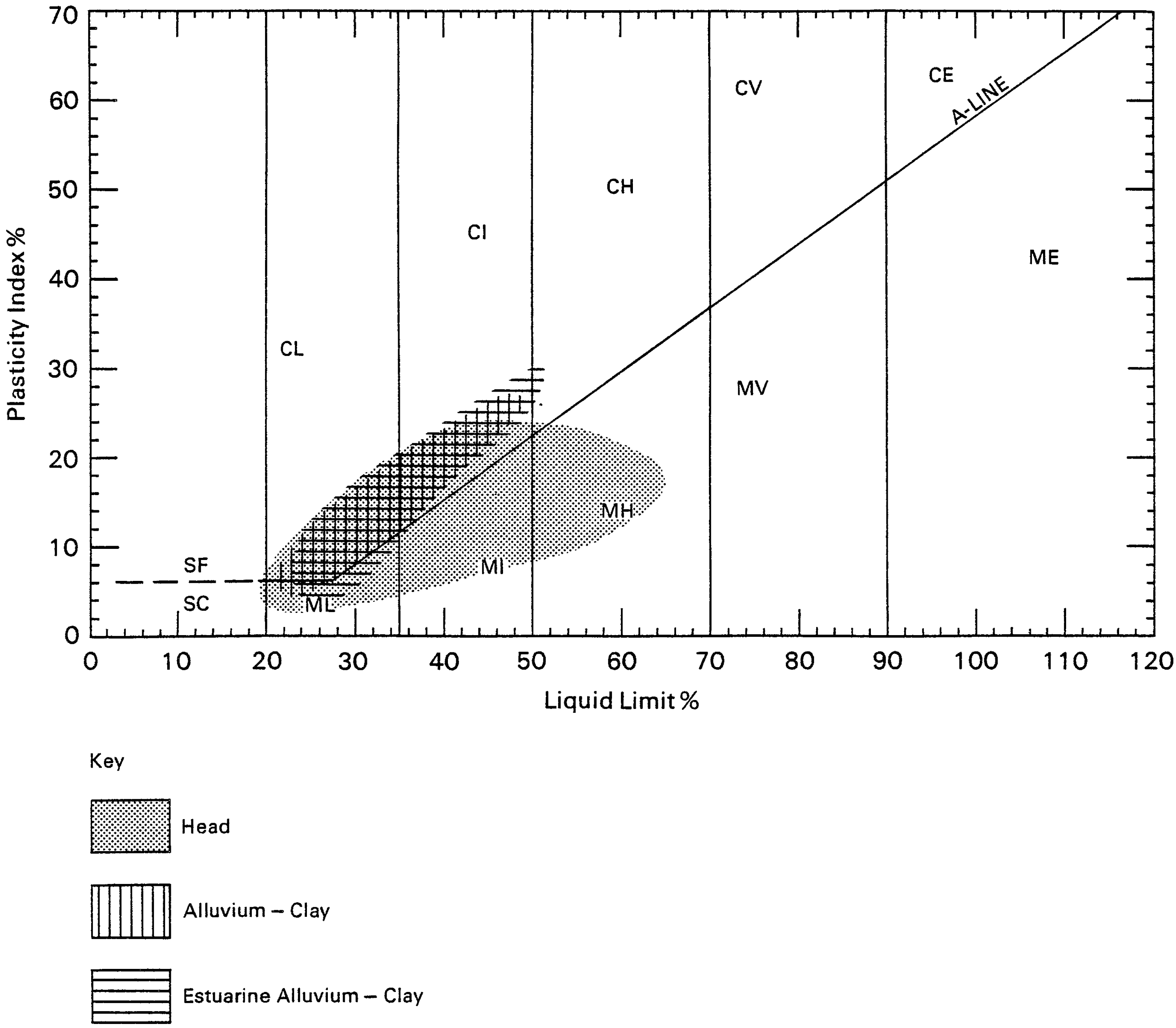


Figure 8 Plasticity Diagram for Head, Alluvial and Esturine Alluvial Cohesive Soils

Table 12 Summary geotechnical data for Alluvium (Clay and Silt)

Geotechnical Group		N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Alluvium; soft compressible silty clay/clayey silt.	No. of samples	9	36	28	25	25	29		4	8	8	8	8
	Average (Standard Deviation)*		22(6.1)	30(7.2)	17(2.2)	15(5)	2.04(0.11)						
	Range	5–19	11–40	13–48	11–23	5–25	1.80–2.32		2.34–2.64	1–35	40–60	5–50	0–2

FILE FORMAT

	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv^+ m^2/MN	Cv^+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3^+	CBR %	Comments
No. of samples	31	31	11	11				1	1		**Very heterogeneous. Low nett bearing capacities, unsuitable for support of lightweight structures.**
Average (Standard Deviation)*	64(80)	9(12.2)	3,4	2,3,4					2		
Range	0–140	0–32						7.0			

* quoted where no. of samples ≥ 10
\+ class values see relevant tables below

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 - 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 - 0.3	Fluvio-glacial clays Late clays
2	Low	0.05- 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
			CLAYS
1	<0.1	Greater than	Montmorillonite
2	0.1 - 1	25	High plasticity
3	1 - 10	25 - 5	Medium plasticity
4	10 - 100	15 or less	Low plasticity
			SILTS
5	>100		

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 - 120 parts in 100 000
3	0.5–1.0%	1.9 - 3.1 grams/ litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 - 5.6 grams/ litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/ litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 13 Summary geotechnical data for Alluvium (mainly clayey, silty fine sand)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Alluvium, mainly clayey, silty fine sand.	10 29(9.1) 17–45	12 16(15) 9–60	4 20–57	4 13–23	4 7–34	7 1.84–2.34						

FILE FORMAT

No. of samples
Average (Standard Deviation)*
Range
* quoted where no. of samples ≥ 10 + class values see relevant tables below

Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv^+ m^2/MN	Cv^+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3^+	CBR %	Comments
5 65–119	5 0									**Very heterogeneous. Low nett bearing capacities, unsuitable for support of lightweight structures, though gravelly layers show much higher bearing capacities.**

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 – 0.3	Fluvio-glacial clays Late clays
2	Low	0.05– 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
			CLAYS
1	<0.1	Greater than	Montmorillonite
2	0.1 – 1	25	High plasticity
3	1 – 10	25 – 5	Medium plasticity
4	10 – 100	15 or less	Low plasticity
			SILTS
5	>100		

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 – 120 parts in 100 000
3	0.5–1.0%	1.9 – 3.1 grams/ litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 – 5.6 grams/ litre	250–500 parts in 100 000
5	> 2.0%	5.6 grams/ litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

quoted, though gravelly layers show much higher bearing pressures (100 kPa for foundations 1.2 m wide, reducing to 80 kPa for foundations greater than 3 m wide). Sulphate contents are not high.

5. Estuarine Alluvium

These deposits occur in the Dee Estuary (including those below the high water mark). Three lithological units showing distinctive geotechnical properties were identified in borehole logs:

i) Alluvial clay: very soft to soft, occasionally firm, grey and brown, occasionally sandy, silty clay with sandy and organic layers. The deposit reaches 3 m in thickness, is of low to intermediate plasticity (CL to CI) (Figure 8), normally consolidated and is of high compressibility and low strength.
ii) Clayey, silty, fine-grained sand: an uncommon lithology, intercalated with the alluvial clay and alluvial sand.
iii) Alluvial sand: grey, brown and grey/brown, uniformly graded, slightly silty sand, commonly with sea-shells and occasional gravel. Generally saturated, loose but becoming denser with depth, reaching medium dense at about 10 m.

The geotechnical properties are summarised in Tables 14-16.

A broad trend of coarsening with depth and away from the estuary margins is paralleled by increasing N values from the S.P.T., and decreasing moisture contents. This trend is a regional one, though on a site scale the different lithologies are intercalated.

6. Lacustrine Alluvium

This lithology occurs only locally. It consists mainly of a soft to stiff, laminated, compressible clay of low to high plasticity (CL to CH) (Figure 9), or a soft to stiff, gravel-free, compressible clay of low to high plasticity associated with glacial till. The limited geotechnical data available are summarised in Table 17. S.P.T. results should be interpreted with caution (see Engineering Problems below).

7. Heterogeneous deposits (Head)

Head deposits are heterogeneous and are found as a relatively thin veneer on many hillslopes, minor valley sides and valley bottoms. They are transported deposits formed by solifluction (in glacial and immediately post-glacial times) and hillcreep. Typically, the material is a sandy, silty clay with occasional gravel. The composition is very much controlled by the nature of the soils and rocks immediately up-slope. For example, southeast of Holywell, the head consists of completely weathered mudstone with a large proportion of fresh and slightly weathered mudstone fragments and occasional rounded grey limestone gravel. This originates from the mudstones of the Halkyn Formation and the Carboniferous limestones of the area. The soil is stiff to very stiff.

Head does not necessarily occur at the surface. It may underlie the till (boulder clay). The thickness of the head is very variable, ranging from less than 1 m up to at least 5 m.

Geotechnical data on head are limited, being restricted to sites around Holywell and Penyffordd. However, it is much more extensive than shown on Thematic Element, Map 2, which shows head only where greater than 1 metre thick. Its geotechnical properties are summarised in Table 18.

The more cohesive head can be described as a soft to firm clay and silt of low to intermediate and sometimes high plasticity (CL to CI and ML to MI and MH) (Figure 8) and medium to high compressibility. S.P.T. N values are extremely variable, probably reflecting the heterogeneous nature of the deposit.

8. Glacial Sand and Gravel

This is a widely occurring and locally thick deposit, found at surface as well as within the till. It is a very variable, heterogeneous deposit; the material is in general, medium dense and well sorted. The main lithology is a well-sorted sand and gravel, with several subordinate lithologies. Clay can occur as a soft to firm matrix with the granular material but more commonly forms thin bands which can vary from very weak to very stiff. Loose gravelly or sandy silt layers, and lenses of silty sand are also found. Geotechnical properties are summarised in Table 19.

In some areas, stratified medium dense to dense, occasionally loose silty to very silty sand and subordinate gravel occurs. The geotechnical properties of these sands are summarised separately in Table 20.

9. Till (Boulder Clay)

This is often a very thick and widespread deposit occupying, together with glacial sand and gravel,

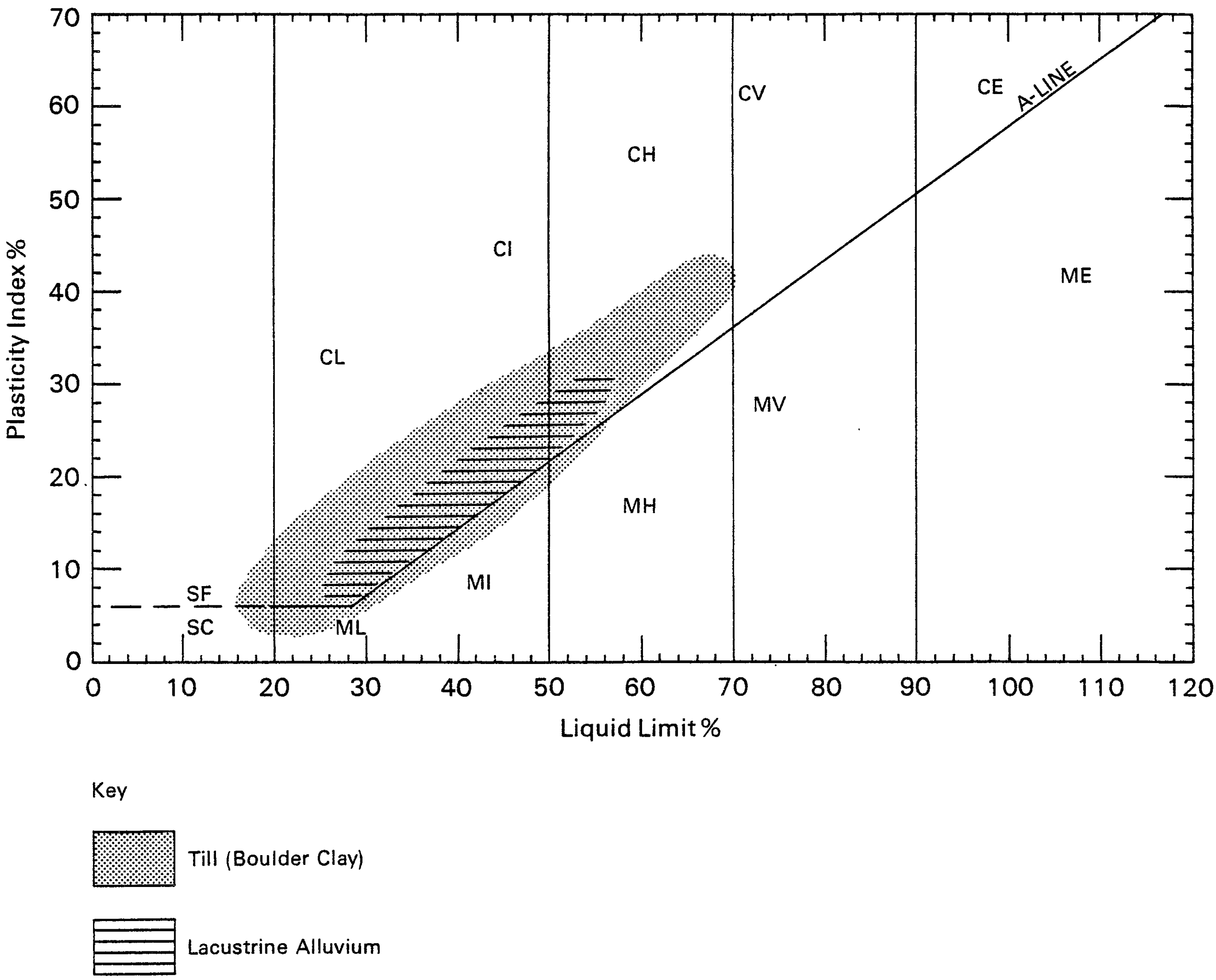


Figure 9 Plasticity Diagram for Till (Boulder Clay) and other Glacial Cohesive Soils

Table 14 Summary geotechnical data for Esturine Alluvium (Clay and Silt)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Estuarine Alluvium; soft, compressible silty clay/clayey silt.	**22**	**36**	**11**	**10**	**10**	**21**	**1**		**8**	**8**	**8**	**8**
	7(7.25)	**33(14.3)**	**37(8.6)**	**21(3)**	**17(8)**	**1.87(0.27)**			**22(12.7)**	**38(18.8)**	**36(17.1)**	**5(11.1)**
	1–19	**5–75**	**23–52**	**14–24**	**6–31**	**1.13–2.30**	**1.62**		**3–36**	**18–67**	**15–73**	**0–32**

FILE FORMAT

	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv+ m^2/MN	Cv+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3+	CBR %	Comments
No. of samples	**21**	**21**	**5**	**5**				**7**	**12**		**High water-table, tidally induced fluctuations in hydrostatic pressure. Very low bearing capacity, unsuitable for light structures. Prone to large differential settlements. Excavations need support and de-watering.**
Average (Standard Deviation)*	**24(19.9)**	**7(9.6)**	**2,4**	**3,4**					**1,2**		
Range	**3–70**	**0–33**						**6.5–7.9**			

* quoted where no. of samples ≥ 10
+ class values see relevant tables below

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 – 0.3	Fluvio-glacial clays Late clays
2	Low	0.05 – 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv m^2/year	Plasticity Index Range	Soil Type
			CLAYS
1	<0.1	Greater than	Montmorillonite
2	0.1 – 1	25	High plasticity
3	1 – 10	25 – 5	Medium plasticity
4	10 – 100	15 or less	Low plasticity
			SILTS
5	>100		

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 – 120 parts in 100 000
3	0.5–1.0%	1.9 – 3.1 grams/litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 – 5.6 grams/litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 15 Summary geotechnical data for Esturine Alluvium (mainly clayey, silty fine sand)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Estuarine Alluvium; mainly clayey, silty fine sand.	87	25	1			6	2		17		17	17
	20(13.4)	25(13)							5(7.9)		86(16.4)	4(9.7)
	2–50	8–70	19			1.61–1.98	1.53–1.58		0–31		38–98	0–35

FILE FORMAT

No. of samples / Average (Standard Deviation)* / Range	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv^+ m^2/MN	Cv^+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3^+	CBR %	Comments
No. of samples	6	6	1	1	2			4	5		Near-surface water-table, prone to tidally induced fluctuations in hydrostatic pressure.Risk of 'running' and 'piping'.Excavations require shoring and dewatering.Unsuitable for support of lightweight structures.
Average (Standard Deviation)*			4	3					1,2		
Range	0–16	0–38			$4–7 \times 10^{-5}$			6.5–7.8			

* quoted where no. of samples ⩾ 10
\+ class values see relevant tables below

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 – 0.3	Fluvio-glacial clays Late clays
2	Low	0.05– 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
1	<0.1	Greater than	CLAYS Montmorillonite
2	0.1 – 1	25	High plasticity
3	1 – 10	25 – 5	Medium plasticity
4	10 – 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 – 120 parts in 100 000
3	0.5–1.0%	1.9 – 3.1 grams/ litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 – 5.6 grams/ litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/ litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 16 Summary geotechnical data for Esturine Alluvium (Sand)

Geotechnical Group		N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Estuarine Alluvium; alluvial sand with or without shells, no significant gravel.	No. of samples	549	38	1	1	1	38			163		163	163
	Average (Standard Deviation)*	31(20.9)	21(5.6)				1.84(0.06)			2(4.9)		94(14.6)	34(45.8)
	Range	6–120	5–38	35	20	15	1.72–2.03			0–27		0–100	0–100

FILE FORMAT

No. of samples / Average (Standard Deviation)* / Range	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv+ m^2/MN	Cv+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3+	CBR %	Comments
No. of samples	5	5	1	1	4			25	28	34	High water-table, risk of 'running' and 'piping'. Tidally-induced fluctuations in hydrostatic pressure. Excavations need shoring and de-watering. Bearing capacities increase with depth. SPT unreliable due to 'blowing' in sands. CBR 10%.
Average (Standard Deviation)*			2	4				7.9(0.4)	1,2	38(10)	
Range	3–30	0–34			$2x10^{-4}$–$7x10^{-6}$			7.2–9.2		5–45	

* quoted where no. of samples ≥ 10
+ class values see relevant tables below

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 - 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 - 0.3	Fluvio-glacial clays Late clays
2	Low	0.05- 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
			CLAYS
1	<0.1	Greater than	Montmorillonite
2	0.1 - 1	25	High plasticity
3	1 - 10	25 - 5	Medium plasticity
4	10 - 100	15 or less	Low plasticity
			SILTS
5	>100		

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 - 120 parts in 100 000
3	0.5–1.0%	1.9 - 3.1 grams/litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 - 5.6 grams/litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 17 Summary geotechnical data for Lacustrine Alluvium

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Lacustrine Alluvium; soft to stiff, laminated, compressible clay.	10	53	24	24	43	4	4		10	10	10	10
	40(23.5)	18(5.1)	34(9.1)	17(2.7)	17(7.7)	2.09(0.11)			16(10.4)	30(23.4)	34(27.5)	20(25.1)
	10–60	10–34	21–54	14–24	6–34	1.90–2.35	1.64–2.04		5–33	5–63	8–85	0–58

FILE FORMAT

	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv^+ m^2/MN	Cv^+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3^+	CBR %	Comments
No. of samples	32	32	9	9				7	7	4	**Problems of stability and settlement, mainly in softer clays, the presence of which should be assumed rather than considered as an exception when this deposit is identified.**
Average (Standard Deviation)*	80(46.6)	5(8.6)	2,3	3,4					1		
Range	20–140	0–32						6.6–8.2		7.3–19.0	

* quoted where no. of samples ≥ 10
\+ class values see relevant tables below

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 - 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 - 0.3	Fluvio-glacial clays Late clays
2	Low	0.05- 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
			CLAYS
1	<0.1	Greater than	Montmorillonite
2	0.1 - 1	25	High plasticity
3	1 - 10	25 - 5	Medium plasticity
4	10 - 100	15 or less	Low plasticity
			SILTS
5	>100		

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 - 120 parts in 100 000
3	0.5–1.0%	1.9 - 3.1 grams/ litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 - 5.6 grams/ litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/ litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 18 Summary geotechnical data for Hetrogeneous Deposits (Head)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Heterogeneous Deposits (Head)	37	100	68	63	63	69	2	8	13	13	13	13
	23(15.5)	18(9.3)	29(8.1)	18(5.6)	13(5.3)	2.10(0.19)			9(6.4)	14(11.3)	41(23)	34(23.3)
	3–75	8–72	18–67	12–48	1–26	1.49–2.46	1.90–1.97	2.61–2.71	0–23	1–40	20–93	0–70

FILE FORMAT

No. of samples
Average (Standard Deviation)*
Range

* quoted where no. of samples ⩾ 10
+ class values see relevant tables below

Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv+ m^2/MN	Cv+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3+	CBR %	Comments
70	55	14	1		2	2	9	9	4	Very heterogeneous, variable SPT N-values, very extensive as a thin veneer. Possible presence of shear planes, which loading may reactivate, with sloping sites particularly at risk. Perched water and running conditions in coarser horizons.
36(28.6)	4(6.7)	3,4	4					1,2		
10–120	0–30				1.93–2.04	9–10	7.1–7.9		3.8–10.2	

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 – 0.3	Fluvio-glacial clays Late clays
2	Low	0.05– 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv m^2/year	Plasticity Index Range	Soil Type
			CLAYS
1	<0.1	Greater than	Montmorillonite
2	0.1 – 1	25	High plasticity
3	1 – 10	25 – 5	Medium plasticity
4	10 – 100	15 or less	Low plasticity
			SILTS
5	>100		

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 – 120 parts in 100 000
3	0.5–1.0%	1.9 – 3.1 grams/litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 – 5.6 grams/litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 19 Summary geotechnical data for Glacial Sand and Gravel (or Sandy Gravel associated with Till)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Glacial Sand and Gravel or Sandy Gravel associated with Till.	398	88	6	5	5	18			64	64	64	64
	37(26.9)	20(99.5)				21.2(1.65)			5(2.75)	7(8.2)	23(21)	50(24)
	0–140	0–21	24–57	13–25	11–32	1.80–2.35			0–12	0–55	2–87	0–97

FILE FORMAT

No. of samples / Average (Standard Deviation)* / Range	Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv+ m^2/MN	Cv+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3+	CBR %	Comments
No. of samples	18	18				4	4	21	21		**Very heterogeneous. High hydrostatic pressures in granular materials cause sagging/heaving on excavation, water ingress and unreliable SPT results. Bearing pressures variable, differential settlements possible. Cuttings 1:2–3 with drainage. CBR 10%. Excavations need support and de-watering.**
Average (Standard Deviation)*	122(141.5)	10(12.6)						7.5(0.5)	1,2		
Range	20–140	10–40				1.90–2.22	6–9	6.5–8.5			

* quoted where no. of samples ⩾ 10
\+ class values see relevant tables below

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 – 0.3	Fluvio-glacial clays Late clays
2	Low	0.05– 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv m^2/year	Plasticity Index Range	Soil Type
1	<0.1	Greater than	CLAYS Montmorillonite
2	0.1 – 1	25	High plasticity
3	1 – 10	25 – 5	Medium plasticity
4	10 – 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 – 120 parts in 100 000
3	0.5–1.0%	1.9 – 3.1 grams/litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 – 5.6 grams/litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 20 Summary geotechnical data for Glacial Sand/stratified

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Glacial Sand/Stratified; silty sand with gravel and occasional clay.	74	43	4	3	3	6	1		22	22	22	22
	25(16.6)	16(6.4)							8(9)	13(15.6)	69(23)	9(14.5)
	3–81	3–40	20–29	12–14	12–15	1.98–2.22	1.72		0–35	0–62	29–100	0–47

FILE FORMAT

	No. of samples
Average (Standard Deviation)*	
Range	

* quoted where no. of samples ⩾ 10
\+ class values see relevant tables below

Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv^+ m^2/MN	Cv^+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3^+	CBR %	Comments
4	4	1			3	9	9	9	8	**Very heterogeneous; bearing pressures variable, dependent on gravel content and prone to differential settlement. Water ingress at coarser horizons, perched water above clays. Suitable as fill material where no clay is present.**
		3						1,2		
10–323	0–3				1.84–1.98	10–11	6.7–7.9		0.15–12.5	

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 - 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 - 0.3	Fluvio-glacial clays Late clays
2	Low	0.05- 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
1	<0.1	Greater than	CLAYS Montmorillonite
2	0.1 - 1	25	High plasticity
3	1 - 10	25 - 5	Medium plasticity
4	10 - 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 - 120 parts in 100 000
3	0.5–1.0%	1.9 - 3.1 grams/litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 - 5.6 grams/litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

much of the area to the southeast of the A548 (see Thematic Element, Map 2). It is dominantly a red-brown to dark brown, and occasionally grey, silty and sandy clay with coarse-, medium- and fine-grained gravel and cobbles and boulders. This clay has low to intermediate and occasionally high plasticity (CL to CI and CH) (Figure 9) and low to high compressibility. Subordinate bands and lenses of sand or sand and gravel, and occasionally firm to stiff, grey, laminated, sandy, silty, pebbly clay also occur. Generally, the till is massive to well-bedded, but occasionally it is laminated. A weathered upper surface up to 2.5 m thick of orangey brown and grey, sometimes mottled, sandy clay with pebbles is usually present, but may be absent where alluvium overlies the till. The weathered material is soft to stiff while the underlying fresh glacial till is generally stiff to hard. Granular materials are very loose to loose while the clayey material are firm to stiff. Gravel content includes local Carboniferous rock types as well as exotic ones, and in some areas a correlation exists between gravel and underlying bedrock. Such local correlations are not mappable, and with the exception of the Carboniferous mudstone gravel, were found to have no significant effect on geotechnical properties. In the case of the tills with mudstone gravel content, higher plasticities (CH) have been measured and the till becomes darker grey in colour. Geotechnical properties are very variable (Tables 21 and 22), with three factors, lithology, depth and weathering state being the main causes of these variations.

Groupings of Superficial Deposits in Engineering Terms

The soils of the study area fall into seven main groupings in engineering terms, as indicated previously. The relationship of these groupings to the geological interpretations of the soils are:

Engineering Grouping	Geological Interpretation
1. Backfill and made ground	Backfill and made ground
2. Peat	Peat
3. Normally consolidated cohesive soils	i) Lacustrine alluvium ii) Alluvial clays and silts iii) Estuarine alluvial clays and silts
4. Loose sands and gravels	i) Wind-blown sands ii) Estuarine alluvial sands iii) Stratified glacial sands and gravels
5. Heterogeneous deposits	i) Head ii) Alluvial clayey, silty, fine-grained sands iii) Estuarine alluvial clayey, silty, fine-grained sands
6. Overconsolidated cohesive soils	Glacial till (boulder clay)
7. Dense sands and gravels	i) Glacial sands and gravels ii) Estuarine alluvial sands

The seven engineering groups correspond with the five groups determined for the purpose of assigning presumed bearing values in C.P. 2004 (British Standards Institution 1972) except that here, the cohesive soil is divided into normally and overconsolidated, and the non-cohesive soil into loose and dense.

Engineering Problems associated with Superficial (Unconsolidated) deposits

1. Backfill and Made Ground - Engineering Problems

In general, these deposits are unsuitable in their present state for the support of light-weight, single-storey structures (safe bearing pressure $\leq$ 50 kPa). Mining waste has been observed to produce contamination of groundwater giving high sulphate contents and a subsequent risk of damage to concrete foundations. This risk should be appreciated in the vicinity of such waste tips, regardless of local geology.

2. Peat - Engineering Problems

If peat is identified as being present at a site, care will have to be taken to determine its thickness and extent (which is not likely to be great) to avoid structures being founded on it, as it is highly compressible.

3. Alluvium - Engineering Problems

Generally low maximum nett bearing pressures make alluvium problematic even for the support of light-weight, single-storey structures, though gravelly layers show much higher bearing pressures (100 kPa for foundations 1.2 m wide, reducing to 80 kPa for foundations greater than 3 m wide). The heterogeneity of the deposit makes foundation problems much more site-specific than in the case of the estuarine

Table 21 Summary geotechnical data for Till (Boulder Clay)

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Till (Boulder Clay) sandy, silty clay with gravel.	596	997	286	284	284	549	51	11	106	106	106	106
	38(36.5)	19(70.4)	31(8.0)	16(3.75)	13(4.3)	2.18(0.15)	2.25(0.25)	2.62(0.07)	10(8.4)	14(12.8)	37(21.9)	38(24.7)
	1–180	2–50	3–67	7–33	2–39	1.60–2.50	1.49–2.30	2.45–2.68	0–42	0–68	0–91	0–100

FILE FORMAT

No. of samples
Average (Standard Deviation)*
Range
* quoted where no. of samples ≥ 10
+ class values see relevant tables below

Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv+ m^2/MN	Cv+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3+	CBR %	Comments
603	603	48	26	2	29	29	84	81	46	Variable deposit, stiff to hard when fresh. Weathering proved to 2.5m, stronger with depth. Water ingress and perched water in granular soils. Suitable as fill at natural mc. Embankment slopes 1:2. Cutting slopes 1:2–2.5 with drainage. CBR 5%.
112(73.1)	2(5.9)	3,2,4	3,2,4		1.96(0.13)	11.3(3.4)	7.6 (0.5)	1,2	10(7)	
0–619	0–34			$3x10^{-8}$–$1x10^{-5}$	1.61–2.21	6–21	6.2–8.4		1.0–3.7	

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 – 0.3	Fluvio-glacial clays Late clays
2	Low	0.05– 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
1	<0.1	Greater than	CLAYS Montmorillonite
2	0.1 – 1	25	High plasticity
3	1 – 10	25 – 5	Medium plasticity
4	10 – 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 – 120 parts in 100 000
3	0.5–1.0%	1.9 – 3.1 grams/litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 – 5.6 grams/litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

Table 22 Summary geotechnical data for Till (Boulder Clay) Selected data

Geotechnical Group	N-value	Moisture Content %	Liquid Limit %	Plastic Limit %	Plasticity Index %	Bulk Density Mg/m^3	Dry Density Mg/m^3	Specific Gravity	Clay %	Silt %	Sand %	Gravel %
Till (Boulder Clay); sandy, silty clay with gravel. SELECTED DATA	141	215	66	65	65	76	3	11	46	46	46	46
	39(30.6)	14(6.3)	33(10.3)	17(4.5)	15(7.2)	2.14(0.15)		2.62(0.07)	9(6.7)	17(12.9)	31(18.0)	39(21.2)
	6–173	2–43	15–66	10–31	2–39	1.63–2.37	1.49–1.96	2.45–2.68	0–34	1–68	2–74	0–97

FILE FORMAT

No. of samples	
Average (Standard Deviation)*	
Range	

* quoted where no. of samples ⩾ 10
\+ class values see relevant tables below

Undrained Cohesion kPa	Angle of Internal Friction (°)	Mv+ m^2/MN	Cv+ m^2/yr	Permeability m/s	Maximum Dry Density Mg/m^3	Optimum Moisture Content %	pH	SO_3+	CBR %	Comments
64	30	10	4		14	14	6	13		
63(39.1)	9(11.3)	3	3		2.02(0.12)	10.3(3.6)		1		
0–175	0–33				1.74–2.21	6–21	7.2–8.0			

Class	Description of Compressibility	Mv m^2/MN	Examples
5	Very high	above 1.5	Very organic alluvial clays and peats
4	High	0.3 - 1.5	Normally consolidated alluvial clays, eg. estuarine clays
3	Medium	0.1 - 0.3	Fluvio-glacial clays Late clays
2	Low	0.05- 0.1	Boulder Clays
1	Very low	below 0.05	Heavily overconsolidated Boulder Clays. Stiff weathered rocks

After Head (1982)

COEFFICIENT OF VOLUME COMPRESSIBILITY Mv

Class	Cv $m^2/year$	Plasticity Index Range	Soil Type
1	<0.1	Greater than 25	CLAYS Montmorillonite
2	0.1 - 1		High plasticity
3	1 - 10	25 - 5	Medium plasticity
4	10 - 100	15 or less	Low plasticity
5	>100		SILTS

After Lambe and Whitman (1979)

COEFFICIENT OF CONSOLIDATION Cv

Class	Total SO_3	SO_3 in soil 2:1 water extract	In Groundwater
1	<0.2%		30 parts in 100 000
2	0.2–0.5%		30 - 120 parts in 100 000
3	0.5–1.0%	1.9 - 3.1 grams/litre	120–150 parts in 100 000
4	1.0–2.0%	3.1 - 5.6 grams/litre	250–500 parts in 100 000
5	>2.0%	5.6 grams/litre	500 parts in 100 000

After Building Research Establishment (1975)

SULPHATES IN SOILS AND GROUNDWATERS

alluvium. No groundwater problems in terms of high sulphate contents were identified.

4. Estuarine Alluvium - Engineering Problems

Inherent in their low-lying, tidal to supratidal location, the estuarine alluvium has characteristic groundwater problems associated with it. The water-table is ubiquitously near-surface (1-3 m depth) and may reach the surface in wet weather. The sediments are generally saturated with moisture contents commonly approaching liquid limits for the cohesive soils, and the risk of running conditions being produced in the non-cohesive soils. Excavations require groundwater control in the form of well-point dewatering and/or sheet piling with pumping to prevent flooding, piping and running conditions. In general, such work should be avoided at peak tides. Tidally-induced fluctuations in hydrostatic pressures make S.P.T. values, and the subsequently calculated safe bearing pressures, unreliable, unless such effects are accounted for. The loose nature of the material necessitates shoring of vertical excavations to ensure stability. Calculated safe bearing pressures are low, but increase to reasonable values with depth, making piling of foundations to these denser materials the most reliable technique. Safe bearing pressures for various sites on estuarine alluvium are summarised in Table 23. No serious groundwater sulphate problems are apparent as long as a good quality dense cement is used below the water-table, since seawater chloride counteracts the effects of the sulphate. Higher groundwater sulphate concentrations, however, have been observed in the vicinity of mine waste tips.

4a. Estuarine Alluvial Clay - Engineering Problems

Very low safe bearing pressures (23-50 kPa) and high compressibility combine to make this a difficult material for the support of even light-weight, single-storey structures; generally, piling is essential. Large settlements can occur with small loads, and differential settlements can also occur. Better materials are found at depth, though skin-friction values in the soft clay can vary from zero to 7 kPa for bored piles or 8 kPa for driven piles, making this foundation type, where adopted, complex to assess.

Excavated faces soften rapidly on exposure to rain, so should be protected as soon as possible. Bogging down of plant in the clay, particularly in wet weather, is avoidable by placing a layer of gravel over the site prior to work commencing or by the use of geotextiles.

4b. Estuarine Alluvial Sand - Engineering Problems

This material has higher safe bearing pressures (107-220 kPa) than the alluvial clay, which increase with depth, making the depth of foundations critical to their stability. Loose sand is marginally suitable for the support of light-weight, single-storey structures at surface level. However, the situation improves with depth, as the sand becomes medium dense at about 10 m depth. Its loose nature, particularly at shallow depths, may cause blowing during Standard Penetration Tests, rendering the results unreliable, and may necessitate deeper than usual sheet piling to prevent boiling. Water ingress at coarser, cleaner horizons is also common.

California Bearing Ratios of 10% have been assumed for preliminary design purposes.

5. Lacustrine Alluvium - Engineering Problems

Problems of stability and settlement have been observed, mainly in the softer clays, and "as a consequence of the variable composition and fabric of glacial clays, the presence of weaker, more compressible layers under stronger, stiffer layers should be expected rather than considered as an exception" (Marsland, 1977). S.P.T. results should be treated with scepticism.

6. Heterogeneous deposits (Head) - Engineering Problems

Where the head is coarser grained, and overlies finer grained deposits, perched water-tables may be found within it. These may lead to possible running conditions in excavations which will require pumping.

Head is formed by slow, down-slope movement and accumulation, and there is always a possibility that it may contain shear planes. Increases in pore pressure, undercutting of slopes or loading at the top of slopes may reactivate movement, causing failure. If head is identified, therefore, care should be taken to examine samples for the presence of shear planes. Sloping sites (including those where the gradient is only a few degrees) should also be inspected for the presence of small curved ridges representing the toes of solifluction lobes.

Piles founded on stronger underlying strata may be necessary where the head is weak and sheared. No appropriate bearing pressure data are available. There is no evidence of high sulphate

Table 23 Foundation loading criteria for Esturine Alluvium at different individual sites within the Deeside area

LITHOLOGY	Safe Bearing Pressures: Unpiled		Piled	
	Pad	**Strip**	**End Pressure**	**Skin Friction**
Alluvial Clay	25-50 kPa			7 kPa (bored) 6 kPa (driven)
Alluvial Silty Clay	23 kPa		0 kPa (loose)	0 kPa (loose)
Sandy Silt	50-70 kPa			
Assorted Alluvium	20-57 kPa			
Rafts on Compacted, Crushed Rock	95-100 kPa			
Alluvial Sand	100-160 kPa			
greater than 3.0m depth	300 kPa (allowable)		335-850 kPa	
Clay Lens	115 kPa			

contents associated with head, all but one of the few samples tested falling into class 1 (Building Research Establishment 1975). (However, note the comment in the Fill and Made Ground section, above, with regard to sulphate contents in the vicinity of mine tips).

7. Glacial Sand and Gravel - Engineering Problems

Maximum safe bearing pressures of the stratified sands and gravels are variable and largely depend on gravel content; where no gravel layers are present, safe bearing pressures of 80 kPa (strip footing 1 metre wide) have been quoted, while with the presence of gravel, values of 130 kPa have been used (Table 20). For sand and gravel with clayey or silty layers, nett safe bearing pressures are generally between 100 and 200 kPa, but where the clay occurs as a matrix, lower safe bearing pressures of 53 to 107 kPa can be expected. The clay layers themselves vary from very weak to very stiff, with the latter giving safe nett bearing pressures of 500 to 600 kPa for pad foundations, with an end bearing pressure of about 900 kPa for piles. Water ingress is a problem at the coarser horizons, and intercalated clays and sand and gravel can give rise to perched water-tables. The heterogeneity of the deposit can give rise to variations in geotechnical properties on a site scale, making differential settlements a possible problem. As a fill material the glacial sands are suitable only where no clay is present.

Being well-sorted and of low cohesion, the glacial sands and gravels are characteristically prone to running, causing rapid deterioration of excavations. Shoring is, therefore, a necessity, and where long-term stability is required, cutting slopes back to 1:1 and perhaps covering with a protective material (for example, coarse-grained sand and gravel, or vegetation) may be needed. Groundwater control during excavation can reduce these problems, especially in coarser material where high water inflows can occur, though support by timbering or sheet-piling will be required during pumping.

High hydrostatic pressures pressures can occur in granular materials, exacerbating the above problems. Where the sand and gravel is overlain by a clayey layer, heaving and sagging conditions can arise on excavation, and there is an ever-present danger of such conditions existing just below the depth of investigations. These hydrostatic pressures, where present, render S.P.T. results unreliable, and give rise to perched water within the sand and gravel deposit.

Differential settlements are a problem caused by the heterogeneity of the deposit and, combined with the effect of hydrostatic pressures on S.P.T. results, make safe bearing pressures very site-specific, and generalisation difficult. Nevertheless, this soil grouping can be characterised, to some degree in this respect (Table 24).

For cuttings, side slopes of 1V:2H have been recommended for the glacial gravels, grading to 1V:3H for the more sandy deposits. Counterfort and toe drains may be necessary where the water-table is high. Well-graded glacial gravels can be used as embankment fill with side slopes of 1V:2H. C.B.R.'s of 10% may be used for preliminary pavement design purposes.

8. Till (Boulder Clay) - Engineering Problems

Geotechnical properties are very variable within the glacial till (Tables 21 and 22), with three factors, namely lithology, depth and weathering state being the main causes of these variations. These three factors combine in a complex manner and make generalisations and predictions about engineering behaviour in this material difficult. Nevertheless, several engineering problems have been observed to be associated with one, or more, of these factors.

Maximum nett safe bearing pressures range from 80 to 500 kPa. The upper weathered zone and softer clays occupy the lower part of this range from 80 to 240 kPa, with an improvement in weathering grade or an increase in depth of the clay layer giving higher values. Piles in the weathered zone can be expected to have skin friction values of 16 to 19 kPa (bored), 24 to 29 kPa (driven), and safe end bearing pressures of 240 to 270 kPa compared with 40 kPa skin fraction (driven or bored) and 630 to 950 kPa safe end bearing pressures in the fresh, underlying material. The upper part of the safe bearing pressure range is occupied by very stiff to hard, unweathered clays, and unweathered to slightly weathered stony clays. These are end-member conditions, and various combinations of depth, weathering and lithology give rise to intermediate properties. Safe bearing pressures for various sites are summarised in Table 25. S.P.T. and triaxial test results respond similarly to these variables, and piping in sands can render the former unreliable. Softer horizons may not support piles or may make them uneconomical,

Table 24 Foundation loading criteria for Glacial Sand and Gravel at different individual sites within the Deeside area

LITHOLOGY	Safe Bearing Pressures: Unpiled	Safe Bearing Pressures: Piled – End Pressure	Safe Bearing Pressures: Piled – Skin Friction
Sand and Gravel with clayey zones	200 kPa (B≥1.0m) 200 x B kPa (B<1.0m)		
Very stiff clay zones	500 kPa (strip) 600 kPa (pad)	900kPa	
Sand and Gravel with thin clay band	133 kPa		
Sand and Gravel with clay layers	200-300 kPa (0.5m wide strip footings)		
Sand and Gravel clay zones and lenses of clay	160 kPa (B≥1.0m) 160 x B kPa (B<1.0m)		
Sand and Gravel firm clay binding	53-107 kPa		
Sand and Gravel with clay binding	100 kPa	630 kPa	

Table 25 Foundation loading criteria for Till (Boulder Clay) at different individual sites within the Deeside area

LITHOLOGY	SAFE BEARING PRESSURES Unpiled	Piled End Pressure	Piled Skin Friction
Unweathered, gravel in a matrix of clayey, very sandy silt, with cobbles & boulders	230 kPa (strip) 290 kPa (square)	630 kPa at 7.0 m depth	
Firm sandy clay with stone inclusions, slightly weathered	100 - 150 kPa at 1 m depth		
Stiff sandy clay with stone inclusions and lenses of sand and sand and gravel	150 kPa (strip) 180 kPa (pad)		
Firm to hard sandy clay with stone inclusions and sand lenses. Slightly weathered	145 kPa (strip) 170 kPa (pad)	265 kPa	19 kPa (bored) 29 kPa (driven)
Unweathered		950 kPa	40 kPa (bored/driven)
Firm to stiff sandy clay with stone inclusions and lenses of sand.		260 kPa	18 kPa (bored)
Unweathered, very stiff to hard			40 kPa (bored/driven)
Slightly weathered			27 kPa (driven)
Moderately weathered		240 kPa	16 kPa (bored) 24 kPa (driven)
Firm, brown, stony clay	133 kPa		
Firm to stiff sandy clay with stone inclusions and occasional silt pockets	160 - 185 kPa (strip) 160 - 245 kPa (pad)		
Stiff, sandy silty clay with a little c, m & f gravel	268 kPa (strip)		
Clay	125 kPa (strip) 145 kPa (pad))same site)different 300 kPa (strip))clay 350 kPa (pad)		
Sandy clay, laminated with stones and sand and gravel	250 kPa		
Sandy clay	250 kPa		
Clays in stony ground	160 - 520 kPa		
Sandy clay with stones	Allowable		
Below weathered zone	220 - 290 kPa (F.S. = 3)		
In weathered zone	180 - 230 kPa		
Stiff (top) to very stiff at depth, with thin layers of water-bearing sand	150 - 200 kPa (Allowable)		
Sandy, silty clay with a little gravel. Weathered	80 - 110 kPa (Allowable)		
Unweathered	100 - 150 kPa		
Stiff upper glacial clay	200 kPa (strip) 240 kPa (pad)		
Firm, weathered material	80 kPa		
Glacial sand (loose-medium dense)	150 - 200 kPa ($B>1$ m) 150 - 200 x B kPa ($B<1$ m) (less if underlain by clay)		
Lower glacial clay (stiff)	110 - 140 kPa (strip) 130 - 170 kPa (pad)		
Lower glacial clay (very stiff to hard)	230 - 420 kPa (strip) 500 kPa (pad)		

and granular materials are subject to seepage and collapse during boring, making driven piles preferable in such lithologies. In addition, sloping sites have been observed to reduce expected safe bearing pressures, and differential settlements can result from localised variations in geotechnical properties. Underlying lithologies can produce unexpected local variations, notably a decrease in safe bearing pressures in sands where they are underlain by clay.

Groundwater can present problems in the form of perched water-tables and seepages in more permeable granular materials. Clays are liable to softening on exposure to rain, so excavations should be protected as soon as possible. No groundwater sulphate problems were observed, with the exception of one locality where a high sulphate content and a pH of 3.2 occurred. This may have been due to contamination from a nearby mine waste-tip. Excavations may require well-point dewatering in areas of high water-table, and will require support to ensure stability.

At natural moisture content the till is in general suitable as a fill material. Side slopes of 1V:2H have been recommended. Cuttings in the material should be stable at slopes of 1V:2H to 1V:2.5H, though shallower angles and provision of drainage to avoid pore-pressure build-up may be required, especially in the granular deposits, and most particularly the sands. C.B.R. values of 5% may be adopted for preliminary pavement design in these materials.

SUMMARY OF GEOLOGY

The generalised geological sequence of the area is shown in Figure 10, and a simplified geological sketch map is given in Figure 4.

The following geological summary is a comparatively brief review of the main observational and interpretive findings of the field survey undertaken between 1985 and 1987. It is intended to be used as an aid to understanding the 1:10 000/10 560 geological base maps and open file reports listed in Appendix A. Furthermore, it lists, in context, most of the scientific literature relevant to the area.

The bedrock geology, in outcrop, comprises sedimentary rocks which range in age from Upper Silurian (Lower Ludlow) to Triassic, spanning approximately 200 million years. An overburden of consolidated glacial and post-glacial sediments (Quaternary to Recent) blankets much of the area.

The bedrock sequence can be regarded in general terms as a gently eastward dipping sequence, but in detail is considerably more complex due to faulting and local folding.

Silurian

Elwy Group

The oldest rocks of the area are Ludlow (Upper Silurian) strata (c.350 m thick) assigned to the Elwy Group, and are exposed in the Clwydian Hills along its western margin. Although this terrain is well-featured, with relatively little superficial overburden, the bedrock is surprisingly poorly exposed and consequently there are no extensive sections. These rocks were included in the area mapped and described by Simpson (1940). They comprise mostly grey, thinly laminated, silty mudstones with subordinate sandstones and localised slumped horizons and debris flows ('Disturbed Beds'). The sandstones have been interpreted regionally (Warren and others, 1984) as the distal products of turbidity currents deposited in a marine environment between 420 and 410 million years ago, and the disturbed beds as slump and slide units which developed on the sea floor. No fossils were found during the survey but Woods and Crosfield (1924) recorded graptolites from some localities in the area.

Dip and strike of these rocks varies considerably (maximum dip 60°), reflecting their folded nature. The rocks are also tectonically cleaved, and particularly so in the finer-grained lithologies. The cleavage is steep (65° - 90°) and its strike is relatively constant between WNW to ESE, and NW to SE. The cleavage is generally considered to have formed during a regional tectonic compressional event which occurred between the end of the Silurian and the middle of the Devonian.

Carboniferous

Strata of Carboniferous age can be assumed to rest unconformably on the Silurian rocks. The unconformable contact is not exposed, but it can be mapped with precision as it has a marked topographic expression. Rocks of Devonian age are presumed absent, as is the case in surrounding areas. The unconformity is an angular relationship, and the Carboniferous rocks, dipping gently to the east and northeast, overlie a previously folded and eroded Silurian terrain.

Carboniferous Limestone (Dinantian)

The first major study of the Carboniferous Limestone of north Wales was carried out by Morton (1870) who recognised a general regional tripartite stratigraphy of Lower Brown, Middle White and Upper Grey limestones. He applied this stratigraphy to the Mold district in 1878. Subsequent workers in this area have tended to substantiate Morton's classification (e.g. Neaverson, 1929, 1946). More recently, Oldershaw (1969) has recognised four lithological units about Halkyn Mountain, and Banerjee (1969) has established a similar stratigraphy further south, near Rhydymwyn.

The limestones (carbonate sediments) in this report have been described using the classification of Dunham (1962). This involves the interpretation of textural features and is ideally suited to rapid assessment based on field observations. Furthermore, it produces data which can be represented as graphic logs (Figure 9) demonstrating grain-size variations in a section.

The Dunham classification has four main categories: (1) grainstone, (2) packstone, (3) wackestone and (4) calcite mudstone. These are defined in the glossary with other less frequently used descriptive categories. In general terms, the average grain size of the limestones decreases from grainstone through categories 2, 3 and 4. The individual carbonate grains are typically greater than 0.1 mm in size. Classification of the limestones in this way provides direct information relevant to the resource characteristics and engineering properties. Two types of carbonate grain are recognised, skeletal and pelloidal. The

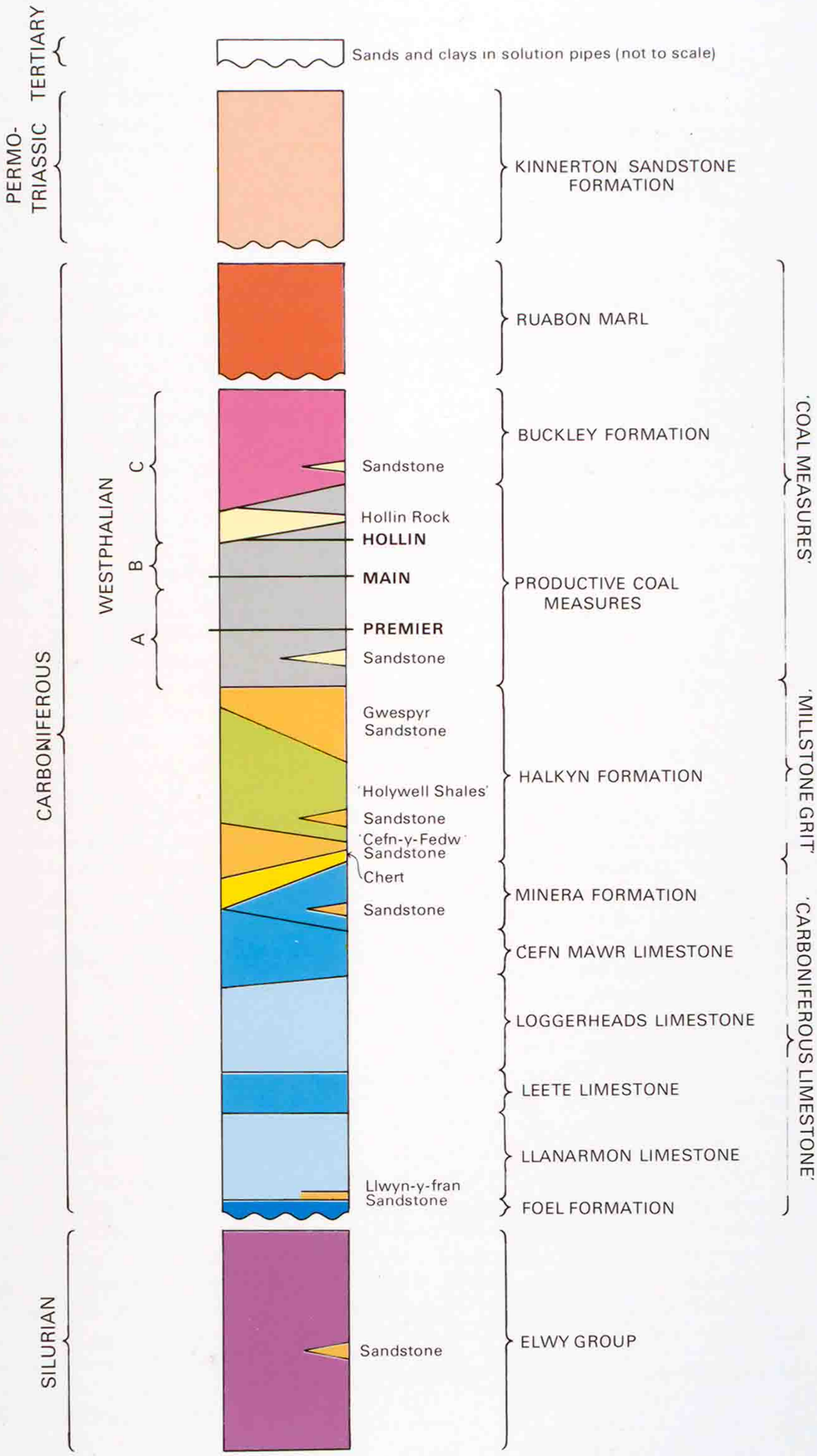


Figure 10 Generalised geological sequence of the study area

former are fragments of marine fossils and the latter were formed by sedimentary processes on the sea-floor.

The Carboniferous Limestone outcrop forms a well-featured escarpment which trends NNW-SSE along the western side of the study area. Natural exposure is good in the south of this tract, which widens northwards from 2.5 to 4 km, and in the area about Halkyn Mountain. Complete exposure of substantial parts of the stratigraphy is available in the quarries of the district. The sequence dips gently to the east in the south of the area and has a more northeasterly dip in the north. The dip typically varies between 5° and 15° but in the vicinity of the Nant Figillt Fault (see Structure below) open periclinal folding occurs.

The following sections give brief descriptive and interpretive details of the constituent formations:

Foel Formation
The 'Basement beds' of the Carboniferous Limestone are poorly exposed and were only seen in small isolated exposures, e.g. south of Nannerch (SJ 1700 6783), where variably calcareous and dolomitised, locally oncolitic, packstones and grainstones overlie poorly exposed red clays (Strahan, 1890; Davies and others, in press). These have yielded microfossils of late Chadian age (see Palaeontological Reports in Appendix A) implying that the rocks are approximately 350 million years old. The main body of the Foel Formation is a limestone sequence comprising approximately 20 m of dark brown, pelloidal grainstones with scattered oncolites, porcellanous pelloidal wackestones and dolomitised, fine-grained pelloidal packstones with carbonaceous laminae and scattered plant remains. These sediments record the initial transgression (inundation) of the Carboniferous seas over the Silurian landmass, with alternating phases of peritidal deposition and quiescent deposition.

Llanarmon Limestone
The base of this formation is marked in the southwest by the Llwyn-y-fran Sandstone (member), a yellowish brown, fine- to medium-grained, dolomitised, calcareous sandstone, up to 20 m thick. The sandstone marks a second, more important regional marine transgression which drowned an extensive area of north Wales (Somerville and Strank, 1984b). This is succeeded by c.150 m of white to pale grey and cream, well sorted pelloidal and skeletal grainstones and packstones. The limited lithological variation both vertically and laterally reflects a prolonged period of stable carbonate platform deposition in a shallow-marine, high energy environment in warm subtropical seas. A local conglomerate occurs towards the top of the formation. Microfossils (e.g. foraminifera) of Arundian age have been obtained from the formation in addition to a scattered fauna of fossil brachiopods and corals (Somerville and Strank, 1984b; and see Palaeontological Reports in Appendix A).

Leete Limestone
The Leete Limestone (c.75 m thick) includes a complex array of carbonate sediments. It comprises irregularly bedded, dark brownish grey, porcellanous wackestones and calcite mudstones, with fine- to coarse-grained skeletal and pelloidal packstones. A thick unit of pale grey to white pelloidal grainstones and packstone-grainstones occurs in the lower part of the formation. The formation as a whole was probably deposited in a fluctuating environment of peritidal and platform carbonate deposition with short periods of emergence and desiccation. The formation has yielded microfossils of Holkerian age (Somerville and Strank, 1984a and b; and see Palaeontological Reports in Appendix A) and is typified by a large brachiopod named *Daviesiella llangollensis*. The upper part of the formation may be Asbian in age.

Loggerheads Limestone
This formation (c.170 m thick) bears some similarities to the Llanarmon Limestone but is somewhat finer-grained in character. It comprises pale grey, cream and white, massive to rubbly bedded, pseudobrecciated, pelloidal and skeletal packstones and subordinate packstone-grainstones. Thin light grey clays (< 30 cm thick) occur, commonly towards the top of the formation. The upper parts of the formation are well exposed in all of the large working limestone quarries of the area and detailed sections have been measured. Generalised sections of these quarries are given in Figure 11a, with suggested correlations. Most of the formation is Asbian in age (Somerville and Strank, 1984a and b; and see Palaeontological Reports, Appendix A).

Correlations of the limestones across the area are based on the cyclic repetition ('minor cyclicity') of variations in lithology. This cyclicity (Somerville, 1979) is very apparent in the upper 50 m of the formation and is most readily observed in Cefn Mawr and Trimm Rock quarries [SJ 202 635 and SJ 191 669 respectively]. Within each cycle there is an upward increase in grain

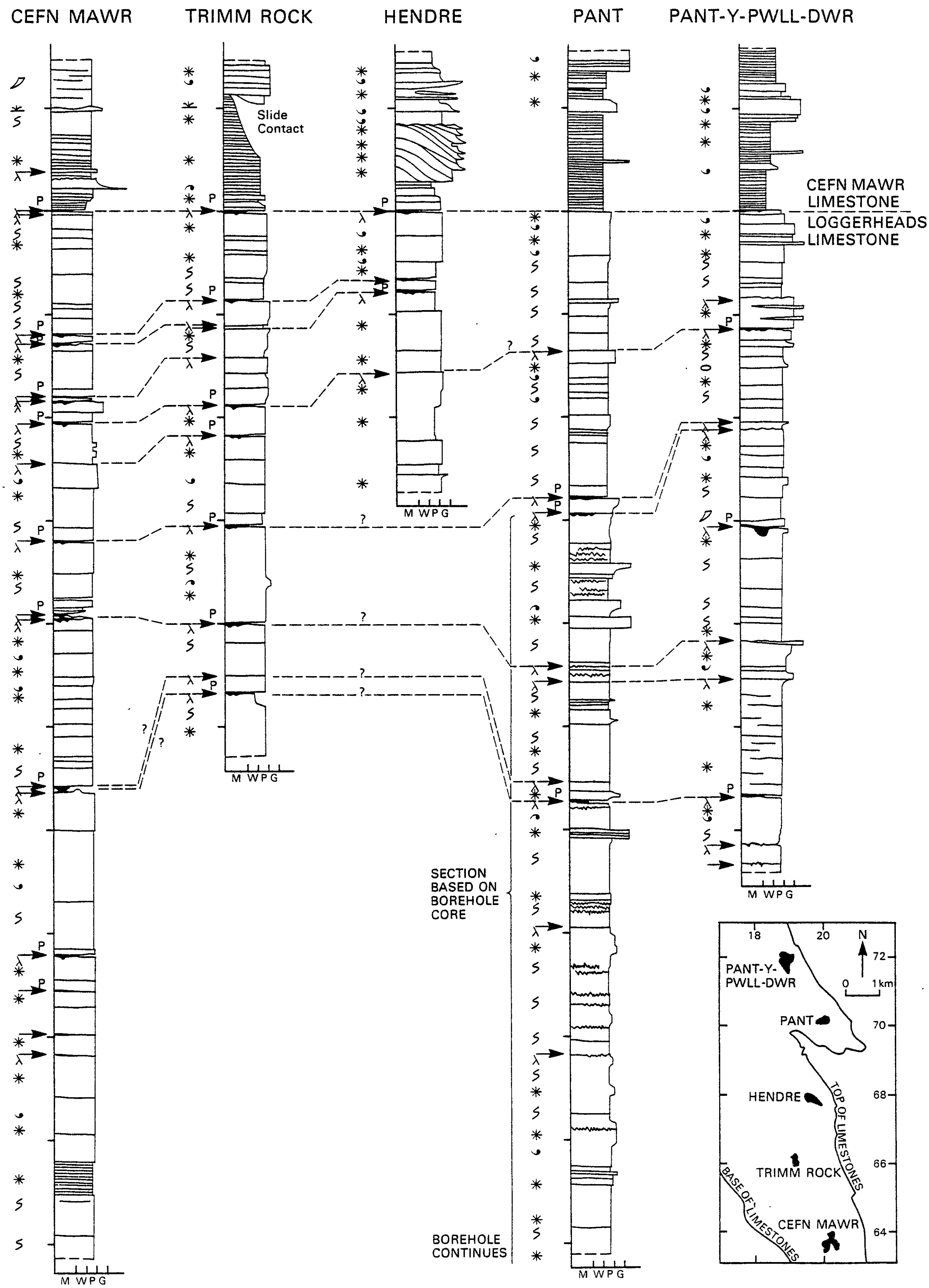
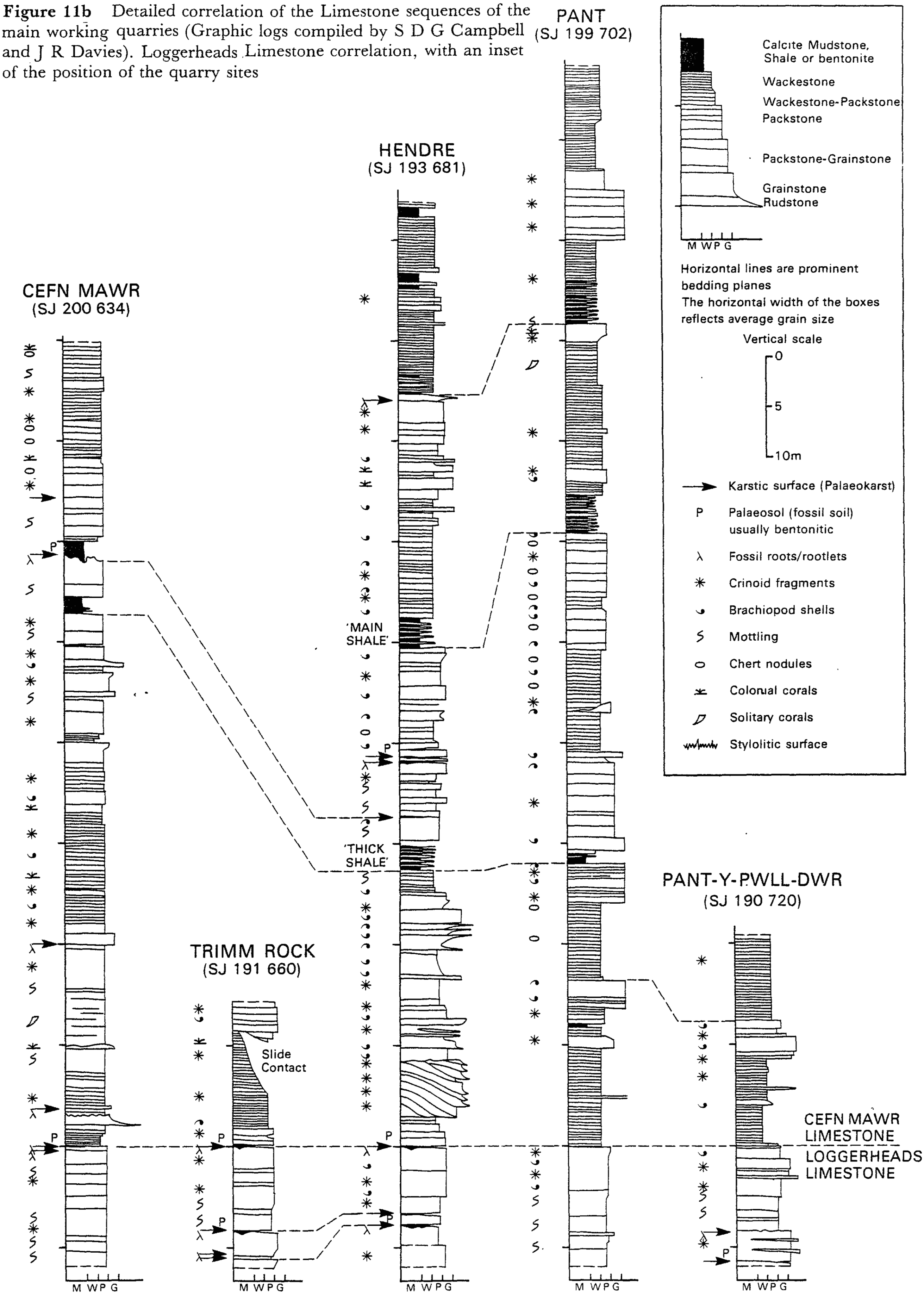


Figure 11a Detailed correlation of the Limestone sequences of the main working quarries (Graphic logs compiled by S D G Campbell and J R Davies). Cefn Mawr Limestone correlation

Figure 11b Detailed correlation of the Limestone sequences of the main working quarries (Graphic logs compiled by S D G Campbell and J R Davies). Loggerheads Limestone correlation, with an inset of the position of the quarry sites



size with packstones passing up into grainstones. In lower parts of the formation, the next cycle succeeds with or without an initial coarse-grained bioclastic deposit, and then a sharp reversion to finer grained lithologies. In places, stylolites and small carbonate nodules are developed between cycles. Dark grey-brown mottling (patches of 0.5-2 cm) is also common in the lower parts of many of the cycles. Towards the top of the formation, the cycle boundaries are made more obvious by the appearance of light-grey clays which rest on an irregular bedding plane surface within which are preserved fossil plant roots and rootlets. The tops of these cycles are commonly rich in coarse fossil debris. Laminar carbonate (calcrete) is sometimes observed and iron oxide staining is common. The clays themselves have been interpreted as being potassic bentonites (altered volcanic ash) and represent a fossil soil (palaeosol) preserved on an irregular karstic (palaeokarstic) surface with depressions up to 50 cm deep. Each cycle is interpreted as a gradual shallowing of the general marine carbonate platform environment, with eventual emergence of a low topography land surface. The surface was subsequently drowned and followed by another phase of gradual shallowing of the sea. George (1974) and Ramsbottom (1973, 1977) suggest interpretations for the cyclicity.

Cefn Mawr Limestone

This formation (c.120 m thick) mostly consists of thinly bedded, brown and dark-brown, fine-grained pelloidal, skeletal packstones, wackestones and shaly mudstones. Interbedded, mainly towards the base, are thicker-bedded, pale, coarser packstone-grainstones. The basal part is exposed in all of the large working limestone quarries (Figure 11b). Although the Cefn Mawr Limestone is substantially finer grained overall than the Loggerheads Limestone, a similar cyclicity is present. Generally the karstic surfaces and bentonites are absent but some are occasionally observed (e.g. Hendre Quarry), suggesting that emergence from the general low energy marine carbonate seas was less common. The base of the formation is marked by an obvious colour change in the rocks, with the brown and dark brown limestones of the Cefn Mawr Limestone contrasting with the pale grey of the underlying Loggerheads Limestone. This boundary coincides with the Asbian/Brigantian stage boundary (Somerville and Strank, 1984a and b) and the Cefn Mawr Limestone is entirely within the Brigantian stage.

Two thick mudstone (shale) packets (3-4 m thick) are recognised and can be mapped across country. The lower is the 'Thick shale' and the upper, the 'Main shale'. A coral-rich horizon with abundant colonial and solitary corals occurs approximately 10 m above the 'Main shale'. The upper parts of the formation are very mudstone-rich (c.50%). White and black chert nodules, up to 10 cm in size, often occur along selected bedding planes, mainly at high levels in the formation. The formation has a rich fossil content and large productid brachipods are very common, while a stratigraphically useful band with *Girvanella* occurs low in the formation. In the middle and upper parts of the formation, there is evidence of tectonism and instability during deposition with low-angle slide surfaces (e.g. at Waen Brodlas Quarry, SJ 1875 7315; see front cover) and rotated fault blocks (e.g. Pant Quarry, SJ 200 702) evident. In the vicinity of Halkyn Mountain, the formation is reduced in thickness to approximately 50 m where it is overlain unconformably by cherts.

Minera Formation

In the southern half of the area (south of the Nant Figillt Fault; see below) the Minera Formation (c.170 m thick) is present. It thins progressively to the north. Much of the formation is very similar to the Cefn Mawr Limestone, but it differs in the presence of massive and cross-bedded, fine- to medium-grained and occasionally pebbly, calcareous and quartzitic sandstones up to 40 m thick. The bases of the sandstones are sharp. Scattered fossils, trace fossils and carbonaceous material occur in the sandstones. Pebbles in the sandstones are generally of vein quartz. The sandstones, which represent an important change in sediment provenance, are either marine transgressive sheet-sands or prograding fan-delta systems. With the disappearance of the sandstones to the north, the Minera Formation passes laterally into the Cefn Mawr Limestone in part. A particularly coarse-grained crinoidal limestone commonly occurs at the top of the formation.

Millstone Grit Series (Namurian)

Halkyn Formation

The formation comprises the 'Cefn-y-Fedw Sandstone' of earlier terminology (Strahan, 1890) at the base, the Holywell Shales, and the Gwespyr Sandstone at the top. A chert unit occurs at the base in the north. The formation crops out in two main areas, along the eastern margin of the limestone terrain and south of Hawarden [SJ 316 659]. There is a marked lateral and vertical variation in the constituent lithologies. Thus, the 'Cefn-y-Fedw Sandstone' thins out towards the north and is absent in the vicinity of Holywell; it is replaced laterally by a locally thick chert unit at the base of the formation, and by mudstones. The Gwespyr Sandstone has a complex distribution, and was probably derived from the north. Significantly, it is a feldspathic sandstone, in stark contrast to the quartzitic 'Cefn-y-Fedw Sandstone' and underlying sandstones of the Minera Formation. As such, it is similar to the typical feldspathic sandstones of the Coal Measures. With the exception of the sandstones and cherts, the formation is poorly exposed, with exposure of the finer grained lithologies being restricted largely to sections in streams. The sandstones and cherts have been quarried and exposed at many sites and they form strongly featured ground which also provides limited exposure.

'Cefn-y-Fedw Sandstone' The sandstones (up to 80 m thick) at the base of the Halkyn Formation are well exposed in Gwyn-bryn Quarry [SJ 214 623], south of Gwernymyndd, where the crudely cyclic nature of the sediments is displayed. The first element of the cycle is a poorly sorted, relatively mature, pebbly sandstone, occurring in units of c.2 m. The larger clasts are well-rounded, relatively low sphericity, quartz grains. These pass upwards into finer grained quartzitic sandstones with well-rounded and high sphericity grains (mature). Bedding is flaggy to massive, with low-angle cross-bedding evident. Continuing upwards in the cycle, flaggy bedding is on the centimetre scale and the lithology is an intercalation of cherty (silicified) fine-grained sandstones, siltstones and mudstones. These beds were variably calcareous prior to silicification. Their habit is not dissimilar to the flaggy limestone and mudstone intercalations of the Minera Formation, the only real difference being the extent of silicification. The flaggy cherts are then succeeded by another massive sandstone. As the sandstones are traced northwards, the medium- to fine-grained element of the cycles becomes increasingly dominant, and intercalations of siltstone and mudstone with less chertification increase in thickness at the expense of the sandstones. The sandstones die out just to the north of Halkyn [SJ 2171]. In the area south of Hawarden, the lower part of the formation comprises quartzitic sandstones.

Chert In addition to cherts intercalated with the 'Cefn-y-Fedw Sandstone' in the south, a substantial sequence (maximum 180 m) of cherts occurs at the base of the formation and below the 'Cefn-y-Fedw Sandstone' south of Halkyn. North of Halkyn the cherts rest with apparent unconformity on a karstic surface of the Cefn Mawr Limestone which is thus greatly reduced in thickness. The cherts (known locally as the Pentre Cherts around Holywell) are thinly laminated, black and white, glassy cherts and flaggy, cherty siltstones. They are structurally complex; disharmonic tight folding and low-angle faulting have been observed at many localities. This structure is interpreted as being in part due to collapse of the cherts into solution cavities within the underlying limestones and also to gravitational collapse on a slope. The nature of the folding and low-angle faulting suggests that the cherts were not fully lithified at the time of their disruption, implying that the solution and collapse occurred largely during the Carboniferous period or soon after. Their age is problematic. Ramsbottom (1974) considered they are Dinantian in age but they are thought here to be more probably Namurian.

The mode of their formation is problematic. The main point at issue is whether the chert formed as a silica gel on the sea floor or originated by replacement of existing strata. The evidence here suggests that replacement is an important factor and that much of the process of silicification occurred soon after deposition of the strata while they were still plastic in habit. Local interbedding of chert and calcareous siltstone suggests that the chertified strata were likely to have been calcareous siltstones prior to their silicification. A sparse marine fauna and the occurrence of fossil crustaceans in the cherts suggests that the strata were deposited in a low salinity, low energy, possibly lagoonal environment. Occasional incursions of coarser sand, probably derived from the south, record short-lived, higher energy conditions of sedimentation. The spatial association of the thickest development of the cherts with the pronounced unconformity at their base may not be fortuitous.

Halkyn Formation - general The main body of the formation comprises 250 to 350 m of dark grey and brown, well-bedded and laminated mudstones, silty mudstones and black fissile mudstones. These thinly bedded sediments are intercalated with thin yellowish brown and white quartzose sandstones which vary from a few centimetres to several metres thick. Thin coal horizons with seatearths occur at various localities but are not laterally extensive. The environments of deposition were fluvio-deltaic with periodic marine incursions. The thin sandstone units decrease in thickness and abundance towards the north, where the sediments have been termed the Holywell Shales.

The sequence of the Holywell Shales was proved in its entirety by the Abbey Mills boreholes sunk near Holywell (see Appendix C). Occasional 'Marine' bands yield the characteristic and stratigraphically useful goniatite zonal fossils of the Namurian and these have been described extensively for the area (Hind and Stobbs, 1906; Sargent, 1927; Wood, 1936; Jones and Lloyd, 1942; Ramsbottom, 1974; and see Palaeontological Reports, Appendix A). The zonal fossil *Cravenoceras leion* has not been found at the base of the Holywell Shales in the north of the area which otherwise includes a fairly complete succession of goniatite zones. The Pendleian strata below the horizon of *Cravenoceras malhamense* are a condensed succession with phosphatic nodules. Further south, there may be an important break in the sequence since some of the goniatite zones are unrepresented (Jones and Lloyd, 1942; Ramsbottom and others, 1978).

Gwespyr Sandstone This sandstone occurs at the top of the formation and its distribution is complex. It comprises up to 150 m of buff-coloured, feldspathic, medium- and fine-grained, cross-bedded sandstones with varying interleaves and intercalcations of siltstones and mudstones. It is Yeadonian in age. Its thickest development is in the north and this is consistent with current direction data suggesting a northerly source. In most areas, mudstones containing the Subcrenatum Marine Band, which is used to delineate the top of the Namurian/base of the Westphalian (Coal Measures), occur immediately above the Gwespyr Sandstone. In the east of the area, south of Hawarden, the Subcrenatum Marine Band occurs within the sequence of feldspathic sandstones and the term Gwespyr Sandstone is restricted to the strata underlying the marine band.

Coal Measures (Westphalian)

In the British Isles, it is common practice to subdivide the Coal Measures in terms of the biostratigraphy (i.e. fossil content) rather than lithostratigraphy (variation of rocktype). Thus, elements of the sequence are referred to Westphalian A, B, C, and D. Though questionable as a method of depicting stratigraphy within what is otherwise a lithostratigraphic context, the approach is retained here to facilitate comparisons with other areas.

The most recent accounts of the 'Flintshire Coalfield' of which this area forms a northern part, are those of Magraw and Calver (1960) and Calver and Smith (1974). The earlier account of Wedd and King (1924) provides important detail. Coal Measures occupy much of the central, northern and northeastern parts of the area. Exposure is very poor, mainly due to the considerable cover of superficial deposits, and most information derives from boreholes, mine-shafts and underground workings. The sequence varies in thickness from 360 m to 410 m.

Productive Coal Measures
In terms of earlier classifications, the Productive Coal Measures are the 'Grey Measures' (cf. Calver and Smith, 1974) and are succeeded by 'Red Measures' which lack any significant coal seams. The Productive Coal Measures comprise cyclic sedimentary sequences which ideally comprise initial grey and dark grey mudstones. These are followed by: siltstones; a yellowish brown, feldspathic, cross-bedded sandstone; a seatearth (fossil soil), and coal. The coal is then succeeded by the mudstone at the base of the next cycle. Mudstone is the dominant lithology of the cycles. Bands of dark grey mudstone, which usually occur immediately above the coals, contain marine fossils including stratigraphically diagnostic goniatites. Non-marine bivalves are also used in correlation.

The cyclicity of the sediments demonstrates a systematic pattern of subsidence and infill of the basin within which they accumulated. The overall sedimentary regime was of fluvio-deltaic sedimentation in shallow brackish water with occasional marine influxes. The sandstones were deposited both by sheet-floods and by migrating channels. The coals represent condensed vegetation which accumulated in stagnant swampy conditions, whereas the seatearths which underlie them reflect soils in which vegetation flourished, but without accumulating as a coal.

A correlation of the principal coal seams within the area is given in Figure 12.

Westphalian A Few of the standard goniatite zones of Westphalian A are represented. The exceptions are the Subcrenatum Marine Band which marks the base of Westphalian A and lies about 20 m above the Gwespyr Sandstone in the north of the area (Shanklin 1956), and the Listeri Marine Band

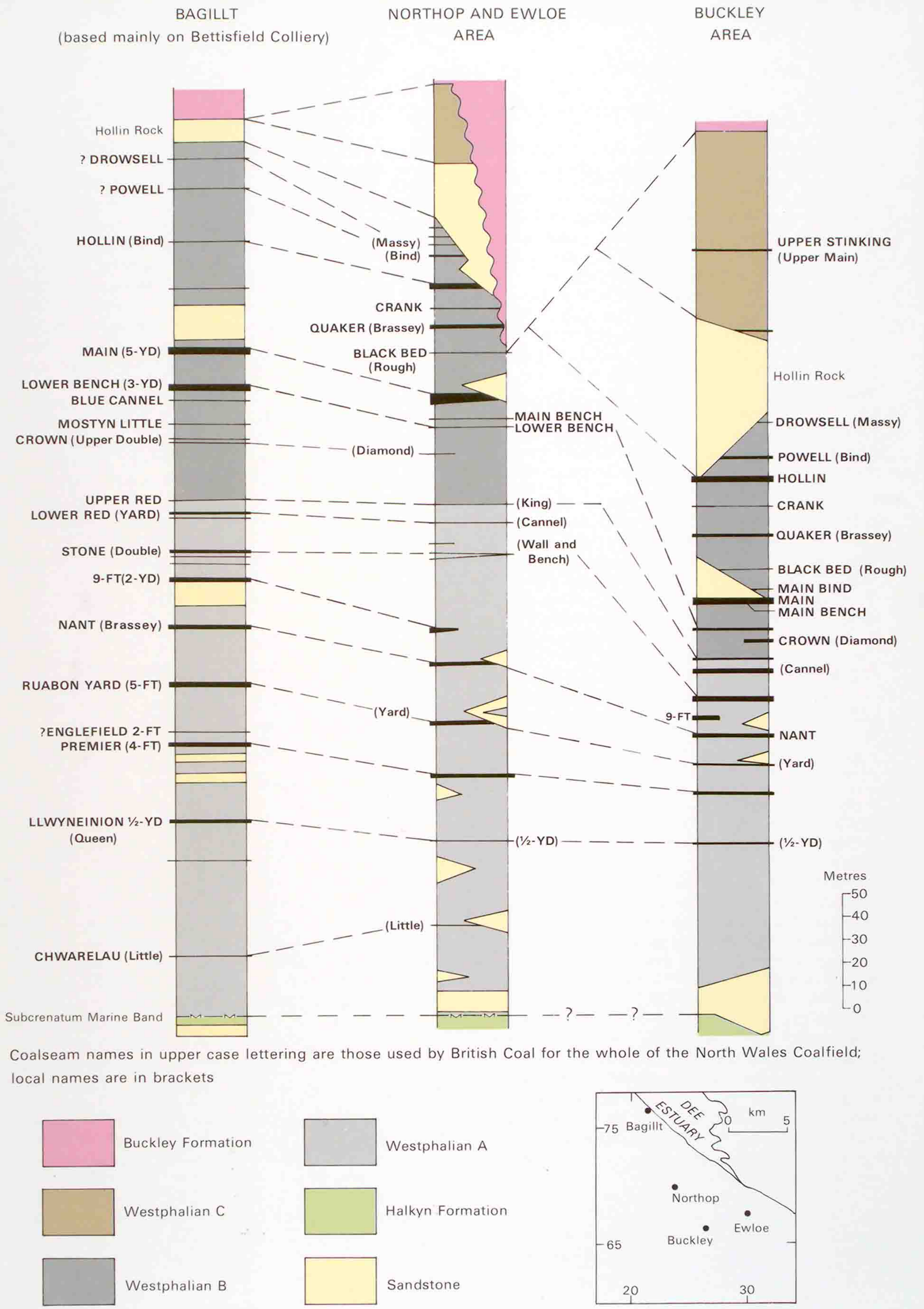


Figure 12 Correlation of the Productive Coal Meaures (Westphalian A–C)

which occurs approximately 30 m higher, and immediately above the Chwarelau coal seam.

Strata of Westphalian A age vary in thickness from 160 m in the south of the area to 230 m in the north. The principal coal seams are, in ascending order, the Chwarelau, Llwyneinion Half Yard, Premier, Ruabon, Yard, Nant, Nine Foot, Nine Foot Rider, Stone (or Wall and Bench). Lower Red (or Cannel), and the Upper Red (or King). Seam splitting of the Stone and Lower Red occurs in the north of the area. The thickest of the seams are the Premier (0.45-2.13 m), the Nant (0.48-1.93 m), the Wall and Bench (locally up to 4.14 m) and the King (0.35-1.8 m). The Nine Foot and the Nine Foot Rider are more variable in thickness and distribution but attain thicknesses of 2.87 m and 3.0 m respectively.

Westphalian B The base of Westphalian B is taken as the Marine Band which overlies the Upper Red Coal. Westphalian B varies in thickness from c. 80 m in the Mold area to c. 150 m around Bagillt. The principal coal seams are the Crown (or Diamond), Lower Bench, Main, Black Bed (or Rough), Quaker (or Brassey), Crank, Hollin, Powell (or Bind), and the Drowsell (or Massy). The Main is consistently the thickest seam (1.8-4.5 m) of the Productive Coal Measures in the area. With the exception of the Hollin coal (0.7-2.75 m), the other seams are generally less than 1 metre thick and are not as laterally continuous as seams in Westphalian A. Seam splitting of the Crown occurs in the north of the area.

Westphalian C The base of Westphalian C is considered, arbitrarily, to lie at the base of the Hollin Rock, a thick, feldspathic, cross-bedded, medium- to fine-grained sandstone. It has a transgressive, erosive base and rests at various horizons above the Hollin, Bind and Massy coals. The Hollin Rock is thickest in the south where it is up to 70 m thick, and thins to the north where, around Bagillt and Flint, it is about 10 m thick. Relatively few and only thin coal seams occur. The thickest development of Westphalian C Productive Coal Measures is 150 m around Buckley. In the northeast and around Mold in the southwest, there may be none, as the Buckley Formation (see below) succeeds Westphalian B directly. In the Bagillt and Flint areas, Westphalian C is represented respectively by the Hollin Rock alone, and 30 m of strata including the Hollin Rock.

Buckley Formation (=Buckley Fireclay Group of Calver and Smith, 1974)

This formation (maximum thickness >190 m) is intermediate in character between the Productive Coal Measures and the Ruabon Marl (see below). It is well exposed in large 'fireclay' quarries in the Buckley area where it comprises pale and pinkish grey, quartzose sandstones and siltstones, and grey, red, maroon and purple mudstones and seatearths. Rare fossils indicate a Westphalian C age (Wood, 1937). The transition from the Productive Coal Measures to the Buckley Formation is complex, since the Buckley Formation appears at varying stratigraphic levels at different places in the area. Thus, in the vicinity of Ewloe (SJ 285 655), it occurs as low as the Black Bed coal (Westphalian B) but elsewhere its base is recorded at higher levels up to Westphalian C (i.e. representing 110 m of the sequence). This relationship might suggest unconformity but it is considered here to be a lateral facies change, shifting position with time until the facies of the Buckley Formation eventually extended across the whole area.

Ruabon Marl

This formation (up to 120 m thick) comprises predominantly red, brown and purple mudstones, thin siltstones and sandstones, with rare thin limestones, some thin coals and some grey mudstones. The sequence is poorly known due to lack of exposure. It is recognised only in the northeast of the area and around Flint. These sediments were probably laid down in shallower brackish water than most of the Productive Coal Measures. Their age is poorly constrained due to a lack of fossils but is thought to be Westphalian C to D (Calver and Smith, 1974). An unconformity is inferred here between the Ruabon Marl and lower beds (Buckley Formation and Productive Coal Measures), but the possibility of there being a lateral facies change in part (cf. Calver and Smith, 1974) between the two formations has not been ruled out. At Flint the unconformity or facies change cuts down to below the Main coal.

Permo-Triassic

Kinnerton Sandstone Formation

Strata of Permo-Triassic age (between 280 and 210 million years old) overlie the Carboniferous rocks with pronounced angular unconformity. The unconformity is only poorly exposed now at one locality in the southeast [SJ 3275 6022], south of Higher Kinnerton, but it was described in detail in days of better exposure (Hull, 1869). The Kinnerton Sandstone Formation rests on the Gwespyr Sandstone (Halkyn Formation) at this locality. Further north, it rests on various levels of the Productive Coal Measures (Westphalian A and B). It is very poorly exposed, underlying thick superficial deposits on the edge of the flat Cheshire Plain. Where exposed, and proved in boreholes, it comprises brownish red and yellow, cross-bedded, fine- to medium-grained sandstones (up to 300 m thick within the area).

? Tertiary

Solution pipes within the Carboniferous Limestone are infilled at several localities with red and brown sands, silts and clays, thought to be of Tertiary age (Walsh and Brown, 1971).

Structure

The structure of the area is dominated by major faults trending NNE-SSW and N-S. They have downthrow components to both east and west. They define horsts and grabens in the coalfield area. A major fault of this orientation, the Nant Figillt Fault (Strahan, 1890), causes a marked offset of the Carboniferous Limestone and Namurian outcrop in the vicinity of Rhosesmor [SJ 214 684]. Although its apparent displacement is a downthrow (c. 275 m) to the WSW, the fault may have an important dextral strike-slip (lateral) component. As the Carboniferous Limestone and Namurian sequences differ markedly across the fault, it is probable that the fault was active during their deposition. Open, periclinal folding in its vicinity is probably related to movement on the fault. Further south, an *en echelon* fault of even greater magnitude, but with an easterly downthrow of up to 700 m and possibly more, has been invoked. It juxtaposes the Buckley and Halkyn Formations. A pronounced gravity anomaly is associated with this fault (Cornwell, 1987). A further important fault of similar orientation runs along the Wheeler Valley in the west of the area, and downthrows to the west. Faults of NNW-SSE and N-S orientation are referred to as 'cross-courses' in the mineralised district in the west of the area.

The Carboniferous Limestone outcrop is disrupted by numerous faults of a general E-W orientation. As the outcrop is traced from south to north, these faults swing from NW-SE through E-W to NE-SW in the area south of Holywell. A set of WNW-ESE faults occurs south of Holywell with downthrow to the south.

The dominant synclinal and anticlinal structure of the area (see Thematic Element, Map 1 - Cross section) reflects the extensional basin within which the Carboniferous was deposited. Many of the dominantly N-S and conjugate E-W faults were probably generated during the Carboniferous as extensional, normal faults related to the formation of the basin. Some of these faults may also have had a strike-slip component. There is little evidence to constrain post-Westphalian faulting. End-Carboniferous movements (Hercynian) are likely to have occurred but have not been differentiated. Also, as many of the faults are sub-parallel to the main faults west of the area which bound the Vale of Clwyd graben, which is a Permo-Triassic basin, activation and, or, reactivation of these faults seems likely to have occurred at that time.

Mineralisation

The locally intense lead, zinc and copper mineralisation which occurs mainly in Carboniferous Limestone rocks was influenced (? controlled) by the NW-SE, E-W and NE-SW faults and joints. In the south of the area, there is virtually no mineralisation associated with the N-S 'cross-courses'. Further north, however, and north of the Nant Figillt Fault, extensive mineralisation is associated with N-S faults (particularly in the area immediately south of Holywell). The WNW-ESE faults south of Holywell are also extensively mineralised.

The mineralisation occurs mainly as discontinuous veins (? solution infills) along faults and joints, but it also occurs in steep pipes (probably infilled solution pipes) and along selected bedding planes ('flats') (see Smith, 1921). The chief ore is galena (lead sulphide), with sphalerite (zinc sulphide) and minor amounts of chalcopyrite (copper, iron sulphide). The main associated vein mineral is calcite, with minor amounts of zinc and lead carbonate.

Most of the mineralisation occurs within the upper part of the Loggerheads Limestone and in the Cefn Mawr Limestone. Many of the mineralised faults in the upper Loggerheads Limestone splay upwards into many faults with lesser displacement close to the boundary with the Cefn Mawr Limestone. South of the Nant Figillt Fault, there is little mineralisation above the level of the 'Main shale' in the Cefn Mawr Limestone. North of the Nant Figillt Fault, mineralisation extends up into the cherts of the Halkyn Formation.

The nature and stratigraphic distribution of the ores suggest that they were precipitated in solution voids within the limestone and particularly along pre-existing faults. The stratigraphic restrictions probably reflect the optimum conditions for precipitation of the mineralising fluids (e.g. pH).

Quaternary

The area was affected by glaciation during the Quaternary, but only evidence of the later stages of glaciation (Devensian) has been preserved. Glaciation affected a post-Triassic erosion surface and accentuated existing valleys. In addition new dissections were caused by subglacial and periglacial processes. Ice-sheets from two directions impinged on the area, one from the direction of north and central Wales (the 'Welsh' ice-sheet) and the other from the Irish Sea to the north ('Irish Sea' ice-sheet). These ice-sheets merged in the vicinity of the Alyn River (Ball and Adlam, 1982; Thomas, 1985). Extensive basal tills (boulder clays) were deposited. The two different ice-sheet sources are reflected in the different clast compositions of the two till deposits. The 'Welsh' ice-sheet till comprises grey clays with clasts mostly of Lower Palaeozoic cleaved siltstones and sandstones, vein quartz and acidic volcanic rocks. The 'Irish Sea' ice-sheet till comprises reddish brown clays with abundant clasts of Carboniferous Limestone, mudstone, sandstone, chert and coal of local derivation, in addition to Triassic sediments and granitic, volcanic, metamorphic and vein quartz clasts of more distant provenance.

Subglacial drainage channels, particularly related to the 'Irish Sea' ice-sheet, have been recognised (Peake, 1961). Thick fluvioglacial deposits were deposited along the Alyn and Wheeler rivers and more extensive sheets occur to the north of Mold. Further deposits occur as 'terraces' along the southwest side of the Dee Estuary. These fluvioglacial deposits are of both subglacial (Brown and Cooke, 1977) and proglacial lacustrine origin (Peake, 1961; Thomas, 1984), the latter related particularly to retreat of the ice-sheets. Minor ice-sheet readvance occurred resulting in local interdigitation of till and fluvioglacial sand and gravel. During glacial retreat, patches of dead ice were left and the melting of these produced kettle holes (depressions) in the sand and gravel deposits. These were sites of small lakes and ponds and laminated clay and peat accumulated within them. In the periglacial freeze-thaw conditions of the immediate postglacial era, glacial deposits suffered downslope mass-movement by solifluction processes producing head deposits. Landslip also occurred at this time, both in bedrock and superficial deposits, and it persists to the present time. Some of the major pre-glacial valleys, and particularly the Wheeler, Alyn and Dee valleys, were largely infilled by glacial deposits; the thickness of superficial deposits in the infilled Dee Valley may locally exceed 90 m. Flood conditions continue to infill the valleys with alluvial deposits and estuarine alluvium is accumulating in the Dee Estuary. Part of the Dee Estuary has been drained in recent times.

CONCLUSIONS AND RECOMMENDATIONS

New geological maps and a revised stratigraphy have been produced for the Deeside area. These provide the basis for thematic geological maps and assessment of resources, geological hazards, geotechnical properties and hydrogeology.

Geological conclusions are presented in the context of:

A. Resource potential and future extraction
B. Geological problems and hazards
C. Engineering properties and problems
D. Hydrogeology and water supply

A. Resource potential and future extraction

The main economic resources of the area are limestone, sand and gravel, and coal. Of these, only limestone and sand and gravel are currently exploited. Other significant resources which have been exploited are metalliferous (lead, zinc and copper) ores, chert, feldspathic and quartzitic sandstones, moulding sand, and brickclay and refractory clay. Minor cementstone, calcspar and peat deposits have been exploited.

A.1 Limestone quarrying

1a. Limestone is volumetrically the most significant resource and supports the largest extractive industry of the area with 7 large working quarries.

1b. Limestone crops out over approximately 39 km^2 along the western side of the area and continues at depth beneath the area east of the outcrop. The theoretical resource within the area of outcrop and above Ordnance Datum is approximately 2.75×10^{10} tonnes. Less than 1% of this resource has been extracted.

1c. New subdivision of the limestone sequence and its detailed mapping provide a rational basis for future extraction and constrain the distribution of limestones with different characteristics (e.g. aggregate potential). These characteristics are directly related to grain size and are readily recognised in terms of the Dunham classification (i.e. calcite mudstone to grainstone).

1d. The greater part of the limestone outcrop is suitable for aggregate and cement making. Interbedded shale and sandstone are generally restricted to the upper part of the sequence. Small, local, clay and sand-filled solution pipes occur.

1e. There is only localised and generally limited superficial overburden.

1f. There is considerable scope for deepening existing quarries. All existing quarries are in upper levels of the limestone sequence with at least 200 m of limestone underlying them.

1g. The Halkyn-Holywell drainage tunnels (and particularly the Milwr sea-level tunnel) could have an important rôle to play in future deep-level quarrying by reducing the level of the water-table and providing a direct means of drainage.

1h. The main restrictions for future limestone extraction are likely to be:

i) The height of the water-table.

ii) Areas of sterilised ground due to housing and roads.

iii) Areas of former intensive metalliferous mining in limestones.

iv) The occurrence of two Sites of Special Scientific Interest situated on the limestone outcrop.

v) Environmental considerations in areas of natural beauty.

vi) The effect of extraction on the local topography.

vii) The effect on local land use (principally agriculture).

Hence only a small proportion of the theoretical resource is likely to be available for extraction. Current extraction removes approximately 0.01 to 0.02% of the maximum resource per annum.

A2. Sand and gravel extraction

2a. Available sand and gravel resources at surface and beneath limited overburden cover approximately 43 km^2.

2b. Deposits are patchily distributed across the area, concentrated:

i) Along or near the Alyn and Wheeler rivers.

ii) North of Mold.

iii) Along the southern and southeastern side of the Dee Estuary.

2c. Despite the large area of the resource, the deposits are relatively thin, rarely exceeding 30 m. The maximum theoretical resource is estimated at 5 to 7.5 x 10^8 tonnes.

2d. As the resource is relatively thin, large areas need to be excavated to produce significant volumes of aggregate.

2e. Large areas of the resource (>10%) have been sterilised by urban development (e.g. Mold, Bagillt, Hawarden and Greenfield), and approximately 2% of the resource has already been extracted.

2f. Deposits vary rapidly in thickness and grain size, particularly in the case of the coarser gravel fraction. This variation is hard to predict.

2g. The clast content in the southwest is radically different from that elsewhere, being dominated by siltstone and greywacke.

2h. The most common sand and gravel type in the area is dominated by locally derived rock types, including coal. Unpredictable concentrations of coal are problematic since they reduce the quality of the resource for aggregate use.

2i. As many of the deposits have a pronounced, moundy topography, their removal would have significant environmental impact. Depressions (kettle holes) between the mounds are locally clay and peat filled to considerable depth, thus reducing the resource potential of some areas.

2j. The available sand and gravel resource is considerably smaller than that of limestone and its rate of extraction relative to limestone should be carefully considered by planners and developers.

A.3 Coal mining and opencasting

3a. Coal is a substantial resource, with coal seams underlying approximately 132 km^2. Westphalian B seams underlie 65 km^2 of this area.

3b. Records indicate the mining of 20 different coal seams in the area. No mining or opencasting is current, though planning permission has recently been sought to renew opencasting.

3c. The 'theoretical' coal resource, (before allowing for coal already extracted), assuming an average total coal thickness for Westphalian A and B seams of 10 m and 9 m respectively, is estimated at 3 x 10^8 tonnes. Two thirds of the resource occurs in Westphalian A strata.

3d. Records suggest that approximately 20 km^2 of the area is undermined. Older, unrecorded workings significantly increase this area but no estimate is possible.

3e. Records of working indicate that up to 30% of major Westphalian B seams (including the Main and Hollin coals, the most extensively worked and consistently thickest seams) and up to 15% of major Westphalian A seams have been substantially worked. This represents approximately 20% of the theoretical coal resource.

3f. A wide range of extraction techniques has been used including opencasting, adits, bell pits and deep mining (via shafts) by pillar and stall and longwall methods. Records are insufficient to define depths of workings or methods used.

3g. The Coal Measures are extensively faulted and structurally complex, much reducing any potential for future economic deep mining.

3h. The main limiting factors for opencast mining are:

i) The generally thick superficial deposits covering the Productive Coal Measures, except around Buckley.

ii) The presence of bedrock overburden lacking significant coal seams over substantial areas of the coalfield.

iii) Structural complexity.

iv) The unpredictability of thickness variations and washouts of the coal seams, and the apparent lateral passage from Productive Coal Measures into barren strata (the Buckley Formation and Ruabon Marl).

v) Earlier unrecorded mining of the principal seams.

vi) Urban sterilisation of resources.

vii) Environmental considerations.

A.4 Other extractive industries

Limited resources of chert, metalliferous deposits, sandstone, and brickclay occur.

4a. Metalliferous mining - Ores are restricted to veins, joints, pipes and some bedding planes in the limestone and chert terrains. Their spatial restrictions, unpredictable concentration and the extent of past extraction at shallow levels preclude further extraction in volume under present and foreseeable economic terms.

4b. Chert - Chert is a limited resource. Deposits are structurally complex. As chert is an uncommon resource nationally, possible future demand should be considered.

4c. Sandstone - Various types occur but scattered distribution precludes major extraction in most areas. Poorly cemented Triassic sandstone is worked on a small scale for moulding sand and other purposes.

4d. Brickclay and refractory clay occurs in moderate quantity in the Buckley area, where one site is currently worked, and possibly beneath thick superficial deposits, west of Mold and at Bagillt.

4e. Other resources (calcspar, cementstone, peat) are very localised and small-scale.

B. Geological problems and hazards

Few parts of the area are unaffected by some form of quarrying or mining. Natural hazards also occur.

B.1 Shafts and underground workings related to metalliferous mining

1a. In excess of 5000 shafts and trial pit sites related to metalliferous mining were identified on the limestone terrain. Only a small proportion of these have been capped.

1b. Uncapped shafts pose problems and dangers since they may appear filled at surface while being open at depth and are thus liable to collapse and reopening, particularly if disturbed. Active collapse was recorded at several sites.

1c. Halkyn Mountain is the most intensely mined part of the area. Although many shafts here have been capped, many remain open.

1d. A list of some open shafts has been prepared (Appendix E) but any uncapped shaft must be regarded as potentially unstable and dangerous. Even capped shafts where unfilled may be affected by collapse.

1e. In addition to recorded shafts, others are likely to exist of which there may be little or no surface evidence.

1f. The practice of persons bulldozing areas of shafts to recoup farmland is ineffective in removing hazards and resolves the problem at surface only, not at depth.

1g. The extent and depth of underground workings are rarely known.

B.2 Coal mining

2a. More than 1000 shafts and adits related to coal mining have been recorded.

2b. Only a small proportion of shafts are capped. Collapse has been recorded at several shaft sites.

2c. Unrecorded shafts and underground workings may be present anywhere within the Productive Coal Measures outcrop.

2d. Shallow workings must be anticipated in any part of the Productive Coal Measures outcrop and particularly near the crops of the thicker seams (e.g. the Main and Hollin coals) and where superficial deposits are thin.

2e. There is little evidence of active subsidence in the 20% of the area of the Coal Measures known to be undermined. Recorded collapse is generally associated with shafts. This may reflect the lengthy period since most of the workings were abandoned. Furthermore, thick superficial deposits would subdue the effects of subsidence at depth. Collapse associated with longwall mining is likely already to have occurred in the main part. Unrecorded pillar and stall workings, particularly at shallow level, would pose the biggest possible threat of subsidence and ground stability problems.

B.3 Quarrying

3a. Numerous quarries (active and disused) occur, mainly in limestone, sandstone, chert and brickclay.

3b. Some of the quarries are flooded to considerable depth (particularly the brickclay quarries near Buckley).

3c. Many have steep and unstable faces (particularly the chert quarries). Secure fencing is important.

3d. Many are used as rubbish tips and, as most are in rocks which are the major aquifers of the area, protection from the dumping of soluble toxic waste is important.

B.4 Waste tips

Waste tips of all kinds are liable to instability though major problems have not been identified.

B.5 Landslip and poorly consolidated ground

5a. Active and recent landslip was recognised at several sites.

5b. Many ancient and apparently stable landslips were recorded. These could however be reactivated if disturbed.

5c. Although many landslips occur in superficial deposits, others occur in bedrock, most commonly along steep valley sides in the Halkyn Formation and Productive Coal Measures.

5d. Local peat and clay-filled kettle holes occur which would be unsuitable for foundations.

5e. Dissolution of the limestone causes cavities to develop. Some are open at the surface (swallow holes). They locally coalesce to cause substantial areas of foundered ground. The solution cavities are infilled to varying extents with clay, silt and sand.

C. Engineering properties and problems

The coverage of geotechnical data for most of the bedrock formations is poor (except for the mudstones and shales of the Halkyn Formation, Buckley Formation and Productive Coal Measures), whereas that for the superficial (unconsolidated) deposits is reasonably comprehensive. The available geotechnical properties of all of the bedrock formations and superficial deposits have been reviewed and summary tables prepared, synthesising data for 4273 individual samples covering up to 16 geotechnical tests and measurements (laboratory and in situ). Only in a small minority of instances has the full range of tests been carried out. Maximum nett safe bearing pressures have been quoted where available.

C.1 Bedrock, engineering properties and problems

1a. Limestones

i) Three categories of limestone were considered, reflecting to a large extent the relative mudstone/shale content. The limestones are generally strong but mass strength is affected by mudstone/shale layers, their thickness and separation, and jointing. Open or infilled cavities present an engineering hazard.

ii) Rockhead is very irregular because of open jointing and fracturing. Thus ripping without blasting would be practicable for depths up to 5 m from surface.

iii) Cuttings in shaly limestone must not be steeper than 1:1.

iv) The limestone is generally a suitable fill.

1b. Sandstones

i) Three categories of sandstone were considered; the Kinnerton Sandstone Formation which is generally highly to moderately weathered; sandstones in the Ruabon Marl; and sandstones in the Productive Coal Measures and the Halkyn Formation.

ii) If the sandstones in the Ruabon Marl are used as a pile foundation in the vicinity of the Dee Estuary, there is likely to be contact between the *in situ* concrete piles and saline waters. Care must be taken also to determine the nature of strata below the pile founding depth to avoid the possibility of over-stressing any mudstones or shales.

1c. Mudstone and shales

i) Three categories of mudstone/shale were considered. All are characterised by very variable weathering zones (up to 6 m depth from surface and possibly greater). When weathered, they can be classified as clays of low to intermediate plasticity and low compressibility. Strength is inversely proportional to weathering, and weathering tends to increase where cover of superficial deposits is less.

ii) For sites along the Dee Estuary (and elsewhere), piles should be taken through the weathered zone (at least 3 m, though this is dependent on the site) into the hard mudstone/shale beneath.

iii) Landslips occur in several areas, particularly within the Halkyn Formation. Failure planes appear to be in highly weathered mudstones or shales. Where slopes are greater than approximately 7° on these shales, careful investigation must be made to determine if any slope movement has taken place and to check the effect on any proposed structure.

iv) Confirmation should be obtained that weathered mudstone or shale horizons are not present within the stressed zone beneath the piles.

v) As the mudstones and shales soften on contact with water, excavations should be protected against wetting and they need supporting. Precautions may have to be taken to prevent weathering and swelling.

vi) The mudstones and shales are unsuitable for fill, unless no alternative is available and then they should only be used for low embankments.

C.2 Superficial (unconsolidated) deposits, engineering properties and problems

2a. Backfill and made ground

i) These are very variable and are generally unsuitable for the support of light-weight, single-storey structures.

ii) There is a possibility of sulphate contamination from these deposits.

2b. Peat

i) Peat is highly compressible, and has high moisture contents and Atterberg limits. Consequently, there is a need to avoid structures being founded on it.

2c. Alluvium

i) Alluvium is relatively heterogeneous. Therefore, foundation problems are very site-specific.

ii) Generally low maximum nett bearing pressures have been quoted, making it problematic for the support of light-weight, single-storey structures without piling, though gravelly layers show much higher bearing pressures.

2d. Estuarine Alluvium

i) It is relatively heterogeneous though less coarse-grained material occurs than in other alluvium.

ii) It varies from very soft, highly compressible low strength clay to loose, generally saturated sand which increases in density with depth. The deposits broadly coarsen with depth and away from estuary margins.

iii) Being low-lying, the water-table is near (or at) surface, the sediments are saturated (with moisture contents for the clays approaching liquid limits) and there is a risk of running conditions.

iv) Excavations require groundwater control (e.g. well-point dewatering, pumping etc.), vertical excavations require shoring and excavation activity should avoid peak tides.

v) Safe bearing pressures are low but increase with depth, and therefore piling to these denser materials at depth will be more reliable. Depths of foundations are therefore critical to their stability. The clays have very low safe bearing pressures and high compressibility and are therefore generally unsuitable for light-weight, single-storey structures, whereas the sands have higher safe bearing pressures.

vi) Good quality dense cement must be used below the water-table.

vii) As the deposits are heterogeneous, and variably compressible, large settlements can occur (even with small loads) and differential subsidence is a possibility.

2e. Lacustrine Alluvium

As it comprises soft to stiff compressible clays, problems of stability and settlement would be anticipated.

2f. Heterogeneous deposits (Head)

i) Head is very heterogeneous. Relatively thin veneers are extensive and deposits occur not only at the surface.

ii) Geotechnical characteristics are very variable.

iii) Perched water-tables may occur and there is the possibility of running conditions in excavations.

iv) Deposits may contain shear planes, and increased pore pressures, undercutting of slopes, or loading at the top of slopes may activate (or reactivate) movement causing failure. Therefore, care must be taken to examine slopes (even of only a few degrees) for shear planes and solifluction lobes. Piles may be necessary into stronger underlying strata.

2g. Glacial Sand and Gravel

i) These deposits are very heterogeneous and may be stratified. Therefore differential settlement problems may occur. Maximum safe bearing pressures reflect the gravel content to a large extent.

ii) Deposits are prone to running, and excavations will deteriorate rapidly. Thus they require shoring and slopes should be cut back to 1:1.

iii) Groundwater problems are likely, with high water flows in coarser material. High hydrostatic pressures can occur.

iv) Safe bearing pressures are very site-specific. There is a danger, if clay bands are present, of heaving and sagging just below the depth of the site-investigation.

2h. Till (Boulder Clay)

i) Deposits are very heterogeneous and geotechnical properties are very variable, reflecting lithology, depth and weathering. Differential subsidence may be a problem.

ii) Higher maximum nett safe bearing pressures occur at depth, but softer horizons may not support piles.

iii) Sloping of sites reduces expected safe bearing pressures.

iv) Perched water-tables may occur.

v) Clays are liable to softening on exposure to rain. Therefore, excavations should be protected, and supported to ensure stability.

vi) At natural moisture content, till is a suitable fill deposit.

D. Hydrogeology and Water Supply

There are several groundwater abstractions for public supply and industrial purposes, but most of the water used comes from outside the area. As groundwater commonly receives little treatment, it is important that aquifers are protected from potential pollutants. Two main sources of pollution are point sources (e.g. landfill and waste disposal sites) and diffuse sources (e.g. agricultural fertilisers and biocides). However, these represent little risk to groundwater quality over much of the area, due to the extent of impermeable superficial deposits.

D.1 Kinnerton Sandstone Formation

1a. This is the major aquifer in the area.

1b. It is being predominantly recharged from east of the study area.

1c. The quality of water derived from it is good, but hard.

D.2 Carboniferous Limestone

2a. This is the second most important aquifer in the area.

2b. Drilling for water within it is highly speculative as groundwater movement is largely restricted to fissures enlarged by solution, which are hard to predict. Groundwater movement can be rapid.

2c. Tunnels associated with old mineral workings have had a significant effect on the hydrogeology of the area. The Halkyn-Holywell mine drainage scheme has been used for water supply.

2d. The quality of water derived from the limestones is generally hard, but good. Metals are present where the water has been in contact with old mineral workings.

D.3 Sandstones in the Halkyn Formation

3a. Only one small yield is recorded in the area.

3b. The water is of good quality, but hard. Iron may, however, be a problem.

D.4 Sandstones in Westphalian strata

4a. Water occurs particularly within joints and fractures caused by mining subsidence.

4b. Yields of water from boreholes are rarely sustained since recharge is limited by separation of the aquifers into fault-blocks, and because of the extensive cover of low permeability superficial deposits.

4c. The quality of water is variable, but usually non-potable. Water is often polluted by mining activities.

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GLOSSARY

ALLOWABLE BEARING PRESSURE The maximum allowable net loading intensity on the soil allowing for both shear *and* settlement

ALLUVIUM Detrital material transported by a river and deposited along its floodplain

AQUIFER A body of rock that contains sufficient saturated permeable material to conduct *GROUNDWATER* and to yield economically significant quantities of groundwater to wells, boreholes and springs

ARGILLACEOUS A deposit containing an appreciable amount of clay

ARTESIAN HEAD The hydrostatic head of an artesian *AQUIFER*, or of the water in the aquifer

ARTESIAN PRESSURE Hydrostatic pressure of artesian water, or height above land surface of a column of water that would be supported by the pressure

BASIN A depression in which sediments accumulate

BEARING CAPACITY The load per unit of area which the ground can safely support without excessive yield

BEDDING The arrangement of a sedimentary rock in beds or layers of varying thickness and character

BEDROCK Geological strata at surface and below *SUPERFICIAL DEPOSITS*

BIOCLASTIC A SEDIMENT comprising fragments of *SKELETAL* material

BIVALVE A (fossil) mollusc with two shells which are symmetrical with respect to each other

BLOWING Failure of *STANDARD PENETRATION TEST* due to movement of non-cohesive *SAND* around the sample tube

BRACHIOPOD A marine animal (fossil) with two symmetrical shells

BULK DENSITY The mass of an object or material divided by its total volume

BURIED CHANNEL An old channel concealed by *DRIFT* deposits

CALCAREOUS A deposit that contains calcium carbonate

CALCITE A common rock-forming mineral, $CaCO_3$

CALCITE MUDSTONE A *LIMESTONE* similar to a *WACKESTONE*, but in which the carbonate grain content must be less than 10% of the whole rock

CALCSPAR Coarsely crystalline calcite, usually in veins

CALIFORNIA BEARING RATIO A standard test for comparing the strength of roads with a standard material

CARBONACEOUS A deposit that contains organic matter

CEMENTSTONE A fine-grained *CALCAREOUS SILTSTONE* or *LIMESTONE*

CHERT A rock comprising very fine-grained quartz

CLAST An individual grain or rock fragment

CLEAVED Pertaining to a rock fabric imposed by compression

COEFFICIENT OF CONSOLIDATION The rate at which volume change takes place for a given increase in stress

COEFFICIENT OF VOLUME COMPRESSIBILITY Change in unit volume per unit change in effective stress

COHESIVE A sticky *SOIL* like clayey silt; some authorities define it as a soil with an undrained shear strength equal to half its unconfined compressive strength

COMPACTION TEST A test to determine the moisture content at which *SOIL* may be compacted to its maximum density; this is called the optimum moisture content

COMPRESSIBILITY The reciprocal of bulk modulus

CONGLOMERATE A coarse-grained sedimentary rock with average clast size greater than 4 mm

CONSOLIDATION Reduction of bulk volume of soil that results from the closer packing of particles caused by an increase in effective stress

CORRELATION The process by which *STRATIGRAPHIC* units in two or more areas are demonstrated to be temporally equivalent

CRINOID A marine organism (fossil) with a structure comprising discs of calcite

CROSS-BEDDING Structure in sedimentary rocks comprising intersecting *BEDDING PLANES*

CYCLICITY A repeated sequence of beds or rock units

DEBRIS FLOW A depositional mechanism akin to a mud slide

DIP The angle of inclination of a surface (e.g. *BEDDING*) in relation to the horizontal

DISHARMONIC Relating to folds which differ in form with respect to one another

DISTAL Distant from

DRIFT A general term for all superficial unconsolidated rock debris of Quaternary age distinguished from solid bedrock

DRY DENSITY The mass of *SOIL* after drying (i.e. solids only), divided by its total volume before drying

FACIES CHANGE A change in the internal characteristics of a rock unit

FAULT A surface or zone of rock fracture along which displacement has occurred; movement may either be vertical (normal or reversed), lateral (strike-slip) or a combination of the two

FELDSPATHIC A deposit that contains the mineral feldspar in significant quantity

FIELD-SLIP The base map on which geological observations and comments are recorded

FIRECLAY A *SEATEARTH* comprising quartzose clay, and capable of withstanding high temperature without deforming

FORAMINIFERA Marine protozoan animals (microfossils)

FORMATION The fundamental unit of subdivision of a rock sequence which is unified in internal characteristics and differs with respect to adjacent formations

GEOTECHNICAL The application of scientific methods and engineering principles to the acquisition, interpretation, and use of knowledge of materials of the Earth's crust to the solution of civil engineering problems

GRABEN A sequence of strata between two *FAULTS*, which is lowered relative to adjacent strata

GRAINSTONE A *LIMESTONE* where the individual grains of carbonate are in direct contact (grain-supported) and fine-grained carbonate mud is minimal

GRAPTOLITE An extinct fossil plankton comprising an elongate tubular structure

GRAVEL An unconsolidated accumulation of rounded grains of average grain size greater than 4 mm

GONIATITE A fossil mollusc with a shell of spiral form

GROUNDWATER Water contained in the soil or rock below the water-table

HARDNESS A property of water causing formation of an insoluble residue

HORIZONTAL SECTION An interpretive diagram displaying the structure and sequence of strata at depth

HORST A sequence of strata between two *FAULTS*, which is raised relative to adjacent strata

IGNEOUS Rock which was originally molten

KARSTIC Relating to irregular topography of a limestone surface by its dissolution

KETTLE HOLE A steep-sided depression in glacial deposits, usually containing clays and peat laid down in a lake or swamp

LACUSTRINE Pertaining to a lake

LAMINATED A very fine type of *BEDDING* less than 1 mm thick

LIMESTONE A sedimentary rock mainly comprising calcium carbonate

LIQUID LIMIT The moisture content at the point between the liquid and the plastic state of a clay

LITHOLOGICAL Pertaining to rocks

LITHOSTRATIGRAPHICAL Pertaining to the classification of rocks on the basis of their physical characters

MATURE (of *SANDSTONE*) Pertaining to a predominance of well rounded and spherical grains

MAXIMUM SAFE BEARING PRESSURE The maximum value of contact pressure to which the soil can be subjected without risk of shear failure; it is based solely on soil strength but takes into account a suitable factor of safety (usually 3)

MEMBER A distinctive unit of strata within a *FORMATION*

METAMORPHIC Pertaining to rocks which have been affected by high temperature and or pressure resulting in changes in their mineral constituents

MOISTURE CONTENT The amount of moisture in a given soil mass, expressed as the mass of water in a soil divided by the mass of solids in a soil

MUDSTONE A sedimentary rock comprising very fine-grained particles

NODULE (phosphatic, ironstone, carbonate) A small body of mineral or mineral aggregate, often rounded or ellipsoidal in profile

ONCOLITIC A small concentrically *LAMINATED CALCAREOUS* sedimentary structure formed by algal growth

OVERCONSOLIDATED Clay that still retains some of the imposed stress from a previous greater overburden

PACKSTONE A *LIMESTONE* which is generally grain-supported (see *GRAINSTONE*) but with significant fine-grained carbonate mud matrix, in some instances resulting in separation of the carbonate grains

PALAEONTOLOGICAL Pertaining to the study of fossil plants and animals

PARTICLE SIZE DISTRIBUTION The percentage of particles in each size fraction of a sample of soil, sediment or rock; the result of particle size analyses

PELLOID (PELOID) A grain formed of fine-grained *CALCAREOUS* material irrespective of size or origin

PERIGLACIAL Said of the process occurring in the region adjacent to glaciers and ice sheets

PERITIDAL A sedimentary environment within or near to the tidal range

PERMEABILITY The property or capacity of a rock, sediment or soil for transmitting a fluid

pH The measure of the acidity or alkalinity of a solution

PIPE A cavity, usually in calcareous rocks, commonly filled with clay, sand or gravel

PIPING Water flow in non-cohesive *SAND* causing erosion and formation of channels within the deposit

PLASTIC LIMIT The water content at the lower limit of the plastic state of a clay; it is the minimum water content at which a soil can be rolled into a thread 3 mm in diameter without crumbling

PLASTICITY INDEX The difference between the water contents of a clay at the liquid and at the plastic limits. It shows the range of water contents for which the clay is plastic

PORE PRESSURE The stress transmitted through the fluid that fills the voids between particles of a soil or rock mass

POROSITY The property of a rock, soil or other material of containing interstices; it is commonly expressed as a percentage of the bulk volume of material occupied by interstices, whether isolated or connected

PLATFORM (as in carbonate) Pertaining to a very gently sloping sea bed, with little topography

PORCELLANOUS Pertaining to a very fine-grained calcareous sediment resembling unglazed porcelain

PRECONSOLIDATION PRESSURE The pressure which must be applied to a sample in a consolidation test to equal the maximum overburden pressure to which the sample has been subjected *in situ*

PROGLACIAL The environment in front of a glacial ice sheet

PROGRADING Relating to sediments laid down as a deposit which builds out in front of the source of the sediments

PSEUDOBRECCIATED Pertaining to a texture in limestone resembling a fragmental rock, but is produced by alteration of the limestone

QUARTZITIC A deposit mainly comprising quartz

QUARTZOSE A deposit containing quartz

ROCK (Engineering) A naturally found material with a uniaxial compressive strength over a certain minimum value (usually taken as $IMNm^{-2}$), and composed of mineral grains

ROCK QUALITY DESIGNATION (R.Q.D.) A measure of core recovery incorporating only those pieces of found core 100 mm in length; indicative of the degree of fracturing; separate values are usually determined for each core run

ROCKHEAD The interface between unconsolidated *SUPERFICIAL DEPOSITS* and *BEDROCK* (and usually taken as the base of the weathering profile of the bedrock)

RUNNING Mass flow of non-cohesive *SAND* due to high water content

SAND(STONE) A sediment (consolidated) comprising grains between 0.063 and 4 mm in average size

SEATEARTH A unit, generally of clay, that underlies a coal and represents the fossil soil on which the vegetation grew

SHALE A *MUDSTONE* with bedding-parallel fissility

SHEET SAND A unit of *SANDSTONE* of wide areal extent and limited thickness variation

SHEAR BOX TEST (DRAINED AND UNDRAINED) A test used to determine the shear strength and residual shear strength of a *SOIL*

SILT(STONE) A sediment (consolidated) comprising grains between 0.063 and 0.004 mm in average size

SKELETAL Carbonate fragments of organic origin

SLUMPED Pertaining to sediment disrupted on the sea floor due to gravitational collapse

SOIL (Engineering) All material formed from aggregates of rock particles which can be separated by gentle mechanical means and excavated without blasting

SOLID *BEDROCK* geology (excluding *DRIFT* deposits)

SOLIFLUCTION A process involving the slow downslope movement of superficial material as a result of the alternate freezing and thawing of the contained water

SPECIFIC CAPACITY The ratio of discharge of a water well or borehole per unit of drawdown

SPECIFIC GRAVITY The ratio of the average density of the mineral grains that make up a soil to the density of an equal volume of water

STANDARD The fair copy of the geological map (scale 1:10 000 or 10 560)

STANDARD PENETRATION TEST An *in situ* test for *SOIL* where the number of blows with a standard weight falling through a standard distance to drive a standard core or sample tube is counted; it is a measure of the *BEARING CAPACITY* of a soil

STRATIGRAPHIC Pertaining to the study and classification of the sequence of rock strata in the Earth's crust

STRIKE The orientation of a horizontal line drawn on an inclined surface (e.g. *BEDDING*)

STYLOLITES Irregular surfaces within limestone due to dissolution, and with insoluble residue preserved along the contact

SUBARTESIAN Said of confined *GROUNDWATER* that is under sufficient pressure to rise above the water-table, but not to the land surface

SULPHATE CONTENT The amount of sulphate in groundwater or soil; this gives an indication of the susceptibility of engineering materials, particularly concrete and steel, to chemical attack

SUPERFICIAL DEPOSITS Unconsolidated glacial and postglacial sediments

SWALLOW HOLES Closed depressions or dolines into which all or part of a stream disappears underground

TECTONIC Pertaining to forces which deform or disrupt strata

TRACE FOSSIL A sedimentary structure comprising the fossilised burrow or track of a marine organism

TRANSMISSIBILITY In an *AQUIFER*, the rate of flow of water through each vertical strip of the aquifer having a height equal to the thickness of the aquifer and under a unit hydraulic gradient

TRIAXIAL TEST (DRAINED AND UNDRAINED) A test of the shear strength of a *SOIL* sample contained in a rubber membrane surrounded by liquid under pressure

TURBIDITY CURRENT A turbulent mixture of sediment and water which flows on the sea floor under the influence of gravity

UNCONFORMITY A break in the sedimentary sequence with strata of a particular age absent and possibly an angular relationship between the strata of different ages

VEIN A mineral infilling of a fault or fracture in a rock, and usually sheet-like

VERTICAL SECTION A diagrammatic representation of vertical variations in a sequence of strata

WACKESTONE A *LIMESTONE* where the fine-grained carbonate mud matrix is predominant and individual carbonate grains (which must comprise more than 10% of the rock) are rarely in contact with one another (i.e. the grains are matrix-supported)

WELL SORTED Pertaining to a sedimentary rock comprising particles all approximately of the same size

ZONAL Pertaining to a subdivision (zone) of strata based on its fossil content

APPENDIX A: List of British Geological Survey open file reports, 1:10 000/10 560 geological maps and palaeontological reports produced as part of the project

Open file reports. (Copies of these reports can be purchased either from the Aberystwyth Office of the British Geological Survey or from the National Geosciences Data Centre, British Geological Survey, Keyworth).

Geological notes and local details for 1:10 560 sheet SJ 16 SE (E of gridline $^{3}17$), by D. Wilson. 1986.

Geological notes and local details for 1:10 000 sheet SJ 26 SW, by J.R. Davies and D. Wilson. 1986.

Geological notes and local details for 1:10 000 sheet SJ 26 SE, by J.R. Davies and B.A. Hains. 1986.

Geological notes and local details for 1:10 000 sheet SJ 36 SW, by J.R. Davies and B.A. Hains. 1986.

Geological notes and local details for 1:10 560 sheet SJ 16 NE (E of gridline $^{3}17$), by S.D.G. Campbell and D. Wilson. 1987.

Geological notes and local details for 1:10 000 sheet SJ 26 NW, by S.D.G. Campbell. 1987.

Geological notes and local details for 1:10 000 sheet SJ 26 NE, by B.A. Hains. 1987.

Geological notes and local details for 1:10 000 sheet SJ 36 NW, by B.A. Hains. 1987.

Geological notes and local details for 1:10 560 sheet SJ 17 NE (E of gridline $^{3}17$ and S of gridline $^{3}78$) by J.R. Davies and S.D.G. Campbell. 1988.

Geological notes and local details for 1:10 560 sheet SJ 17 SE (E of gridline $^{3}17$) by S.D.G. Campbell. 1988.

Geological notes and local details for 1:10 000 sheet SJ 27 NW, by B.A. Hains. 1988.

Geological notes and local details for 1:10 000 sheet SJ 27 SW, by B.A. Hains and S.D.G. Campbell. 1988.

Geological notes and local details for 1:10 000 sheet SJ 27 SE, by B.A. Hains. 1988.

Geological notes and local details for 1:10 000 sheet SJ 37 SW, by B.A. Hains. 1988.

1:10 000/10 560 geological maps. (Copies of these maps can be purchased from the National Geosciences Data Centre, British Geological Survey, Keyworth).

SJ 16 SE by D. Wilson. 1985 (E of gridline $^{3}17$, at 1:10 560 scale)

SJ 26 SW by J.R. Davies and D. Wilson. 1985 (at 1:10 000 scale)

SJ 26 SE by J.R. Davies and B. Hains. 1985 (at 1:10 000 scale)

SJ 36 SW by J.R. Davies and B. Hains. 1986 (at 1:10 000 scale)

SJ 16 NE by S.D.G. Campbell and D. Wilson. 1986-1987 (E of gridline $^{3}17$, at 1:10 560 scale)

SJ 26 NW by S.D.G. Campbell. 1986 (at 1:10 000 scale)

SJ 26 NE by B.A. Hains. 1986-1987 (at 1:10 000 scale)

SJ 36 NW by B.A. Hains. 1986 (at 1:10 000 scale)

SJ 17 NE by J.R. Davies and S.D.G. Campbell. 1987 (E of gridline $^{3}17$ and S of gridline $^{3}78$, at 1:10 560 scale)

SJ 17 SE by S.D.G. Campbell. 1987 (E of gridline $^{3}17$, at 1:10 560 scale)

SJ 27 NW by B.A. Hains. 1987 (at 1:10 000 scale)

SJ 27 SW by B.A. Hains and S.D.G. Campbell. 1987 (at 1:10 000 scale)

SJ 27 SE by B.A. Hains. 1987 (at 1:10 000 scale)

SJ 37 SW by B.A. Hains. 1987 (at 1:10 000 scale)

Palaeontological reports. (Copies of these reports are held on file by the Biostratigraphy Research Group, British Geological Survey, Keyworth to whom all enquiries should be addressed).

The faunal biostratigraphy of selected Silesian localities, N. Wales 1" 96 and 108 for BP West Midlands Silesian Review. Report PD 85/190 by N.J. Riley.

Dinantian calcareous microbiota from North Wales (Deeside), Llanarmon and Spring Quarry ? Limestones, 1" 108. Report PD 86/207 by N.J. Riley.

Dinantian foraminifera and algae from Deeside N. Wales, 1" 108, 121. Report PD 87/336 by N.J. Riley.

Brigantian to Yeadonian ammonoid biostratigraphy of various localities, Deeside N.

Wales, 1" 108. Report PD 87/380 by N.J. Riley.

Namurian faunal biostratigraphy of two localities in the Holywell Shales (Halkyn Formation), Deeside N. Wales, 1" 96. Report PD 87/407 by N.J. Riley.

Dinantian calcareous microbiotas from Deeside N. Wales, 1" 97, 108, 121. Report PD 87/408 by N.J. Riley.

In addition the following files held by the Biostratigraphy Research Group, BGS, Keyworth and relevant to the study area, were produced at an earlier date.

PD/54/20
PD/55/30
PD/55/26
PD/55/50
PDL68/27

APPENDIX B: Geotechnical Tests quoted in the Database and their applications

The Standard Penetration Test (S.P.T.)

The standard penetration Test (S.P.T.) is a dynamic test carried out at intervals during the drilling of a borehole. A standard 50 mm diameter split barrel sampler is driven into the soil at the bottom of the hole for a distance of 450 mm by the blows of a standard weight (65 kg), falling through a standard distance (0.76 m). The number of blows (N) required to drive the last 300 mm is recorded. [Details are given in B.S. 5930 (British Standards Institution 1981)].

A modification of the test for hard material and coarse gravel uses a solid cone instead of a cutting shoe and is called a cone penetrometer test (C.P.T.).

Although this is a field test which is subject to operational errors, the S.P.T. is widely used to give an indication of the relative density of granular soils (very loose to very dense) and the consistency of cohesive soils (very soft to hard). Correlations have also been made between S.P.T. and the bearing capacity of a soil.

Rock Quality Designation (R.Q.D.)

Rock quality designation (R.Q.D.) was introduced by Deere (1964) to give an indication of rock quality in relation to the degree of fracturing from drill cores. It is defined as the sum of the core sticks in excess of 100 mm in length expressed as a percentage of the total length of core drilled. The parameter takes no account of the degree of fracture opening or the fracture condition and does not distinguish between fracture spacings of more than 100 mm. R.Q.D. has been used with uniaxial compressive strength to give an indication of excavatibility and as one input for the classification of rock masses to assist in the design of tunnel support systems (Bieniawski, 1974; Barton and others, 1974).

Moisture Content

The moisture content of a soil is defined as the mass of water in a soil divided by the mass of solids in a soil, expressed as a percentage. It is determined by weighing a sample before and after drying to constant weight at a temperature of 105°C [details are given in B.S. 1377 (British Standards Institution 1975)]. Moisture content is a basic soil property and influences soil behaviour with regard to, for example, compaction and plasticity.

Atterberg or Consistency Limits

As the moisture content of a cohesive soil increases it will pass from a solid state to a semi-solid state in which changes in moisture content cause a change in volume. The moisture content at this change is the shrinkage limit. As the moisture content is increased further, the soil will become plastic and capable of being moulded; the moisture content when this change takes place is the plastic limit.

Ultimately, as moisture content is increased, the soil will become liquid and capable of flowing under its own weight. This change takes place at a moisture content called the liquid limit.

The plasticity index is defined as the liquid limit minus the plastic limit and gives the range of moisture content over which the soil behaves as a plastic material. The methods and apparatus for determining the consistency limits are described in B.S. 1377.

The factors which control the behaviour of the soil with regard to consistency are the nature of the clay minerals present, their relative proportions and the amount and proportions of silt, fine sand and organic material. If plasticity index is plotted against liquid limit on a plasticity diagram, a soil may be classified in terms of its plastic behaviour. The consistency limits also give an indication of soil strength and compressibility.

Density Tests

Bulk density is calculated by dividing the total mass of a soil (solids and water by its total volume. It may be determined by the sand replacement method (in the field) or the core cutter method. In each of these a measured volume of soil at its natural moisture content is weighed and its density calculated.

Dry density is calculated by dividing the mass of soil after drying (that is, solids only) at 150°C to constant weight, by its total volume before drying.

Saturated density is calculated by dividing the mass of soil with its pore spaces filled with water, by its total volume. Full details of the determination of soil density are given in B.S. 1377. The density of soil in its various states of saturation are basic soil properties which are used in a variety of calculations including assessing overburden pressure, slope stability, surcharge pressure, and earth pressure on retaining walls.

Triaxial Compression Test

The Triaxial compression test is the most widely used test for determining the shear strength of cohesive soils and a number of different methods may be used depending on the application of the results.

In the simplest, most common method (quick undrained), a cylindrical specimen (usually 76 mm x 38 mm) is placed between rigid end caps and covered with a rubber membrane. The assembly is then placed in a triaxial cell which is filled with water and all air is removed. The water pressure in the cell is then maintained at a prescribed constant value while the axial load on the specimem is increased at a constant rate of strain. The test continues until either the specimen shears or a maximum vertical stress is reached. Vertical displacement, axial load and pore pressure within the sample are measured during the test. The test is repeated on two further specimens from the same sampling point but at two different confining pressures. The results obtained from the three tests enable the undrained shear strength to be calculated as C_u, the apparent cohesion, and ϕ_u, the angle of shearing resistance. The parameters obtained from this test may be used to determine the immediate bearing capacity of foundations in saturated clay.

Other variations on the test are suited to different applications. In the consolidated undrained test, free drainage of the specimen is allowed under cell pressure for 24 hours before testing (that is, the sample consolidates). Drainage is then prevented and the test carried out as before. This test is applicable to situations where a sudden change in load takes place after a period of stable conditions, for example where rapid drawdown of the water behind a dam takes place.

In the drained triaxial test, free drainage is allowed during the consolidation phase and also during the test itself. The results obtained would be applicable to long-term slope stability assessment.

Consolidation Test

If a saturated cohesive soil is subjected to an increase in loading, the pressure of the water in the pore spaces will increase by the same amount as the applied stress. The water will therefore tend to flow away to areas at a lower pressure at a rate controlled by the soil permeability. The removal of water causes a decrease in volume of the soil; this process is called consolidation.

The consolidation parameters are measured in the laboratory by placing a disc of soil in a metal ring, in a water-filled cell. A constant axial load is applied to the disc and its decrease in thickness measured with time. When it reaches a constant thickness for a given load, the load is increased (usually doubled) and the readings repeated. The loading is continued depending on the soil type and the structure for which the data is required. The coefficient of volume compressibility, M_v, can then be calculated. This is a measure of the amount of volume decrease that will take place for a given increase in stress. The coefficient of consolidation, C_v, which is a measure of the rate at which the volume change will take place for a given increase in stress, is also calculated.

The consolidation test results are important for designing the foundations of a structure and calculating the settlement that will take place during and after the construction of a building to ensure that settlement is neither excessive nor uneven over the foundation. It may also be important to ensure that the settlement (consolidation) which is caused by an early stage of construction has ceased before a second stage is started.

Permeability

The permeability of a soil is its capacity to allow water to flow through it. It may be measured in the laboratory on samples or in the field using boreholes.

In the laboratory, two tests are commonly employed, the constant head test for coarse-grained soils and the falling head test for fine-grained soils. In the constant head test a sample of granular soil is confined in a perspex tube, a constant head of water is applied to one end and water is allowed to flow through the sample. Manometers are connected through the cylinder walls to monitor the pressure along the flow path. Permeability may then be calculated, using Darcy's Law, from the path length, pressure difference, cross-sectional area of the sample and the quantity of water passed in a given time.

In a falling head test a sample of fine-grained soil containing clay or silt is placed in a cylinder standing in a tray of water, a glass standpipe is connected to the top of the sample and filled with water. The time taken for the water level in the standpipe to drop a given distance is then measured. Permeability may then be calculated from the time, the drop in height, the cross-sectional area of the standpipe, the cross-sectional area of the sample and the length of the sample. (Details are given in B.S. 1377).

Laboratory tests do not take into account the structural differences in the soil and may not give a true permeability of the ground *en masse*. Pumping tests using boreholes give a more representative value but are more expensive.

In a field permeability test water is pumped out of a borehole and the effect on the water level in adjacent boreholes is monitored; if a single borehole is being used it may be pumped out and the water level recovery time recorded. An alternative approach is to pump water into a borehole under pressure and measure the volumes of water flowing into the borehole at a number of different pressures (details are given B.S. 5930). The information obtained from either method enables a coefficient of permeability for the ground as a whole to be calculated.

Permeability is used to predict the inflow of water during excavation or tunnelling and to design groundwater control schemes to deal with it. Permeability is important when assessing waste disposal sites or the siting and construction of water-retaining structures such as dams, lagoons and canals. The assessment of potential well yields requires field permeability determination for the formations concerned.

Particle Size Analysis

The particle size distribution of a soil is determined by sieving and sedimentation. A sample of soil is dried, weighed and sieved to remove the fraction greater than 20 mm in size. It is then immersed in water with a dispersing agent such as sodium hexametaphosphate to break up soil aggregates. The sample is then wet sieved to remove particles less than 63 μm. The fraction retained on the 63 μm sieve is dried and passed through a nest of sieves of mesh size ranging from 20 mm to 63 μm. The fraction retained on each sieve is weighed and the cumulative percentage passing each sieve is calculated. A grading curve of percentage passing against sieve size is plotted.

The fines which passed through the 63 μm sieve are graded by sedimentation. A representative subsample is made up into a suspension with distilled water, placed in a tall jar and made up to a volume of 500 ml. It is then agitated vigorously and allowed to settle. Samples are removed by pipette from a given depth at specific times. The samples are dried and the contained solids weighed. The size distribution can then be calculated using Stokes' Law which relates settling time to particle size. The entire grading curve for coarse and fine material can then be plotted. Full details are given in B.S. 1377.

Particle size distribution is used for classifying soil in engineering terms (B.S. 5930). Particle size distribution curves will indicate soil behaviour with regard to permeability, susceptibility to frost heave or liquefaction, and will give some indication of strength properties. Particle size analysis does not, however, indicate structure and will not distinguish between a sandy clay and a laminated sand and clay which may behave very differently.

Compaction

The compaction test determines the moisture content (the 'optimum') at which a soil may be compacted to its maximum dry density. A quantity of soil (5 kg) is compacted in a standard mould using a standard rammer (2.5 or 4.5 kg) which is dropped from a standard height (300 mm or 450 mm) a standard number of times (27). The density of the compacted soil is then measured and its moisture content determined. The procedure is then repeated using the same soil at different moisture contents.

The dry density of the compacted soil is plotted against its moisture content and the moisture content at which maximum compacted density may be achieved is read from the curve. (Details are given in B.S. 1377)

The results of the compaction test show the moisture content at which it is best to place a given soil as fill or in an embankment.

California Bearing Ratio (C.B.R.)

The California Bearing Ratio test is a penetration test carried out in the field, or in the laboratory, which compares the resistance of a soil to penetration by a standard plunger to the resistance to penetration shown by a standard crushed stone.

A series of samples are compacted in a 152 mm diameter mould at moisture contents around the optimum moisture content for maximum compaction. A surcharge weight is placed on the soil which is then immersed in water for four days. The mould is placed in a load frame and a plunger 48.5 mm in diameter is forced into the sample to a penetration of 2.5 and 5 mm. The C.B.R. value is determined as the higher of the ratios of the resistance at 2.5 mm and 5 mm penetration to the standard resistance of crushed stone at the same penetrations. (Details are given in B.S. 1377). In the field, the plunger is jacked into the ground against the reaction of a heavy lorry. (Field values are usually lower than laboratory values). The results of the C.B.R. test are used to assess the suitability of soils for use as base, sub-base and sub-grade in road construction.

Chemical Tests

pH About 30 g of soil are weighed and placed in 75 ml of distilled water in a beaker. The mixture is stirred and allowed to infuse overnight. A glass electrode connected to a pH meter is then placed in the stirred mixture and the pH reading taken. The electrode and meter may also be used to determine the pH of groundwater samples; pH may also be determined colorimetrically. Details are given in B.S. 1377.

The pH of soil or groundwater is important when designing concrete structures below ground surface. Ordinary Portland cement is not recommended in situations with a pH below 6, high alumina cement can be used down to pH 4 and supersulphated cement has been used to pH 3.5. Acidic groundwaters can also cause corrosion in buried iron pipes.

Sulphate The sulphate content of soil is determined by leaching a weighed sample of soil with hydrochloric acid and precipitating the dissolved sulphate by the addition of an excess of barium chloride. The precipitate is then filtered, ignited in a furnace and weighed.

The sulphate content of groundwater or an aqueous soil extract is determined by passing the water through a column of ion exchange resin which converts the sulphate content to hydrochloric acid. The acid content, and hence sulphate, is then determined by titration with sodium hydroxide. Details are given in B.S. 1377.

It is important to know the sulphate content of groundwater and soil because ordinary Portland cement deteriorates in the presence of sulphate. Knowledge of the sulphate concentration present enables a suitable sulphate-resisting or high alumina cement to be used in appropriate concrete mixes for applications below ground level.

Specific Gravity

The specific gravity of a soil is the mass of a dry soil divided by the mass of water displaced by that soil and is, therefore, dimensionless. For fine-grained soils, a 50 ml density bottle is used, whilst for coarse-grained soils, a 500 or 1000 ml pycnometer should be used. Full details of the test are given in B.S. 1377.

Specific gravity is a basic soil property and represents an average for the particles of different minerals present in the soil. The parameter is used to enable calculation of other useful soil properties. For example, voids ratio (which is related to porosity) can be calculated for a saturated soil if the moisture content and specific gravity are known.

APPENDIX C

List of boreholes

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
MAP SJ 16 NE						
1	1895 6613		244.75		60.96	-
2	1910 6625		239.26		60.96	-
3	1909 6610		234.08		60.96	-
4	1917 6610		225.24		60.96	-
5	1922 6625		232.56		60.96	-
6	1822 6802	1964		20.11	51.81	-
8	1703 6964	1978	145.00	11.70	11.70	-
10	1732 6868	"	182.00	8.30	8.30	-
11	1754 6780	"	159.00	7.30	7.40	-
13	1750 6697	1979	184.00	18.00	18.00	-
14	1836 6854	1978	204.00	3.60	3.80	-
15	1832 6776	"	153.00	4.00	4.00	-
16	1796 6674	1979	187.00	10.50	14.00	-
17	1847 6526	"	179.00	18.00	18.00	-
18	1953 6681	1978	169.00	7.50	13.70	-
23	c 183 677		150.00	9.30	9.30	-
MAP SJ 16 SE						
1	1720 6466	1978	215.00	3.50	3.50	-
2	1911 6222	1979	209.00	4.40	4.40	-
3	1887 6302	1978	206.00	6.50	6.70	-
4	1919 6200	"	208.00	4.20	4.30	-
5	1911 6113	"	202.00	4.80	4.80	-
6	1888 6048	1979	213.00	3.50	3.50	-
7	1956 6341	"	228.00	2.10	2.20	-
10	1887 6066	1952		1.68	1.68	-
11	1890 6057	"		1.52	1.52	-
12	1886 6048	"		1.22	1.22	-
13	1883 6038	"		1.22	1.22	-
14	1891 6036	"		1.98	1.98	-
15	1825 6135	1967	268.53	2.44	2.44	-
16	1850 6149	"	249.14	1.98	1.98	-
17	1871 6162	"	228.72	2.44	2.44	-
18	1890 6179	"	218.97	2.44	2.44	-
19	1906 6201	"	213.36	2.59	2.59	-
20	1921 6197	"	208.06	2.44	2.44	-
21	1945 6221	"	201.47	1.83	1.83	-
22	1972 6247	"	183.61	2.44	2.44	-
23	1992 6258	"	186.20	2.74	2.74	-
24	1983 6273	"	179.34	5.79	5.79	-
25	1979 6231	"	194.01	1.83	2.44	-
26	1976 6217	"	216.68	1.37	1.37	-
27	1975 6195	"	228.78	1.37	1.83	-
28	1958 6158	"	228.39	0.23	1.22	-
29	1956 6134	"	232.47	0.23	1.83	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
30	1975 6110	1967	241.74	2.13	2.13	-

MAP SJ 17 NE

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
1	1949 7757	1917-8	15.24	21.33	363.93	-
2	c 1943 7751	1921	c 12.19	18.28	177.69	-
3	c 1953 7749	1921	c 12.19	20.11	77.11	-
4	c 1949 7747	1933	c 12.19	15.60	243.84	-
5A	c 1973 7768	1942		15.54	15.54	-
5B	c 1973 7768	1945	c 6.09	17.37	17.37	-
6	1846 7613	c 1890	c 89.91	23.77	30.63	-
16	1700 7535	1973	230.00	2.00	15.10	Yes
17	1709 7534	"	228.70	3.30	15.30	"
18	1728 7524	"		c 7.00	29.96	"
19	1742 7527	"		c 2.00	20.00	"
20	1755 7520	"		c 6.00	19.54	"
21	1766 7514	"	227.00	6.00	15.05	"
22	1771 7511	"		c 4.00	18.50	"
23	1782 7507	"		c 12.00	28.80	"
24	1792 7501	"	224.50	3.45	3.45	"
25	1788 7503	"	224.50	6.45	6.45	"
26	1784 7505	"	225.00	8.00	8.00	"
27	1777 7505	"	224.50	6.45	6.45	"
28	1775 7509	"	225.00	4.00	4.00	"
29	1756 7517	"	228.50	5.00	5.00	"
30	1747 7521	"	230.00	5.80	5.80	"
31	1745 7518	"		c 6.00	22.00	"
32	1737 7523	"	229.50	2.85	2.85	"
33	1728 7529	"	229.00	3.00	3.00	"
34	1718 7530	"	228.50	3.60	6.15	"
65	? 194 774		c 91.00	24.06	30.48	-
67	1995 7649	1986	c 56.00	4.00	5.00	Yes
68	1990 7685	1973	37.25	2.00	2.00	"
69	1997 7717	"	6.70	5.00	5.00	"
70	1995 7713	"	12.00	7.00	7.00	"
71	1990 7708	"	19.25	3.00	3.00	"
72	1980 7707	"	21.55	3.00	3.00	"
73	1980 7698	"	22.65	3.00	3.00	"
74	1976 7772	"	5.50	3.00	3.00	"
75/1	1898 7537	1975	114.58	10.50	10.50	"
75/2	1896 7541	"	102.51	10.50	10.50	"
75/3	1900 7539	"	109.95	10.50	10.50	"
75/4	1904 7536	"	108.75	10.00	10.00	"
75/5	1907 7535	"	108.60	10.00	10.00	"
75/6	1911 7534	"	108.32	10.30	10.30	"
75/7	1916 7536	"	106.78	11.00	11.00	"
75/8	1913 7538	"	105.48	10.65	10.65	"
75/9	1909 7539	"	105.51	28.50	28.50	"
75/10	1906 7540	"	105.99	11.00	11.00	"
75/11	1903 7545	"	103.93	15.50	15.50	"
75/12	1907 7544	"	104.88	11.00	11.00	"
75/13	1911 7543	"	104.40	12.60	12.60	"
75/14	1914 7541	"	103.89	15.50	15.50	"
75/15	1918 7539	"	104.12	10.00	10.00	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
75/16	1918 7545	1975	100.53	22.50	22.50	Yes
75/17	1916 7545	"	101.81	15.50	15.50	"
75/18	1913 7547	"	103.82	15.70	15.70	"
75/19	1910 7549	"	101.95	10.50	10.50	"
75/20	1911 7552	"	101.47	10.00	10.00	"
75/21	1914 7550	"	103.66	17.00	17.00	"
75/22	1918 7547	"	100.54	15.50	15.50	"
75/23	1922 7546	"	97.60	15.60	15.60	"
75/24	1920 7551	"	99.14	15.60	15.60	"
75/25	1916 7553	"	101.19	20.00	20.00	"
75/26	1912 7555	"	101.51	15.50	15.50	"
75/27	1900 7556	"	103.49	15.50	15.50	"
75/28	1896 7557	"	104.74	10.05	10.05	"
75/29	1895 7553	"	108.29	10.66	10.66	"
75/30	1899 7553	"	108.54	15.50	15.50	"
75/31	1903 7555	"	103.64	10.00	10.00	"
75/32	1903 7552	"	103.64	10.00	10.00	"
75/33	1902 7548	"	105.38	11.00	11.00	"
75/34	1895 7548	"	111.28	10.00	10.00	"
75/35	1891 7549	"	110.82	11.00	11.00	"
75/36	1891 7553	"	109.65	10.00	10.00	"
76	1894 7546	1973	110.85	8.00	8.00	"
77	1892 7549	"	110.90	15.00	15.00	"
78	1890 7552	"	109.70	10.00	10.00	"
79	1895 7549	"	111.20	14.50	14.50	"
80	1871 7602	1974	100.50	15.50	15.50	"
81	1874 7599	"	101.00	15.00	15.00	"
82	1871 7598	"	101.50	15.00	15.00	"
83	1875 7599	"	102.75	15.00	15.00	"
84	1868 7597	"	102.80	15.00	15.00	"
85	1871 7593	"	103.10	15.00	15.00	"
86	1874 7596	"	102.40	15.00	15.00	"
87	1854 7588	1984	109.48	10.00	10.00	"
88	1850 7585	"	114.14	10.00	10.00	"
89	1854 7577	"	116.05	10.00	10.00	"
90	1859 7582	"	111.76	10.00	10.00	"
91	1847 7570	"	124.10	7.90	10.00	"
92	1849 7568	"	121.88	10.00	10.00	"
93	1859 7569	"	117.95	10.00	10.00	"
94	1950 7754	"	14.40	9.00	9.00	"
95	1951 7755	"	11.87	8.00	8.00	"
96	1895 7670	1973	45.20	5.40	5.40	-
97	1907 7698	"	39.00	5.20	5.20	-
98	1925 7719	"	36.30	25.00	25.00	Yes
99	1919 7707	"	35.90	10.00	10.00	"
100	1949 7745	"	20.80	10.00	10.00	"
101	1929 7720	"	31.50	10.00	10.00	"
102	1887 7647	"	93.00	31.50	31.50	"
103	1884 7680	"	70.30	25.00	25.00	"
104	1868 7610	"	100.50	15.50	15.50	"
105	1868 7604	"	91.70	11.00	11.00	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
MAP SJ 17 SE						
2	1944 7287	? 1961		7.31	83.82	-
3-20	C.E.G.B. - Confidential					
21	1818 7485	1973	218.50	22.80	26.00	Yes
22	1822 7482	"	218.00	32.70	32.70	"
23	1933 7429	"	195.50	3.55	9.62	"
24	1933 7427	"	196.50	5.20	10.00	"
25	1936 7418	"	200.00	1.90	5.56	"
26	1949 7417	"	184.50	6.50	10.93	"
27	1966 7400	"	179.50	?4.40	17.50	"
28	1999 7346	"	183.00	6.45	6.45	"
29	1997 7352	"	183.40	8.20	8.20	"
30	1990 7363	"	182.00	8.00	8.00	"
31	1988 7369	"	179.50	5.45	5.45	"
32	1981 7381	"	180.00	4.00	4.00	"
33	1978 7382	"	178.50	4.25	10.40	"
34	1979 7387	"	176.00	4.00	4.00	"
35	1958 7379	"	196.00	5.40	12.15	"
36	1971 7388	"	181.00	3.90	4.30	"
37	1959 7387	"	187.50	1.95	6.22	"
38	1965 7393	"	184.00	0.65	6.22	"
39	1966 7399	"	180.00	c 3.00	17.50	"
40	1968 7400	"	179.00	c 2.30	11.50	"
41	1968 7401	"	178.50	-	6.08	"
42	1965 7402	"	179.00	0.20	8.22	"
43	1962 7402	"	180.50	1.65	8.22	"
44	1964 7410	"	177.00	7.50	7.50	"
45	1959 7409	"	182.50	1.50	4.85	"
46	1956 7414	"	178.50	1.70	4.00	"
47	1939 7411	"	200.00	1.80	3.00	"
48	1943 7421	"	191.50	3.00	3.00	"
49	1931 7427	"	196.00	9.00	9.00	"
50	1924 7432	"	196.00	4.75	4.75	"
51	1928 7441	"	186.00	0.30	4.00	"
52	1915 7436	"	198.00	2.00	3.02	"
54	1903 7439	"	204.50	3.45	3.45	"
55	1897 7443	"	204.00	3.00	3.00	"
56	1889 7445	"	217.50	9.45	9.45	"
57	1880 7449	"	219.30	?2.00	4.57	"
58	1878 7447	"	220.00	2.75	2.75	"
60	1869 7451	"	225.00	11.45	11.45	"
61	1860 7455	"	227.00	20.63	20.63	"
62	1851 7462	"	224.00	9.45	9.45	"
63	1843 7468	"	224.00	4.00	4.00	"
64	1834 7474	"	220.00	5.00	5.00	"
65	1826 7478	"	215.00	10.00	10.00	"
66	1820 7481	"	219.50	6.00	6.00	"
67	1822 7487	"	218.00	6.00	6.00	"
68	1809 7492	"	223.50	6.30	6.30	"
69	1802 7497	"	228.50	2.30	2.30	"
71	1973 7393	"	174.00	3.05	8.07	"
72	190 718	1972	229.00		63.00	-
73	c 198 740	1976-77	27 closely adjacent boreholes			Yes
74A	1913 7443	1978	189.30	6.40	12.30	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
74B	1927 7438	1978	188.30	3.00	10.20	Yes
74C	1899 7435	"	209.90	4.60	14.30	"
74D	1910 7436	"	205.50	3.50	15.40	"
74E	1904 7439	"	205.80	7.50	7.50	"
74F	1906 7444	"	191.00	7.30	7.30	"
74G	1913 7436	"	207.20	7.20	7.20	"
74H	1915 7441	"	188.10	4.70	5.50	"
74I	1921 7433	"	199.70	6.60	6.60	"
74J	1923 7437	"	191.40	3.20	3.20	"
74K	1900 7446	"	194.00	9.20	12.50	"
74L	1911 7443	"	191.00	3.60	6.36	"
74M	1898 7438	"	209.00	4.85	9.50	"
74N	1908 7437	1977	206.75	10.30	10.85	"
74P	1904 7443	"	197.50	7.50	10.80	"
74Q	1918 7438	"	195.25	8.00	18.50	"
74R	1928 7434	"	193.50	13.15	22.50	"
74S	1901 7436	"	213.75	3.10	9.00	"
79	1862 7446	1978	236.02	8.95	14.45	"
80	1875 7437	"	239.96	11.00	20.00	"
81	1890 7427	"	235.71	16.45	19.65	"
82	1899 7419	"	239.84	2.75	15.10	"
83	1904 7408	"	248.06	2.65	18.00	"
84	1916 7400	"	231.30	4.45	7.50	"
85	1938 7374	"	219.78	5.85	11.10	"
86	1956 7356	"	211.14	9.00	12.00	"
87	1951 7350	"	223.87	8.90	14.40	"
88	1972 7331	"	210.48	12.60	16.00	"
89	1906 7410	"	237.68	7.65	9.70	"
103	1778 7453	1986	c 226.00	3.90	3.90	"
104	1706 7105	1972		1.00	1.00	"
105	1704 7109	"		1.80	1.80	"
106	1702 7106	"		1.50	1.50	"
107	1704 7107	"		1.50	1.50	"
108	1787 7417	"		2.00	2.00	"
109	1782 7422	"		2.50	2.50	"
110	1786 7425	"		1.50	1.50	"
111	1790 7428	"		2.00	2.00	"
112	1786 7431	"		2.50	2.50	"
113	1794 7426	"		1.00	1.00	"
114	1791 7423	"		1.20	1.20	"
115	1794 7416	"		3.00	3.00	"
120	1895 7070	"		3.50	3.50	"
121	1896 7073	"		2.40	2.40	"
122	1898 7073	"		2.50	2.50	"
123	1897 7076	"		2.25	2.25	"

MAP SJ 26 NW

1	2090 6598	c 1949	119.78	13.41	13.41	-
5	2316 6502	? 1947		5.33	30.48	-
6	2318 6502	1948		?	35.36	-
7	2319 6501	"		?	35.36	-
8	2054 6710	1979	122.00	4.10	4.10	-
9	2086 6848	"	231.00	7.20	7.70	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
10	2118 6760	1979	208.00	20.30	20.30	-
11	2137 6704	"	174.00	25.50	25.50	-
12	2115 6623	"	145.00	7.40	7.50	-
13	2120 6505	"	164.00	13.80	14.00	-
14	2237 6782	"	202.00	9.00	9.00	-
15	2215 6671	"	178.00	6.00	11.00	-
16	2365 6872	1978	122.00	5.20	6.00	-
17	2350 6717	1979	151.00	7.90	7.90	-
18	2329 6664	"	133.00	14.20	14.20	-
19	2296 6565	"	160.00	25.00	25.00	-
20	2290 6519	"	108.00	11.40	11.50	-
21	2428 6939	1978	90.00	21.60	21.60	-
22	2430 6744	1979	123.00	26.00	26.00	-
23	2404 6526	"	146.00	14.70	15.00	-
24	PSA - Confidential					
25	2292 6990	1981	113.11	5.00	5.00	Yes
26	2316 6981	"	97.25	11.50	12.14	"
27	2317 6977	"	96.08	6.50	6.80	"
28	2321 6981	"	81.22	13.00	13.00	"
29	2320 6976	"	84.75	?16.20	16.50	"
30	2322 6977	"	82.61	14.00	14.00	"
31	2335 6974	"	104.49	5.20	5.20	"
32	2337 6975	"	103.99	5.00	5.00	"
33	2345 6977	"	103.40	6.00	6.00	"
34	2362 6962	"	97.85	5.05	5.05	"
35	2397 6940	"	98.22	6.00	6.00	"
36	2414 6927	"	96.09	5.00	5.00	"
37	2427 6913	"	99.14	7.00	7.00	"
38	2432 6919	"	96.02	5.00	5.00	"
39	2424 6906	"	102.64	?9.70	9.70	"
40	2448 6909	"	89.88	7.50	7.50	"
41	2462 6895	"	90.97	5.00	5.00	"
42	2482 6885	"	90.71	5.50	5.50	"
43	2445 6904	"	93.25	7.50	7.50	"
44	2447 6903	"	93.35	30.00	30.00	"
45	2448 6899	"	94.36	30.00	30.00	"
46	2446 6899	"	95.56	8.50	8.50	"
47-76	British Coal - Confidential					-
87	2480 6594			19.20	39.20	Yes
88	2489 6598			23.00	41.76	"
89	2493 6598			26.50	43.00	"
90	2493 6856			2.00	2.00	"

MAP SJ 26 NE

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
3A	2992 6921	1961	11.73	3.07	3.07	-
3B	2968 6937	"	16.15	4.26	4.26	-
3C	2943 6945	"	19.41	2.74	2.74	-
3D	2909 6948	"	27.96	2.89	5.18	-
3E	2888 6961	"	26.27	3.04	3.14	-
3F	2942 6978	"	19.12	3.96	5.18	-
3G	2991 6888	"	16.30	3.04	3.04	-
4	2683 6675	1861	c 112.77	22.86	196.90	-
6	2599 6674	1878-9	c 122.83	3.04	101.49	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
10	2996 6671	1960	81.56	6.10	6.10	-
11	2796 6598	1967		2.13	41.65	-
12	2797 6573	"		0.60	18.28	-
13	2804 6577	"		2.05	29.36	-
14	2812 6578	"		2.13	6.52	-
15	2801 6559	"		2.13	32.31	-
16	2806 6558	"		2.13	36.27	-
17	2549 6501	1974	152.00	11.80	32.10	-
18	2554 6503	"	152.00	8.10	34.10	-
19	2569 6513	"	148.50	8.90	34.60	-
20	2586 6541	"	140.00	9.20	30.40	-
21	2914 6703	1972	78.68	10.00	12.20	Yes
22	2798 6667	"	92.58	7.10	9.00	"
23	2866 6605	"	108.80	1.00	15.20	"
24	2928 6630	"	85.76	8.90	12.10	"
25	2942 6515	"	117.97	2.40	16.00	"
26	2559 6852	1979	102.00	17.10	17.10	-
27	2631 6764	"	89.00	13.10	13.60	-
28	2706 6589	"	115.00	6.80	9.00	-
29	2823 6871	"	74.00	9.50	10.10	-
30	2795 6753	"	84.00	14.10	14.50	-
31	2825 6646	"	91.00	14.80	15.30	-
32	2915 6701	"	82.00	11.90	12.10	-
33	2650 6865	"	98.00	6.30	6.40	-
34	2751 6910	"	79.00	4.30	5.20	-
35	2835 6771	"	89.00	19.40	19.40	-
36	2502 6869	1981	92.07	10.00	10.00	Yes
37	2501 6867	"	91.40	10.00	10.00	"
38	2528 6830	"	99.84	5.00	5.00	"
39	2529 6828	"	100.89	8.00	8.00	"
40	2534 6823	"	101.20	12.20	12.30	"
41	2535 6821	"	100.80	12.50	12.70	"
42	2536 6823	"	100.45	12.90	13.10	"
43	2540 6815	"	96.78	5.00	5.00	"
44	2549 6800	"	97.36	5.00	5.00	"
45A	c 264 679				137.29	-
45B					187.65	-
46-695	British Coal - Confidential					
715	2991 6938	1983	5.99	4.90	4.90	Yes
716	2985 6941	"	4.85	3.20	3.48	"
717	2975 6949	"	4.70	3.80	4.25	"
718	2970 6947	"	6.06	3.00	4.31	"
719	2961 6954	"	5.96	2.00	3.25	"
720	2948 6962	"	6.15	1.90	2.50	"
721	2551 6502	1972	150.72	9.81	9.81	"
722	2563 6509	"	151.58	8.30	10.00	"
723	2763 6700	1975	90.50	8.90	14.50	"
724	2761 6699	"		8.90	15.70	"
725	2761 6697	"	91.50	5.90	12.20	"
726	2748 6709	"	89.00	10.40	21.30	"
727	2753 6706	"	79.50	-	15.10	"
728	2757 6702	"		2.70	40.00	"
729	2765 6696	"	91.50	7.40	40.00	"
730	2784 6680	"	94.00	3.80	25.00	"
731	2787 6678	"	94.00	4.70	17.00	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
732	2793 6672	1975	94.00	2.50	15.00	Yes
733	2796 6668	"	94.00	3.50	35.00	"
734	2816 6648	"	92.50	7.00	11.50	"
735	2823 6641	"	92.00	6.40	17.50	"
736	2821 6639	"	92.00	6.40	15.00	"
737	2823 6641	"	92.50	7.70	15.25	"
738	2829 6630	"	94.00	2.80	9.00	"
739	2828 6634	"	94.00	4.40	30.00	"
740	2834 6633	"	93.50	2.40	12.00	"
741	2829 6638	"	92.00	4.40	40.00	"
742	2828 6634	"	93.00	4.70	9.50	"
743	2839 6627	"		3.80	17.00	"
744	2843 6632					
744A	2843 6632	1975		1.30	18.00	Yes
745	2845 6624	"	95.00	1.90	30.75	"
746	2848 6620	"	96.50	2.30	37.00	"
747	2857 6619	"		2.30	20.00	"
748	2863 6617	"	104.00	1.40	20.00	"
749	2864 6613	"	106.00	0.80	14.20	"
750	2866 6619	"	100.50	1.40	20.00	"
751	2874 6617	"	95.50	2.70	14.00	"
752	2872 6613	"	100.00	1.80	14.00	"
753	2870 6614	"		2.20	14.10	"
754	2867 6618	"	100.00	2.80	9.00	"
755	2868 6613	"	103.50	1.50	8.80	"
756	2866 6613	"	105.00	1.80	14.00	"
757	2874 6614	"	99.00	0.90	40.00	"
758	2877 6616	"	95.00	2.90	8.00	"
759	2885 6613	"	93.00	2.80	10.00	"
760	2895 6606	"	95.00	3.20	18.00	"
761	2896 6616	"	90.00	4.00	12.80	"
762	2897 6614	"	89.00	3.20	19.30	"
763	2897 6612	"		3.70	18.60	"
764	2898 6610	"	88.50	4.00	8.00	"
765	2900 6611	"	88.00	3.30	9.35	"
766	2899 6612	"	88.00	3.20	30.00	"
767	2899 6614	"	88.00	3.50	19.00	"
768	2899 6616	"		3.20	9.10	"
769	2897 6625	"	88.00	4.80	20.00	"
770	2905 6614	"	87.00	3.50	25.00	"
771	2913 6628	"	86.50	15.00	24.00	"
772	2915 6616	"	86.00	8.50	12.20	"
773	2922 6624	"		6.90	24.00	"
773A	2936 6623	"				
774	2939 6626	"	82.50	10.00	35.90	"
774A	2940 6627	"				
775	2944 6629	"	84.00	10.30	44.00	"
776	2951 6635	"	83.00	5.80	26.00	"
777	2956 6639	"		9.50	25.00	"
778	2961 6644	"	82.00	6.70	28.00	"
779	2968 6649	"	81.00	6.80	30.00	"
780	2963 6649	"	81.50	8.00	28.00	"
781	2973 6653	"	78.50	6.50	39.00	"
782	2971 6653	"	79.00	?4.50	39.00	"
783	2971 6656	"	78.00	6.50	39.85	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
784	2970 6655	1975	79.00	6.40	39.00	Yes
785	2974 6655	"		7.20	40.55	"
786	2973 6658	"	78.00	7.00	41.00	"
787	2984 6656	"	78.00	7.50	39.85	"
788	2976 6660	"	78.50	8.70	39.50	"
789	2981 6664	"	78.50	7.80	41.50	"
790	2979 6663	"	78.50	9.50	44.00	"
791	2978 6661	"	78.50	8.80	40.00	"
792	2982 6662	"	78.50	8.90	40.30	"
793	2984 6669	"	77.50	?	42.30	"
794	2983 6664	"	80.00	?24.00	40.00	"
795	2985 6665	"	80.00	11.35	42.00	"
796	2987 6663	"	80.00	10.90	43.70	"
797	2986 6660	"	78.50	9.40	50.35	"
798	2983 6657	"	78.50	?	50.15	"
799	2911 6605	"	89.50	?3.40	25.00	"
800	2902 6602	"	95.00	1.30	23.50	"
801	2905 6593	"	99.00	1.50	30.00	"
802		"	99.00	2.20	3.00	"
803		"	96.50	1.70	3.90	"
804		"	102.50	c 4.70	7.60	"
805		"	101.50	5.20	8.30	"
806	2918 6550	"	100.00	4.00	15.00	"
807	2920 6545	"	102.50	4.10	25.00	"
808	2924 6536	"	108.00	c 2.00	10.00	"
809	2929 6527	"	113.50	2.70	10.60	"
810	2932 6522	"	116.00	2.50	15.00	"
811	2937 6520	"	117.00	2.40	20.80	"
812	2941 6516	"	120.00	c 9.50	24.10	"
813	2939 6514	"	121.50	9.50	27.50	"
814	2938 6513	"	123.00	4.20	26.00	"
815	2942 6517	"	117.00	?5.00	55.00	"
816	2942 6516	"	119.00	6.50	23.00	"
817	2940 6513	"	121.00	5.90	27.90	"
818	2943 6513	"	120.00	3.50	22.00	"
819	2946 6509	"	119.00	11.70	27.00	"
820	2950 6506	"	114.50	3.20	20.00	"
821	2957 6500	"	114.00	1.80	25.00	"
822	2957 6503	"	114.00	2.80	3.20	"
823	2957 6503	"	114.00	-	25.00	"
824	2956 6501	"	114.50	11.80	35.00	"
825	2956 6503	"	113.00	1.60	25.00	"
826	2958 6500	"	113.00	2.90	25.00	"
827	2543 6609			-	20.12	"
828	2553 6610			-	20.73	"
829	2561 6614			-	23.30	"
830	2583 6617			-	19.20	"
831	2591 6617			-	29.80	"
832	2598 6617			3.05	31.39	"
1170	2878 6918	1984	39.07	4.00	4.00	"
1171	2896 6922	"	38.62	4.00	4.00	"
1172	2902 6920	"	37.20	3.20	3.80	"
1173	2910 6914	"	35.40	4.00	4.00	"
1174	2950 6987	1982	5.80	9.70	11.00	"
1175	2956 6988	"	6.00	18.90	19.00	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
1176	2962 6987	1982	6.50	20.20	20.50	Yes
1177	2967 6987	"	6.20	20.50	20.50	"
1178	2973 6987	"	6.30	21.10	21.60	"
1179	2979 6986	"	6.10	21.50	21.80	"
1180	2946 6982	1981	4.60	4.60	4.60	"
1181	2946 6981	"		3.50	4.00	"
1182	2952 6975	1977	5.70	5.00	5.00	"
1183	2949 6977	"	5.80	5.00	5.00	"
1184	2948 6982	"	4.50	5.45	8.23	"
1185	2952 6986	"	4.50	7.72	14.00	"
1186	2934 6951	1979		5.00	5.00	"
1187	2932 6960	"		4.00	4.00	"
1188	2928 6976	"		2.00	2.80	"
1189	2935 6987	"		0.80	2.00	"
1190	2953 6926	"	24.30	10.00	53.90	"
1191	2949 6929	1978	23.30	8.40	22.00	"
1192	2944 6923	"	27.90	16.00	40.00	"
1193	2939 6914	"	33.20	18.80	22.50	"
1194	2945 6932	"	24.00	8.00	12.40	"
1195	2935 6917	"	31.80	11.80	23.50	"
1202-1313	British Coal - Confidential					

MAP SJ 26 SW

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
3	2418 6348	1934	c 103.63	13.41	122.83	-
8A	2470 6241	1879		18.13	77.18	-
8B	2494 6190	"			45.18	-
8C	2483 6193	"		?	18.90	-
8D	2450 6240	"		14.73	44.82	-
8E	2422 6162	"		8.23	31.39	-
8F	2408 6129	"		11.63	36.65	-
10	2111 6221	1957		?	206.04	-
11	2298 6271	1975	144.50	13.60	29.80	-
12	2412 6256	"	116.00	6.50	27.60	-
13	2416 6256	1974	115.00	18.20	38.30	-
14	2429 6259	1974/5	106.50	5.10	30.70	-
15	2428 6255	"	106.50	6.65	31.40	-
16	2431 6260	1974	106.50	5.50	27.30	-
17	2437 6262	"	106.50	9.50	31.10	-
18	2479 6311	1974/5	97.00	13.00	33.20	-
19	2482 6312	"	97.50	16.75	36.00	-
20	2478 6316	"	97.50	14.10	34.00	-
21	2203 6476	1979	142.00	18.10	18.10	-
22	2264 6473	"	122.00	17.80	17.80	-
23	2260 6375		135.00	13.30	13.30	-
24	2299 6264	1978	145.00	13.00	14.00	-
25	2333 6153	"	155.00	5.80	5.80	-
26	2355 6197	"	149.00	12.80	12.80	-
27	2366 6019		176.00	13.80	13.80	-
28	2400 6080	1978	148.00	12.20	12.20	-
29	2424 6162	1979	142.00	8.80	10.70	-
30	2462 6271	"	107.00	20.00	20.00	-
31	2499 6355	"	100.00	6.50	8.00	-
32	2370 6001	1981	175.05	32.00	60.40	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
33	2373 6007	1981	176.30	39.90	60.00	-
34	2494 6456	1974	131.00	11.00	40.20	-
35	2498 6461	"	134.00	19.50	39.50	-
36	2500 6463	"	134.50	17.40	37.00	-
37-144	British Coal - Confidential					
156-182	British Coal - Confidential					
185	2392 6334		c 109.00	8.70	154.30	-
186	239 621		137.00	18.14	77.11	-
187	c 235 606		c 166.00	14.94	61.57	-
188	2000 6100	1968	269.50	2.13	2.13	-
189	2020 6100	"	284.96	2.44	2.44	-
190	2034 6009	"	286.36	2.44	2.44	-
191	2032 6266	1967	209.40	2.44	2.44	-
192	2355 6411	1979		10.00	10.00	Yes
193	2344 6403	"		10.00	10.00	"
194	2351 6400	"		10.00	10.00	"
195	2347 6403	"		2.00	2.00	"
196	2353 6403	"		2.00	2.00	"
197A	2421 6339	1976		5.50	5.50	"
197B	2430 6340	"		6.50	6.50	"
197C	2425 6335	"		6.50	6.50	"
197D	2422 6330	"		6.50	6.50	"
197E	2430 6333	"		6.00	6.00	"
197F	2436 6335	"		6.15	6.15	"
197G	2427 6325	"		5.50	5.50	"
198	2440 6326	"		4.00	4.00	"
199	2444 6333	"		4.00	4.00	"
200	2448 6329	"		3.50	3.50	"
201	2439 6319	"		6.50	6.50	"
202	2446 6320	"		4.00	4.00	"
203	2448 6316	"		4.00	4.00	"
204A	2439 6328	1978		8.00	8.00	"
204B	2441 6332	"		3.80	6.50	"
204C	2443 6331	"		2.70	6.50	"
204D	2441 6328	"		4.40	8.00	"
204E	2443 6335	"		5.50	5.50	"
204F	2447 6334	"		3.30	4.50	"
205	2452 6309	1979		4.00	4.00	"
206	2454 6296	"		5.00	5.00	"
207	2456 6287	"		4.00	4.00	"
209	2390 6287	1983	122.71	13.50	13.50	"
210	2387 6284	"	118.81	7.30	7.30	"
211	2394 6281	"	117.38	6.00	6.00	"
212	2395 6262	"	121.12	2.00	2.00	"
212A	2395 6262	"	121.12	2.00	2.00	"
212B	2395 6262	"	121.12	2.50	2.50	"
213	2392 6260	"	122.37	2.00	2.00	"
213A	2392 6260	"	122.37	2.00	2.00	"
214	2441 6268	"	111.21	6.00	6.00	"
215	2443 6227	"	109.89	6.00	6.00	"
216	2434 6266	"	110.88	6.00	6.00	"
217	2435 6263	"	106.43	7.40	7.40	"
217A	2435 6263	"	106.43	5.50	5.50	-
218	2433 6280	"	104.64	10.70	15.00	Yes
219	2436 6281	"	103.83	14.60	45.20	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
220	2449 6272	1983	105.14	18.50	20.50	Yes
221	2434 6278	1984		8.90	30.00	"
222	2448 6275	1984/5		18.20	57.00	"
223	2433 6262	1985		8.90	10.50	"
224	2450 6324	1977		19.50	40.00	-
225	2450 6331	"		21.00	41.00	-
226	2445 6335	"		19.50	45.00	-
227	2404 6334	1976	109.98	4.00	4.00	Yes
228	2405 6334	"	110.06	4.30	4.30	"
229	2407 6333	"	109.87	4.50	4.50	"
230	2479 6400	1972	103.90	5.30	7.85	"
230A	? 2479 6400	"	101.28	6.40	10.50	"
231	2480 6410	"	116.12	?13.10	13.10	"
232	2474 6412	"	119.01	5.90	7.03	"
233	2481 6418	"	120.47	9.80	9.80	"
234	2484 6418	"	122.54	10.00	10.00	"
235	2480 6429	"	127.11	15.20	18.00	"
236	2483 6428	"	127.97	11.60	14.60	"
237	2486 6428	"	129.38	10.30	10.30	"
238	2487 6439	"	124.21	8.40	18.10	"
239	2488 6446	"	123.78	6.60	18.00	"
240	2491 6456	"	130.85	6.00	6.00	"
241	2285 6261	"	151.99	8.80	8.80	"
242	2278 6276	"	147.60	8.00	8.00	"
243	2274 6288	"	145.27	7.50	7.50	"
244	2272 6294	"	144.05	6.30	6.30	"
245	2299 6270	"	145.05	10.50	10.50	"
246	2313 6266	"	142.62	8.00	8.00	"
247	2342 6261	"	135.23	6.00	6.00	"
248	2355 6261	"	130.12	1.80	1.80	"
248A	2355 6261	"	130.12	1.80	1.80	"
248B	2355 6261	"	130.12	4.80	4.80	"
249	2371 6259	"	129.52	4.10	4.10	"
249A	2371 6259	"	129.52	5.10	5.10	"
249B	2371 6259	"	129.52	4.30	4.30	"
249C	2371 6259	"	129.52	9.20	15.30	"
250	2386 6257	"	127.80	13.50	20.00	"
251	2403 6256	"	120.90	9.60	18.00	"
252	2410 6255	"	116.34	?6.00	18.00	"
252A	2410 6255	"	116.34	5.10	5.80	"
253	2418 6257	"	112.98	22.00	25.30	"
254	2430 6260	"	108.02	7.50	18.00	"
254A	2430 6260	"	108.02	7.20	8.70	"
255	2442 6264	"	105.17	7.30	7.30	"
255A	2442 6264	"	105.07	14.70	14.70	"
256	2458 6270	"	105.00	20.00	21.45	"
257	2460 6273	"	104.96	19.50	19.50	"
258	2477 6299	"	98.72	11.50	11.50	"
259	2478 6311	"	97.95	13.40	13.40	"
260	2480 6315	"	97.99	16.50	16.50	"
261	2480 6325	"	98.00	10.00	10.00	"
262	2478 6334	"	98.16	10.50	10.50	"
262A	2478 6334	"	98.16	2.50	2.50	"
263	2475 6346	"	104.04	10.00	10.00	"
264	2473 6360	"	101.51	10.00	10.00	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
265	2482 6372	1972	99.37	8.50	10.50	Yes
266	2476 6384	"	99.60	8.20	9.75	"
267	2320 6271	"	136.66	6.40	6.40	"
268	2356 6233	"	127.63	2.50	2.50	"
268A	2356 6233	"	127.63	3.80	3.80	"
268B	2356 6233	"	127.63	3.95	3.95	"
269	2410 6256	"	109.88	7.90	20.00	"
270	2421 6260	"	111.70	16.00	17.90	"
271	2428 6236	"	106.59	1.00	1.00	"
271A	2428 6236	"	106.59	1.80	1.80	"
271B	2428 6236	"	106.59	4.10	18.00	"
316	2467 6293	1981		11.00	30.00	-
317	2473 6303	"		16.80	30.00	-
318	2457 6275	"		15.60	30.00	-
319	2463 6283	"		15.10	30.00	-

MAP SJ 26 SE

1	c 2537 6307	1937		?17.72	99.36	-
1A		1939		?13.87	67.06	-
5	2684 6491		c 136.55	8.71	62.15	-
9				10.67	78.69	-
10	2851 6086	1927		12.34	12.34	-
16	2636 6180	1955	99.97	4.57	333.14	-
17A	2624 6460	1975	158.70	2.10	15.00	-
17B	2636 6461	"	154.30	2.10	10.50	-
17C	2628 6466	"	154.60	1.50	16.00	-
17D	2632 6455	"	156.40	3.00	16.80	-
17E	2630 6459	"	156.40	1.80	16.20	-
17F	2625 6456	"	158.50	2.80	15.00	-
17G	2634 6464	"	154.90	2.10	21.00	-
17H	2621 6468	"	155.80	2.90	15.00	-
17I	2678 6469	"	153.50	1.80	23.00	-
17J	2636 6464	"	153.00	1.50	7.70	-
17K	2643 6458	"	152.20	2.10	21.00	-
17L	2637 6458	"	155.20	2.40	11.00	-
17M	2635 6458	"	155.80	2.10	22.00	-
17N	2637 6455	"	154.80	1.80	18.00	-
17/O	2636 6458	"	155.50	2.20	10.00	-
17P	2637 6458	"	155.20	2.20	10.00	-
17Q	2638 6467	"	151.60	2.00	12.00	-
17S	2649 6457	"		2.40	19.00	-
17T	2652 6460	"		5.30	22.50	-
17U	2650 6462	"		4.00	18.00	-
17V	2632 6446	"		4.30	20.00	-
17W	2640 6449	"		3.00	15.00	-
17X	2645 6441	"		3.40	8.00	-
17Y	2648 6452	"		1.80	8.00	-
17Z	2672 6448	"		3.40	17.00	-
18	2525 6483	"	146.50	20.40	40.00	-
19	2552 6498	"	152.00	10.10	32.90	-
20	2990 6468	1972	116.31	Nil	2.16	Yes
21A	2951 6362	1975	124.30	c 3.00	31.00	"
21B	2952 6359	"	124.20	4.00	8.40	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
21C	2953 6356	1975	124.60	4.00	6.30	Yes
21D	2949 6361	"	124.90	4.00	6.30	"
21E	2949 6358	"	125.20	3.50	7.50	"
21F	2950 6355	"	125.60	3.26	30.00	"
21G	2946 6360	"	126.40	3.80	30.50	"
21H	2946 6357	"	126.90	4.60	7.70	"
21I	2947 6354	"	127.00	4.70	7.30	"
21J	2943 6362	"	128.50	6.90	9.50	"
21K	2950 6351	"	125.00	?3.80	5.70	"
21L	2950 6346	"	123.80	3.20	5.20	"
21N	2950 6352	"	124.80	4.50	30.00	-
21/0	2949 6349	"	125.30	?3.80	34.00	-
21P	2947 6348	"	125.40	6.40	35.00	-
21Q	2952 6347	"	123.70	3.50	20.80	-
23	2555 6483	1979	155.00	4.50	5.50	-
24	2535 6304	"	122.00	13.80	14.50	-
25	2518 6074	"	148.00	13.00	13.10	-
26	2561 6207	"	95.00	19.50	20.00	-
27	2644 6309	"	144.00	11.00	11.50	-
28	2675 6245	"	100.00	18.70	19.30	-
29	2680 6212	"	97.00	22.50	22.50	-
30	2658 6061	"	166.00	16.00	16.10	-
31	2772 6277	"	113.00	16.20	16.20	-
32	2766 6160	"	96.00	23.30	23.80	-
33	2856 6250	"	114.00	16.00	16.00	-
34	2852 6108	"	98.00	18.50	18.50	-
35	2871 6037	"	?93.00	14.00	14.00	-
36	2958 6305	"	121.00	7.20	8.00	-
37	2926 6089	"	86.00	18.30	18.30	-
38	2990 6233	"	115.00	4.00	5.20	-
39	2564 6218	1948	97.23	12.19	12.19	-
40	2542 6208	"	99.35	10.97	10.97	-
41	2543 6224	"	98.40	9.14	9.14	-
42	2543 6248	"	96.74	14.33	14.33	-
43	2548 6223	"	98.17	13.41	13.41	-
44-489	British Coal - Confidential					
512	c 2530 6274				70.56	-
513	c 2569 6253				65.07	-
514	c 2573 6265				34.82	-
515	c 2540 6293				89.18	-
529-545	British Coal - Confidential					
546A	2927 6303	1971	120.00			
546B	2927 6303	"	120.00	11.40	100.00	-
547	2849 6327	"	134.20	13.00	100.00	-
548	2849 6347	"	134.30	12.40	62.00	-
549A	2852 6325	"	122.70	14.20	42.00	-
549B	2851 6325	"	133.10	10.00	68.00	-
550	2857 6325	"	133.70	10.00	100.00	-
551A	2753 6155	"	93.80	10.00	103.00	-
551B	2753 6155	"	93.80	10.30	57.90	-
552	2751 6153	"	93.30	12.40	21.40	-
553A	2662 6107	"	170.80	3.50	94.00	-
553B	2662 6107	"	170.70	3.50	68.40	-
554A	2628 6474	"	151.10	3.00	100.00	-
554B	2628 6474	"	151.10	3.50	44.40	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
555A	2644 6020	1971	170.40	6.40	52.00	-
555B	2647 6019	"	169.40	5.40	94.00	-
555C	2648 6019	"	169.50	5.00	92.00	-
556A	c 284 610			2.90	18.29	-
556B	c 284 610			3.66	19.20	-
556C	c 284 610			12.37	12.37	-
557	2999 6076	1982	111.66	5.00	5.00	Yes
558	2998 6080	"	112.37	5.00	5.00	"
559	2998 6082	"	112.56	5.00	5.00	"
560	2995 6083	"	110.98	5.00	5.00	"
561	2992 6088	"	107.52	5.00	5.00	"
562	2990 6088	"	106.64	5.00	5.00	"
563	2991 6091	"	106.35	5.00	5.00	"
564	2989 6092	"	106.93	5.00	5.00	"
565	2988 6094	"	106.94	5.00	5.00	"
566	2986 6095	"	108.03	5.00	5.00	"
567	2982 6099	"	108.11	5.00	5.00	"
568	2979 6103	"	108.21	5.00	5.00	"
569	2975 6109	"	108.03	5.00	5.00	"
570	2972 6115	"	107.34	5.00	5.00	"
571	2970 6122	"	106.58	5.00	5.00	"
572	2968 6130	"	106.65	5.00	5.00	"
573	2968 6140	"	103.71	5.00	5.00	"
574	2968 6146	"	102.66	5.00	5.00	"
575	2970 6150	"	102.51	5.00	5.00	"
576	2973 6159	"	105.62	5.00	5.00	"
577	2975 6165	"	106.72	5.00	5.00	"
578	2978 6168	"	106.08	5.00	5.00	"
583	2951 6141	"	101.52	0.70	2.00	"
584	2925 6109	"	84.86	5.00	5.00	"
603	2719 6231					
604	2722 6162					
605	2722 6210				32.00	-
606	2717 6201				34.75	-
608	2645 6404				3.35+	-
609	2642 6393				10.06+	-
615	2587 6004					-
616	2524 6175				44.81	-
617	2530 6174				43.89	-
633-638	British Coal - Confidential					
644	2956 6300				c 3.66	-
645	2957 6280					-
646-739	British Coal - Confidential					
763	2655 6080				68.58	-
765	2650 6109					-
766	2629 6096					-
767	2662 6105				?42.06	-
768	2796 6097	[British Coal "Shaft" No 277]				-
807	2786 6066				14.63	-
808	2761 6074				27.43	-
809	2788 6026					-
810	2792 6027	[Possibly same borehole as No 809]				-
835	2794 6189				54.86	-
836	2748 6141				56.69	-
863	2675 6113				31.09	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
864	2674 6112				31.09	-
885	2907 6364				9.14	-
886	2911 6364					-
894	2987 6401				38.10	-
904	2869 6348	[British Coal "Shaft" No 58]				-
1011	2500 6464	1972	136.16	5.70	5.70	Yes
1012	2507 6472	"	139.22	4.00	6.30	"
1013	2515 6480	"	142.12	2.50	6.30	"
1014	2524 6484	"	146.36	12.00	12.00	"
1015	2534 6491	"	150.33	11.30	12.50	"
1016	2550 6499	"	152.03	11.10	11.60	"
1017	2966 6495	1975	111.00	Nil	11.70	"
1018-1043	British Coal - Confidential					

MAP SJ 27 NW

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
1A	2015 7711	1947		18.28	18.28	-
1B	2020 7718	"		18.28	18.28	-
1C	2020 7748	"		18.28	18.28	-
1D	2027 7754	"		18.28	18.28	-
4	British Coal - Confidential					
8	2070 7557	1986	c 67.00	9.30	12.00	Yes
9	2075 7724	1973	6.85	5.00	5.00	"
10	2078 7713	"	4.30	4.00	4.00	"
11	2088 7717	"	1.10	5.00	5.00	"
12	2084 7712	"	4.15	4.50	4.50	"
13	2080 7707	"	4.85	12.00	12.00	"
14	2076 7704	"	4.05	12.00	12.00	"
15	2070 7698	"	4.25	4.50	4.50	"
16	2064 7680	"	4.40	4.50	4.50	"
17	2061 7687	"	4.45	4.50	4.50	"
18	2051 7676	"	6.15	4.50	4.50	"
19	2045 7676	"	5.75	4.50	4.50	"
21	2038 7678	"	10.90	5.00	5.00	"
23	2029 7669	"	17.45	5.00	5.00	"
24	2033 7661	"	15.70	3.00	3.00	"
25	2031 7654	"	16.30	2.00	2.00	"
26	2020 7664	"	26.00	4.50	4.50	"
27	2014 7664	"	28.50	3.00	3.00	"
28	2006 7656	"	45.05	2.00	2.00	"
29	2012 7650	"	47.10	2.00	2.00	"
30	2082 7695	"	3.80	3.00	3.00	"
31	2077 7690	"	3.75	3.00	3.00	"
32	2086 7687	"	3.90	3.00	3.00	"
33	2012 7700	"	13.45	7.00	7.00	"
34	2014 7702	"	9.60	5.00	5.00	"
35	2017 7703	"	5.25	5.00	5.00	"
36	2019 7706	"	4.65	4.50	4.50	"
37	2025 7698	"	4.60	4.50	4.50	"
38	2032 7690	"	4.80	4.50	4.50	"
39	2038 7683	"	4.85	4.50	4.50	"
40	2011 7714	"	4.50	4.50	4.50	"
41	2004 7724	"	5.15	4.50	4.50	"
42	2001 7720	"	4.75	5.00	5.00	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
43	2188 7518	1973	20.40	7.30	34.50	-
44	2192 7522	"	12.20	5.50	29.00	-
45	2189 7523	"	17.80	9.10	33.50	-
46	2189 7515	"	21.70	7.30	22.00	-
47	2197 7533	1985		4.00	4.00	Yes
48	2181 7546	"		6.00	6.00	"
49	2159 7570	"		6.00	6.00	"
50	2037 7707	"	4.20	5.00	5.00	"
51	2047 7698	"	4.50	3.00	3.00	"
52	2054 7690	"	4.80	3.00	3.00	"
53	2053 7696	"	4.50	3.00	3.00	"
54	2046 7704	"	4.50	3.00	3.00	"
55A	2197 7515	1972	23.40	2.74	5.30	"
55B	2196 7516	"	22.90	6.40	10.30	"
55C	2195 7520	"	18.90	9.50	10.59	"
55D	2193 7517	"	19.50	5.00	6.70	"
55E	2196 7518	"	18.90	6.40	8.15	"
55F	2199 7515	"	23.80	6.50	6.50	"
55G	2197 7511	"	26.40	4.10	6.30	"
55H	2195 7513	"	25.40	?4.15	10.05	"
55I	2190 7514	"	19.70	4.60	7.05	"
55J	2189 7518	"	20.80	c 4.40	5.58	"
55K	2190 7521	"	16.60	9.30	11.50	"
55L	2192 7522	"	15.80	11.80	12.57	"
56	2192 7525	"	15.60	12.00	12.40	"
57	2195 7527	"	10.10	10.50	11.50	"
58	2194 7534	"	6.40	10.00	10.50	"
59	2194 7539	"	4.00	18.00	18.00	"
60	2189 7541	"	5.20	10.00	10.00	"
61	2188 7545	"	4.60	10.00	10.00	"
62	2220 7540	1973		10.00	10.00	"
63	2230 7530	"		10.00	10.00	"
64	2238 7520	"		10.00	10.00	"
65	2238 7534	"		10.00	10.00	"
66	2234 7533	"		10.00	10.00	"
67	2226 7543	"		10.00	10.00	"
68	2108 7647	"		10.00	10.00	"
140	2055 7643				?128.00	-
144	2188 7518	1978		7.00	27.00	-
145	2173 7504	"		9.00	24.00	-
146	2180 7509	"		5.50	36.60	-
147	2155 7523	"	49.85	1.70	16.00	-
148	2159 7528	"	44.70	3.00	35.00	-
149	2163 7532	"	39.90	4.30	20.00	-
150	2160 7524	"	44.74	7.00	30.00	-
151	2164 7523	"	41.39	5.00	28.00	-
152	2172 7524	"	35.64	7.00	15.00	-
153	2183 7534	"	21.05	7.60	15.60	-
154	2174 7538	"	29.45	7.50	32.00	-
155	2197 7523	"		9.80	9.80	-
156	2162 7530	"	40.58	5.50	14.00	-
157	2171 7536	"	31.94	7.60	18.00	-
158	2198 7508	1979		1.00	30.00	-
159	2200 7513	"		1.00	30.00	-
160	2185 7540	1978		10.50	30.00	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
161	2186 7541	1978		9.00	30.00	-
162	2188 7541	"		c 3.00	30.00	-
163	2188 7543	"		11.00	30.00	-
164	2188 7545	"		c 3.00	30.00	-
165	2196 7537	"		9.00	30.00	-
166	2202 7529	"		c 6.00	30.00	-
167	2203 7532	"		9.00	30.00	-
168	2196 7524	"		3.00	30.00	-
169	2198 7526	"		c 6.00	30.00	-

MAP SJ 27 SW

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
2	2361 7154	1912	36.58	40.23	233.78	-
3	2468 7036	1935		21.34	21.34	-
21	2427 7290		11.89	6.25	7.77	-
22	2427 7308		10.67	3.05	24.39	-
23	2434 7314		8.84	3.20	24.39	-
24	2430 7295	1968	11.74	3.30	5.74	Yes
25	2437 7286	"	14.01	3.81	7.42	"
26	2446 7292	"	10.50	7.32	9.82	"
27	2444 7303	"	8.90	7.62	10.01	"
28	2432 7292	"	12.09	3.66	17.99	"
29	2441 7292	"	11.18	2.59	6.20	"
30	2450 7300	"	8.65	7.60	9.34	"
31	2444 7297	"	9.74	6.10	18.29	"
32	2434 7293	1970		1.07	60.96	-
36	2477 7408	"	0.91	23.09	25.15	Yes
43	2042 7268	1972	172.20	6.00	6.00	"
44	2043 7263	"	172.30	6.00	6.00	"
45	2042 7261	"	174.70	6.00	6.00	"
46	2048 7260	"	169.30	10.00	10.00	"
47	2046 7259	"	170.80	15.00	15.00	"
48	2046 7259	"	170.80	15.00	15.00	"
49	2044 7258	"	172.20	10.00	10.00	"
50	2043 7256	"	173.70	10.00	10.00	"
51	2046 7257	"	171.60	10.00	10.00	"
52	2047 7258	"	169.80	11.80	11.80	"
53	2049 7259	"	168.90	10.00	10.00	"
54	2047 7252	"	174.40	10.00	10.00	"
55	2050 7254	"	171.20	6.50	6.50	"
56	2056 7245	"	173.10	5.00	5.00	"
57	2065 7235	"	169.30	6.00	6.00	"
58	2034 7279	"	176.20	4.00	4.00	"
59	2028 7291	"	178.80	3.00	3.00	"
60	2023 7302	"	180.30	3.00	3.00	"
61	2018 7312	"	183.00	4.00	4.00	"
62	2012 7322	"	179.70	4.00	4.00	"
63	2006 7334	"	181.90	4.00	4.00	"
64	2467 7297	1973	8.05	4.60	7.20	"
65	2468 7298	"	8.00	5.20	7.80	"
66	2470 7296	"	8.45	4.50	6.50	"
67	2470 7296	"	8.45	4.50	25.00	"
68	2091 7203	1976		5.00	5.00	"
69	2106 7184	"		4.00	4.00	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
70	2134 7146	1976		5.00	5.00	Yes
71	2145 7132	"		5.00	5.00	"
72	2214 7061	1981	152.62	3.80	6.00	"
73	2228 7046	"	152.61	5.45	5.45	"
74	2229 7048	"	154.43	2.00	5.20	"
75	2236 7039	"	147.80	3.90	5.15	"
76	2238 7040	"	149.93	4.50	9.00	"
77	2235 7038	"	150.00	2.45	6.00	"
78	2248 7027	"	146.46	3.00	4.10	"
79	2246 7024	"	145.18	5.40	7.00	"
80	2253 7019	"	146.36	1.00	12.00	"
81	2253 7022	"	144.74	0.30	1.00	"
82	2251 7018	"	142.57	2.90	9.00	"
83	2266 7010	"	133.67	5.00	5.00	"
84	2265 7008	"	137.39	c 1.50	7.00	"
85	2277 7001	"	123.83	5.00	5.00	"
86	2013 7302	1978	185.95	8.00	13.20	"
87	2048 7356	"	107.92	13.60	19.00	"
88	2032 7377	"	178.04	19.80	19.80	"
89-238	British Coal - Confidential					
246A	2163 7361	1986	c 108.00	7.80	7.80	Yes
246B	2163 7361	"	c 108.00	7.70	8.20	"
247	2377 7105	"	c 67.00	25.00	25.00	"
248	2267 7312	"	c 84.00	?25.00	25.00	"
249	2495 7057	"	c 69.00	11.20	11.20	"
250	2169 7060	"	c 183.00	2.20	3.20	-
251	2073 7235	"	c 167.00	12.00	12.00	Yes
252	2039 7322	"	c 172.00	7.60	8.80	"
253	2440 7317	1976	8.23	3.50	22.00	"
254	2439 7315	"	8.51	3.20	22.00	"
255A	c 2422 7294	1964		4.26	6.40	"
255B	c 2422 7294	"		6.25	7.77	"
255C	c 2422 7294	"		7.16	9.75	"
255D	c 2422 7294	"		4.63	6.10	"
256	2392 7326	1981		?17.00	18.00	-
257	2389 7335	"		6.00	6.00	-
258	2387 7330	"		6.00	6.00	-
259	2382 7326	"		5.00	5.00	-
260	2388 7323	"		6.00	6.00	-
261	2391 7318	"		6.00	6.00	-
262	2396 7314	"		6.00	6.00	-
263	2393 7309	"		6.00	6.00	-
264	2388 7306	"		6.00	6.00	-
265A	c 2409 7338	1985		13.10	13.10	Yes
265B	"	"		7.50	7.50	"
265C	"	"		7.40	7.40	"
265D	"	"		7.60	7.60	"
265E	"	"		13.50	30.00	"
265F	"	"		13.00	24.00	"
265G	"	"		12.50	23.10	"
266	2388 7304	1982	16.11	12.10	12.10	"
267	2396 7304	"	11.91	12.00	12.00	"
268	2390 7312	"	10.77	6.50	6.50	"
269	2383 7317	"	15.00	15.00	15.00	"
270	2378 7326	"	13.65	1.16	1.16	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
270A	2378 7326	1982	13.65	11.00	11.00	Yes
271	2384 7371	"	10.01	12.00	12.00	"
272	2399 7294	"	10.00	7.40	10.08	"
274	2369 7356	1981		7.05	18.00	"
275	2375 7356	"		19.20	30.13	"
276	2380 7358	"		c 57.90	70.00	"
277	2378 7338	"		28.90	42.65	"
278	2381 7334	"		32.45	43.00	"
283	2349 7375				10.00	"
284	2377 7364				15.00	"
285	2395 7351				10.00	"
286	2335 7365				10.00	"
287	2356 7337				15.00	"
288	2371 7340				10.00	"
289	2385 7328				10.00	"
290	2389 7301				10.00	"
291	2249 7498	1976		9.00	9.00	"
292	2253 7491	"		8.00	8.00	"
293	2260 7487	"		8.00	8.00	"
294	2259 7481	"		8.00	8.00	"
295	2267 7481	"		8.00	8.00	"
296	2269 7472	"		8.00	8.00	"
297	2276 7473	"		8.00	8.00	"
298	2275 7467	"		8.00	8.00	"
299	2281 7462	"		8.00	8.00	"
300	c 2295 7454	"		9.15	9.15	"
301	c 2289 7453	"		9.15	9.15	"
302	c 2282 7463	"		9.15	9.15	"
303	c 2296 7450	"		7.79	7.79	"
304	c 2290 7456	"		8.38	8.38	"
305	2482 7314	1974	5.74	7.35	9.05	"
306	2481 7303	"	6.04	1.45	5.00	"
307	2494 7292	"	6.72	5.75	7.90	"
309	2350 7313	1984	19.62	3.80	5.80	"
310	2358 7317	"	19.75	2.90	5.10	"
311	2367 7320	"	16.96	6.25	6.25	"
312	2353 7308	"	19.75	3.60	6.07	"
313	2359 7310	"		0.50	2.40	"
314	2366 7310	"		7.50	7.50	"
315	2371 7317	"		6.20	6.20	"
316	2355 7302	"	19.76	0.30	2.26	"
317	2370 7308	"		6.20	6.20	"
318	2354 7296	1983	25.39	10.75	10.75	"
320	2375 7202	"		10.00	10.00	"
321	2360 7293	"	22.82	4.40	6.00	"
322	2367 7293	"	20.57	6.05	6.05	"
323	2375 7294	"		1.67	1.67	"
323A	2375 7294	"		10.05	10.05	"
324	2390 7297	"	13.68	10.00	10.00	"
325	2362 7284	"	26.67	1.30	5.55	"
326	2374 7290	"	18.14	21.25	21.25	"
327	2370 7281	"	24.30	6.45	6.45	"
328	2379 7286	"	16.09	10.65	10.65	"
329	2393 7288	"	13.06	12.45	12.45	"
330	2376 7275	"	22.26	8.50	8.50	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
331	2382 7276	1983	17.33	8.45	8.45	Yes
332	2395 7289	"	13.68	10.45	10.45	"
333	2381 7309	"		8.10	8.10	"
334	2389 7336	1981	9.73	3.05	3.05	"
335	2394 7340	"	6.58		3.00	"
336	2393 7335	"	9.55		12.50	"
337	2396 7332	"	9.67		12.50	"
338	2390 7327	"	10.85		15.05	"
339	2395 7326	"	10.27		15.45	"
340	2395 7319	"	10.68		12.00	"
341	2397 7345	"	6.12		3.00	"
342	c 244 738	1985	Boreholes in tip, up to 15 m			
347	2333 7351			?10.40	11.30	-
348	2358 7356			?9.00	11.50	-
349	2376 7370			9.50	9.50	-
350	2398 7354			14.50	14.50	-
351	2381 7346			?22.60	30.30	-
352	2360 7326			8.00	23.00	-
353	2388 7328			25.25	25.25	-
355	2326 7426	1974	9.10	7.80	9.60	Yes
356	2329 7423	"	8.30	4.50	6.10	"
412	2231 7465	1978		2.20	13.80	-
413	2234 7468	"		-	16.00	-
414	2228 7463	"		3.00	28.00	-
415	2235 7464	"		1.00	26.00	-
416	2233 7461	"		3.00	52.00	-
417	2236 7458	"		1.50	23.00	-
418	2215 7492	"		1.80	18.00	-
419	2230 7499	"		4.60	20.00	-
420	2201 7490	1974		2.80	18.30	-
424	2313 7312			?36.58	?36.58	-
425	2281 7250			c 9.14	c 9.14	-
435	2392 7091			26.52	26.52	-
436	2499 7120			15.24	15.24	-
437	2499 7108			12.19	12.19	-

MAP SJ 27 SE

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
1	2776 7058		c 9.14		62.17	-
2A	2616 7161				123.75	-
2B	c 2628 7150	?1943		-	114.78	-
3	C.E.G.B. - Confidential					
4	c 2643 7087			-	38.25	-
5	2850 7035	1939	4.87	2.79	4.57	-
9-15	British Coal - Confidential					
16-30	C.E.G.B. - Confidential					
35	2561 7370	1970	0.46	?20.73	21.03	Yes
43	2603 7477	"	0.30	30.48	30.48	"
46B	2650 7326	"	2.41	21.34	21.34	"
61	2751 7374	"	2.59	15.24	15.24	"
64	2777 7248	"	2.32	20.27	20.27	"
66	2806 7170	"	3.87	25.45	25.45	"
79	2902 7224	"	5.06	18.29	18.29	"
95	2896 7223	1978	5.41	15.45	15.45	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
96-166	British Coal - Confidential					
175-176	British Coal - Confidential					
177	2545 7072	1986	c 57.00	17.10	17.10	Yes
211-213	C.E.G.B. - Confidential					
214	2846 7034	1984	6.38	3.30	4.70	Yes
215	2854 7028	"	6.57	4.60	5.00	"
216	2850 7033	"	5.39	3.50	4.00	"
217	2502 7289	1974	6.51	4.10	6.00	"
218	2739 7260	1983	2.66	20.00	20.00	"
219	2711 7273	"	1.79	20.00	20.00	"
220	2728 7291	"	1.75	20.00	20.00	"
221	2768 7262	"	2.55	20.00	20.00	"
222	2748 7240	"	3.84	20.00	20.00	"
223	2721 7284	"	1.61	20.00	20.00	"
224	2749 7279	"	1.71	20.00	20.00	"
225	2758 7251	"	3.14	20.00	20.00	"
226	2729 7257	"	2.87	20.00	20.00	"
227	2697 7265	"	1.54	20.00	20.00	"
228	2686 7275	"	1.16	20.00	20.00	"
229	2696 7287	"	2.37	20.00	20.00	"
230	2784 7288	"	2.43	20.00	20.00	"
231	2674 7292	"	2.63	20.00	20.00	"
232	2700 7277	"	1.68	20.00	20.00	"
233	2728 7278	"	1.84	20.00	20.00	"
234	2717 7261	"	2.33	20.00	20.00	"
235	2724 7261	"	2.31	20.00	20.00	"
236	2735 7282	"	1.82	20.00	20.00	"
237	2744 7254	"	2.94	20.00	20.00	"
238	2754 7265	"	2.89	20.00	20.00	"
239	2762 7241	"	3.59	20.00	20.00	"
240	2770 7250	"	3.38	20.00	20.00	"
241	2778 7260	"	2.00	20.00	20.00	"
242	2710 7280	"	1.19	20.00	20.00	"
243	2734 7262	"	2.80	20.00	20.00	"
244	2744 7274	"	2.58	20.00	20.00	"
245	2790 7257	"	1.93	20.00	20.00	"
246	2808 7247	"	2.44	20.00	20.00	"
247	2790 7242	"	3.85	20.00	20.00	"

MAP SJ 36 NW

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
1	3091 6974	?1913	3.66	43.89	67.67	-
2	3116 6994	1905	?3.66	48.01	66.85	-
3	? 3170 6966		?4.57		?62.58	-
4	3186 6973	1891	c 6.10	46.89	179.98	-
	Boreholes 3 and 4 may be the same					
5	? 3382 6837	?1820/30	c 6.10	91.44	91.44	-
7	3228 6813	1891	5.49	44.81	225.20	-
8	3331 6701		5.49	50.29	85.80	-
9	3393 6751	1900	c 5.49	43.13	44.04	-
10	3332 6748		c 5.18			-
11	3333 6749		5.18	59.59	209.22	-
12	3383 6702		c 5.18	59.40	204.80	-
13	3338 6670		c 5.18		92.68	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
14	3326 6814			43.97	113.94	-
15	3114 6997	1913		51.66	61.37	-
21	?	1853		7.92	91.74	-
24	c 328 688			59.44	72.54	-
25	3280 6874	1957		67.06	76.20	-
26	3202 6572	1913	c 53.34	26.97	141.63	-
27	3202 6572	1911		27.74	51.21	-
28	? 3394 6539	1890	c 9.14	15.24	15.24	-
29	3466 6630		c 10.67	50.90	51.82	-
30	c 316 664				130.20	-
31	3314 6540	?1862		38.40	124.59	-
32	3288 6516	?1862	c 33.53	23.47	120.88	-
33	3339 6512	?1862	c 19.81	40.23	163.85	-
34	3405 6561	1862	c 6.10	69.49	69.49	-
35	3321 6566	?1862	15.24	39.62	73.30	-
36	3371 6516	1862	c 12.19	59.44	77.24	-
37	3331 6592	?1862	c 12.19	36.58	179.58	-
38	3352 6586	?1862	c 9.14	46.79	124.08	-
39	3179 6614			26.97	101.73	-
40	3167 6654				91.14	-
43/1	3021 6926	1961	4.26	6.10	6.10	Yes
43/2	3019 6924	"	4.34	6.10	6.10	"
43/3	3011 6929	"	4.69	3.05	3.05	"
43/4	3019 6913	"	9.44	3.66	3.66	"
43/5	3000 6915	"	6.70	1.98	1.98	"
43/14	3030 6936	"	4.26	3.05	3.05	"
43/15	3028 6938	"	4.26	6.10	6.10	"
43/16	3032 6937	"	4.26	4.88	4.88	"
43/17	3035 6938	"	4.26	1.52	1.52	"
43/18	3030 6940	"	4.26	1.52	1.52	"
43/19	3033 6941	"	4.26	6.10	6.10	"
43/20	3026 6942	"	4.26	7.62	7.62	"
44/1	3018 6914	1959	7.92	3.20	3.66	"
44/2	3021 6914	"	5.49	2.67	2.82	"
44/3	3021 6911	"	6.71	3.35	3.51	"
44/4	3021 6907	"	6.45	2.29	3.05	"
44/5	3018 6904	"	6.71	1.83	2.26	"
44/6	3016 6902	"	7.16	3.35	3.78	"
44/7	3014 6902	"	8.84	5.94	7.60	"
44/8	3010 6904	"	11.58	10.21	10.36	"
45/1	3227 6846	1960	7.01	22.86	22.86	-
45/2	3275 6883	"	81.56	6.10	6.10	-
45/4	3008 6678	"	82.30	10.06	10.06	-
45/5	3018 6684	"	78.58	12.19	12.19	-
45/6	3007 6683	"	81.44	9.14	9.14	-
45/7	3003 6680	"	83.61	11.28	11.28	-
45/8	3001 6674	"	83.70	10.67	10.67	-
45/9	3015 6681	"	81.08	10.67	10.67	-
45/10	3019 6679	"	74.07	10.67	10.67	-
47/11	3026 6678	"	78.49	9.14	9.14	-
45/12	3029 6691	"	63.82	9.14	9.14	-
45/13	3023 6688	"	72.79	11.58	11.58	-
45/14	3014 6689	"	77.52	6.10	6.10	-
45/15	3035 6683	"	75.83	6.10	6.10	-
45/16	3035 6677	"	78.24	11.58	11.58	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
45/17	3038 6677	1960	76.35	10.97	10.97	-
45/18	3039 6679	"	71.24	4.57	4.57	-
45/19	3133 6786	"	11.13	6.10	6.10	-
45/20	3130 6784	"	11.89	6.10	6.10	-
45/21	3148 6795	"	7.47	6.10	6.10	-
45/22	3179 6805	"	5.21	4.57	4.57	-
45/23	3192 6808	"	5.09	6.10	6.10	-
45/24	3223 6846	"	5.03	17.30	17.30	-
45/25	3317 6930	"	4.48	6.10	6.10	-
45/26	3315 6923	"	4.57	6.10	6.10	-
45/27	3314 6914	1960	4.54	6.10	6.10	-
45/28	3047 6705	1961	5.08	18.29	18.29	-
45/29	3044 6703	"	51.25	18.29	18.29	-
45/30	3043 6704	"	51.25	11.13	11.13	-
45/31	3045 6702	"	51.51	10.36	10.36	-
45/32	3046 6706	"	50.02	9.45	9.45	-
45/33	3048 6704	"	50.06	9.45	9.45	-
47/A1	3323 6937	1971	4.33	12.95	12.95	Yes
47/A2	3321 6936	"	4.48	12.19	12.19	"
47/A3	3322 6938	"	4.48	12.19	12.19	"
47/A4	3324 6936	"	4.30	10.67	10.67	"
47/A5	3325 6937	"	4.27	12.50	12.50	"
47/1X	3323 6936	"	4.30	20.42	20.42	"
47/A6	3327 6925	"	4.36	6.10	6.10	"
47/A7	3329 6929	"	4.15	9.14	9.14	"
47/1	3321 6931	"	4.66	3.96	3.96	"
47/2	3328 6948	"	4.57	3.96	3.96	"
47/3	3329 6957	"	4.60	3.96	3.96	"
47/4	3332 6967	"	4.66	3.96	3.96	"
47/5	3332 6973	"	4.85	3.96	3.96	"
47/6	3337 6982	"	4.66	3.96	3.96	"
48	3148 6795	1973	8.22	15.45	15.45	"
49	3160 6803	"	6.34	10.00	10.00	"
50	3159 6794	"	6.90	10.00	10.00	"
51	3171 6799	"	6.84	30.00	30.75	"
52	3179 6804	"	6.33	25.00	25.00	"
53	3186 6806	"	5.48	15.00	15.00	"
54	3193 6813	"	5.48	15.00	15.00	"
55	3157 6793	1974	7.19	?25.00	45.00	"
56	3171 6796	"	5.36	28.00	49.00	"
57	3153 6791	"	c 8.20	20.50	20.50	-
58	3161 6791	"	c 6.40	c 24.20	25.40	-
59	3164 6792	"	c 5.50	16.40	16.40	-
60	3169 6796	"	c 5.30	20.20	20.20	-
61	3175 6796	"	c 6.30	15.40	15.40	-
62	3176 6799	"	c 7.00	20.10	20.10	-
63	3180 6798	"	c 6.00	15.30	15.30	-
64	3184 6806	"	c 5.05	5.00	5.00	-
65	3165 6814	"	c 6.00	5.00	5.00	-
66	3165 6808	"	c 6.15	5.40	5.40	-
67	3162 6801	"	c 5.85	5.00	5.00	-
68	3166 6786	"	c 7.00	5.20	5.20	-
69	3024 6687	1972	71.89	15.30	15.30	-
70	3079 6661	"	65.02	8.80	8.80	-
71	3113 6644	"	56.30	10.50	10.50	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
72	3145 6627	1972	51.13	15.00	15.00	-
73	3222 6583	"	39.60	8.10	8.10	-
74	3254 6533	"	41.17	9.30	9.30	-
75/1-6	PSA - Confidential					
76/1	3010 6578	1975		4.60	19.80	-
76/2	3007 6580	"		7.60	22.90	-
76/3	3005 6570	"		1.80	5.20	-
78-154	British Coal - Confidential					
160	British Coal - Confidential					
162	c 325 678	1983	5.00	51.00	51.00	-
163	British Coal - Confidential					
165	3280 6559					-
166	3286 6565					-
167	3337 6535					-
168	3344 6666	1867		53.04	91.44$^+$	-
	[Boreholes 168 and 13 may be the same]					
169	3331 6674	1867		47.55	166.42$^+$	-
170	3367 6678	1867		62.18	146.30$^+$	-
175	3240 6657			10.97	103.33$^+$	-
176	3291 6652				31.09$^+$	-
177	3210 6823	[? same borehole as 178]				-
178	3218 6825				126.49$^+$	-
180	3061 6820				91.44	-
181	3080 6827				41.15	-
182	3073 6827				57.61	-
183	3046 6523				3.35	-
196	3043 6911	1985		4.00	4.50	Yes
197	3044 6910	"		3.80	4.50	"
198	3040 6907	"		3.50	5.00	"
199	3309 6754	1977	5.45	6.50	6.50	"
200	3306 6749	"	5.30	6.50	6.50	"
201	3313 6752	"	5.45	6.50	6.50	"
202	3308 6748	"	5.30	6.50	6.50	"
203	3311 6758	"	5.50	12.50	12.50	"
204	3009 6928	1983	4.98	4.90	4.90	"
205	3001 6935	"	4.54	4.90	4.90	"
206	3168 6885					-
207	3153 6862				71.32	-
233	3125 6819				36.58$^+$	-
243	3189 6757			16.20	36.88	Yes
244	3191 6763			17.79	43.00	"
245	3196 6767			19.70	42.00	"
246	3182 6753			16.80	36.58	"
247	3197 6768			20.60	31.80	"
248	3360 6738	1978	c 4.90	11.00	11.00	"
249	3369 6735	"	c 4.60	11.00	11.00	"
250	3366 6735	"	3.14	3.10	3.10	"
251	3367 6734	"	3.31	3.50	3.50	"
252	3334 6786	1973		18.50	18.50	"
253	3324 6773	"		15.30	15.30	"
254	3314 6758	"		15.30	15.30	"
255	3332 6763	"		15.20	15.20	"
256	3334 6755	"		15.20	15.20	"
257	3352 6775	"		14.17	14.17	"
258	3352 6756	"		15.20	15.20	"

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
259	3351 6736	1973		15.20	15.20	Yes
260	3280 6750	1972		6.55	6.55	"
26	3299 6738	"		6.55	6.55	"
262	3307 6748	"		6.55	6.55	"
263	3327 6735	"		6.55	6.55	"
264	3307 6718	"		6.10	6.10	"
265	3290 6733	"		18.59	18.59	"
266	3271 6741	"		9.30	9.30	"
267	3290 6724	"		9.45	9.45	"
268	3310 6732	"		6.55	6.55	"
269-295	British Coal - Confidential					
296	3377 6742	1987	0.48	55.00	55.00	-
297	3367 6989	1986	4.75	12.00	12.00	Yes
298	3371 6989	"	4.70	8.00	8.00	"
299	3369 6986	"	5.00	8.00	8.00	"
300	3364 6988	"	4.85	8.00	8.00	"
301	3365 6991	"	4.90	8.00	8.00	"

MAP SJ 36 SW

1	3279 6483	1862	c 45.70	25.53	70.61	-
2	3334 6463	"	c 27.40	?29.51	97.41	-
3	3393 6493			42.01	42.01	-
5	3230 6205	1899	57.30	2.82	52.88	-
6	3221 6175	"	57.30	2.06	32.92	-
8	c 3230 6225	1938	c 54.80	?10.36	36.58	-
9	c 3285 6220	1937	c 30.50		37.80	-
10	3372 6121	1947		46.63	72.54	-
11	3374 6136	1945		40.84	106.55	-
12	3376 6134	1948		40.84	152.40	-
13	3069 6386	1972	113.34	3.10	12.31	Yes
14	3099 6368	"	126.27	Nil	18.00	"
15	3124 6361	"	120.93	Nil	13.00	"
16	3271 6315	"	43.35	10.10	10.10	"
17	3393 6309	"	22.83	7.20	7.20	"
18	3060 6485	1979		13.50	13.80	-
19	3202 6454	"		7.30	7.50	-
20	3283 6290	"		9.20	9.80	-
21	3038 6036	1982	117.86	5.00	5.00	Yes
22	3034 6045	"	116.49	5.00	5.00	"
23	3035 6049	"	117.03	5.00	5.00	"
24	3028 6052	"	116.72	5.00	5.00	"
25	3020 6059	"	113.55	5.00	5.00	"
27	3005 6072	"	109.99	5.00	5.00	"
28	3002 6200	"	107.49	5.00	5.00	"
29	3008 6208	"	110.59	1.30	3.80	"
30	3014 6216	"	112.38	3.20	5.00	"
31	3019 6224	"	113.58	2.90	4.75	"
33	3024 6233	"	114.31	3.50	4.00	"
34	3029 6242	"	114.43	2.50	5.00	"
37	3006 6392			Nil	75.44	-
39	3340 6153	1939	c 29.00	15.85	28.96	-
40	3307 6026		c 37.00	0.30	7.00	-
41	3033 6289				4.57	-

BGS Number	Grid Reference	Date of drilling	Surface level	Drift thickness	Depth	Engineering properties
MAP SJ 37 SW						
4	3199 7258	1938	c 4.57	17.67	183.18	-
5	3293 7183	"	c 4.88	16.46	182.88	-
7	3367 7124	"	c 4.88	14.48	174.04	-
8	c 3316 7080		4.57		?155.45	-
9/7	3346 7006	1971	4.57	3.96	3.96	Yes
9/8	3349 7015	"	5.15	3.96	3.96	"
9/9	3353 7024	"	4.88	3.96	3.96	"
9/10	3357 7034	"	4.66	3.96	3.96	"
9/13	3374 7073	"	4.63	3.96	3.96	"
9/14	3378 7083	"	4.69	3.96	3.96	"
9/15	3381 7092	"	4.88	3.96	3.96	"
9/16	3385 7100	"	4.88	3.96	3.96	"
9/17	3388 7107	"	5.18	3.96	3.96	"
9/18	3383 7063	"	4.66	3.96	3.96	"
9/19	3342 7043	"	4.66	3.96	3.96	"
9/21	3351 7067	"	4.82	3.96	3.96	"
9/22	3347 7081	"	4.88	3.96	3.96	"
9/B1	c 3370 7065	"	5.27	19.51	19.51	"
9/B2	"	"	5.18	20.12	20.12	"
9/B3	"	"	5.12	17.37	17.37	"
9/B4	"	"	4.88	16.76	16.76	"
9/B5	"	"	4.88	17.22	17.22	"
9/B6	3358 7071	"	4.57	8.53	8.53	"
9/B8	3370 7037	"	4.88	6.10	6.10	"
9/B9	3374 7062	"	4.97	12.04	12.04	"
9/B10	3379 7066	"	4.94	9.14	9.14	"
9/B11	3380 7074	"	4.57	9.14	9.14	"
11	3202 7256	"		15.39	183.49	-
12	3367 7124	1969		14.32	185.01	-
13	C.E.G.B. -	Confidential				
14	3244 7150	1974		12.10	12.10	Yes
15	3208 7165	"		12.10	12.10	"
16	3179 7172	"		9.10	9.10	"
17	3145 7191	"		12.10	12.10	"
18	3220 7114	"		12.10	12.10	"
19	3169 7138	"		9.10	9.10	"
20	3128 7144	"		12.10	12.10	"
21	3177 7095	"		9.10	9.10	"
22	3181 7044	"		9.10	9.10	"
23	3209 7018	"		9.10	9.10	"
24	3097 7211	1984		?33.50	38.50	"
25	3097 7209	"		?35.00	37.50	"
26	3102 7210	"		34.00	39.00	"
27	3104 7205	"		34.00	38.50	"
28	3109 7207	"		35.50	39.50	"
29	3125 7205	"		34.00	43.50	"
30	3090 7208	"		36.50	41.00	"
31	3082 7211	"		35.00	40.00	"
32	3088 7205	"		40.00	42.50	"
33	3072 7207	"		38.00	46.50	"
34	3037 7134	1949		c 47.24	54.86	-
35	3046 7135	"		45.72	49.68	-
36	3040 7167	"		c 42.67	45.72	-

APPENDIX D

List of shafts sunk for coal

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
MAP SJ 17 NE					
59	16	1907 7799		150.88	
122	17	1906 7796		?36.58	?Adit
123	18	1907 7794		69.49	
134	29	1961 7746		59.44	?Position
MAP SJ 26 NW					
2	7 or 8			79.85	
(See SJ26NW/97 and 98)					
3		Site uncertain	4.11	57.30	
4	14	2469 6563	3.04	60.42	
(See SJ26NW/104)					
91	1	2415 6594			Adit
92	2	2412 6592			Adit
93	3	2414 6588			Adit
94	4	2415 6586		7.01	
95	5	2416 6582			Adit
96	6	2412 6578			Adit
97	7	2489 6593		79.85	
(Depth may apply to this or next shaft)					
98	8	2490 6595			Capped
99	9	2494 6593			
100	10	2499 6585		?70.10	
101	11	2498 6580		64.01	
102	12	2447 6561			
103	13	2450 6563			
104	14	2469 6563	3.04	60.42	Same as 26NW/4
105	15	2465 6557			
106	16	2438 6541		67.97	Capped
107	17	2440 6538		67.97	
108	18	2441 6534			
109	19	2450 6538			
110	20	2453 6539			
111	21	2448 6530			
112	22	2446 6511			
113	23	2451 6513			
114	24	2460 6504		7.92	Borehole to 50.90
115	25	2492 6520		?32.00	
116	26	2488 6514			Adit
117	27	2489 6514			Adit
118	28	2489 6513			
119	29	2489 6512			
120	30	2486 6507			
121	31	2494 6507			
122	32	2337 6723			
123	33	2492 6504			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
124	34	2493 6501			
125	35	2471 6623			
126	36	2489 6501			
127	37	2403 6842			
128	38	2408 6837		13.72	
129		2070 6766			
130		2069 6764			
131		2074 6758			

MAP SJ 26 NE

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
1	45 or 46	c 2726 6757	11.88	135.94	See 26NE/877 and 878
2	British Coal - Confidential				
5	162	2648 6501		85.34	Borehole to 122.22
7	85	2986 6608		?303.58	
8	124	?2846 6535		147.19	Capped
833	1	2669 6883		85.95	
834	2	2668 6882		85.95	
835	3	2690 6880		c 86.87	
836	4	2688 6877			
837	5	2847 6908			
838	6	2932 6925			
839	7	2978 6835			
840	8	2999 6836			
841	9	2989 6823			
842	10	2988 6821			
843	11	2990 6818			
844	12	2971 6808			
845	13	2972 6811			
846	14	2973 6812			
847	15	2977 6813			
848	16	2981 6814			
849	17	2984 6813			
850	18	2988 6810			
851	19	2994 6788		137.46	
(Depth may apply to this or next shaft)					
852	20	2995 6790		137.46	
853	21	2624 6797			Capped
854	22	2630 6806			Capped
855	23	2633 6805		25.91	
856	24	2656 6814			
857	25	2654 6806		91.59	
858	26	2676 6821			
859	27	2674 6809			
860	28	2685 6813			
861	29	2685 6812			
862	30	2694 6805			
863	31	2704 6796			
864	32	2656 6796			
865	33	2659 6790			
866	34	2638 6780		130.58	Capped
867	35	2641 6781		101.41	Capped
868	36	2686 6787		1.52	
870	38	2690 6787			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
871	39	2687 6784		1.52	
872	40	2668 6770			
873	41	2672 6764			
874	42	2697 6763			
875	43	2702 6763			
876	44	2704 6764			
877	45	2727 6760			
(Section for SJ26NE/1 may apply to this or next shaft)					
878	46	2726 6753			
879	47	2746 6769			
880	48	2774 6711			Adit
881	49	2775 6713			Adit
882	50	2781 6717			Adit
883	51	2787 6717		?24.38	
884	52	2781 6710			Adit
885	53	2781 6708			Adit
886	54	2895 6753			
887	55	2894 6749		14.63	
888	56	2898 6747			
889	57	2890 6736		24.69	
890	58	2884 6732		27.43	
891	59	2903 6737			
892	60	2905 6729			
893	61	2897 6722		109.73	
894	62	2936 6720		85.03	
895	63	2945 6702		122.22	
896	64	2950 6693			
897	65	2602 6696			
898	66	2607 6663			
899	67	2631 6645		94.18	
900	68	2633 6645		94.18	
901	69	2635 6633			
902	70	2744 6625		305.41	
903	71	2749 6625		317.60	
904	72	2754 6624		168.86	Capped
905	73	2845 6633		19.80	Capped
906	74	2848 6631	88.30	5.00	
907	75	2850 6627			Capped
908	76	2853 6627			
909	77	2839 6614		21.64	
910	78	2834 6607			
911	79	2844 6607		2.44	
912	80	2940 6640		52.12	
913	81	2941 6635		52.12	
914	82	2961 6612			
915	83	2969 6613			
916	84	2977 6613			
917		2962 6829			Adit
918	86	2651 6593			
919	87	2647 6587		73.15	
920	88	2645 6583		54.86	
921	89	2659 6584		36.58	
922	90	2666 6585			
923	91	2655 6566			
924	92	2652 6561			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
925	93	2651 6557			
926	94	2663 6563			
927	95	2658 6548			
928	96	2658 6547			
929	97	2653 6539			
930	98	2654 6537			
931	99	2656 6534		22.86	
932	100	2660 6536		99.06	Capped
933	101	2658 6523			Adit
934	102	2663 6512		17.37	
935	103	2696 6557			Adit
936	104	2705 6561		25.60	
937	105	2705 6559			Adit
938	106	2722 6596			Adit
939	107	2728 6559			
940	108	2729 6554			Capped
941	109	2746 6567		c 128.02	Capped
942	110	2753 6570		c 109.73	
943	111	2765 6512		c 109.73	
944	112	2768 6510		c 109.73	
945	113	2827 6570			
946	114	2828 6571			
947	115	2836 6566			
948	116	2837 6566			
949	117	2842 6564			
950	118	2844 6564			
951	119	2843 6556			
952	120	2855 6562			
953	121	2858 6560			
954	122	2829 6543			
955	123	2827 6535		116.13	
956		2944 6791			
957	125	2845 6531		118.87	Capped
958	126	2878 6538			
959	127	2880 6540			
960	128	2859 6590			
961	129	2857 6584		54.86	Capped
962	130	2862 6589			Capped
963	131	2937 6593		164.59	
964	132	2939 6590		164.59	
965	133	2921 6542		26.60	Capped
966	134	2917 6535		27.43	
967	135	2898 6502		27.43	
968	136	2932 6531			
969	137	2927 6527		46.80	
970	138	2925 6508		54.86	
971	139	2930 6509		45.72	
972	140	2966 6565		8.84	
973	141	2967 6563		13.11	
974	142	2974 6559		?82.30	Capped
975	143	2979 6564			Capped
976	144	2985 6572			
977	145	2964 6549		?59.44	Capped
978	146	2969 6550			
979	147	2974 6541			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
980	148	2964 6530		73.15	
981	149	2973 6531			
982	150	2543 6506			
983	151	2546 6508			
984	152	2608 6657			
985	153	2610 6656			
986	154	2622 6646			
987	155	2623 6615			
988	156	2623 6610			
989	157	2641 6601			
990	158	2645 6595			
991	159	2668 6584			
992	160	2660 6558			
993	161	2651 6537			
994		2894 6758			
995	163	2705 6577			
996	164	2729 6562			
997	165	2731 6548			Capped
998	166	2740 6542			
999	167	2745 6531			
1000	168	2711 6522			
1001	169	2713 6510			
1002	170	2717 6515			
1003	171	2726 6514			
1004	172	2730 6506			
1005	173	2737 6511			
1006	174	2740 6511			
1007	175	2738 6518			
1008	176	2844 6585			Capped
1009	177	2850 6585			Capped
1010	178	2865 6614			?Shaft
1011	179	2858 6649			
1012	180	2861 6667			
1013	181	2915 6636			
1014	182	2835 6643			
1015	183	2961 6679		54.86	
1016	184	2963 6680		54.86	
1017	185	2999 6640			
1018	186	2999 6640			
1019	187	2906 6575		36.58	
1020	188	2946 6564			
1021	189	2971 6560			
1022	190	2976 6563			?Same as SJ26NE/975
1023	191	2962 6549		59.44+	
1024	192	2975 6536			
1025	193	2974 6534		32.00	
1026	194	2948 6522			
1027	195	2937 6515		49.20	
1028	196	2915 6531			
1029	197	2959 6520			
1030	198	2965 6500			
1031	199	2524 6568		?91.44	
1032	200	2509 6544			
1033	201	2656 6529			Adit
1034	202	2703 6570			Adit

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
1035		2954 6808			
1036		2956 6808			
1037	205	2850 6609			
1038	206	2964 6566			Adit
1039	207	2965 6573			
1040	208	2925 6617			
1041	209	2875 6572			Capped
1042	210	2845 6606			Adit
1043	211	2980 6573			
1044	212	2980 6573			
1045		2953 6806			
1046	214	2652 6517		14.63	
1047	215	2643 6590			
1048	216	2709 6862			
1049	217	2508 6547			
1050	218	2842 6999			?Same as SJ27SE/11
1051	219	2901 6742			Adit
1052	220	2900 6739			Adit
1053	221	2894 6720			
1054	222	2724 6600			
1055	223	2849 6659			
1056	224	2869 6662			
1057	225	2980 6661		77.70	Capped
1058	226	2979 6660		55.00	Capped
1059	227	2908 6598			
1060	228	2840 6597			
1061	229	2826 6550			
1062	230	2833 6565			
1063	231	2821 6573			
1064	232	2830 6566			
1065	233	2820 6565			
1066	234	2780 6715			?Adit
1067	235	2786 6690			Adit
1068	236	2787 6687			
1069	237	2971 6808			
1070	238	2722 6544			
1071	239	2720 6537			
1072	240	2701 6521			
1073	241	2727 6519			
1074	242	2735 6530			
1075	243	2606 6717			
1076	244	2747 6550			
1077	245	2751 6547			
1078	246	2999 6624			
1079	247	2923 6627		8.05	
1080	248	2924 6623			
1081	249	2952 6634			
1082	250	2959 6628			
1083	251	2955 6635			
1084	252	2824 6600			
1085	253	2822 6596			
1086	254	2861 6595			
1087	255	2848 6540			
1088	256	2839 6520			
1089	257	2988 6652			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
1090	258	2863 6623			
1091	259	2922 6560			
1092	260	2940 6530			
1093	261	2997 6842			
1094	262	2984 6808			
1095	263	2984 6796			
1096	264	2986 6791			
1097	265	2983 6790			
1098	266	2999 6856			
1099	267	2958 6671			
1100	268	2925 6704		79.25	
1101	269	2928 6703		109.73	
1102	270	2969 6635			
1103	271	2983 6632			
1104	272	2984 6626			
1105	273	2981 6624			
1106	274	2987 6622			
1107	275	2981 6616			
1108	276	2944 6598			
1109	277	2608 6647			
1110	278	2609 6679			
1111	279	2610 6676			
1112	280	2613 6664			
1113	281	2619 6660			
1114	282	2608 6662			
1115	283	2608 6660			
1116	284	2598 6671			
1117	285	2599 6669			
1118	286	2597 6667			
1119	287	2600 6673			
1120	288	2603 6672			
1121	289	2628 6600			
1122	290	2966 6531			
1123	291	2736 6785			
1124	292	2749 6998			
1125	293	2749 6997			
1126	294	2748 6995			
1127	295	2916 6502			
1128	296	2931 6501			
1129-1137	297-305	c 2948 6503			
(Bell-pits, not individually sited)					
1138	306	2920 6500			
1139-1143	307-311	c 2950 6512			
(Bell-pits, not individually sited)					
1144	312	2503 6542			
1145	313	2706 6767			
1146	314	2680 6830		3.05	
1147	315	2613 6653			
1148	316	2614 6651			
1149	317	2610 6651			
1150	318	2615 6649			
1151	319	2616 6648			
1152	320	2617 6647			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
1153	321	2618 6614			
1154	322	2614 6613			
1155	323	2617 6612			
1156	324	2620 6613			
1157	325	2712 6790			
1158	326	2708 6787			
1159	327				
1160	328				
1161	329				
1162	330				
1163	331	2841 6632		19.50	Capped
1164	332	2857 6620			Capped
1165	333	2957 6639		23.50	Capped
1166	334	2958 6642		25.00	Capped
1167	335	2954 6639		26.00	Capped
1168	336	2924 6539			Capped
1169	337	2932 6520			Capped
1196		2911 6574			
1197		2944 6603			
1198		2992 6829			
1199		2548 6717			?Shaft
1200		2627 6635			?Shaft
1201		2692 6806			
1314		2934 6782			?Shaft
1315		2891 6754			?Shaft

MAP SJ 26 SW

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
1	11	2449 6464	11.28	85.95	
4A	23	2422 6328	?13.79	222.81	
4B	24	2417 6331		192.02	
5	48	2430 6375		132.54	
6	42	2421 6145	9.25	49.37	
7A	27	2382 6284	13.96	201.78	
7B	26	2379 6286	?4.57	?133.50	Drilled to 150.00
7C	25	2383 6288			
146A	1	2377 6450		100.58	Capped
146B	2	2374 6454		85.95	Capped
147A	13	2470 6412		137.16	Capped
147B	14	2472 6409		137.16	Capped
148A	37	2434 6205		?42.67	
148B	38	2434 6203			
149	43	2374 6023		222.50	
183A	31	2378 6220		93.27	
183B	33	2398 6227		82.30	
184	20	2359 6335	19.81	?132.59	
185	22	2389 6332		68.58	?Drilled to 153.82
208	53	2435 6271			
272	10	2454 6466		72.24	
273	3	2490 6496			
274	4	2491 6483			
275	5	2480 6468		46.63	
276	6	2482 6464		31.09	
277	7	2483 6463		16.46	

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
278	8	2479 6463		46.63	
279	9	2474 6461		?66.75	
280	12	2486 6437			
281	15	2492 6406			
282	16	2494 6404			
283A	17	2390 6412		28.96	
283B	18	2392 6411			
284	28	2413 6285			
285	29	2413 6258			
286	30	2371 6224		111.56	Capped
288	32	2390 6224		?91.44	
289	34	2405 6227		73.15	
290	35	2408 6226		54.86	
291	36	2441 6217		12.80	
292	39	2346 6150		?82.30 or 171.13	
293	40	2348 6150		?171.13 or 82.30	
294	41	2420 6150			
295	44	2377 6023		122.07	
296	45	2434 6011		c 176.48	
297	46	2424 6004			Adit
298	47	2424 6002			Adit
299	19	2435 6372			?Capped
300	49	2423 6373		14.63	
301	50	2393 6375		45.72	
302	51	2419 6358			
304	52	2441 6135	9.14	9.14	
305	54	2448 6292		59.44	
306	55	2427 6267		45.72	
307	56	2428 6272			
308	57	2439 6381		21.95	
309	58	2421 6333			
310	59	2420 6228			
311	60	2430 6247		45.72	
312	61	2438 6238		14.63	
313	62	2440 6239		14.63	
314	63	2439 6236			
315	64	2428 6230		79.55	
320	21	2363 6335		129.84	
321	65	2378 6218			
322	66	2466 6292			?Shaft
323	67	2436 6258			?Shaft
324	68	2429 6257		?36.58	?Shaft

MAP SJ 26 SE

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
3	13	2507 6344	15.24	164.59	Capped
4	100	2935 6400		132.59+	Capped
6	102	2951 6395		121.61	
7	33	2724 6384	15.84	87.17	Capped
8	48	2829 6428	6.62	195.88	Capped
11	120	2721 6286	26.67	52.73	
12	36	2724 6359	5.48	31.69	

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
13	?121				
(See BGS No. 600)					
14	162	2766 6143		169.67	
15	118	2926 6244			
(Adjacent to SJ26SE/586. Depth 110.94 may be either shaft)					
17R		2649 6456		14.60	Drilled to 17.00
22	108	2940 6365		67.05	Capped. Drilled to 69.00
490	163	2772 6145	4.57	144.48	
586	119	2924 6244			See SJ26SE/15
587	233	2938 6244		45.72^{+}	
588		2933 6243			?Shaft
589	117	2937 6273			
590	169	2807 6146			
591	170	2814 6140			
592	171	2800 6131		18.29	
593	172	2804 6114			
594	124	2807 6246		?36.58	
595		2829 6288		36.58	
596		2856 6884		54.86	
597		2830 6286			
598	173	2810 6103			
599	174	2811 6102			
600	121	2723 6242	10.97	27.43	
601	123	2777 6246	?13.72	?	
602	122	2777 6250			
607		2691 6393			?Shaft
610		2643 6449			?Shaft
611	247	2605 6030			
612	248	2590 6024			
613	249	2602 6023			
614	250	2591 6003			
618	125	2555 6183		89.92	Capped
619	126	2555 6180		36.58	Capped
620	127	2561 6180			
621	212	2554 6190			
622	18	2539 6283		79.55	
623	17	2535 6292			
624		2544 6271			
625		2550 6278			
626		2532 6285		91.44	
627	16	2533 6307			
628	14	2508 6341		82.30	Capped
629	15	2511 6334			?Shaft
630	8	2501 6377		64.01	Capped
631	9	2509 6374		64.01	
632	10	2519 6376			
639	115	2947 6298			Adit
640	116	2946 6297			Adit
641	218	2941 6296		18.29^{+}	
642	226	2951 6296		13.11	
643	230	2959 6297		8.53	
740	238	2653 6005			
741	251	2620 6070			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
742	187	2636 6067		23.77+	
743	188	2636 6064			
744		2637 6071			
745	189	2646 6064		?77.72	
746	190	2626 6055		16.15+	
747	191	2628 6056		10.06+	
748	252	2638 6055			
749	192	2629 6041		15.54	
750	193	2631 6041		45.42	
751	194	2643 6039		78.64	Capped
752	195	2650 6042			
753		2654 6041		c 18.29	
(?Same shaft as No. 752)					
754	243	2672 6051			
755	282	2696 6006			
756	152	2655 6102		?54.86	
757	153	2659 6101		?54.86	
758	154	2665 6098			
759	155	2680 6093		82.30	Capped
760	156	2681 6093		?82.30	Capped
761	157	2691 6097			
762	158	2701 6700			Adit
764		2654 6092		?25.60	
768	244	2680 6062			Adit
769	159	2715 6100		51.21+	
770	286	2705 6096			
771	287	2718 6075			
772		2710 6094			
773	198	2712 6027		23.77+	
774	199	2714 6029		28.35+	
775	196	2702 6007		24.99+	
776	197	2702 6005			Adit
777	239	2727 6010			
778	240	2722 6009			
779		2732 6013			
780	201	2739 6014			
781	200	2742 6029			
782	202	2753 6027			Capped
783	203	2750 6036			Adit
784	204	2751 6035		28.35	Capped
785	205	2752 6034			Adit
786	206	2752 6055			Adit
787	207	2752 6051		18.29+	
788	208	2758 6044			
789	209	2758 6042			Adit
790	225	2783 6045		36.58+	
791	210	2795 6050			Adit
792	211	2796 6047			
794	175	2784 6088			
795	176	2787 6085		59.44+	
796	177	2794 6085			
797	178	2772 6084		27.13+	
798	179	2773 6081		27.13+	
799	180	2774 6079		9.14+	
800	185	2780 6070			?Borehole

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
801	186	2793 6070			
802	168	2759 6095		27.43+	
803	181	2759 6079		71.32	
804	182	2761 6076			
805	183	2764 6078		65.43	
806	184	2766 6066		36.58	
811	11	2582 6373			
812	12	2584 6375			
813	219	2588 6370			
814	1	2515 6499		27.74	
815	2	2502 6432		91.44	
816	3	2509 6413		9.14+	
817	4	2526 6412			Capped
818	5	2525 6411			Capped
819	6	2577 6401			
820	7	2587 6404			
821		2516 6484			
822		2501 6401			
823		2501 6396			
824		2507 6402			
825		2508 6400			
826		2526 6414			
828	160	2731 6137			
829	161	2736 6143			
830	164	2753 6130		64.01+	
831	165	2751 6127			?Same as No. 830
832	166	2752 6113		?31.09	
833	167	2771 6106		160.02	
834		2757 6107			
837	128	2683 6142		32.00	
838	246	2660 6126			Adit
839	144	2665 6123		14.63	
840	145	2670 6124		?82.30	Capped
841	146	2672 6120			Adit
842	147	2679 6116			Adit
843	148	2684 6115			Adit
844	149	2688 6112			
845	150	2691 6110			Adit
846	228	2692 6110			Adit. ?Same as No. 845
847	151	2694 6106			Adit
848	129	2701 6147			Adit
849	130	2700 6145			Adit
850	131	2702 6141			Adit
851	132	2700 6139			Adit
852	133	2699 6137		7.32	
853	134	2692 6131			Adit
854	135	2694 6130			Adit
855	136	2682 6135			
856	137	2683 6134			Adit
857	138	2684 6124			Adit
858	139	2689 6127			Adit
859	140	2689 6127			Adit
860		2661 6152			
861		2675 6134			
862		2685 6130			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
865	141	2692 6124			Adit
866	142	2693 6123			Adit
867	143	2694 6120			Adit
868	229	2690 6123			Adit
869	227	2697 6127			Adit
870	113	2964 6315			
871	114	2957 6306			
872	231	2957 6320			
873		2959 6342		73.15	
(Depth may refer to this or next shaft)					
874		2960 6344		73.15	
875	236	2960 6316			
876	232	2925 6332			
877		2920 6301		36.58	
(Depth may refer to this or next shaft)					
878		2920 6300		36.58	
879		2953 6307			
880		2953 6305			
881	111 (253)	2954 6345		?73.15	
882		2943 6311		8.23	
883		2934 6331			
884		2918 6351			
887	112	2942 6340		12.19	
888	110	2942 6350			Adit
889	107	2935 6366			
890	109	2952 6368			
891	101	2926 6391		89.61	Capped
892	103	2958 6395		77.72	
893	104	2959 6394		64.01	
895	69	2901 6397		104.24+	
896	70	2902 6400			Capped
897	71	2915 6393		?73.15	
898	52	2831 6345			
899	53	2838 6328			
900	54	2854 6331			
901	55	2857 6320			
902	56	2863 6337			
903	57	2867 6344			Capped
905	59	2865 6354			
906	60	2874 6356		109.73	Capped
907	61	2875 6360			Capped
908	62	2884 6362			
909	63	2886 6350			
910	64	2886 6350			
911	65	2863 6408			
912	66	2866 6403		196.20	
913	67	2890 6401			
914	68	2893 6399		27.43+	
915	49	2835 6382		100.58+	
916	50	2834 6380			
917	51	2823 6371			
918	105	2895 6377			
919	106	2892 6371			
920	217	2880 6334			
921	279	2820 6350			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
922		2887 6331			
923	32	2721 6383		18.29	Capped
924	34	2730 6383			
925	35	2732 6384			
926	37	2724 6354			Adit
927	38	2742 6392			
928	39	2748 6381			Capped
929	42	2778 6384		19.80	Capped
930	43	2770 6371			
931	44	2771 6321		152.70	
932	45	2770 6309		60.96$^+$	
933	46	2770 6305			
934	220	2755 6367			
935	221	2763 6366			
936	222	2769 6366			
937	223	2771 6356			
938	224	2757 6341			
939		2771 6363			
940	234	2764 6348			
941	271	2748 6334			
942	272	2746 6326			
943	273	2746 6335			
944	274	2745 6334			
945	275	2743 6329			
946	276	2746 6330			
947		2743 6345			
948	19	2703 6467		106.98	
949	20	2705 6469		97.84$^+$	
950	21	2710 6479		73.15$^+$	
951	22	2714 6483		69.49$^+$	
952	23	2730 6496		46.03$^+$	
953	24	2759 6470			
954	25	2746 6464		17.00	
955	26	2739 6439		141.73$^+$	
956	27	2738 6436			Adit
957	28	2725 6424			
958	29	2726 6419		44.20	Capped
959	30	2717 6413			
960	31	2745 6421			
961	40	2771 6412			Capped
962	41	2779 6411			Capped
963	245	2712 6480		?69.49	
964	215	2736 6444			
965	216	2718 6423			
966	47	2830 6429		196.90	Capped
967	72	2883 6486			
968	73	2888 6497		208.48$^+$	
969	74	2891 6499		c 208.48	
970	77	2894 6476			
971	78	2898 6469		?129.84	
972	79	2892 6462			
973	80	2897 6458			
974	75	2915 6490			
975	76	2919 6492			
976	81	2911 6466			Capped

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
977	82	2910 6462		?129.84	
978	96	2919 6434			
979	97	2912 6424			
980	98	2915 6417			Capped
981	99	2940 6426			
982	83	2921 6458			
983		2923 6459			
984	84	2913 6476		54.86+	
985	85 (237)	2936 6467			
986	86	2940 6462		30.00	
987	87	2937 6450			
988	213	2939 6449			
989	214	2941 6449			
990	241	2927 6449			
991	280	2933 6454		18.29	
992	88	2953 6468		77.72+	
993	89	2957 6496		74.98+	
994	91	2957 6466		77.72+	
995	92	2967 6461		20.12	
996	93	2968 6459		6.40	
997	94	2970 6461			
998	95	2970 6460			
999	270	2930 6483			
1000		2776 6436		?64.01	?Borehole
1001	254-269				
(Closely adjacent bell-pits, not individually sited)					
1002		2906 6485			
1003		2916 6487			
1004		2946 6483		?45.72	
1005		2961 6463			
1006		2941 6478		54.86	
1007		2768 6335			
1008	242	2843 6331			
1009		2935 6485		9.14	
1010		2960 6360			
1088	278	?2925 6160		25.60	
1089	281			12.19	Capped
1090	283				
1091	284				
1092	285				
1093	288			14.60	
1094	289				

MAP SJ 27 NW

2	5	2158 7603	25.37	394.11	
69	1	2105 7588			
70	2	2136 7595			
71	3	2137 7594		269.75	
72	4	2140 7590			
74	6	2156 7598		388.16	Capped
75	7	2134 7578		256.03	
76	8	2127 7574			
77	9	2129 7560		63.09	

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
78	10	2132 7551		?292.60	
79	11	2137 7549			
80	12	2123 7542			
81	13	2131 7540		101.50	
82	14	2136 7543			
83	15	2138 7540			
84	16	2136 7538			
85	17	2140 7531			
86	18	2137 7523			
87	19	2131 7519		?64.01	
88	20	2092 7507			Adit
89	21	2089 7505			
90	22	2142 7545			
91	23	2145 7545		?159.10	Capped
92	24	2149 7542			
93	25	2147 7537			
94	26	2154 7540			
95	27	2157 7542			
96	28	2158 7551			
97	29	2161 7562			
98	30	2151 7595		269.70	
99	31	2164 7558		?146.90	
100	32	2168 7560		?147.04	
101	33	2165 7548			
102	34	2166 7543			
103	35	2178 7552			
104	36	2181 7550			
105	37	2173 7531			
106	38	2179 7523			
107	39	2178 7515			Capped
108	40	2184 7512		51.80	
109	41	2197 7522			
110	42	2198 7515		?1.80	?Shaft
111	43	2128 7543			
112	44	2143 7574			?Same as No. 139
113	45	2116 7563			
114	46	2136 7578			?Same as No. 75
115	47	2154 7550			
116	48	2177 7518			
117	49	2181 7518			
118	50	2168 7564			
119	51	2184 7552			
120	52	2215 7521			
121	53	2220 7517			
122	54	2108 7618		82.30	
123	55	2114 7614			
124	56	2131 7619			?Shaft
125	57	2138 7612			?Shaft
126	58	2146 7617			?Shaft
127	59	2135 7596			
128	60	2139 7952			
129	61	2172 7561			
130	62	2103 7456			Adit
131	63	2088 7640			
132	64	2089 7633		27.40	

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
133	65	2106 7617		82.30	
134	66	2143 7552			
135	67	2165 7559			
136	68	2168 7561			
137	69	2190 7589			
138		2094 7508			
139		2145 7576			?Same as No. 112
141		2104 7638		73.15	
142		2106 7636		73.15	
143		2163 7555		97.84	

MAP SJ 27 SW

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
4	36	2352 7321		201.52	
5	34	2328 7323		?110.00	
279		2320 7336		?70.00	
282	55	2361 7322			
343	35	2329 7313		246.89	Capped
344	24	2271 7320		45.72	
345	57	2361 7318			
346	37	2413 7343		79.55	
354	21	2326 7426		154.50	Drilled to 156.20
356	22	2329 7423		187.50	Drilled to 189.00
358	1	2158 7482		48.77	
359	2	2173 7488			
360	3	2200 7469			
361	4	2200 7466			
362	5	2220 7479		128.02	
363	6	2222 7470		95.10	
364	7	2238 7478			
365	8	2248 7471			
366	9	2247 7469		?128.63	Capped
367	10	2248 7467		?128.63	
368	11	2210 7452		97.84	?Same as No. 369
369	12	2213 7452			?Same as No. 368
370	13	2223 7447			
371	14	2207 7442			?Same as No. 372
372	15	2209 7443		75.90	?Same as No. 371
373	16	2210 7430			
374	17	2250 7443			
375	18	2245 7438			
376	19	2262 7426			
377	20	2259 7422			
378	23	2189 7400		7.62	
379A	25	2267 7295			
379B	26	2267 7292			
379C	27	2272 7300			
379D	28	2274 7302			
379E	29	2277 7300			Capped
379F	30	2283 7300			
379G		2278 7297			
379H		2277 7295			
380	31	2290 7306			
381	32	2301 7303			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
382	33	2287 7384			
383	38	2424 7345			
384	39	2426 7344		246.89	
385	40	2413 7337			
386	41	2433 7333			
387	42	2415 7328			
388	43	2408 7316			
389	44	2418 7290		114.30	
390	45	2409 7266		117.04	
391	46	2404 7261			
392	47	2396 7249		112.00	
393	48	2420 7239		130.15	
394	49	2386 7230			
395	50	2385 7226			
396	51	2464 7242		?18.28	
397	52	2479 7240		?18.28	
398	53	2412 7164		149.96	
399	54	2492 7169		?54.86	
400	56	2410 7268		100.58	
401	58	2389 7212			
402	59	2395 7265			
403	60	2429 7271			
404	61	2474 7236		c 15.24	
405	62	2276 7265			
406	63	2207 7422			
407	64	2176 7442			
408	65	2250 7443			Same as No. 374
409	66	2424 7227		6.71	Capped
410	67				
411	68	2417 7288			
421		2211 7305			
422		2075 7436			Adit
423		2191 7405		3.05	
426		2129 7260			
427		2116 7216			
428		2135 7219			
429		2140 7219			
430		2144 7220			
431		2197 7199			
432		2212 7189			
433		2214 7187			
434		2243 7100			
438		2207 7194			
439		2210 7194			
440		2290 7120			Adit
442		2290 7223			

MAP SJ 27 SE

179	2	2667 7142		?54.86	
180	3	2621 7141			
181	4	2622 7119			
182	5	2625 7105			
183	6	2621 7088			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
184	7	2592 7027			
185	8	2587 7025			
186	9	2591 7024			
187	10	2839 7010			
188	11	2845 7000		30.48	Drilled to 31.09. Capped
189	12	2753 7008			
190	13	2753 7004			
191	14	2753 7002			
192	15	2669 7139			
193	16	2617 7117			
194	17	2618 7124			
195	18	2621 7123			
196	19	2624 7121			
197	20	2621 7095			
198	21	2622 7094			
199	22	2620 7092			
200	23	2622 7092			
201	24	2629 7089			
202	25	2632 7090			
203	26	2630 7087			
204	27	2632 7088			
205	28	2628 7084			
206	29	2628 7082			
207	30	2620 7090			
208	31	2592 7023			
209	32	2681 7105			Adit
210	33				
248		2619 7119			
249		2628 7095		c 9.12	
250		2630 7086			
251		2751 7003			

MAP SJ 36 NW

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
16	1	3128 6846	?24.82	88.06	Capped
17	2	3113 6845	?12.80	92.91	
18	3	3181 6778	26.31	153.62	
19	6	3165 6740	7.95	161.09	
41	32	3323 6566	39.62	145.47	
77	7	3192 6720	?10.06	94.06	
171	23	3240 6614			
172	38	3201 6636			
173	21	3205 6647		8.53	?94.18 m deep
174	22	3205 6644		66.00	?94.18 m deep. Capped
179	50	3167 6636		7.62+	
184	24	3004 6570			Capped
185	25	3005 6569			Capped
186	26	3030 6563			Capped
187	27	3046 6567			Capped
188	28	3058 6570			Capped
189	29	3067 6571			Capped
190	49	3069 6571			
191	39	3083 6565			

BGS No.	British Coal No.	Grid Reference	Drift thickness	Depth	Comments
192	30	3084 6564			
193	31	3087 6563			
194		3088 6562			?Shaft
195		3091 6560			Adit
208	4	3178 6774		156.36	
209	?5	3166 6741		91.49	
210	36	3167 6739			
211	33	3172 6764		36.58^+	
212	34	3165 6760		82.30^+	
213	35	3165 6758		54.86	
214	8	3185 6715			
215	9	3129 6699		95.10^+	Capped
216	10	3135 6697		92.35^+	Capped
217	47	3184 6728			
218	48	3182 6727			
220	40	3117 6748			
221	46	3188 6702			
222	11	3170 6696			
223	37	3171 6695			
224	12	3184 6689		30.33	
225	13	3183 6688		30.33	
226	14	3178 6681		34.75	
227	17	3175 6676		30.33	
228	15	3170 6682		15.24^+	
229	16	3172 6681		18.90^+	
230	18	3182 6674		36.58	
231	19	3181 6672		34.14	
232	20	3178 6670		25.60	
234		3132 6813			
235	41	3120 6807			
236		3124 6801			
237		3126 6797			
238	45	3142 6805			
239		3139 6799			
240	44	3143 6800			
241	42	3122 6807			
242	43	3123 6802			

MAP SJ 36 SW

38	1	3012 6485		19.20	Bored deeper

APPENDIX E

List of shafts and adits identified as being open at surface, at the time of survey (1985-87)

(All sites are shafts unless otherwise stated).

N.B. These are subjective assessments made at the time of survey; fencing/capping may have changed subsequently.

	Comments
SJ 1756 7634	
1765 7622	
1721 7574	
1704 7568	
1721 7567	
1724 7566	
1741 7560	
1730 7553	
1739 7543	
1794 7559	
1793 7545	
1809 7542	
1853 7542	
1878 7517	
1767 7526	Surrounded by double wire fence; beside golf course
1737 7482	Inadequate capping; wire fence surround; on golf course
1771 7437	Surrounded by double wire fence; actively collapsing
1877 7367	Wire fence surround; on common land
1871 7354	Inadequate capping; on common land
1863 7359	Inadequate capping; wire fence surround; on common land
1841 7345	Open?; stone-walled shaft

1915 7334	Surrounded by double wire fence; actively collapsing
1910 7316	Surrounded by double wire fence; actively collapsing
1938 7306	
1871 7294	Deep; very poorly fenced off; on common land
1876 7297	
1883 7296	High wire fence surround; on common land
1822 7238	
1820 7237	
1928 7199	Stone-walled shaft; on common land
1925 7164	Covered with rusting car door; adjacent to footpath on common land
1943 7154	Wire fence surround; actively collapsing; on common land
1864 6993	
1865 6918	Wire fence surround
1893 6927	Covered with sheet of corrugated iron
2002 6965	On common land
1999 6918	Poorly fenced off; on common land
2075 6939	Wire fence surround; on common land
2103 6929	Wire fence surround; on common land
2120 6925	On common land
1941 6886	Poorly fenced off
1960 6884	?Open
1867 6888	Wire fence surround
1907 6870	Wire fence surround
1952 6886	?Open
1930 6776	Overgrown
2069 6764	Adit; partly sealed
2070 6766	Wire fence surround
2181 6700	Deep

2005 6687	Actively collapsing
2010 6682	to 2022 6688 Several shafts
1967 6743	Deep collapse structure
1966 6724	
1912 6736	
1909 6732	
1906 6710	to 1932 6712 Several shafts
1877 6653	
1874 6644	
1900 6646	to 1912 6645 Several shafts
1890 6632	to 1928 6641 Several shafts
1898 6560	to 1912 6562 Several shafts
2055 6507	Flooded at depth
2011 6488	
1895 6448	
1893 6444	
1959 6465	
1967 6468	
1974 6402	Several shafts
1910 6364	
1905 6363	Two adits
1978 6310	to 1998 6299 Several shafts
2156 6228	
2211 6242	
2178 6126	
2200 6099	
2101 6088	
2086 6067	

APPENDIX F

Logs of boreholes sunk as part of the project to prove sand and gravel resources, with derived particle size data

Numbers are those of the BGS 1:10 000 record system
Figures preceded by + are levels in metres above Ordnance Datum

<u>SJ 17 NE/67</u> <u>1995 7649</u> <u>Bagillt Hall Farm</u>

Surface level c + 56	Thickness (m)	Depth (m)
TOPSOIL/SLOPE WASH	0.30	0.30
TILL (BOULDER CLAY)		
Variegated, greenish yellow to orange-brown firm silty clay with abundant pebbles and cobbles of sandstone, sandy in places; gradual colour change at base SPT at 3.0-3.5 m (64 blows)	3.70	4.00
COAL MEASURES (Weathered)		
Dark bluish grey stiff silty clay with abundant fragments of dark mudstone and shale	1.00	5.00

<u>SJ 17 SE/103</u> <u>1778 7453</u> <u>Brynford</u>

Surface level c + 226		
MADE GROUND		
Tipped rubbish, stones, ashes etc	0.80	0.80
HEAD		
Yellow-grey silty clay with numerous fragments of limestone and chert	3.10	3.90
CEFN MAWR LIMESTONE		
Fragments of limestone (no penetration)		

<u>SJ 27 NW/8</u> <u>2070 7557</u> <u>Tyn-Twll Farm</u>

Surface level c + 67		
TOPSOIL	0.30	0.30

	Thickness (m)	Depth (m)
TILL (BOULDER CLAY)		
Dark brown to reddish brown and yellow sandy, silty, poorly sorted firm clays with scattered pebbles and fragments of sandstones, coals etc	6.20	6.50
SPT at 3.0-3.5 m (15 blows)		
4.5-5.0 m (9 blows)		
passes down into		
Gravelly sandy clay with occasional large boulders	2.80	9.30
SPT at 7.5-8.0 m (24 blows)		
Bluish grey clay with quartz pebbles and sandstone fragments gradationally passing down into		
SPT at 10.3-10.8 m (67 blows)	2.10	11.40
COAL MEASURES (Weathered)		
Bluish grey pebbly clay with abundant dark grey mudstone fragments	0.60	12.00

SJ 27 SW/246A 2163 7361 Fferm No 1

Surface level c + 108

	Thickness (m)	Depth (m)
TOPSOIL	0.30	0.30
?HEAD		
Dark brown to yellowish grey mottled silty clay with occasional pebbles	0.30	0.60
TILL (BOULDER CLAY)		
Dark reddish brown and orange-yellow firm silty clay with abundant rounded pebbles and cobbles of sandstone and coal fragments	5.60	6.20
Dark grey to brown gravelly clay with occasional lenses of gravelly sands and silty sands (0.2-0.3 m thick)	1.60	7.80
SPT at 7.3-7.5 m (50 blows)		
Borehole terminated at obstruction		

SJ 27 SW/246B 2163 7361 Fferm No 2

Borehole resited 1 m SW of SJ 27 SW/246A
Surface level c + 108

	Thickness (m)	Depth (m)
TOPSOIL	0.30	0.30
?HEAD		
Dark brown silty clay with occasional pebbles	0.20	0.50

		Thickness (m)	Depth (m)
TILL (BOULDER CLAY)			
	Dark reddish brown to yellowish green variegated silty and sandy firm clay with abundant pebbles and cobbles of sandstones, igneous and metamorphic lithologies	6.30	6.80
	Coarse gravel, poorly sorted, with occasional pockets of clayey sand passing down into fine gravel passing down into	0.90	7.70
COAL MEASURES (Weathered)			
	Dark grey silty clay with fragments of dark grey mudstone	0.50	8.20

<u>SJ 27 SW/247</u> <u>2377 7105</u> <u>Plas-y-Mynydd</u>

Surface level c + 67

		Thickness (m)	Depth (m)
TOPSOIL			
	Pale brown sandy clay with roots	0.25	0.25
TILL (BOULDER CLAY)			
	Dark reddish brown to yellowish green variegated sandy clay with pebbles and abundant sandstone fragments	1.15	1.40
	Grey and brown gravelly to sandy clay; large cobbles up to 10 cm, occasional thin lenses of sand SPT at 1.5-2.0 m (19 blows) 4.5-5.0 m (24 blows)	4.25	5.40
GLACIAL SAND AND GRAVEL			
a	Clayey to very clayey sand, medium brown to brown, with gravel lenses and thin beds of laminated fine sand with organic traces	2.55	7.95
	Clean dark brown sand with peaty traces	1.05	9.00
	Clayey sand with gravelly lenses SPT at 6.5- 7.0 m (17 blows) 8.0- 8.5 m (23 blows) 9.5-10.0 m (28 blows)	1.80	10.80
b	Clayey to very clayey fine to coarse sands, medium brown; bedding defined by thin peaty laminae and streaks SPT at 11.0-11.5 m (25 blows) 12.5-13.0 m (31 blows) 14.0-14.5 m (45 blows) 15.5-16.0 m (32 blows)	5.20	16.00
	Clayey to very clayey fine to coarse sand as above, but with numerous sandy clay beds SPT at 17.0-17.5 m (31 blows) 18.5-19.0 m (30 blows) 20.0-20.5 m (51 blows) 21.5-22.0 m (30 blows)	9.00	25.00

Particle size analysis results

Mean for deposit percentages				Depth below surface (m)	Percentages						
	Fines	Sand	Gravel		Fines	Sand		Gravel			
					-1/16	+1/16 -1/4	+1/4 -1	+1 -4	+4 -16	+16 -64	+64 mm
a	20	74	6	5.5- 6.5	21	17	42	5	7	8	0
				6.5- 7.5	22	14	61	3	0	0	0
				7.5- 8.5	20	25	47	5	2	1	0
				8.5- 9.5	21	29	48	2	0	0	0
				9.5-10.0	15	9	42	14	13	7	0
				Mean	20	20	49	5	3	3	0
b	20	80	0	11.0-11.5	18	11	61	10	0	0	0
				11.5-12.0	20	11	58	9	2	0	0
				12.5-13.0	25	21	53	1	0	0	0
				14.0-14.5	26	36	38	0	0	0	0
				14.5-15.0	18	34	47	1	0	0	0
				15.5-16.0	11	33	56	0	0	0	0
				Mean	20	24	52	4	0	0	0
a+ b	20	77	3	Mean	20	22	51	4	2	1	0

	Thickness (m)	Depth (m)
SJ 27 SW/248 2267 7312 April Rise Farm		
Surface level + 84		
?MADE GROUND		
Dark brown to orange-brown clay, ? disturbed	0.40	0.40
TILL (BOULDER CLAY)		
Dark orange and brown clay with abundant pebbles and fragments of sandstone, coaly streaks	2.60	3.00
Pale yellow and brown sandy clay with occasional gravelly lenses SPT 2.0- 2.5 m (13 blows) 4.5- 5.0 m (51 blows)	2.50	5.50
GLACIAL SAND AND GRAVEL		
a Dark brown quartzose sand, clayey in places with gravel lenses and scattered pebbles	2.10	7.60
Well-sorted, bedded, yellow-brown sand SPT at 6.5- 7.0 m (45 blows) 8.0- 8.5 m (36 blows) 9.5-10.0 m (49 blows)	2.20	9.80
b Dark brown clayey and sandy gravel, dense in lower part SPT at 11.0-11.5 m (121 blows) 12.5-13.0 m (99 blows) 14.0-14.5 m (76 blows)	6.90	16.70
c Fine, well-sorted sand passes down into clayey sand (0.3 m at 17.5 m), passes down to yellowish brown medium-fine grained sand with thin clay beds SPT at 17.0-17.5 m (62 blows) 18.5-19.0 m (69 blows) 20.5-21.0 m (40 blows)	6.30	23.00
?LACUSTRINE DEPOSITS		
Laminated reddish brown and yellowish brown sandy and silty clays passing down into greyish brown laminated clay. Laminae defined by thin pale sandy beds up to 0.5 cm thick, occasional small pebbles and possibly shell fragments	2.00	25.00

Particle size analysis results

	Mean for deposit percentages			Depth below surface (m)	Percentages						
	Fines	Sand	Gravel		Fines	Sand		Gravel			
					-1/16	+1/16 -1/4	+1/4 -1	+1 -4	+4 -16	+16 -64	+64 mm
a	12	81	7	5.5- 6.0	10	10	39	19	12	10	0
				7.5- 8.0	13	18	51	8	6	4	0
				8.0- 8.5	13	31	54	2	0	0	0
				9.0- 9.5	10	23	63	3	1	0	0
				9.5-10.0	12	31	47	5	3	2	0
				Mean	12	23	51	7	4	3	0
b	7	45	48	10.5-11.0	9	20	24	12	25	10	0
				11.0-11.5	10	8	17	14	29	22	0
				12.0-12.5	9	8	27	15	28	13	0
				13.5-14.0	11	7	18	16	35	13	0
				15.0-16.0	1	1	17	26	31	24	0
				Mean	7	7	20	18	30	18	0
c	11	89	0	17.0-17.5	9	62	28	1	0	0	0
				18.5-19.0	12	60	28	0	0	0	0
				19.5-20.0	4	25	67	2	1	1	0
				20.5-21.0	15	51	34	0	0	0	0
				21.0-21.5	14	65	21	0	0	0	0
				22.0-22.5	15	82	3	0	0	0	0
				Mean	11	58	30	1	0	0	0
a+ b+ c	10	71	19	Mean	10	30	32	9	12	7	0

SJ 27 SW/249	2495 7057	Troes-y-Mynydd	Thickness (m)	Depth (m)

Surface level c + 69

	Thickness (m)	Depth (m)
HEAD		
Dark brown silty clay	0.30	0.30
TILL (BOULDER CLAY)		
Dark reddish brown clayey sands and stiff silty clay with abundant pebbles and cobbles SPT at 3.0-3.5 m (34 blows) 5.0-5.5 m (63 blows)	5.10	5.10
GLACIAL SAND AND GRAVEL		
Dark reddish brown clayey sand passing down into well-sorted clean orange to reddish brown sand SPT at 6.5- 7.0 m (81 blows) 8.0- 8.5 m (74 blows)	4.10	9.50
TILL (BOULDER CLAY)		
Darks brown very clayey sand and gravel passing down rapidly into firm stony clay Borehole terminated at obstruction SPT at 9.5-10.0 (71 blows) 11.0 (failed)	1.70	11.20

Particle size analysis

Mean for deposit percentages			Depth below surface (m)	Percentages						
Fines	Sand	Gravel		Fines	Sand		Gravel			
				-1/16	+1/16 -1/4	+1/4 -1	+1 -4	+4 -16	+16 -64	+64 mm
14	86	0	5.5-6.0	20	64	14	1	1	0	0
			6.5-7.0	11	69	20	0	0	0	0
			7.0-7.5	13	49	38	0	0	0	0
			8.0-8.5	13	68	19	0	0	0	0
			8.5-9.0	10	65	25	0	0	0	0
			Mean	14	63	23	0	0	0	0

	Thickness (m)	Depth (m)
<u>SJ 27 SW/250</u> <u>2169 7060</u> <u>Penfro</u>		
Surface level c + 183		
HEAD		
Top soil and thin clayey wash	0.40	0.40
TILL (BOULDER CLAY)		
Firm yellow to greyish brown clay with coal and dark shale fragments, sandy in places	1.80	2.20
HALKYN FORMATION (Weathered)		
Light grey mudstone	1.00	3.20
<u>SJ 27 SW/251</u> <u>2073 7235</u> <u>Pistyll Farm No 1</u>		
Surface level c + 167		
TOPSOIL	0.30	0.30
HEAD		
Light brown to yellow-brown sandy clay with pebbles	0.60	0.90
TILL (BOULDER CLAY)		
Reddish brown stony clay with Coal Measures mudstone pebbles	1.50	2.40
Dark greyish brown stiff clay, gravelly and pebbly near base SPT at 3.5- 4.0 m (16 blows)	3.10	5.50
GLACIAL SAND AND GRAVEL		
Reddish brown and greyish brown clayey to very clayey silty sand and gravel, bedding defined by thin carbonaceous laminae SPT at 6.0- 6.5 m (26 blows) 7.5- 8.0 m (13 blows) 9.0- 9.5 m (22 blows)	4.00	9.50
TILL (BOULDER CLAY)		
Greyish brown pebbly clay, very stiff Borehole terminated at obstruction SPT at 10.5-11.0 m (15 blows)	2.50	12.00

Particle size analysis results

Mean for deposit percentages			Depth below surface (m)	Percentages						
Fines	Sand	Gravel		Fines	Sand			Gravel		
				-1/16	+1/16 -1/4	+1/4 -1	+1 -4	+4 -16	+16 -64	+64 mm
19	73	8	6.0-6.5	17	8	33	16	19	7	0
			7.5-8.0	24	74	2	0	0	0	0
			8.5-9.0	25	62	10	1	1	1	0
			9.0-9.5	9	45	35	6	5	0	0
			Mean	19	47	20	6	6	2	0

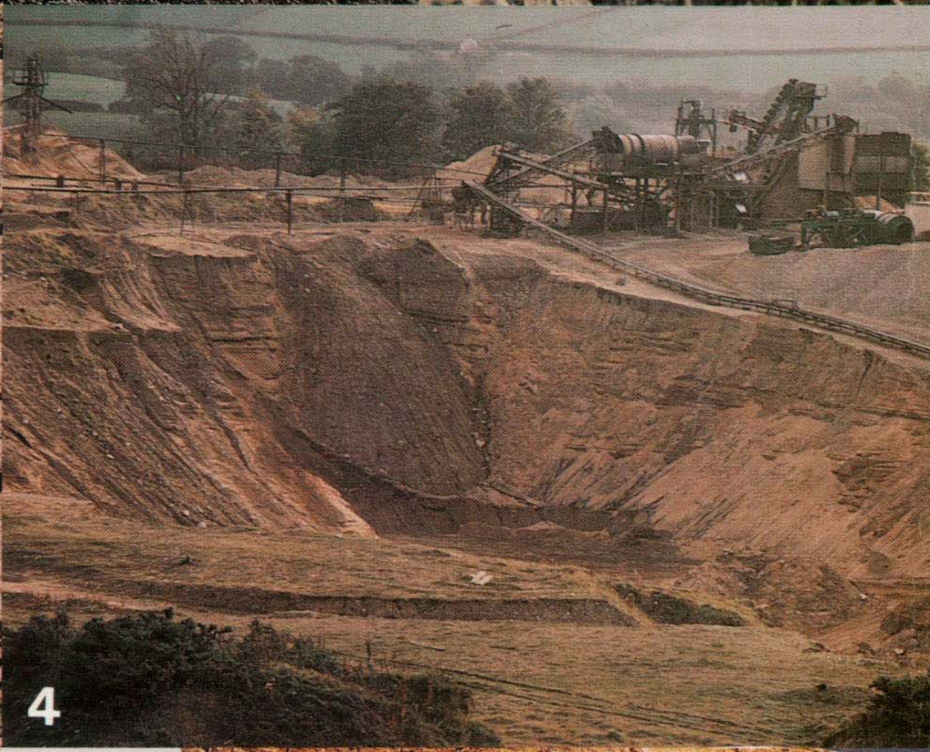
SJ 27 SW/252 2039 7322 Pistyll Farm No 2	Thickness (m)	Depth (m)
Surface level c + 172		
TOPSOIL	0.30	0.30
TILL (BOULDER CLAY)		
Dark to pale brown pebbly clay with lenses of gravelly, sandy clay	2.50	2.80
Sandy stony clay passing into a thin bed of wet brown sand	0.80	3.60
SPT at 3.0-3.5 m (21 blows)		
Stiff greyish brown clay with abundant cobbles and large pebbles	4.00	7.60
HALKYN FORMATION (Weathered)		
Dark grey clay with mudstone fragments and coal fragments	1.20	8.80

	Thickness (m)	Depth (m)
SJ 27 SE/177 2545 7072 Leadbrook Hall Farm		
Surface level c + 57		
MADE GROUND		
Reddish brown clayey sand with occasional pebbles SPT at 2.0-2.5 m (6 blows)		
TILL (BOULDER CLAY)		
Dark reddish brown stony clay with lenses of clayey sand and gravel	12.10	17.10
Borehole terminated due to difficult penetration		


1


2


3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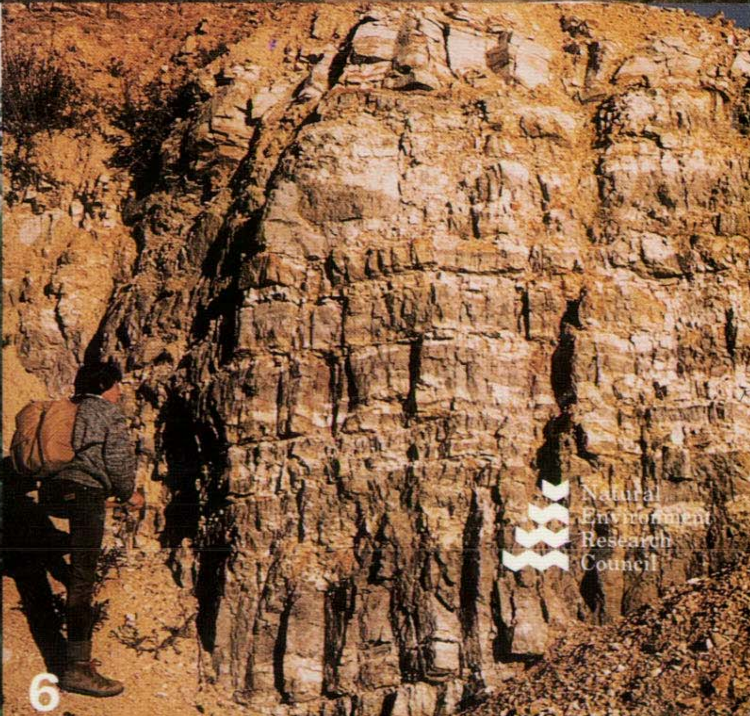
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