TECHNICAL REPORT WA/90/3

A geological basis for land-use planning: Garforth–Castleford–Pontefract

W J Barclay, R A Ellison and K J Northmore

Contributor R A Monkhouse

Results of a survey commissioned by the Minerals and Land Reclamation Division, Department of the Environment

BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WA/90/3

Onshore Geology Series

A geological basis for land-use planning: Garforth–Castleford– Pontefract

1:10 000 sheets SE42 NW, NE, SW, SE, SE43 SW, and SE52 SW

Parts of 1:50 000 geological sheets 70 (Leeds) and 78 (Wakefield)

W J Barclay, R A Ellison and K J Northmore

Contributor

R A Monkhouse

Cover illustration

Prince of Wales Colliery and Cornwall Opencast Site, Pontefract, West Yorkshire (*British Coal*)

This study was commissioned by the Department of the Environment, but the views expressed in it are not necessarily those of the Department

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

Geographical index

UK, England, West Yorkshire, North Yorkshire

Subject index

Land-use planning, mineral resources, geological constraints, thematic maps, Carboniferous and Permian rocks, Quaternary superficial rocks, engineering geology, hydrogeology

Bibliographic reference

Barclay, W J, Ellison, R A, and Northmore, K J. 1990. A geological basis for land-use planning: Garforth–Castleford–Pontefract. *British Geological Survey Technical Report* WA/90/3

Keyworth, Nottingham British Geological Survey 1990

BRITISH GEOLOGICAL SURVEY

The full range of Survey publications is available through the Sales Desks at Keyworth and at Murchison House, Edinburgh, and in the BGS London Information Office in the Natural History Museum Earth Galleries. The adjacent 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.

Keyworth, Nottingham NG12 5GG

☎ Plumtree (06077) 6111 Telex 378173 BGSKEY G
Fax 06077–6602

Murchison House, West Mains Road, Edinburgh EH9 3LA

☎ 031–667 1000 Telex 727343 SEISED G
Fax 031–668 2683

London Information Office at the Natural History Museum Earth Galleries, Exhibition Road, South Kensington, London SW7 2DE

☎ 071–589 4090 Fax 071–584 8270
☎ 071–938 9056/57

19 Grange Terrace, Edinburgh EH9 2LF

☎ 031–667 1000 Telex 727343 SEISED G

St Just, 30 Pennsylvania Road, Exeter EX4 6BX

☎ Exeter (0392) 78312 Fax 0392–437505

Bryn Eithyn Hall, Llanfarian, Aberystwyth, Dyfed SY23 4BY

☎ Aberystwyth (0970) 611038 Fax 0970–624822

Windsor Court, Windsor Terrace, Newcastle upon Tyne NE2 4HB

☎ 091–281 7088 Fax 091–281 9016

Geological Survey of Northern Ireland, 20 College Gardens, Belfast BT9 6BS

☎ Belfast (0232) 666595 Fax 0232–662835

Maclean Building, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB

☎ Wallingford (0491) 38800 Telex 849365 HYDROL G
Fax 0491–25338

Parent Body

Natural Environment Research Council

Polaris House, North Star Avenue, Swindon, Wiltshire SN2 1EU

☎ Swindon (0793) 411500 Telex 444293 ENVRE G
Fax 0793–411501

Printed in England for the British Geological Survey by the Campfield Press, St Albans, Hertfordshire

PREFACE

This report describes the geology of the area south-east of Leeds covered by the Ordnance Survey 1:10 000 maps SE 42SW, SE, NE, 43NW and 52SW, and discusses its application in terms of land-use planning and development. The area is included in the 1:50 000 Leeds (70) and Wakefield (78) geological sheets. It was first surveyed at the 1:10 560 scale by W T Aveline, J R Dakyns, A H Green, T V Holmes, R Russell and J C Ward, and the maps published in 1875 and 1878. It was resurveyed between 1931 and 1934 by W Edwards.

The present study was commissioned in 1987 by the Department of the Environment, in a contract jointly funded with the British Geological Survey, to provide an up-to-date geological database. Field mapping at the 1:10 000 scale was carried out by Mr W J Barclay (SE 52SW), Mr R A Ellison (SE 42SW, SE; 43SW) and Dr M J C Nutt (SE 42NE). The results of a resurvey of Sheet SE 42NW in 1986 by Mr J R A Giles are incorporated in this report in order to square off the study area and allow more coherent coverage. The engineering geology study was carried out by Mr K J Northmore, and a hydrogeological contribution provided by Mr R A Monkhouse. The project leader was W J Barclay, the programme manager Dr A J Wadge and the Department of the Environment nominated officer Dr B R Marker.

The willing cooperation of landowners, tenants and quarry companies in allowing access is gratefully acknowledged. We are also grateful to all the holders of data for allowing us to transfer them into the National Geosciences Data Centre. We are especially grateful to British Coal Deep Mines, North Yorkshire Area for provision of borehole data and seam mine plans, to the Mines Records Office, formerly at Rawmarsh, for allowing us to photograph abandoned mine plans, and to the Opencast Executive for access to exploration data. We acknowledge the assistance provided by the officers of Wakefield Metropolitan District Council, by Dr I.J.Brown, Minerals Officer of Leeds City Council, by Mr M W Gallagher, Leeds Mineral Valuer, and by the HETS Materials Laboratory, Ossett. We also acknowledge the assistance provided by many organisations, including the Yorkshire Water Authority, the Central Electricity Generating Board, the British Waterways Board, Norwest Holst Soil Engineering Ltd., Ground Engineering Northern Ltd., Soil Mechanics Associates and Rendell Palmer and Tritton.

F G Larminie, OBE

Director, British Geological Survey
Keyworth
Nottingham
NG12 5GG

September 1989

Notes to users

This report is divided into two sections. The first describes the study area, and discusses planning considerations in relation to the geology. This is done mainly in the context of the description of fourteen thematic maps which accompany the report, each highlighting a specific aspect of the geology relevant to planning land-use and development. It is presented in a form that requires little or no geological knowledge. The second section contains appendices describing the geology, engineering geology and hydrogeology of the area, and is intended mainly for those with specialised geological knowledge.

There is considerable variation in the quality and reliability of the source data used to compile this report and the accompanying thematic maps, as well as great disparity in the density of site investigation data within the study area. Therefore the accuracy and reliability of the interpreted information reflects that of the source data. However, emphasis has has been placed throughout on the most reliable data, particularly those derived from authoritative sources such as geotechnical engineers and geologists.

Sheets SE 42SW, SE, NE, and 52SW were surveyed from 1987 to 1988, Sheet SE 43SW in 1989. The results of an earlier study of Sheet SE 42NW are incorporated into this report. No information made available after the completion dates of the surveys has been used in its compilation, and thus the report and maps are to be regarded as the *best interpretation of the information available at the time of the surveys. They should be used for preliminary studies only and are not intended as a substitute for on-site investigations or local searches.* The responsibility for assuring that geological, geotechnical and mineral resource data for any given site are as indicated on the maps and in the figures and text of this report must remain solely that of the user.

The possibility of undetected anomalous site conditions should always be anticipated. The indicated occurrence of mineral deposits does not imply an economic resource. The possible presence of unmapped superficial deposits and made ground of variable thickness, particularly within the urban areas, should also be taken into account when formulating development proposals.

There is no substitute for the knowledge provided by a detailed site investigation that takes into consideration the extent, nature and location of a proposed development. Therefore the report and maps are primarily intended to give guidance on when to seek specialist advice, and to aid developers in formulating effective investigations. The statutory authorities with responsibilities for planning and development should always be consulted at the earliest stage. A list of these authorities, including those concerned with waste disposal, coal extraction and water is given in Appendix 4.

All National Grid references in the report lie within the 100 km square SE. Grid references are given to either eight figures (accurate to within 10 m), or six figures for more extensive locations. Each borehole or shaft registered in the BGS National Geosciences Data Centre is identified by a four-element code (e.g. SE 42SW/10), in which the Ordnance Survey sheet on which the borehole or shaft lies is followed by the registration number. Data used in preparing this report and associated maps are lodged at the British Geolocical Survey, Keyworth. Any enquiries concerning these, or about the purchase of the report or maps should be directed to the National Geosciences Data Centre, British Geological Survey, Keyworth, Nottingham NG12 5GG.

CONTENTS

FIGURES

TABLES

PLATES

EXECUTIVE SUMMARY

This report describes a study of the Garforth – Castleford – Pontefract area commissioned by the Department of the Environment and jointly funded by the Department and the British Geological Survey.

The aims of the study were to compile and collate a geological database, and to present the results in terms of their application to land use planning and development as a foundation for:

a. land-use planning for development and redevelopment,

b. safeguarding of mineral resources, and

c. effective future geological research

The study area comprises an area of 150 sq.km. to the south-east of the city of Leeds, Yorkshire. It is covered by the Ordnance Survey 1:10 000-scale maps SE 42SW, SE, NW, NE, 43SW, and 52SW. The sheet SE 42NW was included in a previous study (Giles, 1988), but is included here to square off the map area.

The results of the study are presented as a series of maps and reports. Detailed 1:10 000 geological maps are available as uncoloured dye-line copies A from BGS, Keyworth. Unpublished open file reports (p.00) describe the geology of each of the maps and include local details.

The present report contains fourteen thematic maps which highlight specific aspects of the geology that are relevant to land use planning. Twelve at 1:25 000 scale cover the following topics: bedrock geology; superficial (drift) deposits; made ground; engineering geology of the solid rocks; engineering geology of the superficial deposits; geomorphology; hydrogeology; shallow mining; deep mining; mineral resources and workings – solid rocks; mineral resources and workings – superficial deposits; and distribution of the Coal Measures below the Permo-Triassic rocks. Two maps at 1:10 000 scale present data on the Basal Permian Sand and its workings in the Castleford – Pontefract and Garforth areas.

The first part of this report is aimed for the non-geologist, and is written as far as possible in non-technical terms. It highlights the main geologically related problems and constraints which planners, developers, architects and builders need to be aware of when planning land use and development. Such constraints include natural factors such as dissolution and related subsidence of limestones and gypsum, the presence of buried channels and bedrock hollows, geological faults, natural slope failure and seismic risk. The problems related to human activity include ground stability and subsidence problems caused by coal and sand mining, the disposal of mining, industrial and domestic waste, and groundwater pollution. Also discussed are the problems that engineers need to be aware of when planning site investigations and foundation design in ground underlain by mudrocks, laminated clays and soft ground.

The report describes the mineral resources of the study area, so that balanced planning decisions can be made between sterilising finite reserves by development or waste disposal and preserving them for possible future extraction. The groundwater resources of the area are discussed in terms of their areas of infiltration from the surface and flow direction, so that proposals for development of land or waste disposal can be assessed in terms of the need to avoid or minimise water pollution.

Explanatory accounts of each thematic map are given.

The second part of the report is aimed at the specialist, and comprises appendices on the geology, engineering geology and hydrogeology of the study area. A list of authorities and principal data sources is also appended.

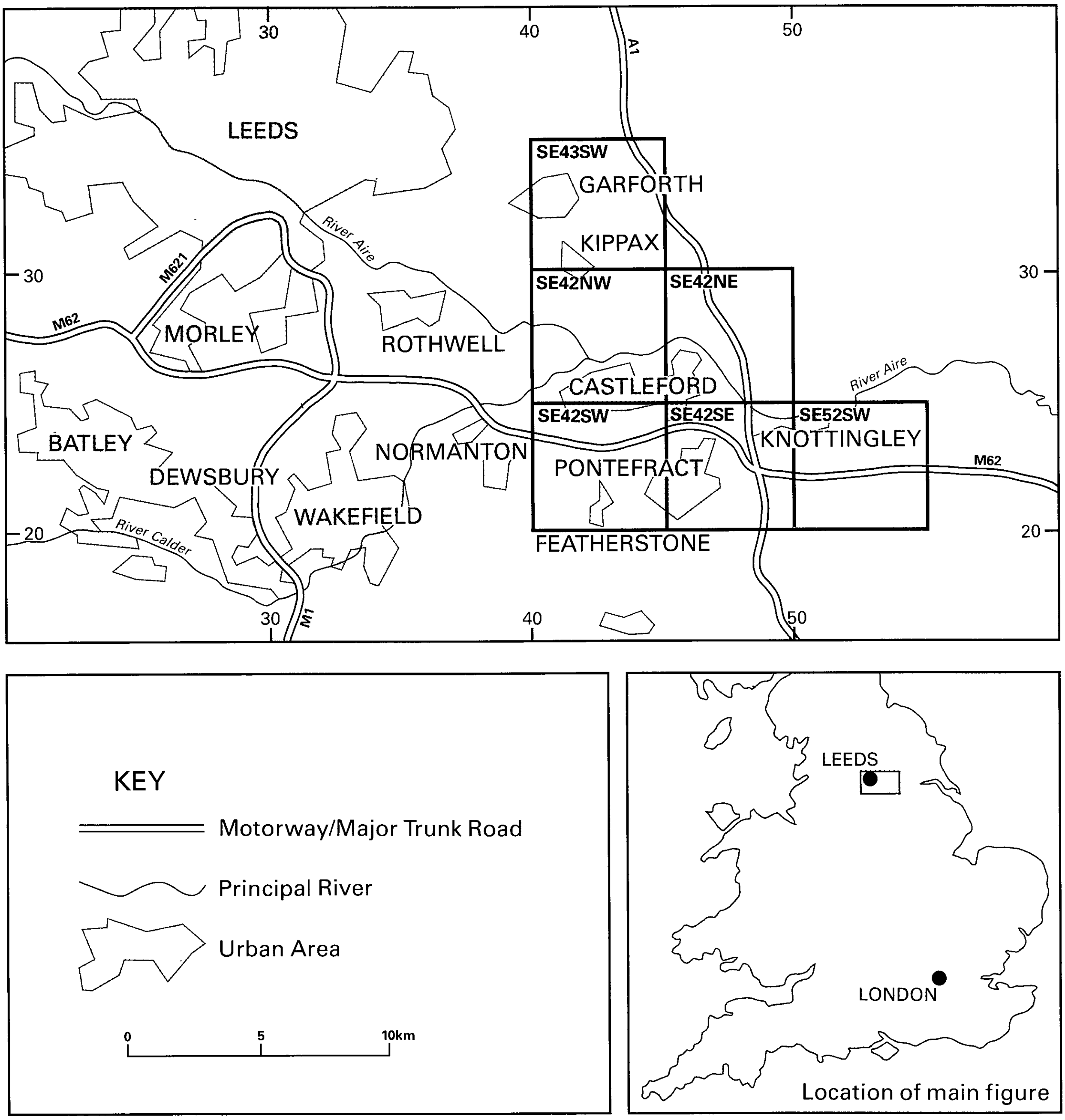


Figure 1 Sketch map showing location of the study area

Map based on the 1:50 000 Landranger Series of the Ordnance Survey of Great Britain, part of sheet 105, dated 1986

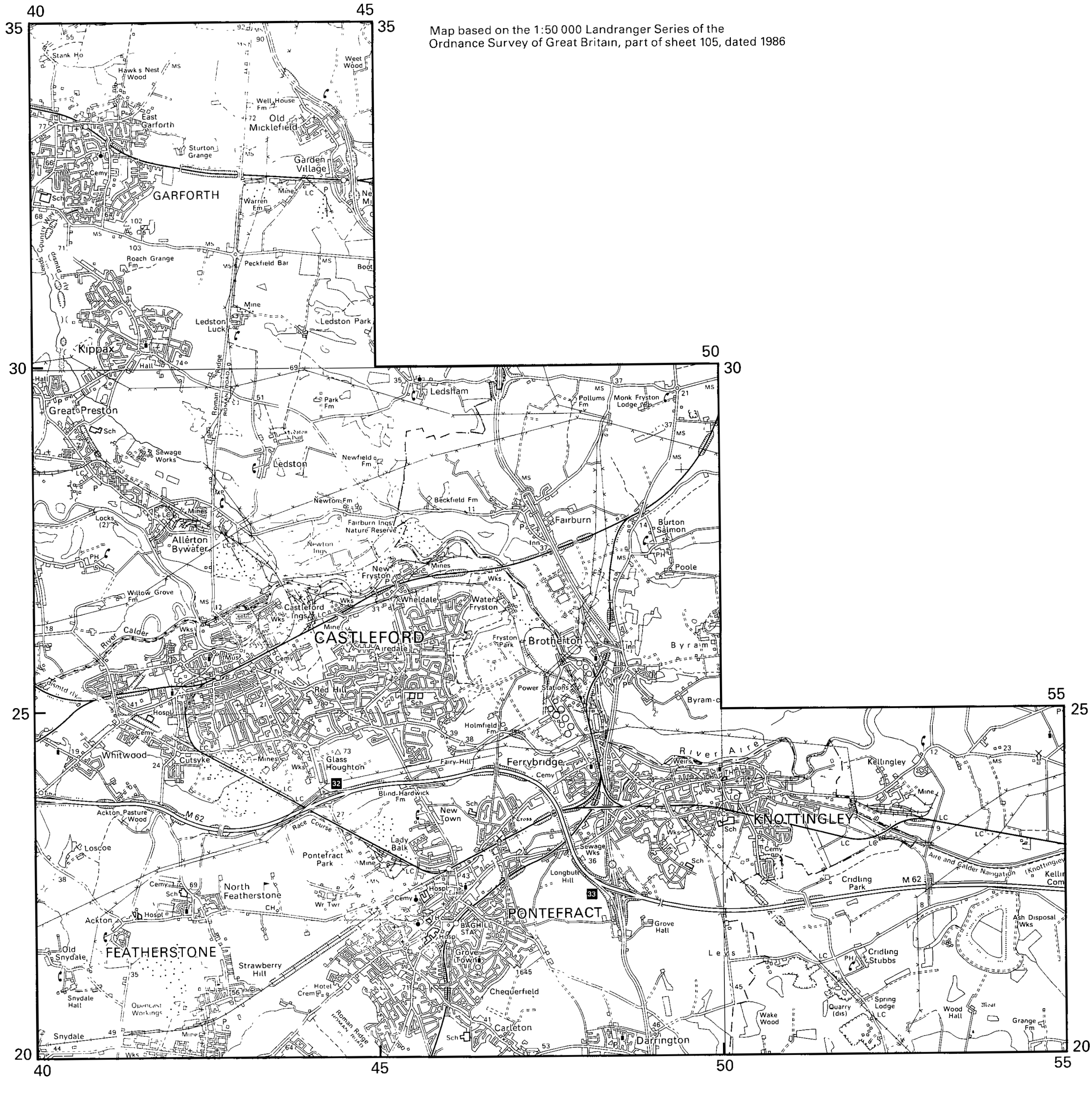


Figure 2 Map of the study area

INTRODUCTION

Background

This report is a synthesis of data obtained during a three-year contract commissioned by the Department of the Environment in 1987. Funding of the work was shared jointly between the Department and the British Geological Survey.

The study was in two phases; the first, carried out in 1987 and 1988, covered the Featherstone, Pontefract, Knottingley and Brotherton areas (sheets SE 42SW, SE, NE, and 52SW). The second in 1989 covered the Garforth area (Sheet SE 43SW). The study was a continuation of a previous one carried out by the British Geological Survey for the Department in the Morley – Rothwell – Castleford area between 1982 and 1986 (Giles, 1988). This previous study covered the area of sheet SE 42NW, which is included in the thematic map set accompanying this report in order to square off the map area of the present contract and give more coherent coverage.

The study area (Figures 1 and 2) covers 150 sq.km. It lies partly within the county of North Yorkshire, but mostly within the former county of West Yorkshire. Since the abolition of the latter on 1st April, 1986 administrative authority rests partly with Leeds City Council and partly with Wakefield Metropolitan District Council. The area lying within North Yorkshire is locally administered by Selby District Council. The area lies in the Yorkshire Coalfield, and encompasses exposed Coal Measures in the west and the concealed coalfield to the east.

Impetus for the study was provided by the legacy of problems facing planners and developers caused by mining dereliction and subsidence. An additional factor was the presence of undetected shallow sand mine workings, some of which have collapsed recently.

The study is one of a series commissioned by the the Department of the Environment as part of the Geological and Minerals Planning Research Programme (Department of the Environment, 1988). A further study in the south-east Leeds area is currently being undertaken by the British Geological Survey.

Aims and Objectives

It is intended that the study will form part of the background to a further project in the area which will assess the extent of underground sand mining and its implications. To this end one of the early objectives was the preparation of a provisional thematic geological map of the Basal Permian Sand of the Castleford-Pontefract area. This was published in March, 1988, and publicised by public and press meetings organised by Wakefield Metropolitan District Council in November, 1988. A final version of this map (Map 12a) is included with this report and this replaces the earlier provisional edition.

The specific objectives of the study are:

a. to complete and produce new revised geological maps and accompanying open file explanatory reports.
b. to collect, collate, evaluate and interpret available information on the geology, mining, solution subsidence, geotechnical properties and ground conditions, geomorphology, and hydrogeology.
c. to organise the information obtained in a database archive.
d. to present basic data and interpretations as thematic maps and an accompanying report in a form easily understood by planners and others not trained in geology, mining, civil engineering or related disciplines.
e. to identify the need for further investigations or specialist advice in relation to specific planning and development objectives and proposals.

Work carried out

Geological field mapping at the scale of 1:10 000 was carried out in 1987 in the Featherstone area (SE 42SW), in 1988 in the Pontefract, Brotherton and Kellingley areas (SE 42SE, NE and 52SW respectively), and in 1989 in the Garforth area (SE 43SW). The field mapping involved the recording and interpretation of geomorphological features, the systematic examination of exposures of solid rock and superficial (drift) deposits and hand augering in selected areas.

The field work was augmented by the synthesis of a large quantity of borehole and trial pit data as well as abandoned and current mine plans. The examinaton of aerial photographs and old topographic maps also provided useful information.

The component 1:10 000 maps were constructed by combining the data described above. They show the distribution of the geological formations that form solid bedrock, and depict their structure, as well as the distribution of the superficial deposits that veneer them. A three dimensional interpretation of each map is assisted by the addition of selected underground mining data, and by a generalised vertical section and selected borehole and shaft data given in the map margin.

Each map has an accompanying open file technical report which describes the geology of the map area, and any engineering hazards posed by the geology. The reports are part of the BGS Onshore Geology Series of Technical Reports, and are:

Barclay, W J, 1989. Technical Report WA/89/56. The geology of the Kellingley district – Sheet SE 52SW

Ellison, R A, 1989. Technical Report WA/89/53. The geology of the Featherstone district – Sheet SE 42SW

Ellison, R A, 1989. Technical Report WA/89/54. The geology of the Pontefract district – Sheet SE 42SE

Ellison, R A, 1989. Technical Report WA/89/99. The geology of the Garforth district – Sheet SE 43SW

Nutt, M J C, 1989. Technical Report WA/89/55. The geology of the Brotherton district – Sheet SE 42NE

Details of the geology of Sheet SE 42NW are given in Giles, JRA,1987 Geological notes and local details for 1:10 000 sheets: SE. 42NW (Castleford).

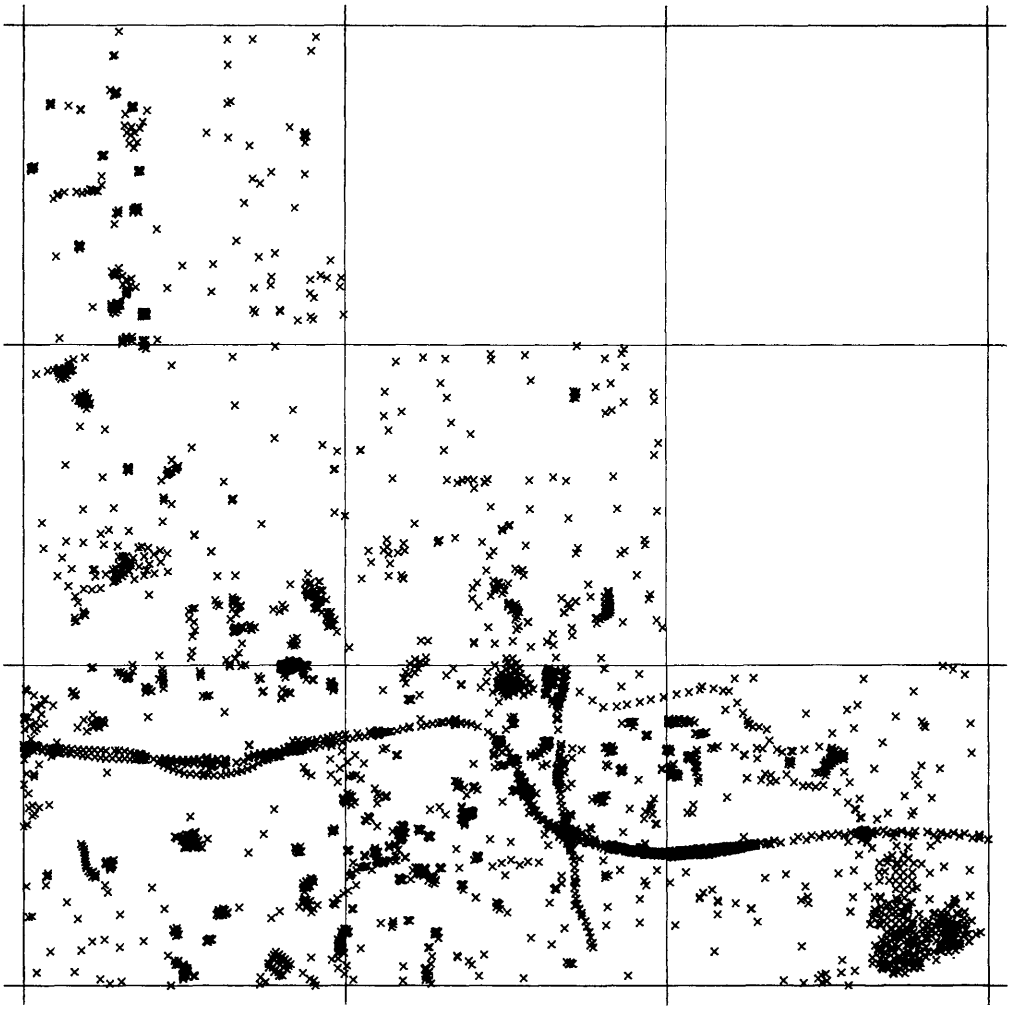


Figure 3 Distribution of boreholes

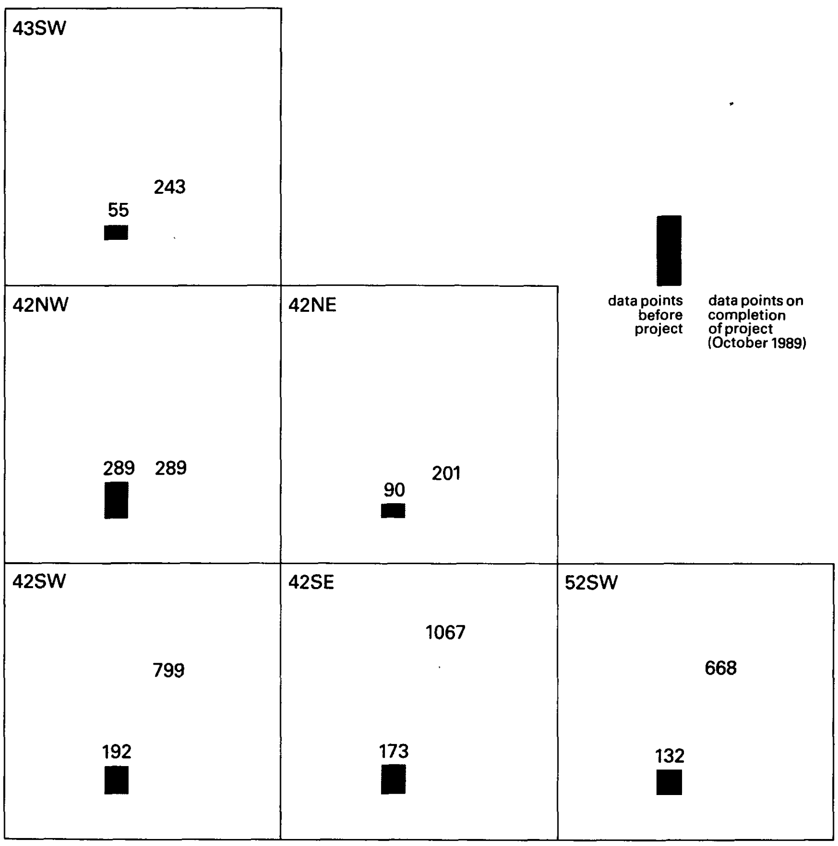


Diagram showing the increase of data in the BGS database during the project

Figure 4

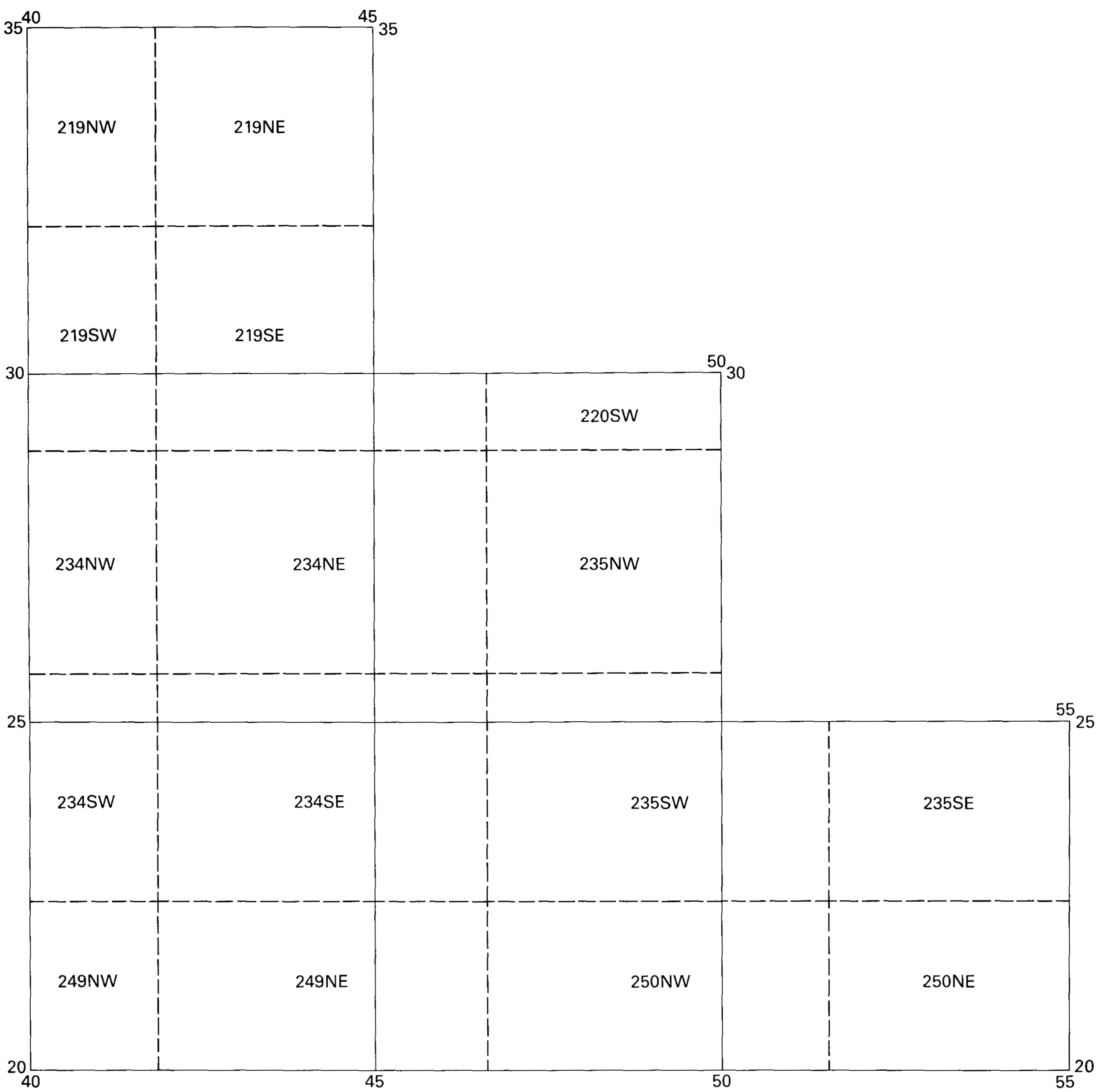


Figure 5 Yorkshire County New Meridian Series Six-inch maps of the project area

Policy development is guided by the economic and social needs of the area and the need to conserve historic centres, fine landscape and wildlife. In broad terms these are concerned with the resources of the area which may be developed and the constraints to such development which are needed for safety, environmental protection and to reduce annoyance to residents. Some of these resources and constraints are of geological origin.

The principal geological resources are minerals and water. An adequate supply of minerals is important to the economy for building and constructions materials, energy production and industrial processes. However, mineral extraction may have adverse effects on the environment. Therefore the options for extraction in various areas have to be weighed carefully by planners. This can only be done if adequate general information on the extent of such resources is available. Minerals will also be needed by future generations and therefore it is equally important to know their locations so that valuable deposits are not sterilised unnecessarily, for example by building over them. Water supply may come from both underground or surface sources, and the locations and behaviour of both relate to the underlying geology. Information on the distribution of water and its quality is essential for development of the resource but also gives indications of those locations in which water quality is most likely to be affected by development for instance by industrial pollution.

Minerals and water are resources which may be developed now or in the future and therefore they may also act as constraints on specific types of other development which may adversely affect the resource potential.

A variety of other factors which relate to the physical and chemical characteristics of the ground may act as constraints to safe, cost-effective development. Some are of natural origin whilst others are caused, or influenced by, human activities.

The most significant of these are:

a) subsidence of ground into natural cavities such as caves and fissures and underground excavations such as mines;

b) risks of people, livestock and machinery falling into open, concealed, or poorly treated openings such as mine shafts, and into natural swallow holes.

c) landslipping of natural slopes, the faces of excavations such as cuttings and quarries, and of tips and embankments which can be triggered by natural processes and by construction activity;

d) rock fall from natural rock faces and from artificial ones such as those of quarries;

e) the possibility of damage to foundations when the design does not take sufficient account of, for example, compressible ground or of ground materials which may shrink and swell as water content varies;

f) chemical reactivity of some minerals with construction materials which can sometimes lead to deterioration of structures;

g) accumulation of gases, which may be explosive, asphyxiating, toxic or radioactive, in underground cavities or in constructions which such gases can enter;

h) occurrence of carbon-rich materials such as coal which can spontaneously combust leading to fires underground or within tips which may be difficult and expensive to extinguish;

i) earth tremors (seismic events) produced by movements on faults within the earth either as a response to natural stresses or to some human activities such as mining;

j) potential for flooding of land;

k) occurrences of natural substances, such as heavy metals, or of contamination from human activities such as waste disposal, industrial processes and agriculture which may affect water quality.

The majority of these constraints can be reduced or overcome if development is located sensibly and appropriate precautionary, remedial and design measures are incorporated. Whilst the onus of carrying out proper site investigations prior to development is placed on the developer, it is useful to have general information on potential constraints to hand before the site investigations are designed. Similarly it is helpful to local planning authorities if such generalised information is readily to hand when planning policies are being developed and, especially, when land allocations in local plans are being considered.

The information can also help local authorities to decide what information on ground conditions can be reasonably requested in support of any planning application.

This report attempts to draw together information on geological resources and constraints which may be of significance in the Garforth-Castleford-Pontefract area and to present it in a convenient form to guide planners, developers and others interested in land use and changes to land use. The British Geological Survey holds more detailed information on which the study has been based and can be consulted if more detailed advice is required.

The report deals only with factors related to the geology of the area and, for planning purposes, needs to be considered with planning policy documents such as the Development Plans prepared by the local authorities and circulars and Planning Guidance notes issued by the Department of the Environment.

Mineral and Water Resources

Mineral resources

Coal The entire study area is underlain by coal resources (Figs 14, 16, 32; Maps 1 and 13). Those exposed and at shallow depth in the west have been mined by traditional methods that are now uneconomic on a large scale because of depletion of the reserves, almost to exhaustion. Opencast mining of shallow and outcropping coal (Fig.19; Map 3) has become increasingly profitable in recent years with the advent of large earth moving equipment, and considerable reserves remain. Large reserves of deep mined coal remain in the concealed coalfield to the east. Planners should consult British Coal to ascertain its plans for future opencast mining, and in order to avoid or design for subsidence effects, its plans for deep mining.

Limestone and dolomite The Cadeby (Lower Magnesian Limestone) Formation and the Brotherton (Upper Magnesian Limestone) Formation crop out extensively, and although much worked, large reserves remain (p.39; Map 10; Fig.28).

Gypsum and anhydrite Anhydrite at depth in the Edlington (Middle Permian Marl) and Roxby (Upper Permian Marl) formations is replaced by gypsum towards the surface. The Upper (Sherburn) Anhydrite is currently being mined to the east of the area (p.42).

Sand and gravel Sand and gravel deposits of economic importance are largely concentrated in the Aire and Calder valleys (p.42; Fig.29; Map 11). They are currently being worked at Dunford House [414 264].

Minestone Colliery spoil (minestone) is abundant in the area, with large volumes being produced from the active mines (p.46; Fig.19; Map 3)

Pulverised Fuel Ash (PFA) Most of the spent fuel ash from the coal-fired power stations at Ferrybridge and Eggborough is dumped at Gale Common (Locality SE 52SW/23, Map 3), but some is converted into PFA for use as fill in the construction industry.

Sandstone The sandstones of the Coal Measures have been quarried on a small scale. There are no current workings, and much of the resource is sterilised by building (p.42).

Moulding sand The Basal Permian Sand was formerly worked in pits and shallow mines, initially for glass making and later as moulding sand in the iron industry (Figs 30, 31; Maps 12a,b; p.39). The workings were confined to four large mines and numerous small ones close to the outcrop, and therefore considerable reserves remain.

Brickclay and fireclay The mudstones of the Coal Measures may be used for the manufacture of bricks and tiles, the mudstone seatearths (fireclays) for pottery, ceramics and as a refractory material. Alluvial and glaciolacustrine silts and clays were formerly dug for brickclay near Knottingley (p.42).

Water Resources (Map 7)

About 4.7 million gallons of water are currently extracted annually from underground and surface sources within the study area (p.37; Fig.24;). Most is for industrial use (61%) and electricity generation (32%), the remainder being for crop irrigation (6%) and domestic and other agricultural requirements (1%). The principal aquifer is the Cadeby (Lower Magnesian Limestone) Formation, but its water is hard and subject to surface pollution. The Sherwood Sandstone is the main aquifer to the east but has only a small outcrop in the study area. The Brotherton (Upper Magnesian Limestone) Formation yields water of similar quality to the Cadeby Formation, but the filling of disused quarries with colliery waste has polluted it in the Knottingley area. The sandstones of the Coal Measures provide water mainly for spray irrigation; although water obtained from shallow depths is of reasonable quality, that from deeper levels contains high concentrations of sodium, chlorides, sulphates and iron, rendering it impotable.

Geological constraints and problems

Geological hazards and problems are considered under two headings; those that are present because of the inherent nature of the rocks and superficial deposits, and those that are caused by human activity. Since the latter pose the greater hazard to development in most of the study area, they are discussed first.

Man-made problems

Considered under this heading are stability and subsidence problems from coal mining, subsidence of sand mine workings (particularly acute in this area), the presence of large areas of colliery waste, landfill sites, and groundwater pollution. Also, natural problems may be exacerbated or induced by human activity.

(1) Coal mining subsidence

Coal has been mined in the district from at least the Middle Ages. The first workings were along the coal outcrops in shallow pits and adits and later from bell pits and shafts. Land that has remained relatively undisturbed since the abandonment of shallow mining is uneven due to spoil tips and collapse of the workings. The location of bell pits is commonly marked by mounds of spoil up to about 100m across and 5m high.

Bell pits were used until the 17th century. An unsupported shaft about 1m in diameter was sunk (Fig.6), and the coal mined radially from its base until the roof became too unstable, ventilation became restricted or excess inflow of water occurred. The pit was then abandoned and a new one sunk nearby. There is a high density of bell pits in the fields between Garforth and Micklefield [425 330] and north of North Featherstone [230 430].

The pillar and stall method of extraction (Fig.7) was widely employed in the 18th and early 19th century, initially from closely spaced shallow shafts (e.g. south-west of Pontefract). Pillars of coal were left to support the roof during working, often aided by wooden props. The stalls, or rooms, were generally 2 to 3m wide and about 50 percent of the coal was left. At the end of mining the roof supports were occasionally withdrawn and some of the pillars removed or reduced (robbed) on retreat. Prior to 1872 there was no statutory obligation to record plans of mines, there are few records, and the extent of old workings is largely unknown. Many of the areas of old workings shown on Map 8 were uncovered during opencast coal mining.

The expansion in mining brought about by the industrial revolution led to numerous shafts being sunk to greater depths, first in the exposed coalfield and later in the concealed coalfield to the east. By the early part of the twentieth century eleven large collieries were operating in the district (Map 9).

In the longwall method, introduced to the area in the mid 19th century, the coal is completely mined in panels between roadways. Following extraction the supports are removed and the roof collapses, only the main roadways remaining supported. Modern longwall retreat mining is in regular panels, designed to maximise production by avoiding faults and areas of poor coal. Working faces are generally 200 to 300m long.

Exhaustion of the most economic seams in the west of the district led to closure of most of the collieries and a progressive easterly shift in deep mining. At present three collieries, Allerton Bywater, Prince of Wales and Kellingley, are operating.

Active and abandoned mine workings can affect ground stability. The main hazards are shallow, undocumented coal workings and mine shafts. In particular the potential for collapse of pillar and stall workings means that their extent must be determined and the ground stabilised before development. of any particular site takes place.

All shafts and bell pits, except those that are properly capped and monitored, should be regarded as potentially dangerous, as their history is rarely known. In many instances the depth is unknown although most were probably sunk to the highest workable coal. Some shafts are capped, but not neccessarily filled. Uncapped shafts may be wholly or partly filled.

Pillar and stall workings (Figure 7)

Ground instability above such workings will arise due to roof collapse, pillar failure, floor heave, or a combination of these factors. Roof collapse involves the progressive upward migration of a void until it is choked by the broken roof debris or a bridge of roof strata is formed (see for example Walton and Cobb, 1984). When the overburden in not thick enough to arrest the void migration a crown hole will occur at the surface. The maximum distance above old workings to which collapse effects will propagate is generally regarded as about ten times the worked coal thickness, but there is no direct relationship. The collapse height may be more closely related to factors such as the roof span of the working. It should not be assumed that there is a safe depth below which the collapse of old workings is complete (Garrard and Taylor, 1988).

Floor heave occurs first in the deterioration of abandoned workings, infilling voids and providing some support and reducing the deterioration of pillars.

Progressive deterioration of pillars can occur due to deeper modern mining, spalling and weathering, the eventual collapse and ensuing surface subsidence taking place 100 years or more after the mining terminated. Loading by new development at the surface can cause renewed settlement of the pillars and more ground subsidence.

Longwall workings (Figure 8)

Ground movement resulting from longwall mining is not usually catastrophic and occurs soon after mining. The processes are reasonably well understood and prediction of ground movement can be made. However, prediction can be inaccurate for workings beneath thick cover of competent Permian and Triassic strata (Fyles, 1987).

A zone of tensile stress occurs above the edges of worked panels. Where a worked area is close to or constrained by a fault this stress is relieved by movement on the fault plane that propagates to the surface. In cases where several seams have been worked up to the same fault a subsidence scarp up to several metres high may develop, for example along the Fairy Hill Fault in the vicinity of Holmfield House [4665 2487] and Fairy Hill Farm [4573 2406]. Where there is a thick Permian cover the subsidence is less pronounced but the ground movement is taken up along joints in the Permian limestones, sometimes suddenly. Such movements have commonly occurred along the major faults in the study area.

(2) Basal Permian Sand mining subsidence (Figure 9)

History of Sand Mining

Sand was used for glass making in the Glass Houghton area in the early 1700's (unpublished MS by John Goodchild, archivist at Wakefield Library). The earliest known documentation is from 1793 when a mineral lease, which included a sand quarry, was taken at Holywell, near Glass Houghton [445 244]. The main period of working was between the mid 1800's and the early 1900's when several small mines were in operation, the sand being used principally for iron moulding. By the time of the geological survey in the 1930's the sand was being dug only in the vicinity of Orchard Head [460 236] and Ledston Sand Mine [430 295]. Underground mining ceased in the 1940's (Hodgkins, 1979), but quarrying continued until the 1960's.

Method of Working

Much of the working was in quarries and small pits along the outcrop. Underground mining was by pillar and stall, from adits on the outcrop. Some adits were dug into the faces of former quarries. Evidence in the workings and on mine plans indicates that some robbing of the pillars took place on retreat. Wooden props were used for support in some places, but the workings were mainly free standing. The thickness worked ranges from 0.8 to 4m. Headings are an average of 3m wide and the pillars are slightly concave and wider at the top. Where plans exist or where workings were examined 30 to 60 percent of the sand has been removed.

The mines are naturally well drained, their extent probably limited by inadequate ventilation. The workings at Wheldale [449 264] extend about 700m from the mine entrance, a distance probably not exceeded in other mines. In the Aire valley mining was probably prevented by groundwater.

Effects on surface stability in undermined areas

Pillar and stall mines, documented and undocumented, are present at more than twenty localities. Their full extent is unknown and it is possible there are undiscovered workings.

Recently there have been a number of instances of their collapse, causing damage to property at Redhill Avenue, Castleford [441 249] (Baldwin and Newton, 1988) and Bexhill Close, Pontefract [4695 2270]. Also, crown holes caused by subsidence occur, for example at East Garforth [418 341], Green Lane, Garforth [418 325], and between Monkhill Lane and Orchard Head Lane, Pontefract [4587 2358 to 4635 2340] (Plate 1).

A number of interdependent factors, common to most pillar and stall mines, contribute to the inherent instability of the sand workings:

(a) the condition of the roof, determined by its lithology (Plate 2) and the relative size of the cavities and pillars in workings. The roof consists of dolomite, and where this is thickly bedded a relatively great roof span can be maintained; where thinly bedded or weakly cemented, roof collapse and void migration to the surface may ensue (Fig. 9; Plate 3). The distribution of these lithologies is not known in detail.

(b) deterioration of the pillars by mechanical weathering, involving surface runoff which enters the mine along roof joints, flows down the pillars and lies on the floor of the workings. It results in a small amount of pillar spalling (Plate 4).

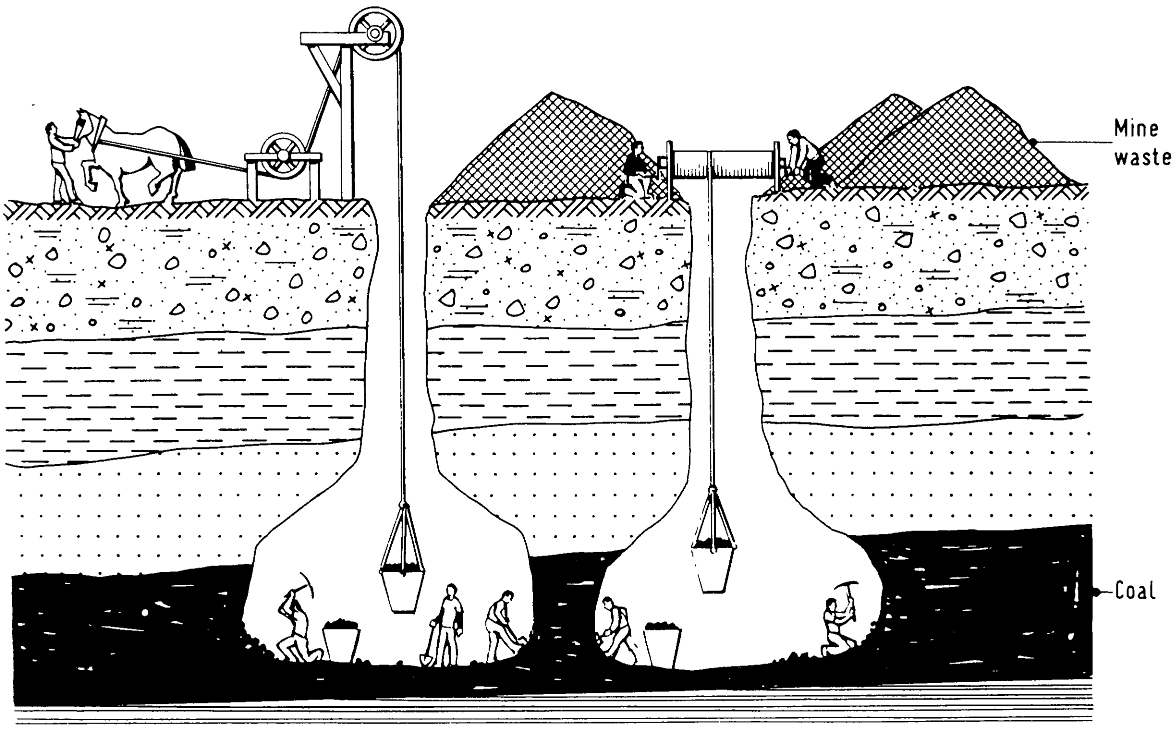


Figure 6 Bell pit mining (after Gregory (1981) in Healy and Head (1984))

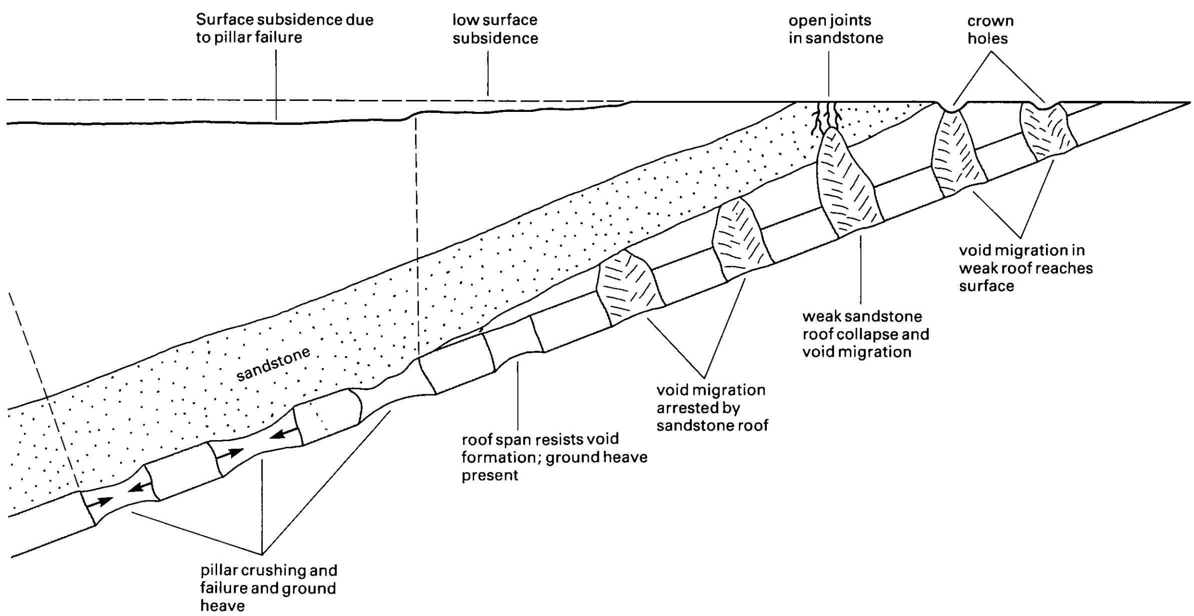


Figure 7 Diagram to show types of subsidence due to pillar and stall workings (after Attewell and Taylor, 1984)

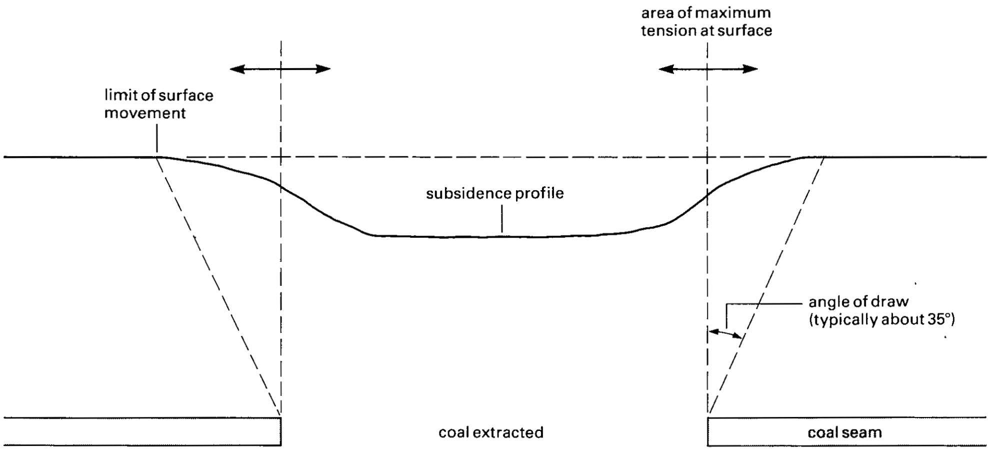


Figure 8 Simplified geometry of subsidence effects resulting from longwall mining

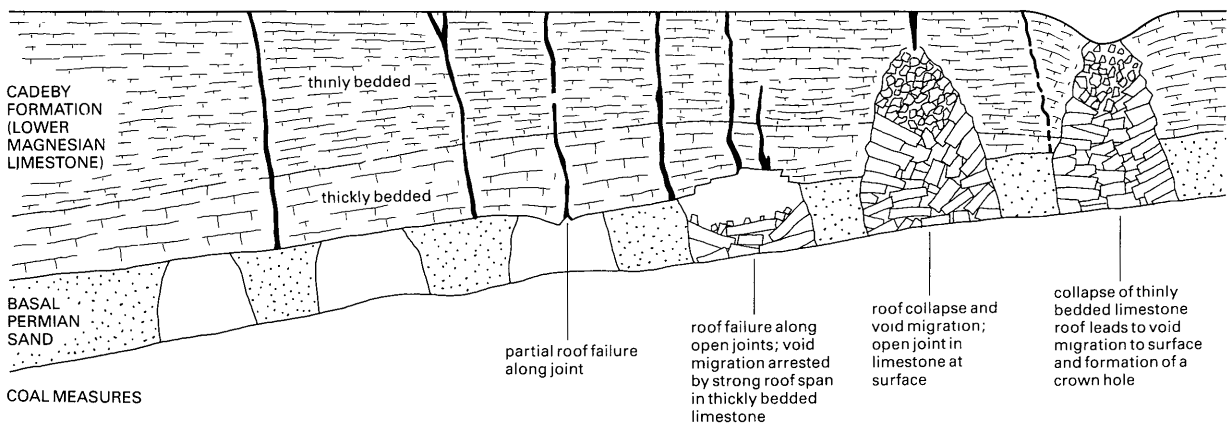


Figure 9 Diagrammatic representation of collapse of Basal Permian Sand mines

Plate 1 Crown holes caused by collapse of pillar and stall mines in the Basal Permian Sand: Orchard Head [4590 2357]

Plate 2 Basal Permian Sand workings at shallow depth uncovered prior to housing development: Sandhill Close, Pontefract [4583 2356]

Plate 3 Roof collapse in Basal Permian Sand mine: Redhill, Castleford [441 249] (photograph by J. Hodgkins)

Plate 4 Deterioration of Basal Permian Sand pillars by spalling: Redhill, Castleford [441 249] (photograph by J. Hodgkins)

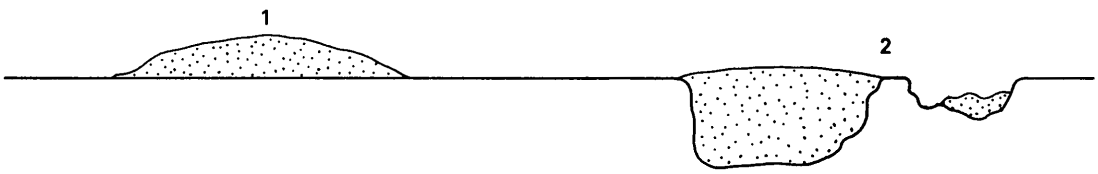


Figure 10 The categories of made ground shown on Map 3
1: On the original land surface
2: Backfilling or partially filling a pit, quarry or excavation

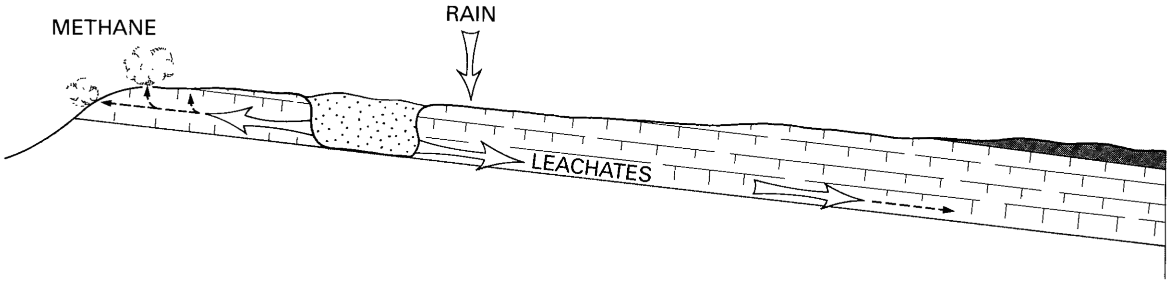


Figure 11 Sketch showing movement of leachates and methane from domestic/industrial landfill in a quarry in an aquifer, such as the Upper Magnesian Limestone.

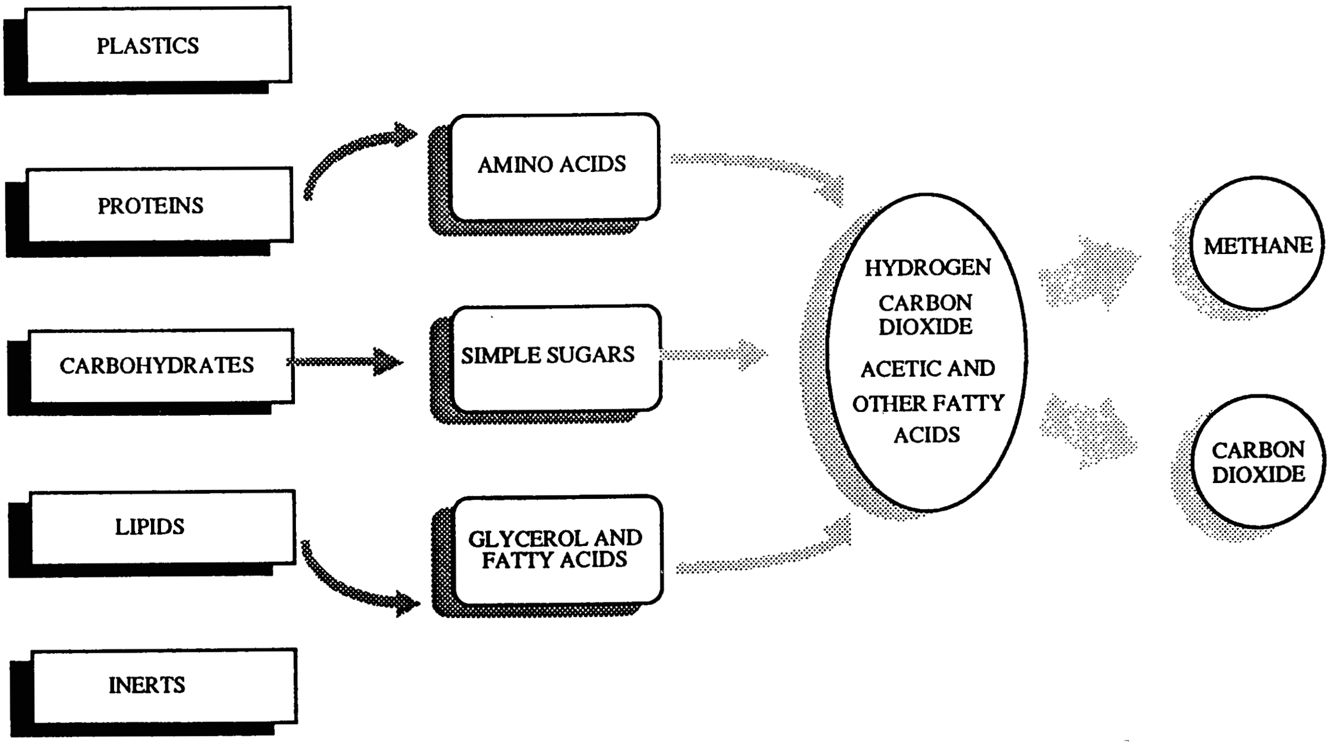


Figure 12 Decomposition of domestic waste (Williams 1989)

(c) chemical weathering by surface runoff, a slow deterioration causing enlargement of roof joints thereby weakening the roof

(d) subsidence caused by deep coal mining could precipitate instability in the workings by enlarging the roof joints. A further generally unconsidered possibility is the collapse of old pillar and stall coal workings close below the sand, those most at risk lying above the edges of deep mined panels where tensional stresses are greatest. Instability of sand workings could be caused by the domino effect of collapse of underlying pillars in old workings triggered by deep mining subsidence.

(e) groundheave occurs at depths of less than 10m below the surface, causing lateral stress on the pillars, spalling and consequent loss of strength.

(3) Made ground (Figure 19)

The principal occurrences of made ground are catalogued on Map 3. They include several major landfill and waste disposal sites.

Where areas of made ground have been restored or redeveloped, there is generally no indication now of the nature and composition of the deposits. Also, even where the surface layer of the deposit was observed during the survey, there is no guarantee that the same material persists throughout, either laterally or vertically. The composition of the fill will need to be ascertained prior to development. Not all made ground will present problems, as much of the material will be inert, but the following points should be borne in mind:

(a) industrial waste may be potentally chemically active and capable of generating dangerous or combustible gases and toxic leachates;

(b) domestic household waste will generate methane gas, which is highly combustible (see below);

(c) colliery spoil, which constitutes the greatest part of the made ground of area, may be liable to spontaneous combustion, and will produce sulphate-rich acidic ground water and leachates causing corrosion problems in foundations. Leachate from colliery spoil tips may also affect the quality of surface water;

(d) the heterogeneous materials that commonly constitute made ground may give rise to widely differing ground conditions and differential settlement under loading may produce foundation failure;

(e) where made ground backfills a pit or quarry, it will be less compacted than the surrounding natural material, producing differential settlement in foundations that straddle the edge of the deposit;

(f) the problem of differential settlement of made ground may be compounded in cases where cavitation results from chemical or bacterial breakdown of the fill material. Cavities may already exist in hard core as a result of the presence of large blocks, again presenting difficult foundation conditions and the possibility of differential settlement.

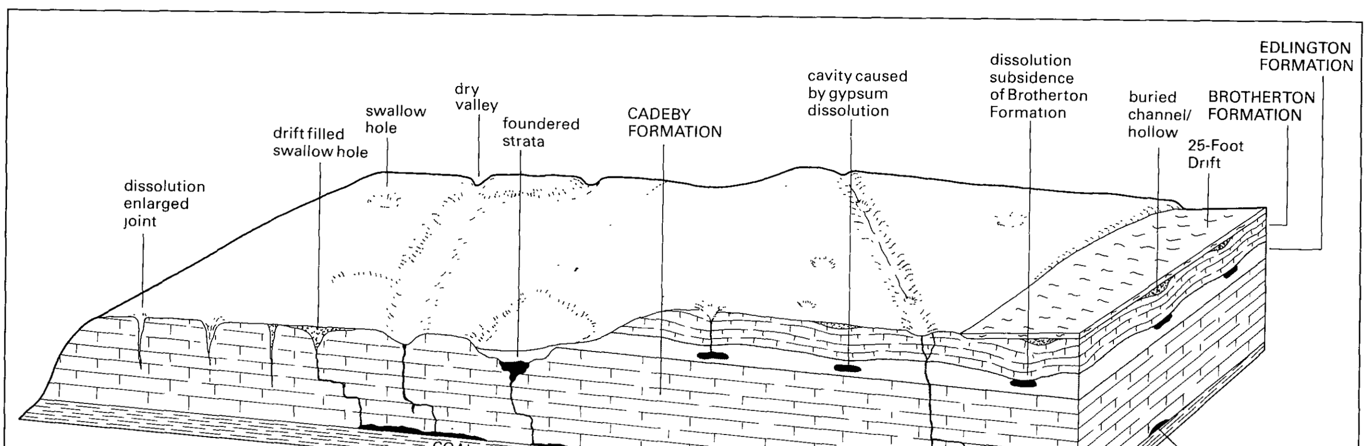


Figure 13 Karst features of the Permian rocks

(4) Methane

Although large quantities of methane are released by mining and quarrying, the main hazard posed to development comes from methane generated in landfill sites (Fig. 11).

Methane produced by the decomposition of domestic refuse (Fig.12) is currently being utilised at Darrington Quarries [510 213]. At Betteras Hill Quarry [497 293] methane is vented by limestone-filled trenches cut through the refuse. Prior to development, it is necessary to investigate the nature of the made ground, and to vent methane from earlier refuse disposal sites. In some cases methane may become trapped in mine shafts, for example below caps, and could give rise to hazards if not vented.

(5) Groundwater pollution

The main water-bearing rocks in the area (Map 7) are recharged by infiltration, the rate of which is determined by the surface geology. It is probably greatest over outcrops of the Cadeby Formation on account of the large number of open joints and fissures. Impermeable clay-rich superficial deposits prevent infiltration, others, including gravels in the Aire and Calder valleys, tend to reduce it.

The pollution of groundwater in the Coal Measures is restricted due to the protection afforded by the thick beds of mudstone, but leacheates can enter through the permeable sandstones.

Mine groundwater contains dissolved iron compounds and its disposal may require some care. If it is pumped into the surface drainage or onto permeable ground it could contaminate river water or local aquifers and cause iron oxide deposition.

The groundwater of the Cadeby and Brotherton formations is highly vulnerable to pollution, particularly where the rocks are at the surface and pollutants can pass quickly into the saturated zone and be transported laterally. The most likely forms of pollution are from landfill sites, road drainage, and runoff from agricultural land containing residues of fertilisers and pesticides. The amount of groundwater in storage is sufficiently large to assure adequate dilution of most single polluting events, providing that pumped groundwater sources are about a kilometre distant. However, the groundwater in the Brotherton Formation east of Knottingley is now unusable on account of its pollution by leachates from the fill materials of disused limestone quarries.

Groundwater in the Sherwood Sandstone in areas of outcrop where the rock is covered by permeable superficial deposits and the water table is close to the ground surface can be polluted quickly. Downward percolation of water through the saturated zone and lateral flow is relatively slow compared to the Permian limestones. This suggests that pollutants are likely to take a long time to reach abstraction sources, although they may be retained in the saturated zone for a longer period. In fact, once a pollutant reaches the saturated zone it may take many years to fall to acceptable values, either by chemical change or by diffusion and dilution.

Although several studies of groundwater flow paths and pollution plumes are taking place within the study area, for example at Gale Common and near Knottingley, no information has yet been published (Aldrick, oral communication, 1989).

Natural constraints

(1) Karst features

Karst features are those formed when soluble rocks are dissolved by surface and ground waters (Fig.13). The Cadeby (Lower Magnesian Limestone) and Brotherton (Upper Magnesian Limestone) formations are affected by limestone dissolution, the Edlington (Middle Permian Marl) and Roxby (Upper Permian Marl) formations by gypsum dissolution. Collapse and subsidence of the strata overlying the dissolved areas is a common feature.

Dissolution results in highly variable rockhead levels and the presence of hollows, depressions and channels in the limestone surface, commonly filled with superficial deposits of highly variable thickness, lateral extent and composition. At depth, dissolution results in the formation of voids, cavities and enlarged, open or partially filled channels following faults, fractures, joints and bedding planes.

Infilled pockets, voids and cavities may result in reduced bearing capacities, cause excessive differential settlements below heavy structures, and preclude the use of shallow foundations except for light structures. Inter-connected cavities resulting from enlarged bedding surfaces, joints and fissures may also cause water inflow in excavations. Site investigations should be designed to locate these features, as ground treatment or special foundation design may be necessary. The irregularities in the limestone surface are often difficult to ascertain by standard site investigation methods. Shallow geophysical techniques (eg. McCann et al., 1987) may determine ground anomalies in order to plan a drilling investigation, but are not always successful.

(a) Swallow holes

These are caused by the dissolution of rocks by ground and surface water, producing collapse of the overlying strata. Dissolution of the limestones and dolomites of the Cadeby and Brotherton formations and of evaporites in the Edlington and Roxby formations (and possibly also in the Cadeby Formation) has taken place over the last 130,000 years at least, and continues at present to a reduced extent. The effects of dissolution and collapse locally propagate up to the Sherwood Sandstone which may "bridge" the cavities or collapse into them.

In the Cadeby and Brotherton formations, ground water movement has produced cavities and passages, frequently encountered in boreholes. Their collapse produces swallow holes at the surface, and several are present in the area (Map 6). The best developed are a series in a dry river channel near Burton Salmon. The channel, incised into the Brotherton Formation, extends from the Punch Bowl [485 280] to Byram Lake [499 262]. Subsidence of some of these in 1932 was recorded by Edwards et al (1940). The largest swallow hole [529 246] in the study area is near Kellingley, and is in the Sherwood Sandstone where it is overlain by 25-Foot Drift deposits. The detection of similar features which may lie hidden below superficial deposits, is necessary prior to development, as they may contain soft ground, or be liable to further collapse.

(b) foundered strata

The dissolution of gypsum in the Permian rocks by circulating groundwater and the consequent collapse of the overlying beds is widespread (Cooper, 1986; Edwards et al., 1940; Smith, 1972). Only one area, thought to be affected by major collapse, is shown as foundered strata on Maps 1 and 6.

Foundering of the Brotherton Formation is mainly of minor extent, and indicated by wide-amplitude shallow folding, termed domes and sags by Smith (1972) to distinguish it from tectonic folding which it closely resembles. In addition to the gentle folding, sharp synclinal sags are common.

The area of foundered strata around Wake Wood [c.507 206] is a wide irregularly shaped depression between an escarpment formed by the Brotherton Formation to the north and east and high ground underlain by the Cadeby Formation to the south and west. Red clay of the Edlington Formation lies in the floor of the depression, and appears to have been let down by foundering of the underlying Cadeby Formation. Two limestone masses occur within the depression, protruding above the red clay.

(c) dissolution along joints and faults

Steeply inclined fractures, joints and bedding discontinuities provide natural pathways for surface water to infiltrate into the limestones. The dissolution of limestone along these pathways produces open fissures that may be filled with superficial deposits. Their presence should be investigated prior to development on the outcrop of the limestones.

(2) Buried channels and hollows

Buried channels and hollows have been proved in a temporary trench section and at several localities where close networks of boreholes have been drilled, and it is likely that others exist undetected. Their presence needs to be ascertained prior to development. Some are caused by the dissolution collapse of limestones and evaporites discussed above, others are channels scoured by ancient river action. Their infill with superficial deposits, some of which is likely to be soft ground, will cause engineering problems. The following occurrences have been proved:

(a) three buried channels cut in the Sherwood Sandstone on the Kellingley-Snaith Ridge [c.547 245], proved in a pipeline trench (Gaunt, *in press*). They are lined with gravels, filled with soft laminated clays, and the largest is up to 200 m wide and 6 m deep.

(b) a buried channel at Cridling Park [516 222] is filled with sand and gravel, its base over 15 m below the surface and 7 m below the base of the 25-Foot Drift. Boreholes suggest that this channel extends to the south, along the western margin of the Vale of York area.

(c) a buried channel or hollow at Beal Lane Bridge [530 224] extends over 15 m below the surface, and 8 m below the base of the 25-Foot Drift. It is filled by gravels with sand and clay lenses.

(d) a buried hollow [535 209] at Gale Common, possibly produced by dissolution collapse, is at least 9 m deep, and filled with sands, gravels and silt below the 25-Foot Drift.

(3) Geological faults

Geological faults are planes about which adjacent blocks of rock strata have moved relative to each other. Movement may be vertical, horizontal, or more likely, a combination of both. The faults in the study area were formed initially about 270 million years ago. Most, if not all were reactivated to a minor extent about 100 million years ago. They do not generally pose a problem today, although they may be reactivated by mining (p.11), occasionally causing earth tremors (below).

Faults are zones of weakened, brecciated, fractured and weathered rock, and may pose engineering problems. They may also cause differential settlement where they juxtapose rocks of differing compressibilities and strengths. Foundation designs should take account of these differences where they cross such lines.

It is important, therefore, that the precise positions of faults be ascertained prior to development.

(4) Natural slope failure

The topography of the study area is generally low and subdued, and natural landslipping is not a serious problem. Five small landslips were noted during the resurvey:

(a) shallow mudflows in weathered Coal Measures mudstones in the valley south of Garforth [4018 3172].

(b) shallow mudflows in weathered Coal Measures mudstones at Town Close Hills [4048 3049].

(c) the Cadeby Formation is affected by cambering and rotational landslipping near locality (b).

(d) shallow mudflows on Park Hill, Pontefract [4430 2227] are in Coal Measures mudstones close below the sandstone which caps the hill. Fresh surface creep of saturated material occurs at present.

(e) shallow mudflows on a slope in mudstones of the Edlington Formation [5025 2077] are present near Wake Wood.

In addition to these, an unmapped area of uneven ground near Ackton [4121 2231] is probably caused by shallow mudslides.

(5) Seismic activity

Seimic activity does not present a serious hazard within the study area, but should be considered in the design of sensitive installations. There are no recorded earthquake epicentres in the study area, but effects of the Lancashire earthquake of 1843 were recorded in Leeds and Wakefield (Burton et al., 1984). A number of major geological faults cross the area, and the Morley-Campsall Fault, which is a deep structure with a long history of movement, lies close to the south-west. Reactivation of any of these faults during or after mining may occur, and seismic activity associated with fault-related mining subsidence, as well as normal collapse of workings is likely. Such an occurrence took place in April 1988, when mining subsidence near Beal [526 249] induced movement of the Knottingley Fault, accompanied by a loud bang and the opening of surface fissures in the Sherwood Sandstone and overlying drift deposits.

(6) Mudrocks

The mudrocks in the Coal Measures (mudstones, siltstones and seatearths) and the Edlington (Middle Permian Marl) and Roxby (Upper Permian Marl) formations soften and weather to clays when relieved of overburden pressure and in the presence of water. A weathered mantle of generally firm clay commonly occurs at the surface, locally reaching depths of 6-10 m in the vicinity of joints and faults. Highly weathered zones have also been reported at depths in excess of 50 m, usually associated with sandstone aquifers or thin coals within the mudstones. Variations in the depth and grade of weathering give rise to differing soil thicknesses and foundation conditions. As a general rule, variable bearing capacities are to be expected in the weathered materials, along with the possibility of very low rates of consolidation settlement. Faulting of the mudrocks gives rise to zones of weak, shattered rock and soft to firm clays with weathered mudstone clasts.

It is recommended that site investigations in mudrocks include trial pitting as a matter of routine in order to ascertain the variations in the weathering profiles.

Mudrocks also pose a problem to shallow foundations during prolonged periods of drought, when they are prone to drying, shrinkage and cracking. Foundations should therefore be sufficiently deep to prevent this.

(7) Laminated clays and silts

Interbedding of clay, silt and sand, and lenticular bedding in drift deposits pose problems in foundation design. Variable consolidation characteristics are due primarily to permeability contrasts, and excessive differential settlements may occur. Gaunt (1976) considered that the settlement problems at St Edmund's Church, Kellington [5477 2456] may be due to the presence of laminated clays which are known to occur in buried channels in this vicinity (p.58). Piled foundations taken to sets in the underlying gravels or Permian bedrock are recommended for heavier structures. Perched water tables occur on the impermeable clay layers and water from sand and silt layers in exposed excavations can cause internal and surface erosion, swelling of clay layers and rapid deterioration. Similar effects may occur in borings for piles and piers.

The laminated clays have highly anisotropic undrained strength and low horizontal shear strengths. These factors must be taken into account in the design of foundations and the construction of embankments and spoil tips to avoid instability.

(8) Soft ground

Areas of soft ground are encountered where the following superficial deposits are present:

– river alluvium, ranging from soft to firm, silty clays and clayey silts to very soft organic clays forming extensive areas in the Aire and Calder valleys, and also occurring in a number of small tributaries.

– peat, comprising soft, fibrous organic debris and soft to very soft, extremely plastic organic clays which are confined to a few patches on the glaciolacustrine deposits and lenses in the alluvium.

– head deposits, comprising poorly-drained soils derived from the downslope movement of weathered material.

All these materials have low shear strengths, high compressibility and slow rates of consolidation, and are generally unsuitable as foundation materials even for light structures. Piled foundations, taken to sets in underlying sound bedrock should be considered for most construction work in these areas. Additional problems can arise from high groundwater levels, and drainage measures may be required.

THEMATIC MAPS

MAP 1 BEDROCK GEOLOGY (Figure 14)

This map shows the surface distribution of the major bedrock units.

The Coal Measures, predominantly composed of mudstones and siltstones, also contain sandstones which are delineated on the map. The surface positions (outcrops) of the principal coals and marine bands are also shown.

The vertical distribution of the bedrock formations is shown on the generalised section of strata and the horizontal cross section in the map margin (Figs.15 and 16).

It should be noted that at rockhead the rocks are generally weathered to material that is not 'rock' in engineering terms. Weathering converts Coal Measures and Permian mudstones to clay at the surface, and the Sherwood Sandstone to soft sand.

This map should be examined in conjunction with Map 2 in order to obtain an indication of ground conditions at a particular site. Where no drift deposits are shown it is likely that rock lies at or close below the surface. If drift deposits are present the rock will be encountered at the base of the drift (rockhead). The contours shown on Map 2 give an indication of the thickness of the drift deposits.

Geological boundaries

The location of geological boundaries in areas which are built on or cultivated is rarely a precise exercise, unless they are exposed in quarries or other excavations, or have been proved by borehole drilling. The boundaries shown on the map, including the limits of sandstones and coal outcrops in the Coal Measures, are therefore to be regarded as conjectural, but as accurate as possible, given the information available at the time of survey.

The boundaries between some rock units are gradational, with an interdigitation of the lithologies of both units in the transitional zone; their positions are therefore arbitrary.

A further factor concerning the accuracy of the boundaries of the rock units is the presence or absence of a cover of superficial deposits. Unless borehole or other subsurface data are available, the positions of boundaries concealed by drift deposits are subject to a degree of conjecture greater than that where they are drift-free.

Geological faults also act as boundaries. A geological fault is a plane of weakness and fracture about which adjacent blocks of rock strata have moved relative to each other. The position of a fault is subject to the same degree of conjecture as a normal geological boundary. Also, the larger faults generally comprise a zone of sub-parallel fractures.

Solid Rocks

The rocks present in the study area are listed in Table 1. A fuller account is given in Appendix 1; the following notes summarise their principal characteristics.

Coal Measures

The Coal Measures are present throughout the study area, cropping out at the surface in the west, and concealed beneath a cover of younger rocks to the east. They consist predominantly of mudstones and siltstones, with smaller proportions of sandstone. Relatively thin but persistent coal seams occur throughout (Fig. 15). The beds are generally gently inclined to the east, but are affected by a suite of north-east – trending faults and minor flexuring. The engineering characteristics of the Coal Measures rocks at outcrop are described in Appendix 2; the mudstones and siltstones weather to stiff heavy clays, subject to soil creep (solifluction), and the sandstones degrade to light sandy soils. The differing water-bearing characteristics of the mudstones and sandstones are described in Appendix 3.

Permian rocks

Basal Permian Sand

The Basal Permian Sand is a pale buff to yellow, soft, weakly cemented sandstone, weathered at outcrop to a sand. Absent locally, it is up to about 3m thick at outcrop, and of variable thickness at depth to the east, ranging up to about 13m. Details of the disused workings (Figs. 30, 31) are given on Maps 12a and 12b (p.46).

Cadeby (Lower Magnesian Limestone) Formation

The Cadeby Formation consists mainly of dolomite (a rock composed mainly of magnesium carbonate, compared to a limestone which is mainly calcium carbonate). It forms the prominent escarpment that extends from north to south and occupies a broad zone in the centre of the study area. It also forms an outlier (an area of outcrop separated from the main one) south-west of Pontefract. Two subdivisions can be recognised. The lower consists of well-bedded dolomites with some harder upstanding reef bodies, the upper of massive dolomites in which cross-bed-

Table 1 Geological succession of solid rock

	Current Names	Previous Names
Triassic	Sherwood Sandstone Group Roxby Formation Brotherton Formation	Bunter Sandstone Upper Permian Marl Upper Magnesian Limestone
Permian	Edlington Formation Cadeby Formation Basal Permian Sand	Lower Permian Marl Lower Magnesian Limestone Basal Permian Sands
Carboniferous	Coal Measures – Upper / Middle / Lower	Coal Measures – Upper / Middle / Lower

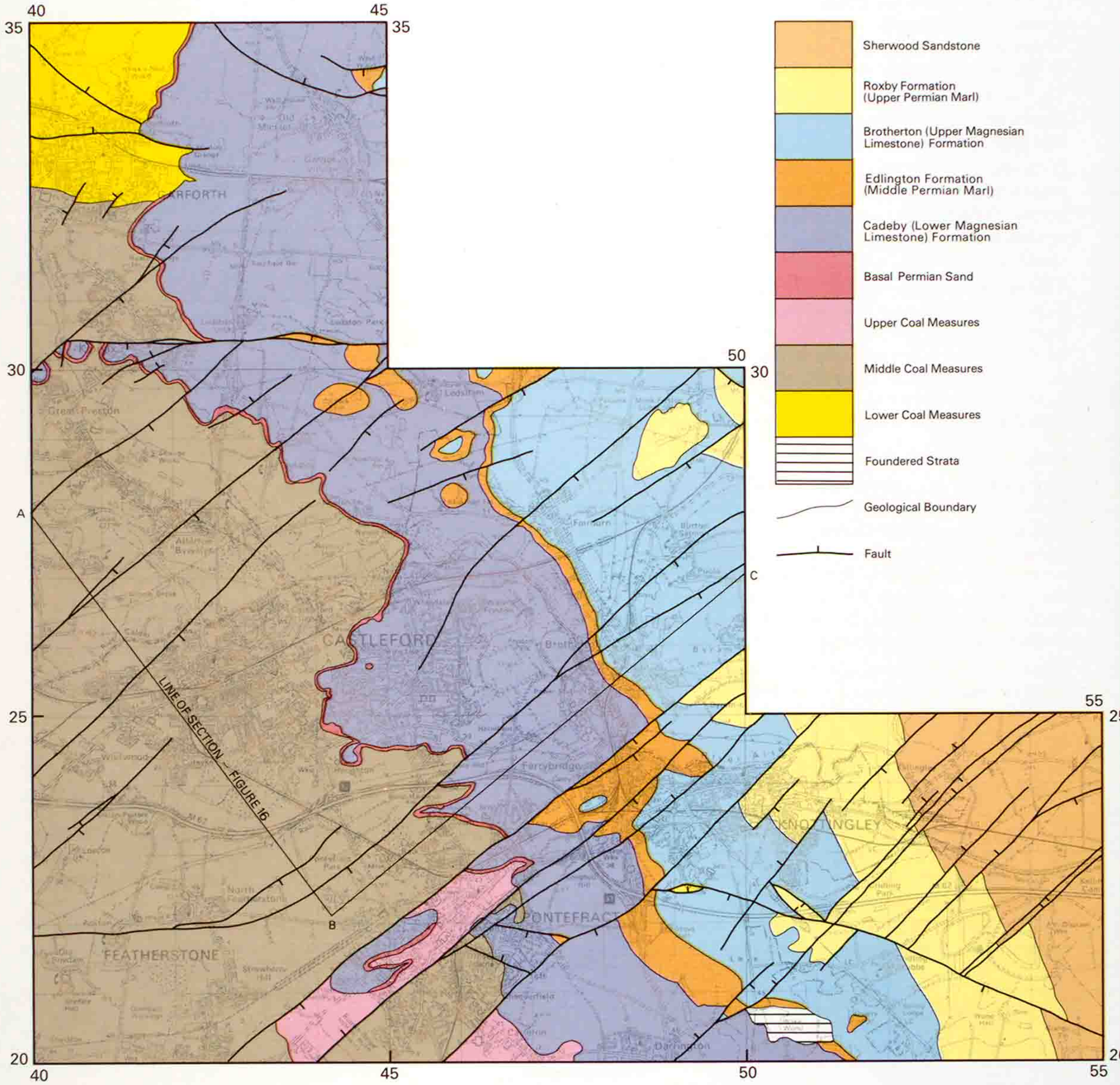


Figure 14 Bedrock geology

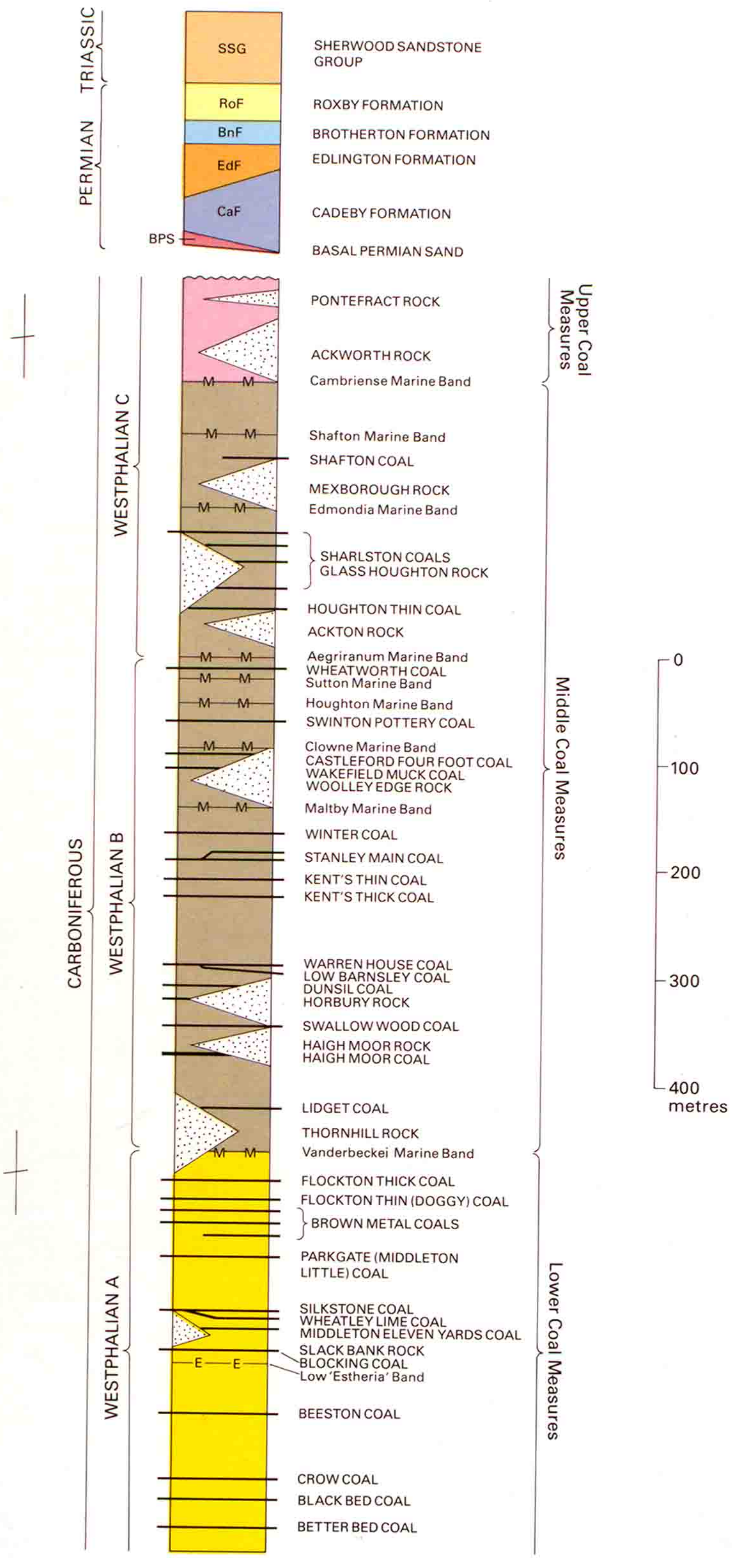


Figure 15
Generalised vertical section of solid strata

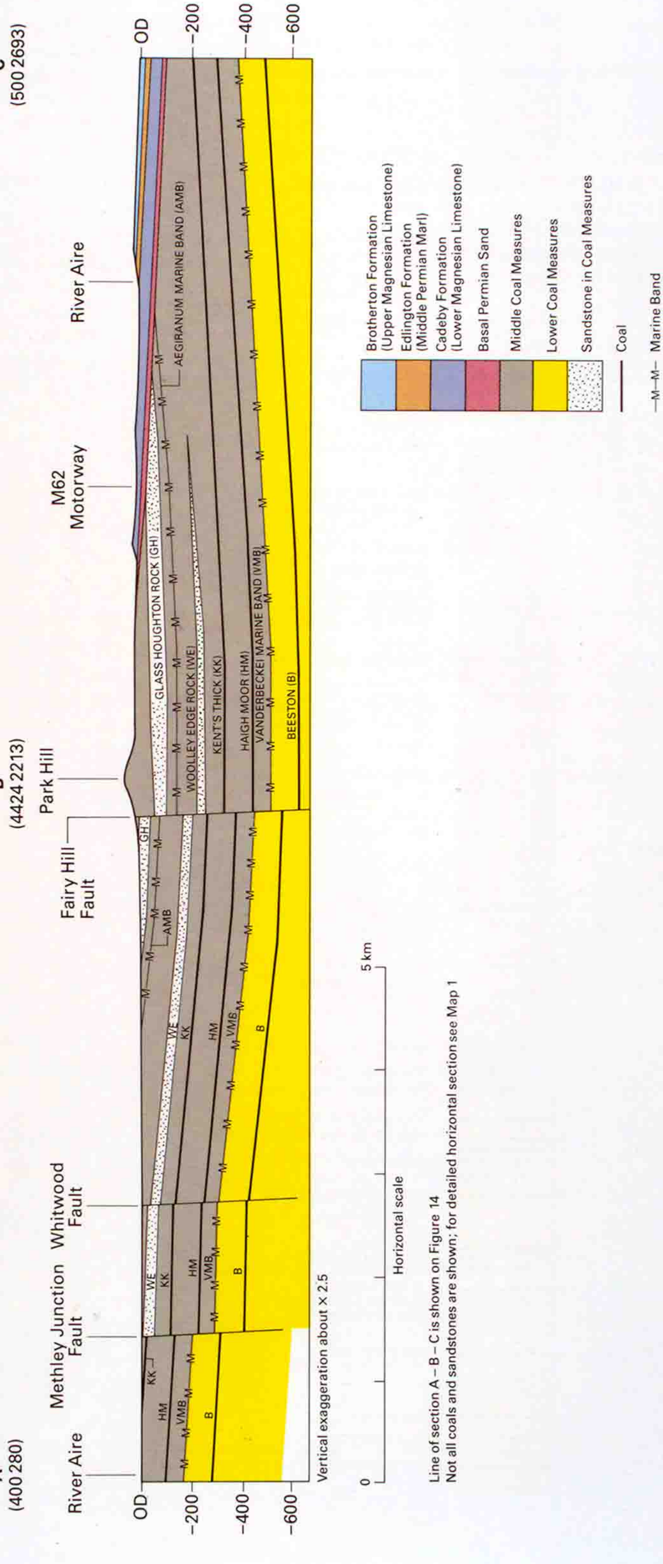


Figure 16 Generalised horizontal cross section

ding is typical. The formation ranges in thickness from 30m in the west to 90m at depth in the east.

Edlington (Middle Permian Marl) Formation

The Edlington Formation consists mainly of reddish brown mudstones and siltstones which weather at the surface to heavy sticky red clays. A characteristic feature is the presence of veins and seams of anhydrite (calcium sulphate) at depth which by the interaction with groundwater at shallower depths is converted to gypsum (hydrated calcium sulphate). Near-surface dissolution of the gypsum by groundwater has produced collapse of the overlying strata (p.19).

Brotherton (Upper Magnesian Limestone) Formation

The Brotherton Formation is a distinctive unit of pale grey and buff to white very thinly bedded limestones, dolomitic in part. Much affected by subsidence caused by dissolution of gypsum in the underlying Edlington Formation, the beds are commonly fractured and gently folded into sags and intervening domes.

Roxby (Upper Permian Marl) Formation

The Roxby Formation is similar to the Edlington Formation, consisting of reddish brown mudstones and siltstones weathered at outcrop to heavy red clays with gypsum and, at depth, anhydrite.

Triassic rocks

Sherwood Sandstone Group

Formerly known as the Bunter Sandstone, the Sherwood Sandstone, present only in the south-east and largely covered by drift, is a weakly cemented red-brown sandstone with some red mudstone layers. At outcrop it is generally weathered to a soft red sand.

MAP 2 – SUPERFICIAL DEPOSITS (Figure 17)

This map depicts the distribution of deposits, mostly unconsolidated, that lie on the solid rocks. They belong to the Quaternary era, all having formed within the last 1.5 million years, during which cold periods, some of them with glaciations, alternated with temperate ones. The area lay beyond the limits of the last (Devensian) ice sheets, and the glacial deposits that are preserved belong to an earlier glaciation (Table 2). The Flandrian period began when the climate ameriolated at the end of the Devensian. Figure 18 is a schematic representation of the deposits and their inter-relationships.

Continuous spreads of superficial deposits occur in the valleys of the Aire and Calder, and in the flat-lying ground in the south-east (the 25-Foot Drift of the Vale of York). Elsewhere they occur in patches that are the dissected remnants of formerly more extensive spreads.

Boundaries of superficial deposits

The mapped boundaries of superficial deposits are rarely be precise. The deposit may thin towards its edge, and locating the exact position of the feather edge may be either impossible or not practical where the deposit is less

Table 2 Geological succession of superficial deposits

Approximate Years Before Present	Stages		
0			
	Flandrian	Landslip Peat Alluvium Head	
10,000			
	Devensian	Glaciolacustrine Sand Glaciolacustrine Silt and Clay Littoral Sand and Gravel Older Littoral Sand and Gravel River Terrace Deposits Till	
70,000			
	Ipswichian	Silt and Clay Older River Gravels	
130,000			
	?Anglian	Till Sandy Till Glacial Sand and Gravel Fluvioglacial Sand and Gravel Older Glaciolacustrine Silt and Clay	'Older Drift'

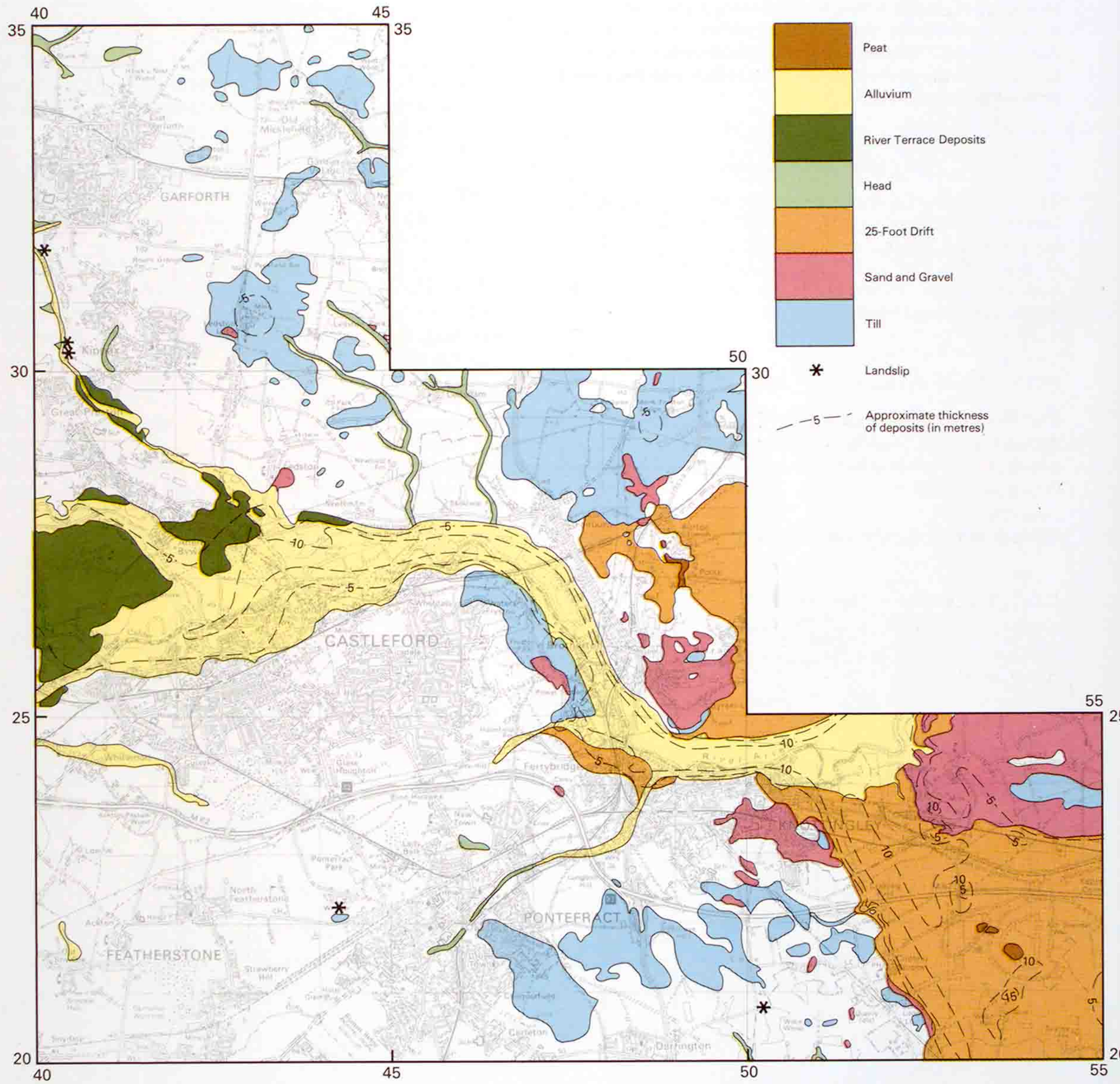


Figure 17 Superficial deposits

than about 1 m thick. The deposit may pass laterally and vertically into another, with a transition zone between the two. Soil creep (solifluction) and downwash of deposits on sloping ground and cryoturbation (disruption by freeze/thaw during cold periods) renders the boundaries diffuse. As with the boundaries of the solid rocks, disturbance by man, through groundwork schemes, agriculture and building, has added to the diffuseness of some boundaries and to the difficulty in locating them precisely. For these reasons, **all superficial boundaries shown on the map should be regarded as conjectural, and as the best approximation and interpretation of the data available at the last date of survey. Trial pitting and boreholes will be necessary to ascertain the precise position and nature of the boundaries of the superficial deposits.**

In addition to the superficial deposits shown on the map, thin deposits may be present in the areas shown as drift-free. It is also likely in the areas of limestone outcrop that small unmapped areas of drift occur, some of which may fill bedrock hollows to depths of several metres (p.19).

Vertical distribution of superficial deposits

The map shows the deposits which occur at the surface. These may persist throughout the total thickness of the deposit down to rockhead. However, it is common for the deposit at the surface to be the top layer of a sequence of variable deposits.

Classification of superficial deposits

The deposits are classified below according to their mode of origin, and grouped accordingly. A fuller description of the deposits is given in Appendix 1 and their engineering characteristics described in Appendix 2. The following notes summarise their main characteristics.

GLACIAL DEPOSITS

Till is a heterogeneous deposit comprising pebbles, cobbles and boulders in a matrix of clay. Two varieties are differentiated on the map, till and sandy till, although there is a gradation between the two and the distinction is arbitrary and based on surface field characteristics. In till the matrix is generally a stiff reddish brown clay derived from outcrops of the Permian mudstones; sandy till has a matrix in which sand is a large component. The stones in the till are predominantly of sandstones derived from the outcrops of the Millstone Grit and Coal Measures.

Glacial sand and gravel is a mixture of sands and gravels which generally occurs in close proximity to till.

Glaciofluvial sand and gravel contains evidence of deposition in streams that flowed from melting glacier ice.

Glaciolacustrine silt and clay formed in lakes or smaller bodies of standing water during glacial periods. They occur mainly in the 25-Foot Drift of the Vale of York, deposited within a lake (Glacial Lake Humber) that existed during the last ice age. Smaller deposits occur in channels cut in the Sherwood Sandstone outcrop east of Kellingley.

Glaciolacustrine sand occurs extensively as part of the 25-Foot Drift, and lies within the area that was occupied by Lake Humber. The sand ranges in grain size from fine to coarse, and contains layers of coal and coaly mudstone fragments.

LAKE BEACH DEPOSITS

Littoral sand and gravel occurs at two levels, the higher up to 30 m above OD, the lower at about 8 m above OD. Both are the beach deposits of Lake Humber, the higher formed during an early high level phase of the lake, the lower during a later, more prolonged period when lake level was at about 8 m. The higher deposits are clean sands and gravels, and were formerly extensively dug on Lunn Hill. The lower ones are pebble gravels and clean sands.

FLUVIAL DEPOSITS

Older river gravels occur below the 25-Foot Drift deposits, and do not appear at the surface.

Alluvium occurs widely, infilling the bottoms of valleys. It comprises a heterogeneous mixture of clay, silt, sand and gravel. The principal occurrences are in the Aire and Calder valleys, where up to 13 m are present.

Terrace deposits in the Aire valley are the remnants of old alluvial deposits, and consist of sand and gravel (mainly), silt and clay.

ORGANIC DEPOSITS

Peat is of minor occurrence; details are given on p.60.

MASS MOVEMENT DEPOSITS

Head is ubiquitous, but generally too thin to map. It occurs on slopes and in the bottoms of dry valleys on the outcrop of the limestones. Formed by solifluction (downward creep) of weathered parent material down a slope, its composition reflects that of the parent source, and therefore ranges from clays to silts and sands with stones. The deposits in the dry valleys, formed by a combination of solifluction and colluvial processes (downwash) are generally thicker than 1 m.

Landslip deposits (p.19) are of minor occurrence, as slopes in the area are generally low. Three in Coal Measures mudstones and one in clays of the Edlington Formation are shallow earth flows. The fourth is a rotational failure in the basal beds of the Cadeby Formation.

MAP 3 MADE GROUND (Figure 19)

The map shows the distribution of man made deposits at the time of survey. Two categories are distinguished (Fig.10):

1. Deposits that lie on the original ground surface.
2. Deposits that fill, or partially fill a former or existing pit, quarry, or other excavation, known as backfill.

The map has been compiled by reference to the following sources:

1. Data obtained during the field surveys for the present study, and, in the case of Sheet SE 42NW, data obtained in 1986
2. Previous Ordnance Survey and Geological Survey six-inch maps
3. Aerial photographs taken in 1971, 1973 and 1980

Not generally shown are the thin, but ubiquitous deposits that occur in the urban areas, and along roads and rail-

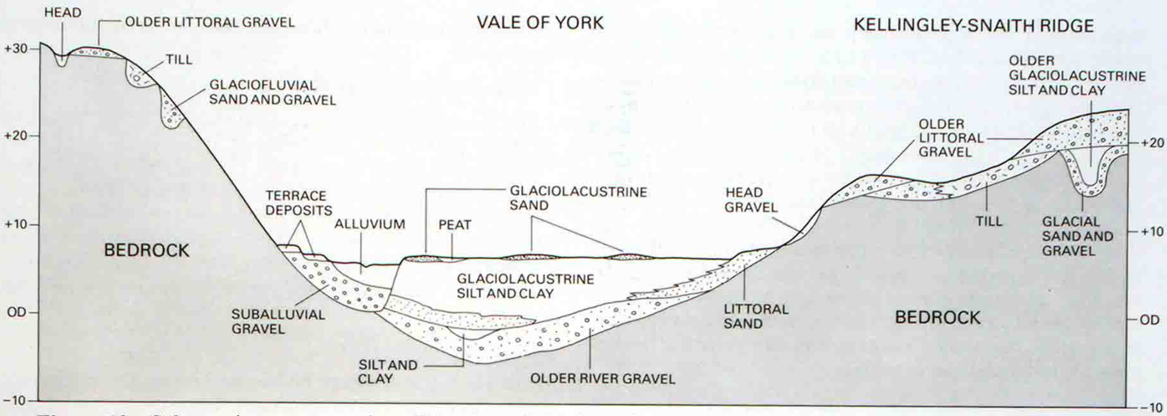


Figure 18 Schematic representation of the superficial deposits

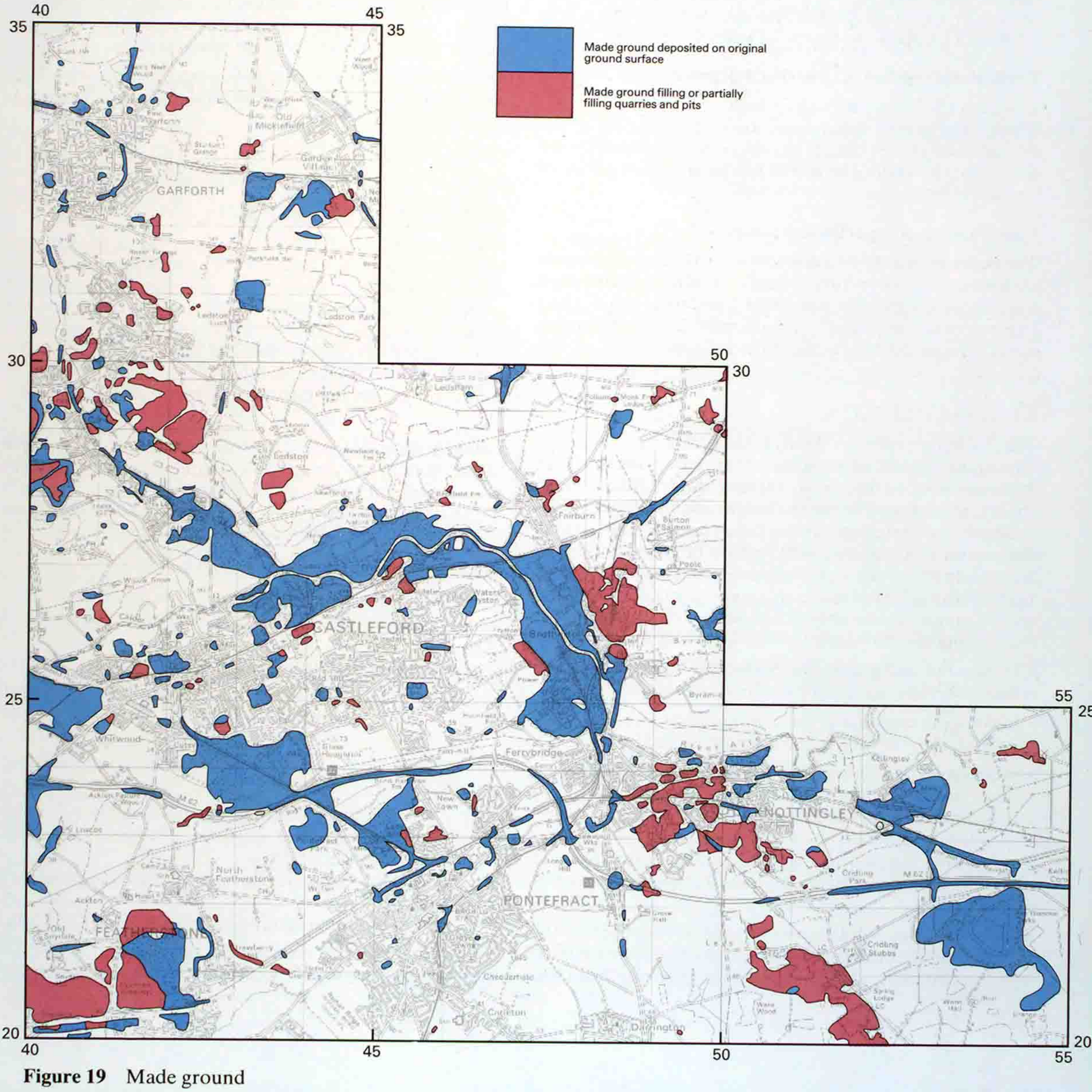


Figure 19 Made ground

ways. These are mainly less than 1 m thick, but may locally exceed 1 m.

The principal occurrences of made ground are listed by number and briefly described in the map margin. They include several major landfill and waste disposal sites. The problems associated with made ground, including methane generation, leaching of toxic pollutants and foundation design are discussed on p.17.

Domestic waste is currently being tipped at the following sites:

1. Disused quarry, Betteras Hill (Locality 42NE/6), where methane is being vented by deep trenches filled with limestone aggregate cut through the fill.
2. Disused quarry, Monk Fryston (Locality 42NE/2).
3. Darrington Quarries (Locality 52SW/14), a working quarry that is being progressively backfilled by West Yorkshire Waste Management Services.There is also some colliery spoil. An adjacent former quarry (Locality 52SW/17) was backfilled with domestic waste, and is now generating methane, some of which is flared off and the remainder used to heat the quarry offices.

Colliery spoil from Kellingley is currently being dumped at Spring Lodge Quarry (Locality 52SW/20), that from Prince of Wales Colliery at Cornwall Opencast Site (Locality 42SE/3).

Industrial waste is being deposited in a disused quarry in the Brotherton Formation at Knottingley (Locality 42SE/18).

Power station waste is pumped as slurry from Ferrybridge and Eggborough power stations and deposited at Gale Common in large slurry lagoons contained by embankments and pulverised fuel ash (Localities SE 52SW/22, 23 and 24).

MAPS 4 and 5: ENGINEERING GEOLOGY

These maps are based on the field mapping carried out for the study, and, in the case of sheet SE42NW, that carried out in 1986. Map 4 shows the engineering geology of the solid rocks, Map 5 that of the superficial deposits. They show groupings of materials with similar geotechnical properties, values of which were extracted from investigation reports on sites within the the area covered by sheets SE 42SW, SE, NE and 52SW.

A detailed discussion of the engineering geology of the study area and descriptions of the geotechnical tests for which results were assessed are given in Appendix 2.

Both maps should be examined to obtain an indication of ground conditions in a specific area, and Map 2 should be examined to obtain an approximate thickness of any superficial (drift) deposits. It should be noted that in areas shown as being drift-free, a mantle of weathered material and thin drift deposits may be present. It is also possible that undetected pockets of thicker superficial deposits may occur. Map 3 should be examined to ascertain if any made ground is present. It is emphasised that these maps present only a general guide to the ground conditions, and examination of them is no substitute for detailed investigation to ascertain the conditions prevailing at any specific site.

Map 4 ENGINEERING GEOLOGY : SOLID ROCKS (Figure 20)

This map shows the distribution of groups of solid rocks with similar engineering properties, and is based on the bedrock geology (Map 1).

Summary values of geotechnical parameters for the groups are presented in Tables 6 to 23 in Appendix 2. It is stressed that they should be considered as a general guide only and not used in detailed design calculations.

The relationship between the engineering geology groups and the solid rock formations are shown in the map margin and Table 3.

The groups encompass engineering rocks and engineering soils, a rough distinction based on differences in physical and mechanical properties. Groups 1 and 2 are classes of engineering rock, Group 3 is an engineering soil. Group 4 includes materials with geotechnical characteristics bordering on those of a 'weak' engineering rock and a 'strong' (overconsolidated) engineering soil. Weathering of the engineering rocks, including mudrocks, may produce material classified as an engineering soil.

Detailed descriptions of the groups are given in Appendix 2.

Table 3 Engineering groups – solid geology

Engineering Geological Group	Geological unit
1. Limestones	Brotherton (Upper Magnesian Limestone) Formation Cadeby (Lower Magnesian Limestone) Formation
2. Moderately strong sandstones	Coal Measures sandstones
3. Friable sandstones and dense sands	Sherwood Sandstone Group Basal Permian Sand
4. Mudrocks	Coal Measures mudstones and siltstones Roxby (Upper Permian Marl) and Edlington (Middle Permian Marl) formations

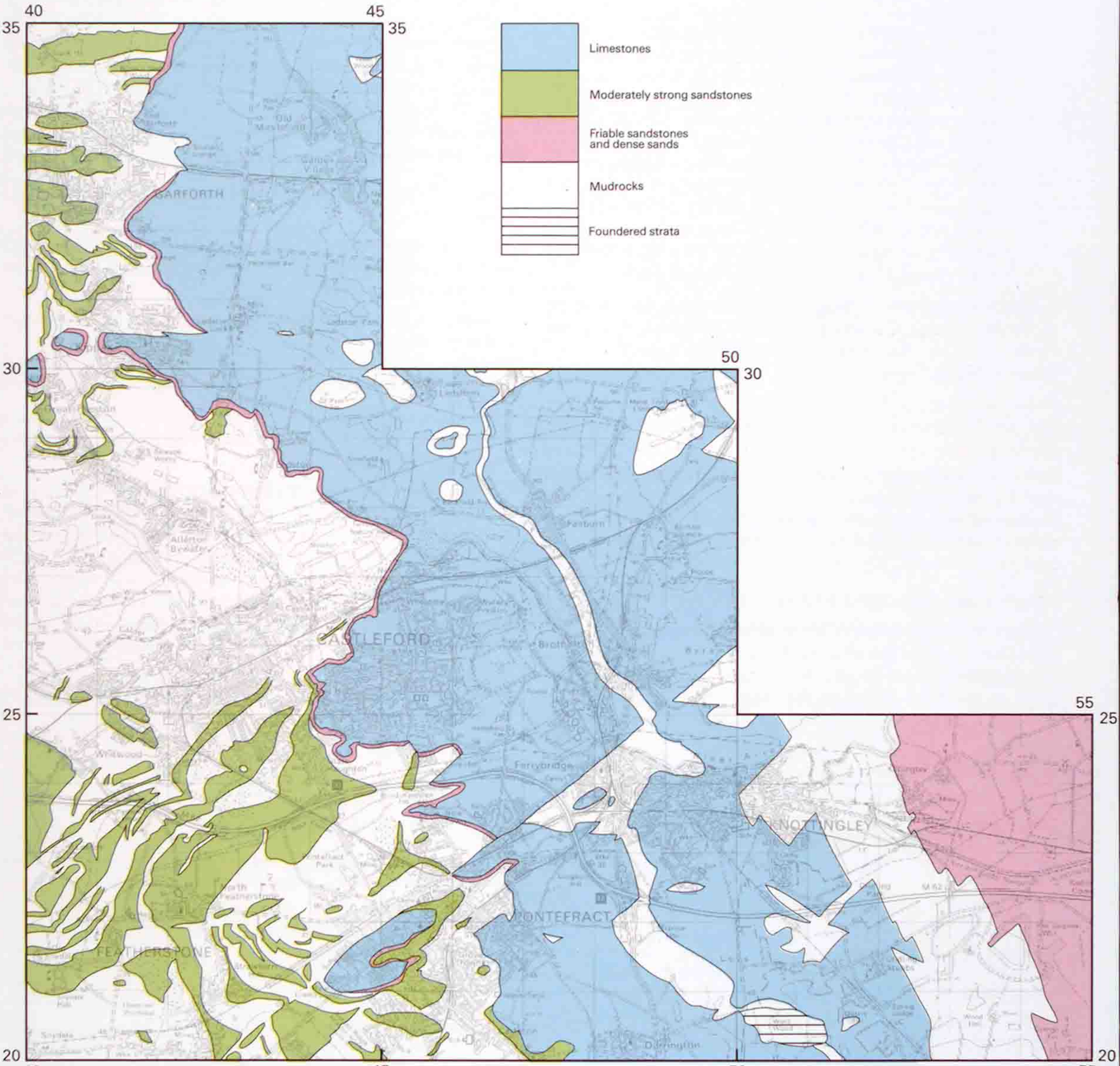


Figure 20 Engineering geology of the solid rocks

Limestones

The limestones and dolomites of the Brotherton (Upper Magnesian Limestone) and the Cadeby (Lower Magnesian Limestone) formations consist of the following rock types:

Upper Magnesian Limestone: pale grey and buff, weak to moderately strong, thinly bedded, dolomitic limestones with thin mudstone layers

Lower Magnesian Limestone: buff, weak to moderately strong, thinly bedded to massive, dolomites and dolomitic limestones, marly limestones and breccias with thin mudstone layers

They have highly variable engineering properties (Tables 6 and 7, pp.65,66). Joint spacing ranges from about 60 – 200 mm to over 2 m. The depth to which weathering extends below rockhead is variable, site investigations recording weathering up to 12 to 15 m below ground level. Weathered zones have also been reported in the vicinity of the water table and at the base of the Lower Magnesian Limestone. Dissolution effects are described on pp.18-19.

Moderately strong sandstones

The sandstones of the Coal Measures are moderately well jointed, weak to moderately strong, well-graded and micaceous; siltstone, mudstone and coal partings are also present. The depth and intensity of weathering is variable but may extend down joints and faults to about 7 m below rockhead; zones of moderately to highly weathered rock have been recorded 40 m below the ground surface. Summary geotechnical properties are given in Tables 9 and 10 (pp.70,71).

Friable sandstones and dense sands

Sherwood Sandstone Group

The Sherwood Sandstones are brick-red to orange brown, weakly cemented, cross-bedded, fine to medium grained sandstones with some thin layers of red mudstone. Although moderately strong at depth, they are weathered to a weak friable sandstone or loose to very dense sand to depths of up to 12 m below rockhead. The small amount of geotechnical data available is summarised in Table 11 (p.73).

Basal Permian Sand

At outcrop the Basal Permian Sand consists of up to 3 m of buff to yellow, generally uncemented, moderately weak, soft friable sandstone and dense, medium to fine uniform sand. The available geotechnical data (Table 12, p.74) are insufficient for a meaningful assessment.

Mudrocks

The mudrocks of the Coal Measures and Permian formations range from weak rock to strong, overconsolidated soil.

Coal Measures mudrocks

These consist of grey to greyish brown, moderately fissured, weak to locally moderately strong, mudstones, silty mudstones and siltstones. Seatearths with these lithologies are common. They are particularly prone to breakdown by weathering, and completely weathered firm to stiff, silty clays may occur up to 6 m below the surface. Moderately to highly weathered material, comprising softened mudstone clasts in a silty clay matrix, may occur to depths of about 10 m. Weathered zones have been recorded at depths over 50 m, due to groundwater movement down faults, joints and in an overlying sandstone aquifer, or because of oxidation in old mine workings. The degree of weathering influences engineering behaviour, and summary geotechnical properties of fresh to slightly weathered and moderately to completely weathered mudrocks are presented in Tables 13 and 14 (pp.75,76). Summary geotechnical properties of the siltstones are given in Table 15 (p.77).

Permian mudrocks

These are reddish brown, green and grey, weak to moderately weak, mudstones and silty mudstones, with greenish grey siltstone. Gypsum layers and mudstone breccias are common. At outcrop, they are invariably weathered to a firm to hard clay. Increasing weathering results in increased plasticity, compressibility and moisture content and decreased strength. Geotechnical properties are given in Tables 16 and 17 (pp.82,83).

MAP 5 ENGINEERING GEOLOGY OF THE SUPERFICIAL DEPOSITS (Figure 21)

The groups of superficial deposits and their geological equivalents are shown in the map margin and in Table 4. Detailed descriptions of the engineering geology of the groups are given in pp.84 – 96.

Made Ground

Made ground (Map 3; Fig. 21) is a superficial deposit, and mention of its engineering characteristics is appropriate here. The materials of landfill sites are variable in composition, thickness and geotechnical properties, and must be investigated prior to development. They range from chemical, mining and quarry waste and domestic refuse to bulk fill derived from the bedrock formations (p.17). A meaningful geotechnical assessment cannot be made because of the variability of the materials.

Peat

Peat is not widespread, and no geotechnical data were obtained. It comprises dark brown to black, fibrous or amorphous, soft organic debris and very soft to firm, organic clays. Geotechnically, peat is extremely plastic and highly compressibile, with very low shear strengths. Excavations are very unstable and prone to severe groundwater problems (p.85).

Normally consolidated/loose heterogeneous deposits

Head

The composition of head (p.85) depends on that of its parent material. It is a soft to firm sandy, silty clay with stones over much of the study area, but head derived from sandstones and sand and gravel deposits is predominantly

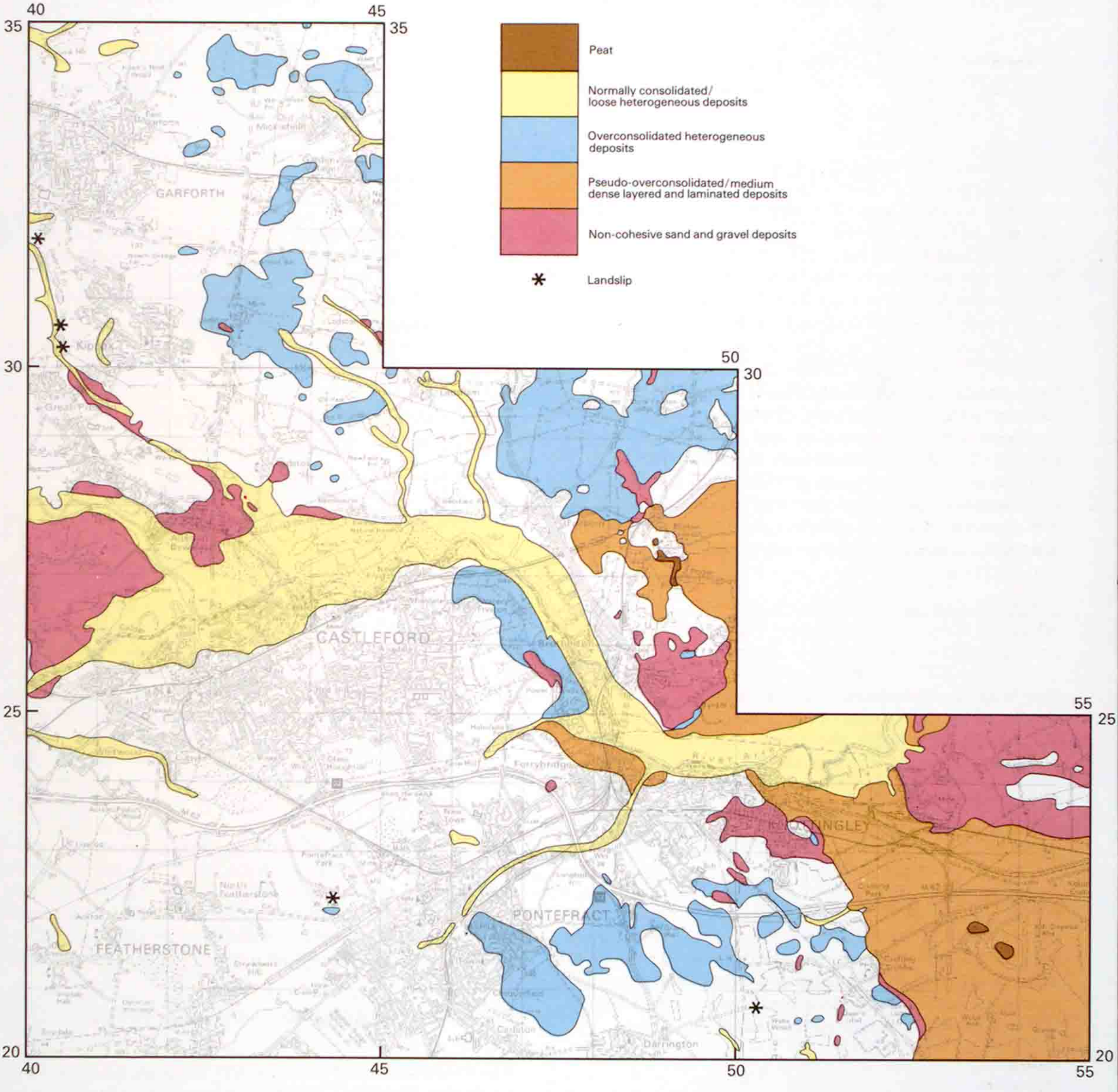


Figure 21 Engineering geology of the superficial deposits

Table 4 Engineering groups – superficial deposits

Engineering geology group	Geological deposit
Made Ground	Made Ground
Peat	Peat
Normally consolidated/loose heterogeneous deposits	Head Alluvium
Overconsolidated heterogeneous deposits	Till (Boulder Clay)
Pseudo-overconsolidated/medium dense layered and laminated deposits	Glaciolacustrine sand Glaciolacustrine silt and clay Older river gravels (not exposed)
Non cohesive sand and gravel deposits	Terrace deposits Littoral sand and gravel Glacial sand and gravel Glaciofluvial sand and gravel
Landslip	Landslip

sandy. Head forms a generally ubiquitous cover on the Coal Measures and Permian rocks, usually as a thin veneer less than 1 m thick, but greater thicknesses accumulate at the foot of slopes and in hollows. Thicknesses ranging up to 6m are recorded in site investigations, but the distinction between head and weathered in situ bedrock is difficult, and the true maximum figure is likely to be considerably less. The mapped occurrences are generally over one metre thick, but head should be assumed to occur on slopes elsewhere as a thin veneer of variable thickness. Summary geotechnical properties are given in Tables 18 and 19 (pp.86,87).

Alluvium

Alluvium is a heterogeneous deposit consisting of soft to firm, silty clays and clayey silts, very soft to soft organic clays and peat, and loose to medium dense sands, with layers, lenses and pockets of sand and silt. Because of the vertical and lateral variation in materials, geotechnical properties (Table 21) will vary markedly across sites, and at depth.

Overconsolidated heterogeneous deposits

This group covers the glacially derived boulder clay (till) deposits which occur as irregular sheets and patches. Geotechnical data (Table 22) have been obtained along the route of the M62 Motorway, where the till is a grey or brown, firm to very stiff, sandy silty clay with subangular to rounded pebbles, cobbles and boulders. The matrix is a silty clay of low to intermediate plasticity, low compressibility and high shear strength, but stones and sand lenses cause local variations in engineering behaviour. High plasticity clays may be encountered locally.

Pseudo-overconsolidated/medium dense layered and laminated deposits

This group consists mainly of the glaciolacustrine deposits of the 25-Foot Drift of the Vale of York (p.27). Also included are the laminated clays filling buried channels on the Kellingley-Snaith Ridge (p.58). The 25-Foot Drift is a complex of silts, sands and clays, considered for the purposes of this study as a single, engineering geological group. The deposits rest on Older River Gravels (p.58), which are expected to have similar engineering properties to the gravels described below. Summary geotechnical data are given in Table 23.

Non-cohesive sand and gravel deposits

Virtually no geotechnical data has been collected for this group, but in general terms, they are medium dense to dense, generally well-sorted, water-bearing sands and gravels of low compressibility and high rates of consolidation settlement.

Landslip

The minor occurrences of landslip in the study area are described on p.19.

MAP 6 GEOMORPHOLOGY (Figure 22)

This map shows the physical aspects of the study area, including escarpments, dry valleys, terraces and karst features. Six categories of terrain are recognised, each dependent on the underlying solid rocks and drift deposits:

(1) the exposed coalfield area

(2) Permian limestone area

(3) Permian mudstone area

(4) the Kellingley-Snaith Ridge

(5) Vale of York 25-Foot Drift area

(6) the floodplain of the rivers Aire and Calder

(1) The exposed coalfield area in the west is one of generally low undulating relief in which thick sandstones make small escarpments. Coal mining has resulted in much of the terrain being covered by mining waste and urban development. Opencast mining has produced substantial

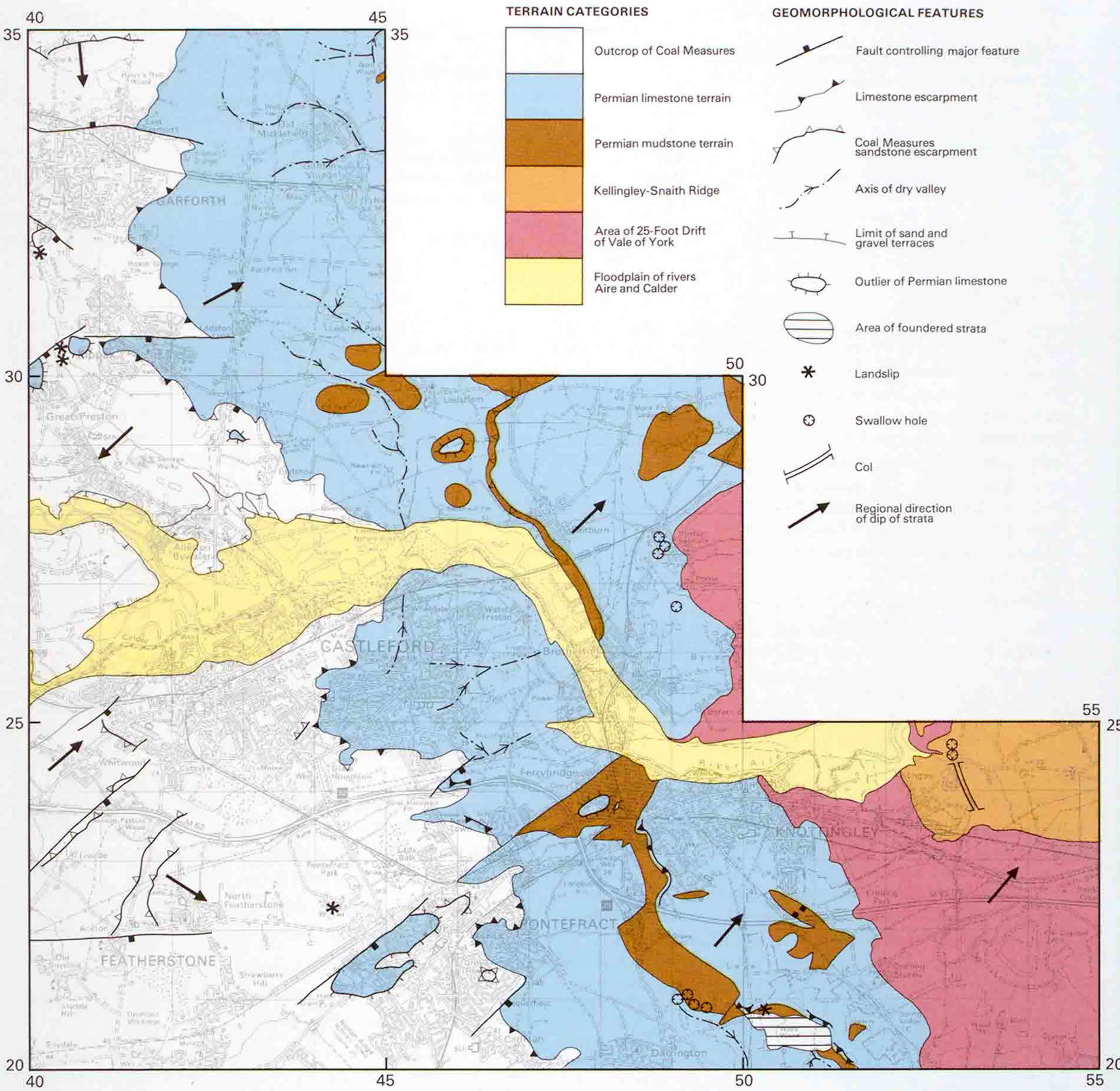


Figure 22 Geomorphology

Table 5 Slope steepness classes and examples of land-use limitations (based on Small and Clarke, 1982)

SLOPE STEEPNESS CLASSES			EXAMPLES OF LAND USE LIMITATION*
Degrees	**Gradient**	**Percent**	
>11°	>1 in 5	>20%	significant engineering problems locally for slopes over 15°; mainly pasture; special vehicles usually required; for slopes between 11° and 15° road building is difficult, absolute limits for most wheeled vehicles, including tractors, are approached, and ploughing is not generally possible without contour terraces
3° – 11°	1 in 20 to 1 in 5	6% – 20%	slopes over 7° are the upper limit for large sites for industrial and housing construction; problems for wheeled tractors and combine harvesters; on slopes between 3° and 7° construction of housing and roads becoming difficult; problems for large-scale mechanised agriculture; maximum for railways and large-scale construction
<30°	<1 in 20	<6%	poor drainage on flat clayey ground; flood risk present on flat low-lying areas; slopes of 1° – 2° are, ideally, the maximum for mainline railways and major roads; soil erosion possible as slopes approach 3°

* Stability of slopes is dependent on a number of inter-related factors such as lithology, structural discontinuities, groundwater regime, etc. Modification of slope profiles by engineering works may result in local shallow slope failures on slopes >3° if equilibrium conditions are adversely affected and appropriate remedial measures are not taken during site preparation and construction.

areas of made ground and extensively remodelled the topography.

(2) The Permian limestone terrain comprises the outcrop of the Cadeby (Lower Magnesian Limestone) Formation in the west and that of the Brotherton (Upper Magesian Limestone) Formation in the east. The basal beds of the Cadeby Formation form the most prominent escarpment of the area, extending in a north-south direction, and reaching a maximum height of 104 m above OD at Garforth. To the east, the limestone terrain slopes gently to the east into the strike vale of the Edlington Formation. The limestones of the Brotherton Formation form a smaller escarpment, to the east of which they slope gently to the 25-Foot Drift area. Isolated from their main outcrops are a few small outcrops of limestone, shown on the map as outliers of limestone.

A range of features are present that result from the dissolution of the limestones and dolomites by ground and surface water (p.18). Dry valleys occur where former streams have gone underground or dried up. Fissures and joints are commonly widened and filled with unconsolidated weathered material. Swallow holes (dolines) are circular depressions caused by collapse above underground cavities. An area of foundered strata around Wake Wood [507 206] (p.19) was caused by dissolution of the topmost beds of the Cadeby Formation. Foundering of the Brotherton Formation (p.19) has also occurred because of dissolution of gypsum in the underlying Edlington Formation.

(3) The Permian mudstone terrain is one of heavy red clay soils. It is mainly restricted to a narrow strike vale in the south-central part of the area, with some small outliers.

(4) The Kellingley-Snaith Ridge occupies a small area in the south-east, and protrudes above the 25-Foot Drift area, reaching a height of 24m above OD. It consists of soft sandstones of the Sherwood Sandstone overlain mainly by sand and gravel, resulting in light sandy soils.

(5) The Vale of York 25-Foot Drift area lies in the south-east. It is almost flat, and has a surface height of about 8m (25′). Sands form slightly raised features locally, and interdigitate with clays and silts. The soils range from light sandy loams to heavy clays. Waterlogging of the clays is common in wet weather.

(6) The floodplain of the rivers Aire and Calder is a flat belt adjacent to the rivers about 4m above normal river level. Alluvial silts cover much of the floodplain, and are underlain by clays, silts and sands. In most of the ground east of Ferrybridge artificial levées now confine the flooding of the river. West of Ferrybridge, mining subsidence has resulted in areas of permanent standing water known as ings, much of which have been used for tipping of colliery spoil.

Terraces

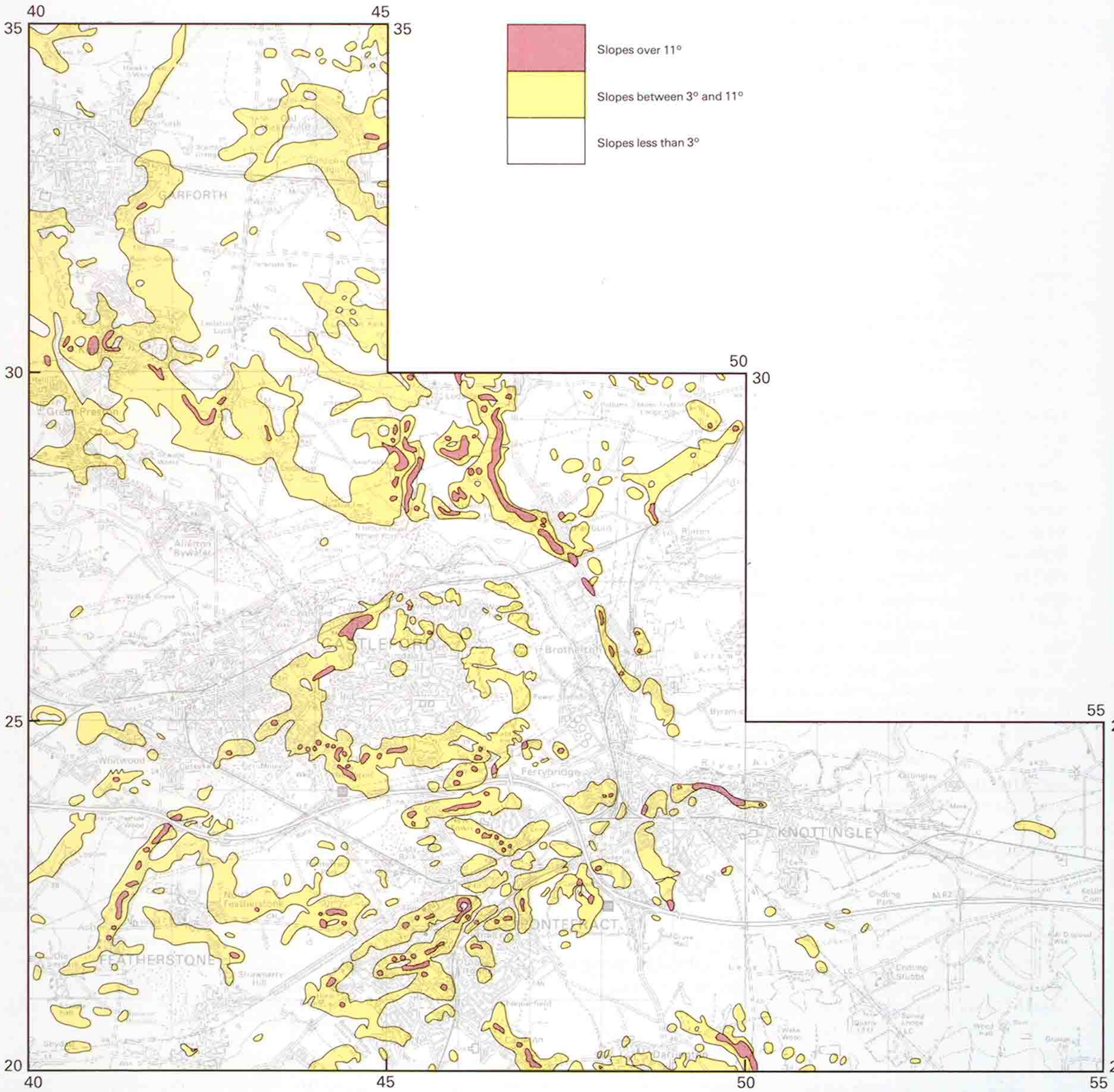
River deposits forming flat terrace features occur west of Castleford near the confluence of the rivers Aire and Calder (p.59).

Landslips

Landslips are of minor occurrence; the five small occurrences are described on p.19.

Slope steepness (Figure 23)

Slope steepness (not shown on Map 6) is an important parameter in planning and development, providing a constraint for some land uses. There is a close relationship between slope steepness and factors such as slope stability, the design gradients of roads and railways, the use of



Slopes over 11°
Slopes between 3° and 11°
Slopes less than 3°
GARFORTH
CASTLEFORD
PONTEFRACT
FEATHERSTONE
KNOTTINGLEY
Ferrybridge
Brotherton
Whitwood
Great Preston
Allerton Bywater
40
45
50
55
35
30
25
20

agricultural machinery and certain types of construction plant, housing density and industrial development.

It is rarely possible to assign a precise slope steepness value to what can or cannot be done safely on a particular slope. Slopes in excess of 15° (1 in 4) may be stable in a coherent massive limestone but unstable in a weak saturated clay. Most rocks and soils have a threshold value of slope steepness beyond which they become unstable. For any particular rock or soil type this value will depend not only on lithology but also on factors such as the presence or absence of discontinuities, the inclination of the bedding, the nature of the underlying and overlying strata, the degree of weathering, the hydrogeological conditions prevailing and vegetation cover. Therefore, the threshold slope steepness value for stability need not be the same for all slopes of the same lithology and will vary according to the inter-relationship of all the controlling factors. However, given similar slope conditions, similar lithologies will tend to have consistent threshold slope values, but these may change with time as weathering of the slope progresses.

Slope steepness has a variable rather than absolute value, which will alter with changes in the factors controlling slope equilibrium. These changes can be brought about by natural processes or by modification of the slope by engineering works. The controlling factors and the effect of changes on them are site-specific. Figure 23 gives only a general indication of slope values. Design judgements or slope stability assessment should be based on site measurements.

Figure 23 was derived from the spacing of 5m contours on the 1:25 000 scale Ordnance Survey topographic maps. The values of slope steepness chosen as class boundaries are generally considered as bounding values for development, construction and other land uses. For example, a slope of 1 in 5 (11°) is often considered as a planning boundary for urban (constructional) and large-scale industrial site development. The slope classification adopted in this study and its significance for land use are presented in Table 5.

Natural slope instability poses no significant problems to planning and development in the study area, but modification by engineering works which adversely alters the conditions controlling slope equilibrium may trigger mass movements locally, for example in excavations and cuttings. Such failures are most likely to occur in the superficial deposits and in the highly weathered materials which mantle slopes in the Coal Measures and Permian mudrocks, particularly on the steeper slopes such as the ones below the base of the Cadeby Formation.

MAP 7 HYDROGEOLOGY (Figure 24)

This map shows the outcrops of the aquifers of the study area, the Sherwood Sandstone, Brotherton (Upper Magnesian Limestone) Formation, Cadeby (Lower Magnesian Limestone) Formation and the main sandstones of the Coal Measures. The map shows approximate depths to the Cadeby Formation, the area's principal aquifer, and the location of wells licensed to abstract groundwater. Appendix 3 (pp. 00-00) gives a detailed account of the hydrogeology of the area, the following notes provide a summary.

For clarity superficial deposits are not shown on this map. In the Aire and Calder valleys the gravels are water-bearing but have little capacity for storage and are recharged with river water and not groundwater. The sands and gravels underlying the Vale of York area are also water-bearing.

Mean annual precipitation ranges from about 650mm in the west to less than 640mm in the east. Annual losses due to evaporation and transpiration are about 430mm.

Water for public supply comes largely from outside the district, the Pontefract area being supplied from underground storage reservoirs at Park Hill [4408 2205] that receive water pumped from boreholes in the Sherwood Sandstone to the east.

The Coal Measures form a multi-layered aquifer, with groundwater contained in the sandstones. Flow of water can occur between the sandstones, mainly along faults and in mine workings. The main sandstone aquifers are the Thornhill Rock and the Glass Houghton Rock; the Haigh Moor Rock, Woolley Edge Rock, Ackton Rock and Ackworth Rock, are locally hydrogeologically important. Their outcrops are shown on this map, the incrops of the Thornhill Rock and Glass Houghton Rock (areas where they occur directly below and are in hydraulic continuity with the Permian rocks) on Map 13 (Fig. 32).

The sandstones are generally sufficiently well cemented to be impermeable, and groundwater is contained in, and flows through, joints and faults.

In the vicinity of working coal mines groundwater levels are commonly depressed by mine dewatering, although when pumping is stopped the workings become flooded, forming a local reservoir. In the study area the discharges from Prince of Wales [451 228] and Kellingley [526 237] collieries appear to have a negligible effect on groundwater levels in the overlying aquifers.

Shallow groundwater in the Coal Measures is usually of fair quality but water from below about 100m, including that in most mine workings, is rarely potable, mainly because of high concentrations of dissolved iron compounds.

The Cadeby Formation is a fissure-type aquifer, the matrix of the rock being generally impermeable, with groundwater contained in and flowing through fissures, including caverns, and faults. Natural rest water levels are generally about 5 to 15m above Ordnance Datum but lower in the river valleys. Fluctuations in natural groundwater levels are unlikely to exceed 5m. Levels are depressed close to continuously pumping wells; at Ferrybridge [470 260] for example, the level is 2 to 3m above OD. On cessation of pumping recovery to natural levels is usually rapid. Water from the formation is hard and with a variable sulphate content that is greatest in boreholes more than 60m deep.

The Edlington Formation is an aquiclude between the Cadeby and Brotherton formations although faults and evaporite dissolution cavities may provide a high degree of hydraulic continuity. The evaporites give rise to a relatively high sulphate content in groundwater in the adjacent limestones.

The Brotherton Formation is similar to the Cadeby in hydrogeology and groundwater quality, but is used much less for groundwater supply. Total hardness and sulphate concentration appear to be slightly lower on the evidence of the few analyses available.

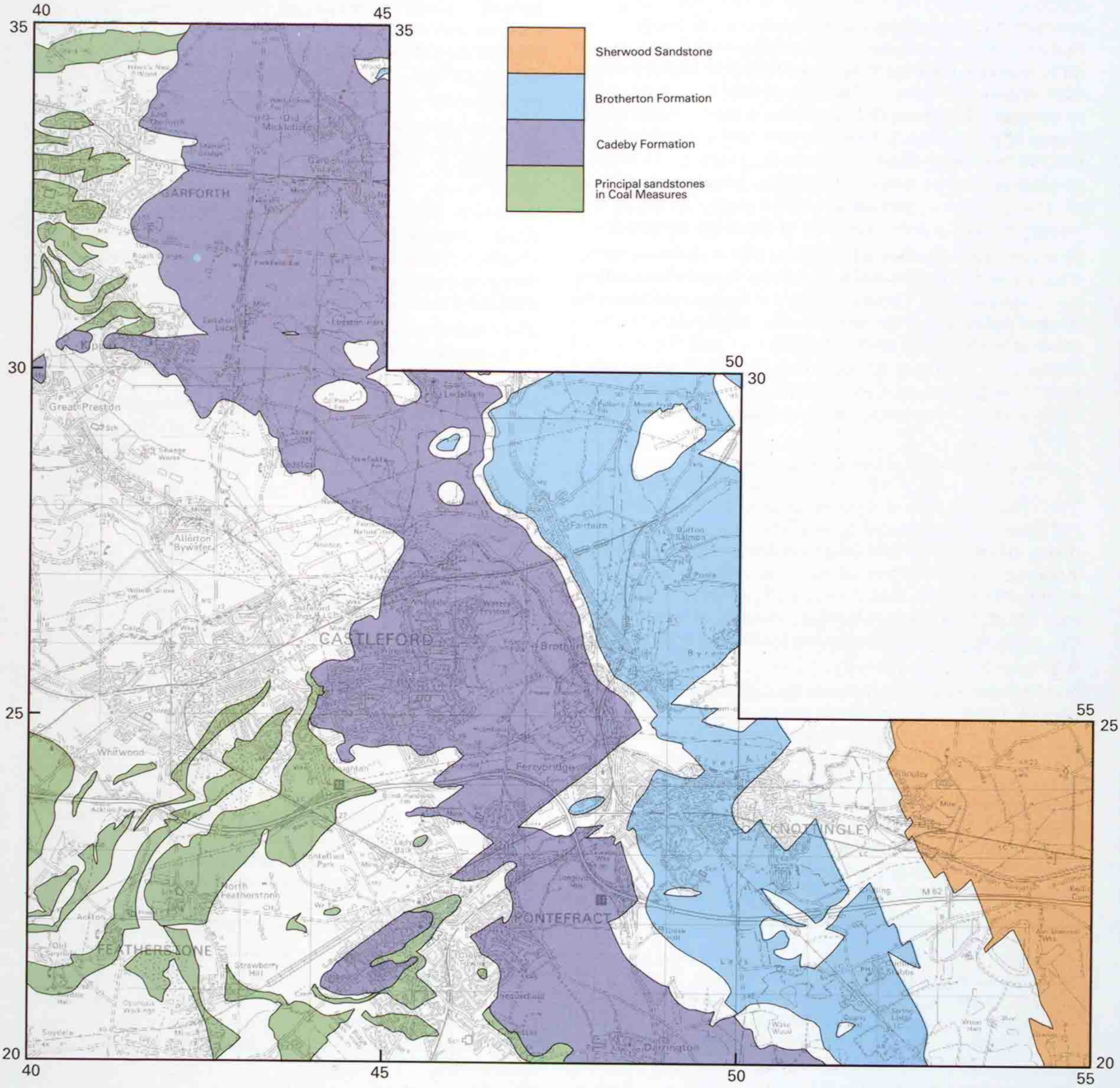


Figure 24 Outcrops of principal aquifers

The Sherwood Sandstone is one of the major aquifers in the United Kingdom. It occupies only a small part of the study area, in the south-east. Water flow is mainly through fissures and there is significant intergranular storage. Rest water levels are generally about 10m above OD, falling to near OD in the east, possibly in response to pumping beyond the district.

Groundwater contamination is discussed on p.18.

MAP 8 SHALLOW COAL MINING (Figure 25)

Shallow mining is defined arbitrarily as mining with less than 30m of rock cover. This thickness is selected because it is considered generally to be sufficient to accommodate the collapse of pillar and stall mine workings in coal seams of average thickness. Where there is more than 30m of rock cover the effects of collapse are unlikely to reach the surface as crown holes.

This map shows areas of shallow coal mining, opencast coal extraction and the location of shafts, bell pits and adits. Also shown are shafts in the exposed coalfield sunk to depths greater than 30m. Most of the information is derived from British Coal data and BGS archives, supplemented by the data from the recent survey. Field evidence of shallow workings is listed in the map margin. Three areas are delineated on the map:

(1) where coal workings are known or inferred to be less than 30m below rockhead, including a 100m-wide zone around known workings, shafts and bell pits

(2) where workable coal occurs at less than 30m below rockhead but there are no known workings

(3) where coal has been opencast mined in one or more seams

There is little information about the depth of shallow mine workings in the district and no plans exist. The general geological framework was used to determine where workable seams occur at less than about 30m below rockhead.

Shafts and bellpits (vertical) and adits (inclined) are openings mainly constructed for access to workings in coal. Shafts were also constructed along the line of drainage tunnels (soughs) for ventilation and access.

The location of all known shafts and bell pits is given on the map. There may be others that have not yet been detected. Some of the locations were recorded during the recent survey but most have been transferred from British Coal plans. The British Coal shaft register, held at the British Coal North Yorkshire Area office Surveyors' Department, includes data originating from earlier geological surveys, some of which have not been validated and could be subject to an error up to tens of metres. A close cluster of shafts may in some cases be due to inaccurate sitings of a single shaft. Other shafts, particularly those in built up areas, have been located and capped. It is essential that the British Coal shaft register is consulted for any specific site.

MAP 9 DEEP COAL MINING (Figure 26)

This map shows the area known from mine plans to be undermined in one or more seams at depths greater than 30m. It is a collation of data held by British Coal. Mining has taken place in twelve principal collieries, the locations of which are shown on the map; their date of sinking and, where appropriate, closure is listed in the map margin. Thirteen seams are mined, the approximate distribution of working in each being illustrated in the map margin (Fig. 27).

Notification of coal abandonment plans became compulsory in 1872. The older plans are at a scale of 2 chains to one inch, and many of them show only an outline of the workings. Modern plans are at the 1:2500 scale and show the workings, faults, seam levels and thicknesses, shafts and other information.

There are several hundred plans covering the study area, held at the Mines Record Office, British Coal Manvers Training Centre, West Yorkshire. All were photographed and reduced to 1:10 000 scale as part of the study.

MAP 10 MINERAL RESOURCES AND WORKINGS – SOLID ROCKS (Figure 28)

This map shows the distribution of the solid rocks which constitute a mineral resource, either as a specific mineral or bulk resource. Coal, the principal mineral resource, underlies the entire study area, and therefore is not separately shown.

Coal The coal at depth could only be worked by underground mining. However, coal at outcrop or under a thin cover of drift or Permian strata may be worked in opencast pits. Extensive underground and surface working has taken place in the past. Even so resources may remain where only part of the mineral was extracted. The distribution of the coals at outcrop in the west is shown on Map 1 (Fig. 14), their distribution at incrop below the Permian in the east on Map 13 (Fig. 32), and their workings on Maps 8 and 9 (Figs. 25, 26). The principal coal seams are discussed in Appendix 1 (pp.53-55).

Details of the other resources (moulding sand, limestone and dolomite, brickclay and fireclay, sandstone, gypsum and anhydrite) are given on pp. 9-10. Former and current workings are listed in the map margin and summarised below.

Moulding sand The Basal Permian Sand outcrop and workings are shown in detail on Maps 12a and b, and described on pp.11,17 and 47. The Sherwood Sandstone is currently dug on a small scale in a small pit [5412 2438] on Lunn Hill.

Limestone and dolomite The Cadeby Formation is mainly dolomite, the Brotherton Formation mainly limestone. The latter has been extensively quarried, the former to a much lesser extent. The Cadeby Formation was dug for lime and local building use in the past, today it is being quarried at Peckfield Quarry, Micklefield for aggregate (Plate 5). The Brotherton Formation is currently being quarried at Fox Quarry, Darrington Quarries and Spring Lodge Quarry. Formerly a building stone and source of agricultural lime, it is today mainly crushed for aggregate, with some used for cement manufacture. The formation is virtually worked out at outcrop between the M62 Motorway and the southern boundary of the study area. There are also extensive quarries in the Brotherton and Knottingley areas (Plate 6), with remaining reserves largely sterilised by building or covered by drift.

Brickclay and fireclay The mudstones of the Coal Measures have been exploited in the past for the manufacture

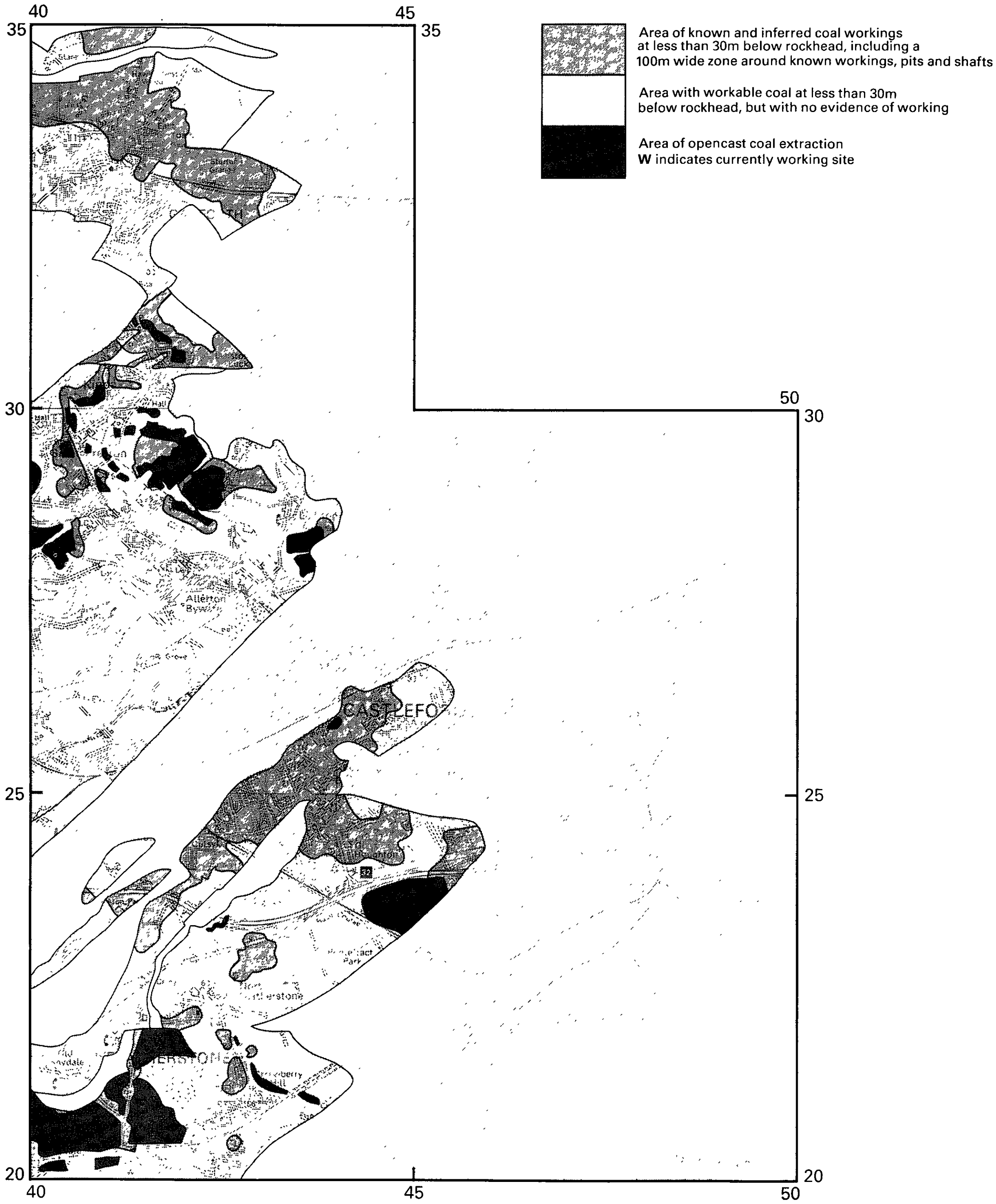


Figure 25 Shallow coal mining and opencast coal extraction

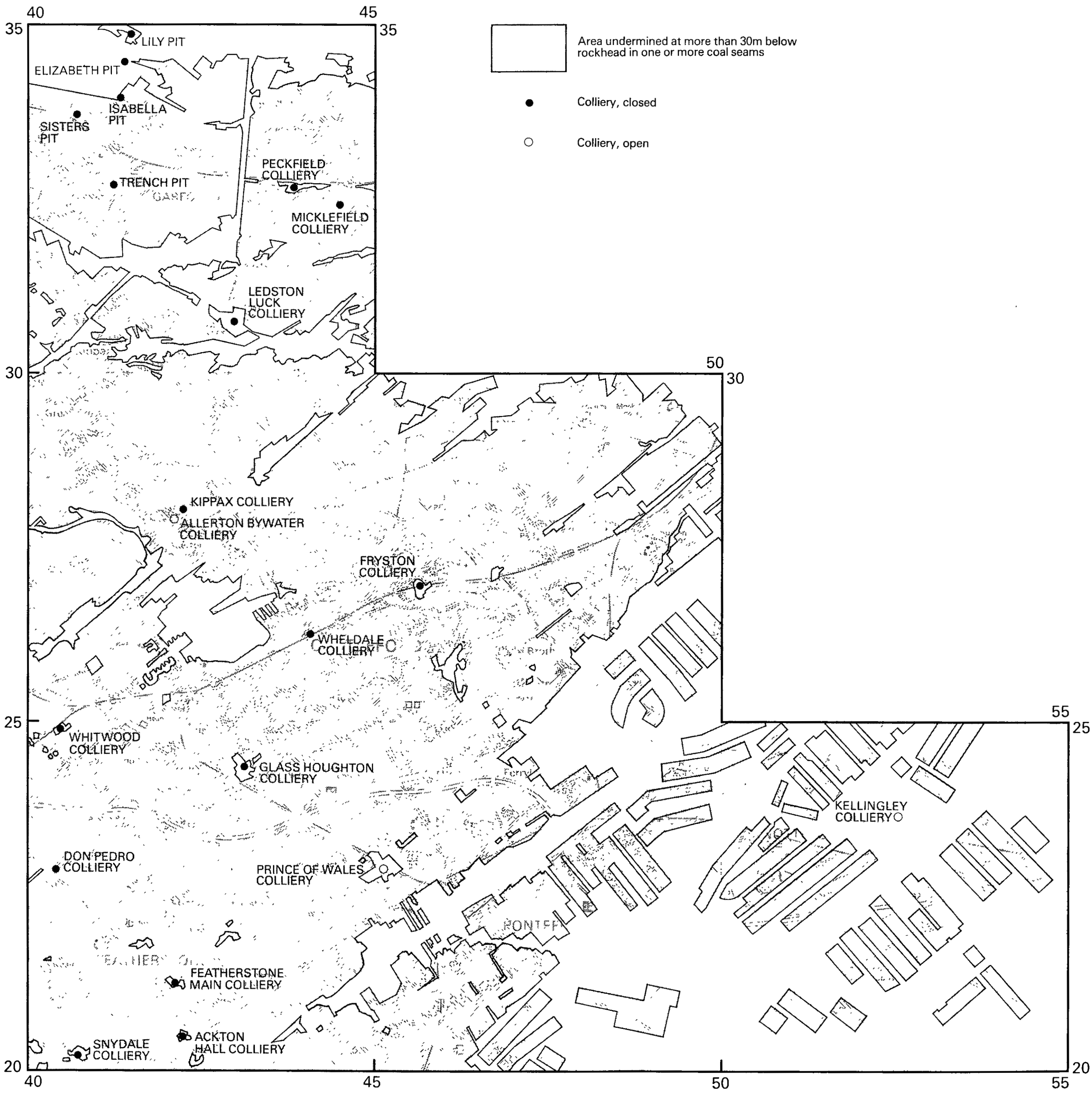


Figure 26 Deep coal mining

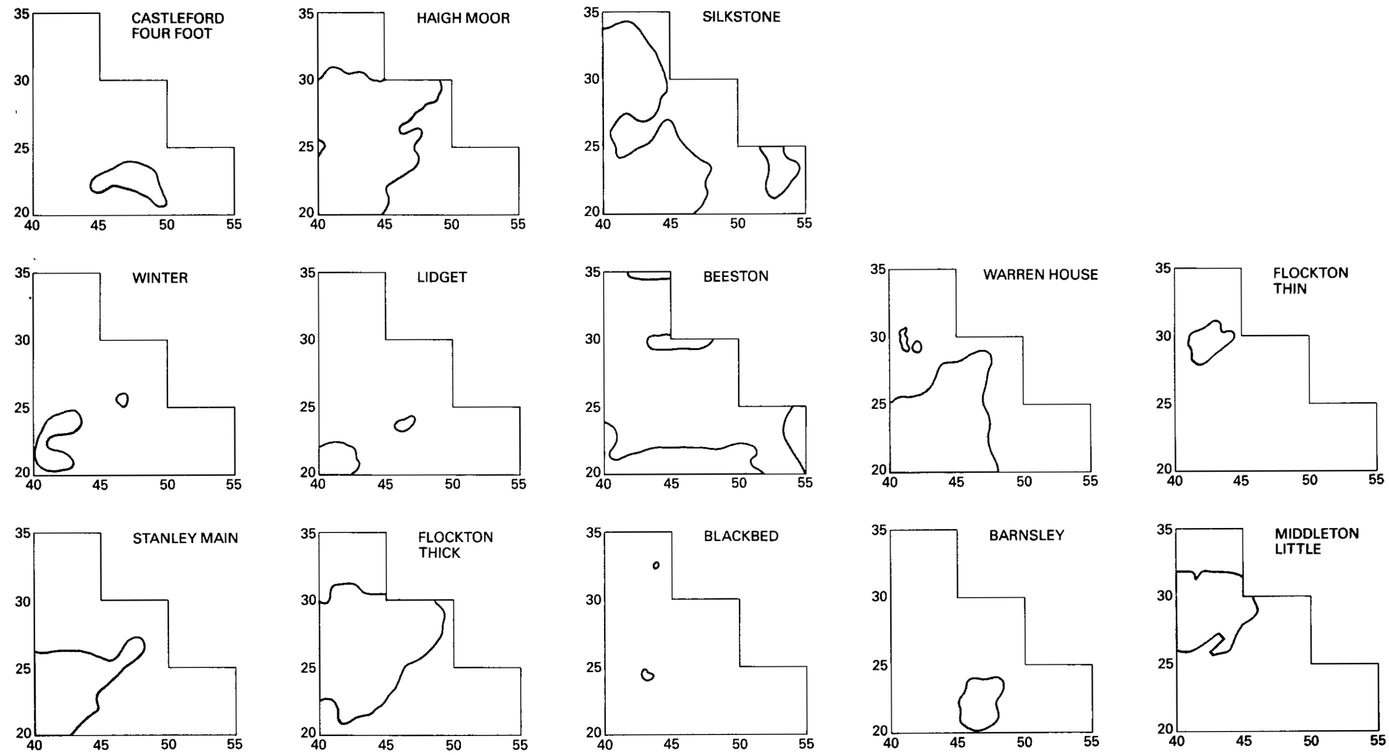


Figure 27 Coal mining in individual seams

of bricks and tiles. The known brickpits are listed in the map margin. The mudstone seatearths of the Coal Measures may be used in the manufacture of pottery, ceramics and as a refractory material, but there are no current workings.

The seatearth beneath the Swinton Pottery Coal had a good reputation as a pottery clay (Edwards et al. 1940). An infilled pit at this level at Whitwood [412 247] may have been dug for this material.

Sandstone The sandstones of the Coal Measures have been quarried on a small scale for building stone and grinding stone and, where relatively poorly cemented, for poor quality coarse aggregate. The former pits and quarries, together with the name of the sandstone exploited, are listed in the map margin.

Gypsum and anhydrite Gypsum occurs as veins and nodules in the Edlington and Roxby formations. It has been dug in the past to a small extent for plaster.

Anhydrite occurs at depth in the Edlington and Roxby formations. Only the Upper (Sherburn Anhydrite), with a thickness of 4 to 6m, is of economic significance, and is currently being mined at Sherburn-in-Elmet to the east of the study area.

MAP 11 MINERAL RESOURCES AND WORKINGS – SUPERFICIAL DEPOSITS (Figure 29)

This map shows the distribution of surface mineral workings in superficial deposits and the areas with a potential resource. Minestone resources are shown on Map 3 (p.17).

Clay

Clay has been dug for brick making at three sites near Knottingley, two [5222 2320;5445 2295] in glaciolacustrine silt and clay, and one [5067 2430] in river alluvium. Similar deposits are widespread in the east of the study area but are unlikely to be exploited in the future.

Sand and Gravel

The study area is divided into five blocks in which potential sand and gravel resources occur in different geological situations. The following account is based on field observations and the BGS borehole database. The resource potential was not specifically investigated during the the present study and consequently the comments are only of a generalised nature. The only active sand and gravel pit is at Dunford House [414 264], operated by Redland Aggregates.

Block A

This block, comprising terrace deposits in the Aire and Calder valleys, contains the most important gravel resource in the study area. The sand and gravel deposits at Methley Mires [41 27] are 5m thick on average, reaching a maximum of 14m (Giles, 1987). They are mainly at the surface, but pass beneath a thin overburden of alluvium in the Dunford House pit. About 90% of the gravels consist of Carboniferous sandstone pebbles, the remainder being of ironstone, quartz, coal, with a few volcanic and igneous rocks.

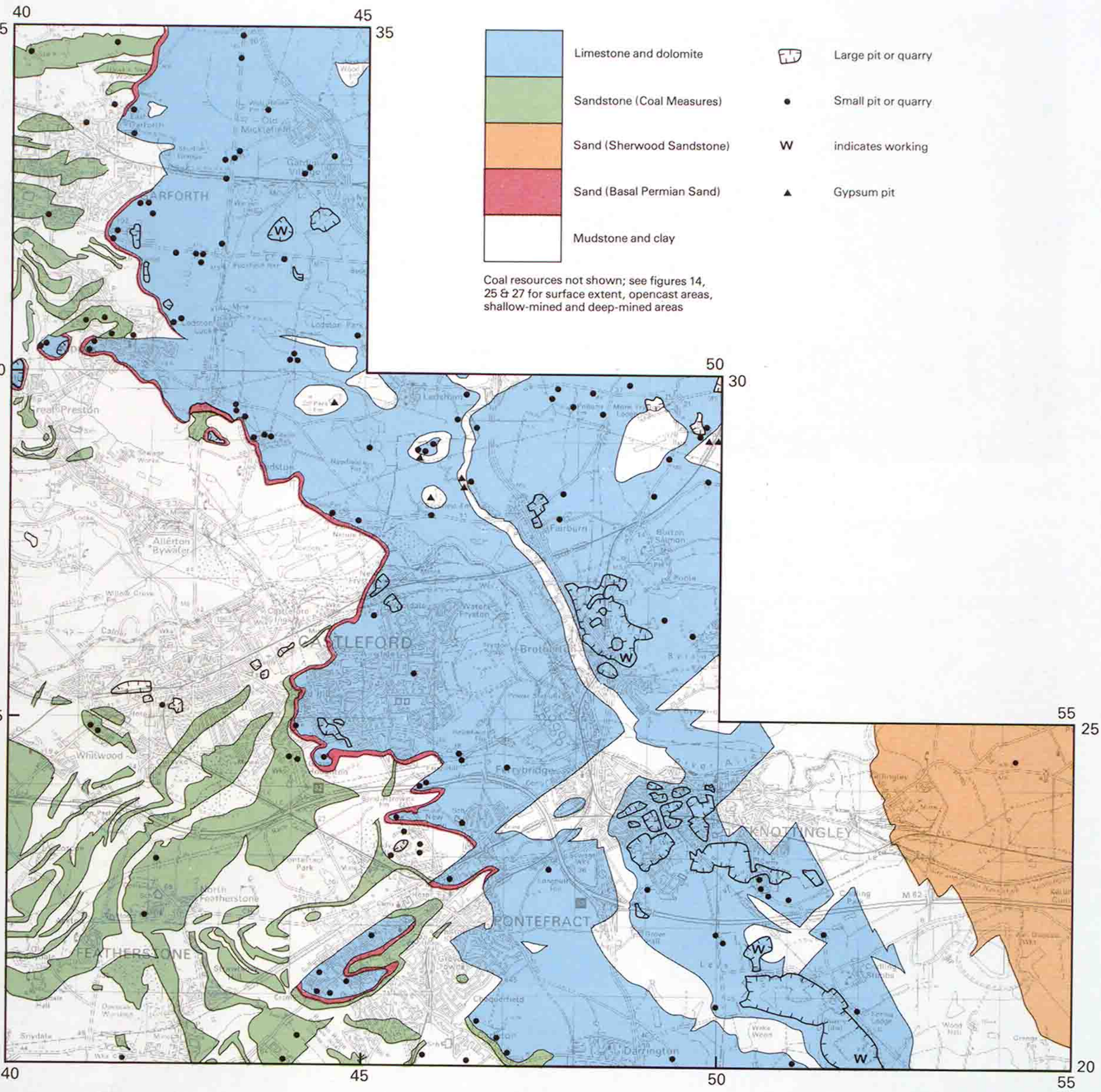


Figure 28 Mineral resources and workings, solid rocks

Plate 5 Working limestone quarry in the Cadeby Formation: Peckfield Quarry, Micklefield [437 321]

Plate 6 Disused limestone quarry in the Brotherton Formation: Leys Quarry, Darrington [4998 2197]. The two main fractures are small normal faults trending NE–SW; the one on the right near an artificial cave has a small associated superficial fold, probably caused by mining subsidence.

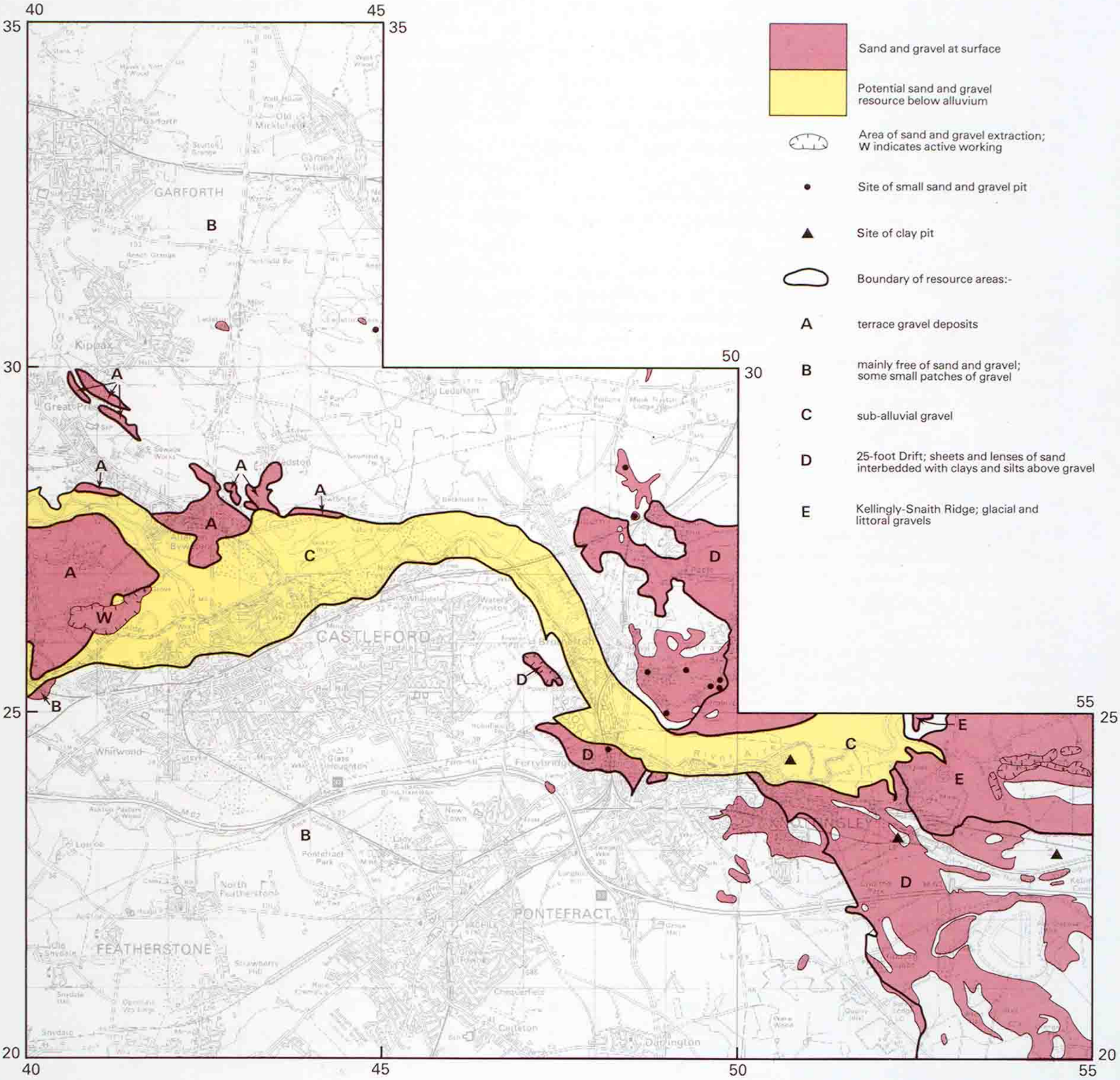


Figure 29 Mineral resources and workings, superficial deposits

Deposits at Allerton Bywater [426 278] are generally less than 4m thick and mostly sterilized by urban and colliery development. In Kippax Beck to the north-west [410 295] the sand and gravel deposits are thin and clayey and the dominant gravel component is ironstone derived locally from the Coal Measures.

Block B

A small amount of sand and gravel has been extracted from three small pits to the north of Burton Salmon [490 273], but there are no deposits of economic significance.

The extensive tract of sand and gravel at Byram has been worked for gravel in three small pits at Sutton [497 254] and for sand at Husseydale [491 256]. South of Byram 3.7m of sand and gravel were worked in a pit now filled with domestic refuse. The gravel contains many dolomite and coal fragments; clay and silt interbeds have also been recorded (Edwards, in manuscript).

An area of about 8 hectares north of Ferrybridge Power Station is worked out and there is no potential for future extraction.

In the Knottingley area sand and gravel deposits are generally less than 3m thick, much of them either removed by limestone quarrying or sterilized by urban development. They are variable in lithology, ranging from silty and clayey sand containing scattered quartzose sandstone pebbles and cobbles close to the margin of the deposit to beds of densely packed limestone pebbles and cobbles with interbeds of relatively clean sand and limestone-dominated gravel. A maximum of about 4m is present in the disused Darrington limestone quarries [5145 2084].

Block C

Sand and gravel in this block occurs beneath an overburden of alluvium ranging from less than 2m around Methley Mires [414 264] to 4m at Ferrybridge [484 248]. The gravel is up to 9m thick at Ferrybridge, its base being about 2m below OD.

East of Ferrybridge ditch sections [5041 2413] reveal sand deposits beneath 2m of alluvium, but their thickness is not known.

Block D

The deposits consist mainly of fine to coarse grained sand which passes laterally into silts and clays. They are generally about 5m thick, but the proportion of sand is variable.

Gravels underlie much of the sands and clays, are generally about 4m thick, and have a base level mainly between 1m below OD and 2m above. Channels and dissolution subsidence hollows result in locally thicker deposits, the maximum recorded being 10m.

Block E

The deposits, lying on the Kellingley-Snaith ridge, are clean sands and gravels, and have been much worked in the past. A limited study of pebbles from 4 to 32mm diameter found 87% to be of Carboniferous sandstone, quartzose sandstone, grit and ganister, 8% vein quartz, 3% metaquartzite and volcanic rock, 1.8% Coal Measures ironstone, and 0.2% chert (or ?flint). A maximum of 6m were formerly worked on Lunn Hill [5388 2418].

Minestone (See Map 3)

The large volumes of colliery spoil, referred to in trade circles as minestone, present an easily accessible resource. It is currently being used in the construction of lagoon embankments at the Gale Common ash disposal site, and is also suitable for construction of embankments and for brick making. The older spoil tips may contain commercially recoverable amounts of small coal.

Maps 12a and b BASAL PERMIAN SAND (Figures 30 and 31)

The Basal Permian Sand is generally 2 to 3m thick, lying between the Coal Measures and the Cadeby Formation. It consists of virtually pure quartz sand with a small amount of iron impurities and has been mined and quarried in the past for glassmaking and moulding sand used in iron founding (see Plates 3 and 4).

These maps, at the 1:10 000 scale, show the outcrop of the Basal Permian Sand, the height of its base above Ordnance Datum, and information about the mining and quarrying.

The following areas are delineated on the maps:

(1) areas of documented sand mining from mine plans

(2) areas of sand mining based on the evidence of undocumented workings, surface subsidence and borehole data

(3) areas of possible sand mining defined up to about 100m from known workings

(4) area of possible sand mining defined up to about 700m from the Basal Permian Sand outcrop, approximately the farthest extent of known workings at Wheldale Sand Mine (Locality 16, Map 12a).

Mining information is derived from the following sources:

(1) mine plans held in the BGS National Geosciences Database

(2) the field maps and notebooks dating from the geological surveys in the 1860's and 1930's; much of the data from these was published on the 1:10 560 scale geological maps.

(3) the geological survey carried out for this study, in which exposures, crown holes and other subsidence features were recorded and new data on undermined areas, including the condition of some of the workings, were collected.

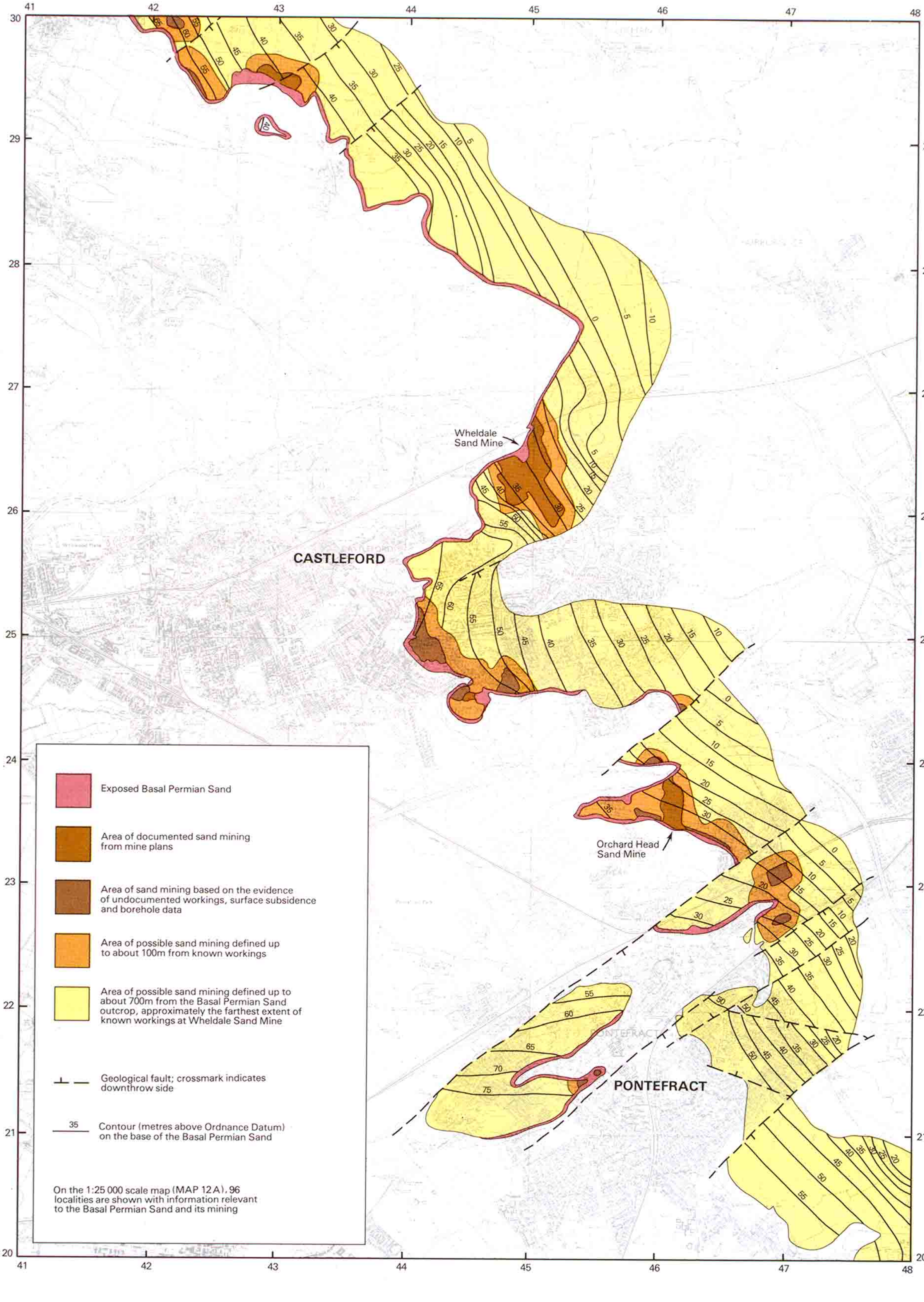
(4) borehole records, including those for several site investigations that have proved voids at depth, indicating sand mining in areas hitherto unsuspected; the borehole records were also used to construct the contours on the base of the sand.

(5) early editions of Ordnance Survey maps, particularly at the 1:2500 scale, which show the sites of former pits and quarries.

The history of sand mining, methods of working and the subsidence problems caused by collapse of the former workings are discussed on pp.11 and 17.

MAP 13 DISTRIBUTION OF THE COAL MEASURES AT THE SUB-PERMIAN SURFACE (Figure 32)

This map shows the conjectured distribution of the rocks of the Coal Measures at the sub-surface below the Permian rocks (the Coal Measures 'incrop'). It is constructed mainly from deep borehole data, and its accuracy therefore reflects the accuracy of these data, and the the spacing


CASTLEFORD
PONTEFRACT
Wheldale Sand Mine
Orchard Head Sand Mine
Exposed Basal Permian Sand
Area of documented sand mining from mine plans
Area of sand mining based on the evidence of undocumented workings, surface subsidence and borehole data
Area of possible sand mining defined up to about 100m from known workings
Area of possible sand mining defined up to about 700m from the Basal Permian Sand outcrop, approximately the farthest extent of known workings at Wheldale Sand Mine
Geological fault; crossmark indicates downthrow side
35
Contour (metres above Ordnance Datum) on the base of the Basal Permian Sand
On the 1:25 000 scale map (MAP 12A), 96 localities are shown with information relevant to the Basal Permian Sand and its mining

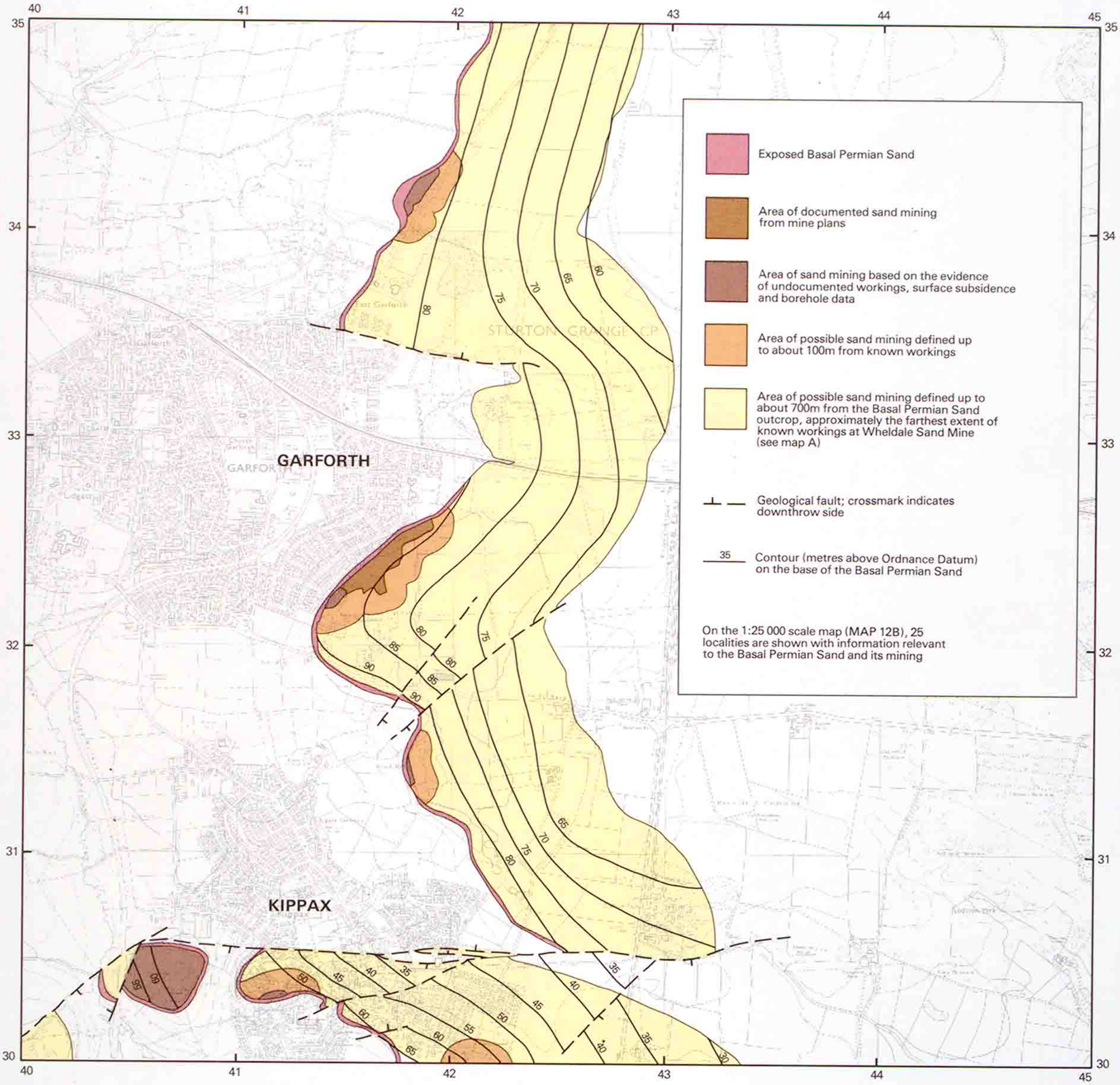


Figure 31 Basal Permian Sand – Garforth-Kippax area

of the boreholes. With new boreholes, and with the availability of recent and new seismic data, the accuracy of the map will be improved.

The distribution of the exposed Coal Measures in the west of the area is shown on Map 1 (Bedrock Geology). Towards the east they are concealed beneath a cover of younger rocks of Permian and Triassic age. The map portrays what would be exposed if the cover of Permian and Triassic rocks were removed. A lengthy period of time elapsed following the deposition of the Coal Measures during which they were uplifted and eroded. By the time the Permian rocks were laid down the surface of the Coal Measures was eroded to a gently inclined surface that was generally of low relief. The hiatus between the Coal Measures and the Permian rocks is an unconformity.

The generalised vertical section in the map margin shows the strata that crop out on the sub-Permian surface. They range from beds below the Blocking Coal to the Pontefract Rock.

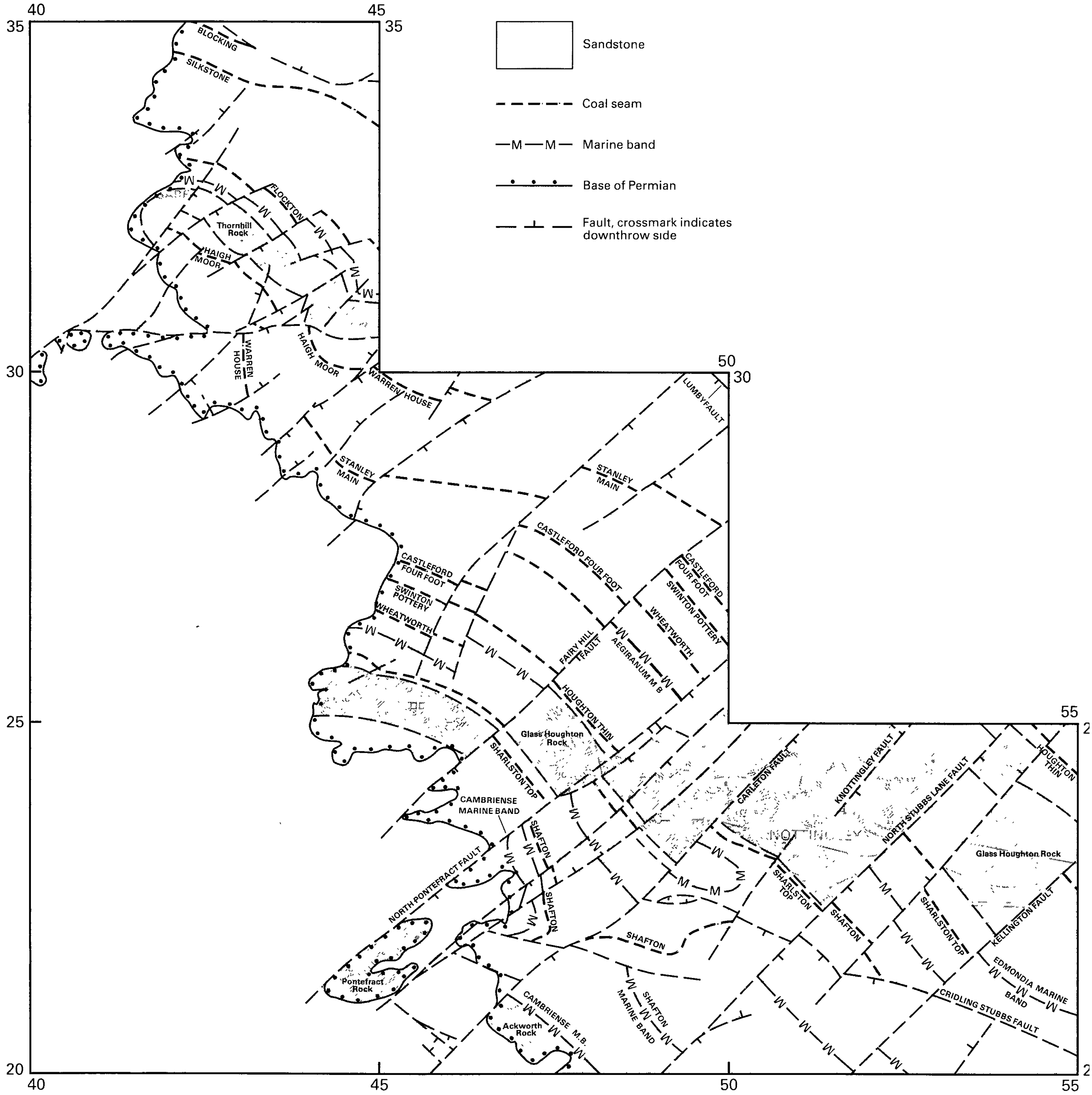


Figure 32 Sub–Permian incrops

Appendix 1 GEOLOGY

The following is a general account of the geology of the study area. It is based on the open file technical reports for the constituent 1:10 000 sheets listed on p.00, to which the reader is referred for local geological details.

SOLID ROCKS

Carboniferous rocks underlie the study area. Coal Measures of early to mid- Westphalian (Langsettian to Bolsovian) age crop out in the west, and lie concealed beneath Permo-Triassic rocks in the east (Fig. 14). Boreholes and shafts in the concealed coalfield have proved the sequence down to a level below the Better Bed Coal. The earliest Westphalian rocks, and the underlying Namurian and Dinantian rocks remain unproved by boreholes, but are inferred to be present from geophysical studies.

GEOLOGICAL HISTORY

The Coal Measures were laid down in the Pennine Basin which covered much of of Northern England, the Midlands and North Wales, extending from the Southern Uplands in the north to the Wales-Brabant Massif in the south. They were formed mainly in an upper delta plain setting (Guion and Fielding, 1988) where a range of lacustrine and fluvial deposits and fresh water peats accumulated. At periodic intervals eustatically induced marine transgressions introduced lower delta plain to brackish shallow marine conditions. In one instance, during the Aegiranum transgression, pro-delta marine conditions may have briefly prevailed, on the evidence of the presence of the eponymous goniatite, *Donetzoceras aegiranum* (Schmidt).

At the end of the Carboniferous, during the Variscan Orogeny, basin inversion resulted in the Coal Measures being uplifted, gently folded and cut by a suite of mainly north-east trending faults. The folds are broad and open with dips on the limbs generally less than 3°. Following this period of deformation there was a long period of erosion that reduced the landscape to a gently rolling peneplain before sediment deposition began in the mid to late Permian.

The Permian rocks were the deposits of the Zechstein Sea, which extended to Holland and Germany. The study area lay close to the western margin of the sea. The rocks belong to two main transgressive-regressive cycles, with deposition of shallow marine carbonate rocks during transgressions and supratidal evaporitic mudstones during regressions. The succeeding fluvial sandstones of the Sherwood Sandstone Group were deposited in increasingly arid conditions and, from the limited evidence within the district, appear to be the deposits of large river channel systems.

Gentle north-easterly tilting during the Tertiary was accompanied by reactivation of some of the faults of the Coal Measures, their throws in the Permo-Triassic rocks being much reduced.

CARBONIFEROUS

Coal Measures (Westphalian age)

The stratigraphy of the Coal Measures was established by the early surveys in the exposed coalfield and details published in Geological Survey memoirs (Green et al, 1878; Edwards et al, 1940). Over 100 exploratory boreholes have been drilled in the area since 1945, almost all in the concealed coalfield, and a new colliery developed at Kellingley. Most of the boreholes post-date the third edition of the Survey's memoir of the concealed coalfield of Yorkshire and Nottinghamshire (Edwards, 1951) and records of only a few of them have been published prior to the present study.

Full details of surface boreholes greater than 300m drilled since 1975, and the results of shallow seismic surveys carried out by British Coal remain confidential. All the borehole logs are held in the BGS National Geosciences Data Centre and details of the coal workings are held by British Coal, North Yorkshire Area , Allerton Bywater, West Yorkshire. Petrological and palaeontological specimens collected at exposures and from boreholes are held by BGS.

Lithology and sedimentation

The deposits were laid down in distributary channels, interdistributary areas and fresh water mires. The accumulation of sediment progressed more or less in equilibrium with basin subsidence, resulting in predominantly shallow, fresh water terrestrial facies. Subsidence was relatively uniform across the study area and there is no great variation in thickness of the sequence. The sediments are commonly arranged in coarsening upwards lacustrine rhythms, mudstone passing up into siltstone. Palaeosols (seatearths) truncate the rhythms, and are generally overlain by coal. Channel, levée and crevasse splay facies occur throughout. Sandstones are the main channel deposit, and generally have a fining-upwards motif. Fluvial scouring prior to sand deposition in the larger distributary channels locally removed peat to give the washouts in coals. Mud-filled and coal-filled channels also occur, indicating abandonment of the channels. Levée and crevasse splay sandstones are finer grained and thinner than the channel ones.

The rocks are predominantly grey and greyish brown, except in the topmost beds below the sub-Permian unconformity, where they were subjected to tropical weathering, oxidised and reddened. The weathering zone is generally only a few metres deep, but reddened beds are recorded locally down to depths of over 20m.

Mudstones, siltstones and rocks gradational between them are the most common lithologies. The mudstones, described in early records as bind, blue bind, metal, blaes or drub, are black to grey and commonly contain non-marine lamellibranchs ('mussels'). They were deposited mainly in quiet water lakes and lagoons in the interdistributary areas. At the present day surface they weather to a sticky orange-brown and pale grey clay, the fossils being leached out. The typical depth of weathering is of the order of 3m but there can be oxidation down joints to at least 8m. Nodules, layers and lenses of siderite (clay ironstone) up to 0.5m thick are common. Locally, they occur in sufficient amounts to have been worked as iron ore in the past, but there are no records of such working in this area.

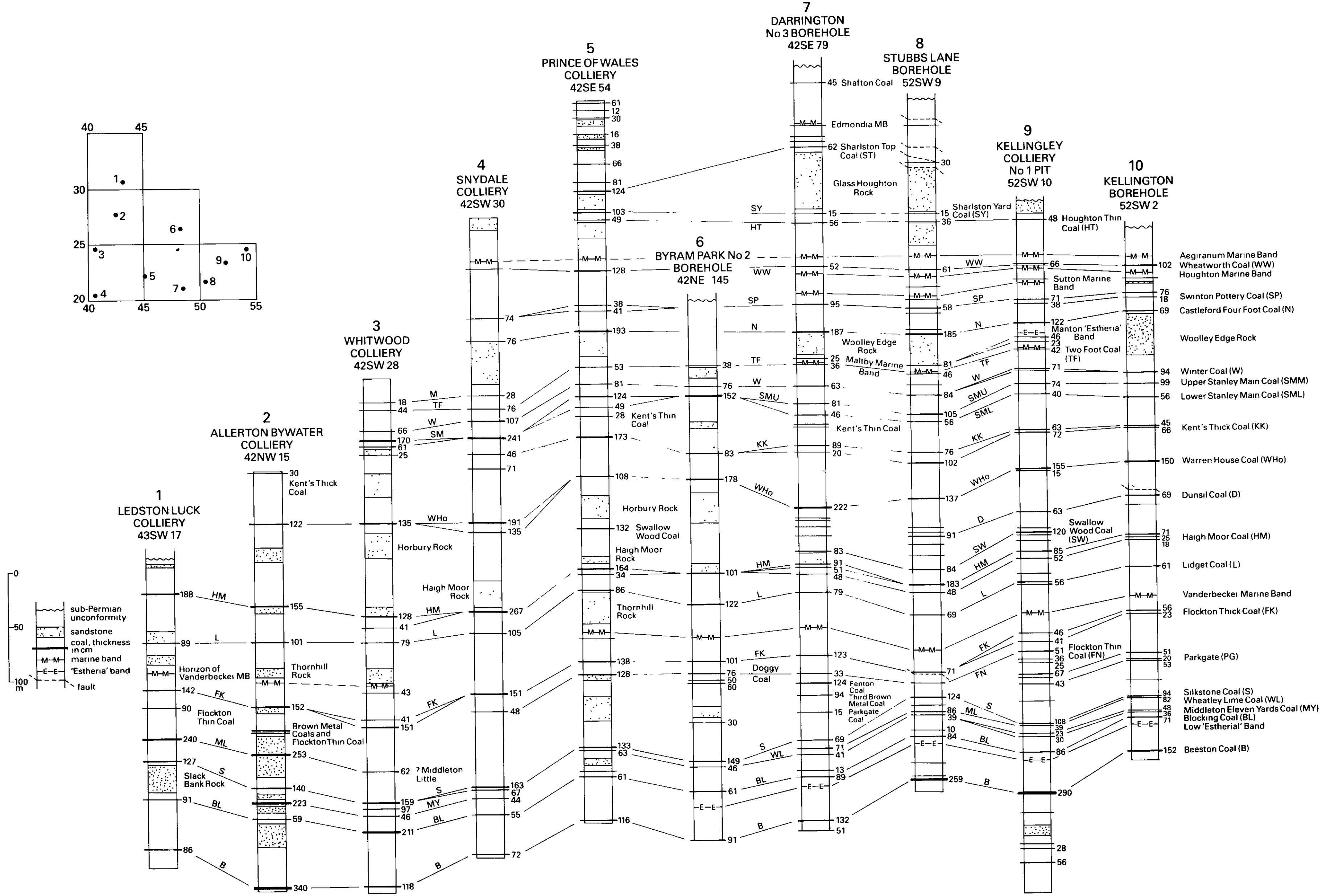


Figure 33 Correlation of Coal Measures in selected boreholes and shafts

Dark grey to black mudstones containing marine fossils occur at ten horizons in the proved sequence. They usually overlie coals or seatearth, are generally only a few centimetres thick, and grade up into paler grey mudstones with a non-marine fauna. They were not usually recorded during early colliery shaft sinkings, their regional significance not realised, but are now identified across the coalfields of Britain and Europe, and can be identified in borehole geophysical logs by their high gamma response.

Siltstones, known to the early miners as stone bind, slaty stone and fakey blaes, are mainly medium grey. Plant remains are the commonest fossil, but burrows and other trace fossils also occur. Ripple lamination, small-scale cut and fill structures and soft sediment deformation structures are common, and indicate a variety of depositional environments, including lagoons, crevasse splays and small river channels.

Sandstones, called galliard or rock by miners, are mostly fine to medium grained, but locally coarse and conglomeratic. They are grey where fresh, and weather to pale brown. Their bases commonly cut down through the underlying strata, including coal. The conglomerates are the deposits of the bases of river channels and contain angular to partly rounded fragments of other Coal Measures lithologies. The sandstones consist mainly of subangular to subrounded quartz, with small amounts of mica and feldspar. Flat parallel bedding and planar, trough and tangential cross bedding are present, as well as small-scale parallel and ripple lamination. The thicknesses of the sandstones range up to tens of metres, the thickest giving rise to bold escarpments.

Seatearths, formerly known in mining circles as clunch or spavin, are palaeosols containing rootlets, and are most commonly leached mudstones and siltstones, but sandstone seatearths also occur. The primary fabric of the sediment was largely destroyed by pedogenic and biogenic processes, at least in the upper part of the soil profiles. Seatearths generally occur below coals but may be laterally more extensive. Mudstone seatearths with refractory properties are known as fireclay and have been worked for the manufacture of firebricks in the past.

Coal seams are peats indurated and compacted by burial. They are laterally extensive, but vary in thickness and composition, and may occur as a single seam or as leaves separated by dirt (coaly mudstone) partings. In this area coals are rarely more than 1.5m thick, and all are bituminous.

Tonsteins, thin but laterally persistent ash fall tuff beds, are uncommon in Yorkshire but are useful markers. Two are recorded in this area, in the Second Brown Metal and the Sharlston Muck coals.

Stratigraphy

The following account is a general description of the Coal Measures in the study area. Figure 15 is a graphic vertical section, Figure 33 gives selected borehole sections.

Lower Coal Measures

The lowest proved coals, the **Better Bed, Black Bed** and **Crow Coal** are less than 0.6m thick and of no economic importance, although the Black Bed was worked in a small area at Peckfield.

The **Top Beeston Coal** is the most widely worked in the district. It is up to 2.6m thick and generally consists of two or three leaves, the top being the most persistent and widely mined. South of Pontefract the seam is less than 1m thick, the bottom leaf poor, thin or absent.

The **Low 'Estheria' Band,** 30 to 40m above the Top Beeston, is a widespread marker bed of dark grey mudstones containing **Euestheria** sp.

The **Blocking Coal** crops out in the Garforth area, where it was named the Barcelona Coal and worked along the crop and at shallow depth [4079 3486]. It is up to 2.11m south of Pontefract, but generally of poor quality, consisting of two or more leaves with dirt partings.

In the Garforth area the measures between the Blocking and Silkstone coals are dominated by the **Slack Bank Rock,** which forms a strong escarpment [4024 3452]. At depth the sandstone thins southwards and eastwards, interfingering with measures containing the Middleton Eleven Yards and Wheatley Lime coals. The **Middleton Eleven Yards Coal** is mainly thin with two or more leaves of inferior quality, reaching a maximum thickness of 2m west of Allerton Bywater. The **Wheatley Lime Coal,** up to 1.2m of inferior and thin coal, joins the Silkstone Coal at Glass Houghton and Ackton and thins east of Pontefract. It improves further to the east, and has a clean top leaf of 0.5m at Kellington.

The **Silkstone Coal,** the Thorncliffe Coal of south Yorkshire and the Middleton Main Coal of the Leeds area, has been worked close to its outcrop near Garforth [4125 3403] and extensively mined throughout the district. It deteriorates north-east of Brotherton and there is a well defined major split from near Kippax to Ackton and eastwards through Fryston Colliery. In the south-west up to 3m of mudstones occur between a worked out top leaf and a dirty, inferior bottom one. In the east the seam is about 1.10m, thickening eastwards.

Measures between the Silkstone Coal and the Vanderbeckei Marine Band crop out in the Garforth – Kippax area where they include the Middleton Little, First Brown Metal, Flockton Thin and Flockton Thick coals. The precise correlation of the coals is difficult because some are impersistent and others split and rejoin.

The outcrop of the **Middleton Little Coal** in Garforth is marked by a line of small spoil heaps from former crop workings west of Croft Lodge Farm [4124 3387]. In the Allerton Bywater and Garforth areas the Middleton Little and Second and Third Brown Metal coals are united in places, the combined seam being up to 3.5m thick but containing four leaves and a high proportion of dirt. Elsewhere at depth the Middleton Little consists of two thin seams separated by up to 7m of mudstone and known as the **Parkgate Coal** in the east.

The **First Brown Metal Coal** and **Flockton Thin Coal** were formerly mined close to the outcrop in the Garforth area where they were known as the Firthfield coals. They probably merge in the south and east of the study area, and are known as the **Fenton.** The Second Brown Metal is reported to contain a tonstein at Allerton Bywater Colliery (Giles, 1987). The Flockton Thin Coal, also known as the Doggy Coal, was mined to a small extent north of Allerton Bywater, but elsewhere it is thin and impersistent.

The **Flockton Thick Coal** is mined extensively. Generally in two leaves, the middle dirt parting is 0.20m south of Pontefract and 6.4m at Kellingley,the coals becoming inferior and thin eastwards.

Middle Coal Measures

Between 520 and 580m of Middle Coal Measures are present. The **Vanderbeckei Marine Band** is a dark grey silty mudstone containing *Lingula mytilloides* and fish remains. It is less than 0.1m thick in the south-east, less than 1m in the centre of the area, and remains unproved proved at outcrop in Garforth and at depth in the Featherstone area.

The **Thornhill Rock** dominates the sequence between the Vanderbeckei Marine Band and the Haigh Moor Coal in the north and west. It crops out south of Garforth and is thickest (38m) around Ledston, where it washes out the Lidget Coal and, locally, the Vanderbeckei Marine Band.

The **Lidget Coal** is generally poor except in two small areas in the south-west and centre of the study area where it has been mined. It deteriorates further in the south-east to two leaves that in total give 0.3 to 0.5m of clean coal.

The **Haigh Moor Coal** was formerly worked at shallow depth at Kippax. It splits southwards, the two leaves 12.2m apart in the south-east of the area. The upper leaf, the Top Haigh Moor Coal, is the main seam, and has been extensively worked. However, it thins and is of poor quality in the east, and is affected by north-east trending washouts around Castleford and east of Fryston and Glass Houghton.

The **Haigh Moor Rock** crops out at Kippax where it was formerly quarried. It has a maximum thickness of 37m in the south-west, thinning eastwards and fingering out between siltstone beds east of Knottingley. The **Horbury Rock** is thickest between Glass Houghton (34m) and Fryston (44m) and absent in the north and east.

The **Swallow Wood Coal**, washed out by the Haigh Moor Rock in the centre of the area, was opencasted around Kippax and Great Preston. At depth elsewhere it is of minor importance, with much inferior coal and dirt.

The **Dunsil Coal** was opencasted at the St Aidan's site [402 283] where pillar and stall workings were uncovered. It is washed out by the Horbury Rock in the south-west and 0.9m thick with a middle dirt parting in the east.

The **Barnsley Coal** is the most important seam of the Yorkshire, Derbyshire and Nottinghamshire coalfields. It is thickest in the Doncaster area, splitting northwards into the Top Softs (the Warren House Coal of the present district), the Hards (here known as the Low Barnsley Coal) and the Bottom Softs. The **Low Barnsley Coal** has been worked south-east of Pontefract, where it is 1.5 to 1.9m thick. Elsewhere it is split into several thin coals and dirts, contained in 7m of beds between Darrington and Knottingley and less than 1m of beds in the west.

The **Warren House Coal** crops out south of Kippax, was opencasted in the Owl Wood site [418 292] and is worked out in a large area in the south-west. It thins regionally eastwards, the best coal usually lying in the top part of the seam. It generally consists of two main leaves with a thin dirt parting, their aggregate thickness in the east being 1.2m. Up to 7 thin leaves of coal lie in the 4.5m of strata below the main coal.

The **Kent's Thick Coal**, opencasted with the Warren House Coal south of Great Preston, is variable and has not been mined. It splits south-eastwards into two seams up to 13m apart in the Brotherton area and 7 to 9m apart south of Kellingley. The **Kent's Thin Coal** is impersistent, comprising a single leaf up to 0.8m in the north and two inferior seams separated by up to 4m of measures south of Pontefract.

The **Stanley Main Coal** is worked out in the west, where it is a single seam with thin dirt partings. It splits to the east of a line roughly between Whitwood and Glass Houghton, the intervening measures reaching 7m south of Pontefract and 12m near Kellington in the east [550 250]. The top coal is of workable quality and up to 1.27m thick south of Pontefract, but splits to the east and north. The lower leaf is best developed in the east where it consists of 0.7m of bright coal overlain by a thin cannel.

The measures between the Stanley Main Coal and the Aegiranum Marine Band thin north-eastwards, from 158m at Snydale to 125m around Burton Salmon, due mainly to the presence of the **Woolley Edge Rock** in the south-west. This sandstone consists of channel sandstones with some siltstone and mudstone interbeds. It is up to 38m thick, being thickest in an east-west trending area between Snydale and north of Knottingley, decreasing to 13m south of Pontefract and east of Cridling Stubbs.

The **Winter** (Abdy), **Two Foot** (Cat) and **Meltonfield** (Wakefield Muck) coals are generally less than 1m thick. Only the Winter has been mined, in a small area between Castleford and Snydale, where it is up to 1.14m. The **Maltby** (Two Foot) **Marine Band** in the roof of the Two Foot Coal is absent, washed out by the Woolley Edge Rock, east of Kellingley. The Meltonfield Coal has been opencasted at Newton Lane [435 282] where two leaves are separated by up to 4m of mudstone, but is washed out over most of the central and eastern part of the area. The **Manton Estheria Band** is also largely washed out, but occurs at Kellingley about 35m above the Maltby Marine Band.

The **Castleford Four Foot Coal** crops out north of Whitwood and below the drift deposits of the Aire and Calder valleys. It has been mined in a small area south of Pontefract where it reaches 1.6m; elsewhere it is thinner and contains dirt partings, although there is more than 1m of clean coal in the vicinity of Cridling Stubbs.

The **Swinton Pottery Coal** crops out south of Castleford [4114 2485].It is generally less than 0.75m thick and split by mudstone up to 5m thick in the east. The seatearth below the coal has been quarried for making firebricks and pottery [417 255].

The **Haughton Marine Band** and **Sutton Marine Band** lie in the 30m of measures above the Swinton Pottery Coal. They have not been recognised at outcrop and are proved in only a few boreholes.

The **Wheatworth Coal** is best south of Castleford where it was formerly mined at shallow depth in bell pits and pillar and stall workings. At outcrop it splits south of Ackton Pasture Wood [417 236] into two leaves less than 0.7m. The top leaf was exposed in a new road section at Ackton

[4096 2192]. At depth it consists of mostly inferior coals and dirt.

Mudstones between the Wheatworth Coal and the Aegiranum Marine Band were formerly dug for brick making in two pits, now backfilled, at Glass Houghton [428 246; 4365 2570]. The **Crow Coal** is thin and impersistent seam, with the **Aegiranum Marine Band** in its roof. The marine band contains a rich fauna, including goniatites, (Edwards, 1932; Edwards et al, 1940), mainly in calcareous nodules and layers. It was recently exposed in a road cutting at Ackton [4096 2192], and yielded *Donetzoceras aegiranum.*

About 110m of strata lie between the base of the Aegiranum Marine Band and the base of the Cambriense Marine Band. Coals, none of them mined, are poor and sandstones make up much of the succession.

The **Ackton Rock** forms a strong feature between Snydale and Glass Houghton where it reaches 18m. It thins at depth north-east of Pontefract, and is represented by up to 30m of thinly interbedded sandstone and siltstone in the east of the study area.

The **Houghton Thin Coal** and **Sharlston** group of coals lie in about 60m of strata dominated by the **Glass Houghton Rock**. The coals are generally less than 1m thick, but in the west are generally clean and have been mined close to the outcrop and opencasted in large areas. The Houghton Thin Coal is a single seam in the west and split by up to 4.5m of mudstone in the east. The **Sharlston Yard, Sharlston Thin, Sharlston Low** and **Sharlston Muck** coals are washed out by the Glass Houghton Rock over much of the area. The Sharlston Yard Coal is generally split, the lower leaf combining with the Houghton Thin locally and separated from the top leaf by up to 9.6m of siltstone and sandstone. The Sharlston Low Coal is up to 1.13m thick west of Pontefract and combines with the Sharlston Muck around Snydale. A tonstein occurs in a parting in the Sharlston Muck, and specimens from Snydale and Hollywell Wood, Castleford are in the BGS collections (nos. E35633 to E35636). The **Sharlston Top Coal** has been opencasted south and south-west of Pontefract, where it is 0.8m of good coal, but it deteriorates eastwards to less than 0.2m of inferior and dull coal.

The **Glass Houghton Rock** is 55m thick at depth south of Knottingley. At outcrop between Featherstone and Castleford it is 20 to 30m thick and forms a strong escarpment. The best exposures are in Ackton and Cornwall opencast sites [418 218; 446 233].

The **Edmondia Marine Band** comprises up to 1.5m of bioturbated grey mudstone with lingulids and foraminifera, and is recorded in boreholes east of Pontefract.

The **Mexborough Rock** is up to 29m thick south of Knottingley where its base cuts down to a level below the Edmondia Marine Band.

The **Shafton Coal,** a workable seam south of this district, is less than 0.5m thick and absent locally. It is exposed in a ditch [4425 2214] on the north flank of Park Hill, Pontefract.

The **Shafton Marine Band** lies 12 to 18m above the Shafton Coal. It is exposed in the Swan Hill railway cutting [4595 2111] at Pontefract (Edwards et al, 1940) and was seen in temporary trenches [4499 2055; 455 202] to the south.

The **Cambriense Marine Band** is not proved, but in adjacent areas lies 40m above the Shafton Marine Band and close below the Ackworth Rock (Goossens and Smith, 1973). On this basis its conjectural outcrop south-west of Pontefract is shown on Map 1.

Upper Coal Measures

The **Ackworth Rock** is up to 44m thick at outcrop between the North and South Pontefract faults, thinning to the north and east. It is exposed in two small quarries [4395 2008; 4412 2045].

The **Pontefract Rock** forms the high ground on which Pontefract Castle stands. It is 5 to 15m thick at outcrop in the vicinity of Marl Pit Hill [4433 2091], where it was formerly quarried for building stone, and 24.3m thick in a borehole at Pontefract Barracks.

Permian

Permian rocks cover about half the study area, occupying a broad south-east trending belt from Garforth in the north to Cridling Stubbs in the south. They dip very gently to the north-east, unconformably overlie the Coal Measures, and are overlain by the Triassic Sherwood Sandstone Group in the extreme south-east. Figure 15 gives a generalised section of the strata.

Basal Permian Sand

Equivalent to the Permian Yellow Sands of other areas, the Basal Permian Sand is a thin, but distinctive formation that crops out on the bold escarpment formed by the Cadeby Formation. Generally 2 to 3m thick at outcrop, it is locally absent, but thickens eastwards; the maximum recorded thickness of 13.72m is in a borehole near Cridling Stubbs. There is, however, marked variation in thickness, which may indicate undulations in the underlying Coal Measures surface, and also possibly the presence of dune forms in the sand. Difficulties in distinguishing the formation from leached Coal Measures sandstones may also explain some of the thickness variations recorded in boreholes.

The dominant lithology is a pale grey medium to coarse grained sandstone, which on weathering becomes buff to yellowish brown. It is weakly cemented at depth, and generally weathered to a friable sand at outcrop. The constituent grains, often recorded as being wind-rounded, are moderately well sorted and comprise mainly rounded to sub-rounded quartz grains, with up to 10% being quartzite, sandstone, chert and feldspar. Pyrite is present at depth, but leached at outcrop. A sparse heavy mineral assemblage includes mainly garnet, along with rutile, zircon, staurolite, barytes, apatite, tourmaline, epidote, ?cassiterite and iron oxides (Versey, 1925; Pryor, 1971). A thin basal lag conglomerate is locally present at outcrop (Versey,1925; Edwards et al., 1940), and in boreholes. Thin breccia beds of sandstone clasts in a sand matrix were recorded in a borehole at Knottingley, and thin pale grey mudstone layers are locally present.

Cross stratification is common, both low angle planar cross bedding and high angle tangential cross bedding being seen at outcrop, where observed set thicknesses range from 0.13m to 1.0m. Depositional dips of 45°, coarse millet-seed sand grains and polished rounded pebbles are recorded in boreholes, and confirm an aeolian origin for much of the sand (Smith, 1974). Pryor (1971) considered that the sands were entirely marine, but it is likely that in the thicker occurrences only the topmost part was reworked during the subsequent marine transgression.

Outcrop and shallow mining data are given on Maps 12a and b (Figs. 30 and 31; pp.11,46).

Cadeby (Lower Magnesian Limestone) Formation

The Cadeby Formation forms a prominent escarpment extending from Garforth to Knottingley. To the east it crops out over a large gently undulating area incised by steep-sided dry valleys. Consisting mainly of dolomites, the formation ranges in thickness from about 30m in the south of the study area to 90m in the south-east around Kellington. About 50 to 55m are present east of Garforth.

The junction with the underlying Basal Permian Sand is generally sharp, but an interdigitation of the lithologies is recorded in some boreholes, and sandy dolomites lie at the base of the formation locally. Also locally present at the base are up to 5.75m of thinly bedded grey dolomitic mudstones and argillaceous dolomites containing plant fragments and lamellibranchs, formerly termed the Marl Slate (Edwards et al., 1940) and the Lower Permian Marl (Edwards, 1951). They are now included as a facies variant of the Cadeby Formation (Smith et al., 1986). The presence of black carbonaceous films around lamellibranchs is common where these argillaceous beds are absent, suggesting that they were mainly reworked during the transgression that instigated deposition of the Cadeby Formation.

Cavities and vugs, commonly lined with gypsum occur throughout; glauconite was recorded in Kellingley Colliery No.1 Shaft.

The formation consists of pale brown to buff dolomites which can be subdivided into two units (Edwards et al., 1940), named the Wetherby Member and the Sprotborough Member (Smith et al., 1986). They are separated by a regional discontinuity, the Hampole Discontinuity, which is overlain by a thin marker bed sequence of thinly bedded mudstones and dolomites up to 1.5m thick named the Hampole Beds (Smith, 1968).

Wetherby Member

The Wetherby Member consists mainly of parallel bedded dolomites in which the original oolitic or grainstone fabric is locally preserved, but generally destroyed by dolomitisation giving a granular fine to medium grained dolomite. The working quarry at Micklefield provides an excellent section (see Plate 5), where about 35m of well bedded dolomites are exposed. Thin grey mudstone interbeds are present in the basal 6m, in which bed contacts are gently undulating, and bedding surfaces littered with oncolites, have interference ripples, horizontal trails and groove marks. Most of the sequence is parallel bedded, but some large-scale low-angle cross stratification also occurs, and a wide shallow channel is present at the disused Wheldon Wood Quarry [454 267] (Plate V in Edwards et al., 1940).

Shell debris is common, but identifiable fossils are relatively rare. Lamellibranchs predominate, *Schizodus* is the commonest, *Bakevillia* and *Strophollosia* are also recorded. The basal beds are the most fossiliferous, with, in addition to the lamellibranchs, foraminifera including *Aggathamina* sp., and polyzoan debris including *Acanthocladia* stems (Edwards et al., 1940).

A characteristic feature is the presence of reef limestones, concentrated near the base and top of the member. They are mainly dolomite breccias that were probably reef flank deposits; small reef knolls are also present around Castleford, forming upstanding bodies of brecciated vuggy dolomite.

Sprotborough Member

The Sprotborough Member consists largely of pale yellow to cream and buff large-scale cross bedded fine grained dolomite, in contrast to the parallel bedded Wetherby Member, and to the Hampole Beds at its base. Primary oolitic texture is only locally preserved. The Hampole Beds are 1.5m thick, and consist of thinly bedded dolomites and clays. The only exposure in the area is at Micklefield Quarry [4460 3246]. A cross bedded vuggy dolomite 1 to 2m thick at the base forms a mappable feature near Castleford. Elsewhere, no feature is present, and it is not possible to map separately the Wetherby and Sprotborough members; the Cadeby Formation is therefore shown as undivided on Map 1.

Edlington (Middle Permian Marl) Formation

The Edlington Formation crops out mainly in a narrow south-east trending belt on the lower part of the Brotherton Formation escarpment and in several small outliers. It is poorly exposed, but gives rise to stiff, heavy red clay soils. Red mudstones and siltstones predominate, but leaching and reduction is common, producing layers and zones of pale green. The topmost and basal beds are generally leached to pale greenish grey or blue grey. Gypsum occurs throughout as beds, layers, nodules, veins and crystals. Two forms are present, impure primary gypsum, and pure white fibrous reprecipitated satin spar. Anhydrite occurs at depth, but is hydrated to gypsum towards the surface. Rock salt was recorded by Phillips (1828), probably near Myson's Chair [4710 2365]. Mudstone breccias, probably caused by gypsum dissolution, occur throughout.

The formation thickens from about 20m in the west to 40m in the east; local thickness variations have no obvious pattern and may be due at least partly to dissolution of the evaporites. Only about 10m are estimated to be present at outcrop in the extreme south near Scrombeck Farm. There appears to be a complementary relationship between the thicknesses of the Cadeby and Brotherton formations. This suggests that, although the junction between the two formations is apparently conformable, the Edlington Formation was deposited on a non-planar undulating surface.

Brotherton (Upper Magnesian Limestone) Formation

The Brotherton Formation crops out in a south-east trending belt from Selby Fork to Cridling Stubbs, and in a small area east of Weetwood [448 303]. The basal beds form a low escarpment, the higher ones gentle easterly dipping slopes. It has been extensively quarried in the Brotherton-Knottingley area, the quarries at Brotherton being the type area of the formation (Smith et al., 1986). Ranging in thickness from 15 to 20m at outcrop to 30m at depth in the south-east, the formation is distinctive because of its thinly bedded nature (see Plate 6). Gentle low amplitude folding is generally held to be due to collapse of beds above dissolution channels in the evaporites of the underlying Edlington Formation (Edwards et al., 1940; Smith, 1972).

The formation consists of pale grey and cream dolomitic limestones, predominantly of fine sand to silt grade, in beds that are generally about 5cm thick. Lenticular beds of coarse vuggy dolomite up to about 0.3m thick also occur, and a few lenticular beds up to 1.4m thick of medium to coarse grained cross bedded locally sandy dolomite with much skeletal debris are present at the top. Slumped beds with penecontemporaneously deformed and contorted lamination are present in places, probably caused by seismic events when the sediments were in a semi-lithified state. Interbed contacts are sharp, gently undulating to wavy and slightly hummocky; thin grey mudstone interbeds are locally present. The limestones are colour-laminated in shades of grey and cream to buff, and individual beds have tractional lamination with cross lamination, rippled sets and small-scale cut-and-fill structures. Gypsum occurs near the base of the formation.

Fossils include *Schizodus* spp. and *Calcinema* sp. (both common), *Tubulites permanus* and plant fragments. Coquinoid layers of shell and other skeletal debris occur throughout.

Roxby (Upper Permian Marl) Formation

The Roxby Formation crops out mainly in a narrow zone in the south-east, from Byram to Wood Hall. It also crops out in a large outlier south of Monk Fryston Lodge, and in several others that are wholly or partly fault-bounded. The main outcrop and most of the outliers are almost entirely drift-covered, the best sections being seen in Darrington Quarries near Cridling Stubbs, where up to about 12m of the basal beds were stripped to work the underlying Brotherton Formation. Where drift-free, the formation gives rise to heavy, sticky red clay soils.

The formation is 30 to 40m thick, and consists mainly of reddish brown mudstones and silty mudstones, with minor pale grey-green dolomitic mudstones and siltstones. Anhydrite occurs at depth, and gypsum is abundant towards the surface. The Upper (Sherburn) Anhydrite (Smith, 1974), lying 8 to 14m above the base of the formation, is 4 to 6m thick, and a good geophysical marker. The Billingham Main Anhydrite (Smith, 1974) is absent, although a massive grey gypsum bed near the base of the formation may correlate with it. This bed occurs at Darrington Quarries, and in the outliers to the north, where it is up to 1.1m thick, and was formerly dug for plaster. The base of the formation has a gradational junction with the Brotherton Formation, the basal beds being pale grey, greenish grey and yellow dolomitic mudstones, locally with thin shelly limestones. The topmost mudstones are sandy, with thin sandstones, and grade into the overlying Sherwood Sandstone.

TRIASSIC

Sherwood Sandstone Group

The Sherwood Sandstone crops out in the extreme south-east, but is largely drift-covered, the only drift-free areas being on the Kellingley-Snaith Ridge. It is a brick red to orange-brown weakly cemented sandstone. A maximum of about 50m are present at outcrop and depth in the area. At and close to the surface the sandstone is weathered to a soft friable sand. Red mudstone occurs as thin beds and as clasts, the latter mainly concentrated on erosion surfaces. A few small quartz pebbles are scattered throughout.

FOUNDERED STRATA

Foundered strata are mapped around Wake Wood [c. 507 206] in the south-east of the study area (p.19).

SUPERFICIAL DEPOSITS

Quaternary superficial (drift) deposits cover much of the north and east of the study area. The deposits, their probable ages, and the climatic regimes in which they were formed are listed in Table 2. The Pleistocene deposits fall into two broad groups; those that pre-date the Ipswichian interglacial stage, referred to as Older Drift, and those that post-date it. The older deposits mainly occur as dissected remnants on the higher ground, the younger ones confined to the valleys and lower ground. Included in the latter category are the deposits of the southern part of the Vale of York, the 25-Foot Drift, which occupy a large area in the extreme south-east.

The ages of the drift deposits are based on evidence from elsewhere. There is no evidence for the age of the Older Drift, but it may be Anglian. The Older River Gravels are Ipswichian in age (Gaunt, 1981). During the Devensian glacial period the main ice advance stopped to the north at the York-Escrick Moraine, although a brief surge may have taken place as far south as Doncaster (Gaunt, 1981). A ridge of till at Monk Fryston may relate to this surge (Nutt, 1989). Glacial meltwater flowing from the Pennine-derived glacier to the north was impounded by North Sea ice in the vicinity of the Humber estuary to the east, and Glacial Lake Humber was initiated. An initial high level phase is indicated by the presence of littoral and strand line gravels at about 30m AOD (Edwards, 1936). The final level was about 8m (25 feet) AOD, when the 25-Foot Vale of York Drift was formed. Since the melting of the glaciers at the end of the Devensian, river alluvium has been the principal deposit formed, until the large volumes of made ground created in recent times.

Sandy Till

Sandy Till occurs in a small area on the south side of the Aire Valley, from New Fryston to Ferrybridge. It is a brown sandy clay or clayey sand with well rounded erratics up to boulder size, mainly of Carboniferous sandstones, chert and quartz. The topmost part is mainly decalcified, but Magnesian Limestone pebbles are abundant near the base where the deposit is thicker. Thin layers of sand and gravel also occur. The deposit is mainly thin, but may exceed 7m locally.

Till

Till is highly variable, its composition depending on the source materials and their relative proportions. It is generally a brown, red-brown and grey sandy clay containing pebbles, cobbles and boulders, mainly of Carboniferous sandstone, but also of chert, Carboniferous Limestone, Magnesian Limestone and coal. Minor amounts of farther-travelled erratics, notably Lake District volcanic and igneous rocks, also occur. Permian mudstones contribute largely to the deposits preserved in the south and south-east, giving a stiff red boulder clay.

In general, the deposits are thin, but at the southern edge of the largest spread, south of Monk Fryston Lodge, they may be up to 8m thick. However, the rockhead surface on which they lie is irregular, and much thickness variation is likely, particularly in the karstic terrain underlain by the Permian rocks, where the deposits fill dissolution and collapse hollows (p.18). Small pockets filled with till may occur in the areas shown as till-free, and a thin veneer of pebbly clay is widespread on the outcrop of the Permian limestones, commonly resting on cryoturbated limestone debris. Erratics and dreikanters on drift free areas (Edwards, 1936, 1940) are probably the remnants of an originally extensive cover of till.

Glacial Sand and Gravel

Glacial Sand and Gravel is mapped in two main areas. The largest spread lies on the Kellingley-Snaith Ridge in the south-east, where it forms an irregular veneer and lines channels in the Sherwood Sandstone. Although probably largely of glaciofluvial origin, the lateral passage into till (Gaunt, 1976; in press), and its occurrence as a glacial channel deposit suggests either an englacial or subglacial origin in close proximity to ice. A smaller spread of sand and gravel around the Punch Bowl [486 282] consists of up to 3.5m of poorly sorted pebbles, cobbles and a few boulders in coarse sand. Other small spreads are present in dry valleys at Ledston Park and Ledston Luck. At the latter a former pit [4488 3053] exposes 1.5m of gravel consisting of coarse sand with fragments of dolomite overlain by head comprising dolomite blocks in silt. The gravels lie close to the Kippax Fault, where the Cadeby Formation is likely to be highly fissured and subject to dissolution, and they may have been deposited in caves in the limestone that are now exhumed.

Glaciofluvial Sand and Gravel

Glaciofluvial Sand and Gravel, interpreted as the outwash from a glacier melting some distance away, is mapped in two large spreads, one in the Knottingley area, the other to the north around Byram. A smaller spread on the west side of the River Aire at Ferrybridge has been largely removed by quarrying. The two main spreads consist of cross bedded sand and gravel with some thin layers of coal fragments. The Knottingley deposit is mainly thin, but locally up to 5m thick, where it consists of brown, medium to coarse gravelly sand up to 4.5m thick above gravel. In the Byram occurrence, the sand and gravel is up to 3.7m in a pit [4900 2495] (Edwards, unpublished MS), and consists of cross bedded sand and gravel with dolomite fragments and coaly streaks, and some silt and clay beds.

Elsewhere, lenses of sand and gravel fill channels and dissolution hollows in the karstic top of the Brotherton Formation, and are particularly well seen in disused quarries south of Stubbs Lane near Knottingley. They consist of interbedded sands and gravels, the latter mainly of angular pebbles of limestone from the Brotherton Formation. Carboniferous quartzite, red (? Triassic) sandstone and Lower Palaeozoic volcanic pebbles account for less than 3 per cent of the pebble suite.

Older Glaciolacustrine Silt and Clay

Older Glaciolacustrine Silt and Clay is confined to the gravel-lined channels on the Kellingley-Snaith Ridge (Gaunt, 1976; in press). They are veneered by pebbly sand soil, and not visible at the surface, but three were proved in a pipeline trench. There is no evidence of the extent of these deposits, their mapped boundaries being conjectural; other channel deposits are likely to be present on the ridge. The deposit is a grey clay, laminated in part, and containing a few small Carboniferous sandstone pebbles and some Permian limestone pebbles. An ice-scratched Carboniferous Limestone boulder and red sand derived from the Sherwood Sandstone were also recorded.

Older River Gravel

Older River Gravel is not exposed within the study area, but underlies the 25-Foot Drift of the Vale of York, and a scattering of derived cobbles and pebbles occurs at the surface. Proved in many boreholes at Gale Common, it is generally about 4m thick, with a base level mainly betweeen 1m below OD and 2m above. The presence of channels and hollows results in increased thicknesses, the maximum recorded being 10m. The gravels are Ipswichian in age (Gaunt, 1981), and their surface was subaerially exposed during much of the Devensian and subjected to arctic weathering. The resultant fossil periglacial surface is covered by ventifacts and frost-cracked and desert-varnished pebbles and cobbles (Edwards, 1936; Gaunt, 1981). Subsequent dissolution subsidence resulted in hollows in the surface, filled with silt prior to the deposition of the 25-Foot Drift.

Older Littoral Sand and Gravel

Older Littoral Sand and Gravel deposits, first recognised by Edwards (1936) as strand-line gravels, are the remnants of lake shore or beach deposits laid down on the margins of Glacial Lake Humber when it reached an initial level of 30m above OD. The term Older Littoral Sand and Gravel is derived from the 1:50 000 Selby Geological Sheet (71). Gaunt (*in press*) refers to them as lacustrine sand and gravel, and on the existing 1:50 000 Wakefield (78) and Goole (79) geological sheets they are shown as Glacial Sand and Gravel.

Several small patches of gravel occur near Knottingley and south-west of Ferrybridge, lying between 25 and 33m above OD. Two larger areas occur on the Kellingley-Snaith Ridge, capping subsidiary parallel ridges. These were proved in a pipeline trench (Barclay, 1989; Gaunt, 1976; *in press*). The northern ridge is up to 25m above OD, the base of the deposits lying between 14 and 20m above OD. The southern ridge lies at about 18m above O.D. and the base of the gravels between 15 and 17m above O.D.

Ventifacts occur at the base and on the surface of the gravels. Small exposures show clean sand and gravel with pebbles mostly of Carboniferous sandstone and minor amounts of metaquartzite, volcanic rocks, chert and Coal Measures ironstone.

A spread of gravel on a slope on the north side of the Aire Valley at Ledston, the topmost height of which is about 30m above OD, was shown by Giles (1988) as undifferentiated terrace deposits. It is reinterpreted as Older Littoral Sand and Gravel. Other small patches of gravel at 30m above OD, and draping the slope below that level in the area between Fairburn and Burton Salmon have not been mapped separately, but included with the younger littoral sand and gravel described below.

Littoral Sand and Gravel

Littoral Sand and Gravel deposits occuring locally around the margins of the 25-Foot Drift deposits of the Vale of York were the shoreline deposits of Glacial Lake Humber when its level was about 8m above OD. Very clean sand forms a low bench [c.5435 2330] south of Thornfield House, and a pipeline trench proved white, yellow, grey, brown and red sands, locally clayey and with clay layers, resting on gravel with ventifacts. Sands are also present in the low col through the Kellingley-Snaith Ridge east of Kellingley Colliery at a slightly higher level, and may mark a lake level that existed immediately prior to the final one. Up to 2m of clean, orange, medium to coarse, locally cross bedded sand are exposed in a drain along Sudforth Lane [5321 2375-5310 2336]. Sand and gravel beach deposits are also present on the western edge of the former lake at Farpark Farm [5190 2190] and south of Cridling Stubbs [5235 2085].

Glaciolacustrine Silt and Clay

Glaciolacustrine Silt and Clay deposits are shown on the published 1:50 000 Wakefield Sheet as silt and clay of the 25-Foot Drift of the Vale of York. They occur in the south-east, in the flat, low-lying area south-east of Knottingley, cropping at the surface and also underlying sands (see below). A smaller area is present north-east of Burton Salmon. Consisting of stiff bluish grey laminated clay, the deposits commonly coarsen upwards from clay into silty clay and then into grey and brown silt. Thin layers of fine red-brown sand also occur. A maximum thickness of 3.5m is recorded in the Gale Common area.

Glaciolacustrine Sand

Glaciolacustrine Sand covers a larger area than the silt and clay. It is buff to pale orange, ranges from fine to coarse, and is locally clayey. A characteristic feature is the presence of thin gravelly layers of coal and carbonaceous mudstone clasts. The sand rests on erosion surfaces cut in the underlying silt and clay locally, and has a gradational base elsewhere. In some sections clay and silt pipes in the sand suggest burrowing activity. Where not veneered by a thin silt layer, the sand forms slightly raised areas above the surrounding silt and clay, probably due to the greater compaction of the clay. Aeolian reworking may have been responsible for some of the more pronounced features. In places silt overlies the sand, forming the topmost part of a fining-upwards cycle, representing a final silting-up phase to the fluvial deposition. The silt layer is mainly less than 1m thick, and is now mixed by ploughing with the underlying sand to give a sandy silty soil. In such areas the boundaries between the silt and sand are diffuse and arbitrary. Silt in depressions on the surface of the sand is probably Flandrian rather than Devensian in age, but is not separately distinguished on the map.

Gaunt (1981) interpreted the upper sands in the Goole and Doncaster areas as mainly levee deposits laid down on an emergent lacustrine clay plain. Furness and King (1978) interpreted the sands of the Selby distict as glaciofluvial, deposited in water derived from melting ice to the north. The upper sands of the present district resemble those of shallow braided streams.

Similar sands occur locally below the silt and clay deposits, and rest on the ventifact-strewn lower periglacial surface. Generally grey to greyish brown, they contain silt and clay laminae and coal fragments. Up to 2.8m are present in the Gale Common area.

Head

Head is widespread, but mapped only where over about 1m thick. The product of solifluction of weathered bedrock debris and superficial deposits in periglacial conditions, its composition varies widely, depending on the source material. Most of the mapped deposits fill the bases of small dry valleys, and include material that is colluvial in origin. The head on the outcrop of the Coal Meaures is a diamict of rock fragments in a silty clay matrix. That on the Permian outcrop, mainly confined to dry valleys in the Cadeby Formation, consists of silt or sandy silt with dolomite fragments. Head draping the slope south of Thornfield House [c.540 234] is a gravel derived from the Older Littoral Gravel.

Several areas shown as head on the Wakefield Geological Sheet and as taele deposits on the previous six-inch map are reinterpreted. The deposit at Wake Wood [c.504 204] was previously interpreted as a glacial mudflow (Edwards et al., 1940). Lying in the base of an irregularly shaped shallow depression, the material, consisting of red clay, is considered to be foundered mudstones of the Edlington Formation. Foundered limestone masses protrude up through it (p.19). Deposits draping the slopes of the Kellingley-Snaith Ridge were previously referred to as taele gravels. Although a thin veneer of sandy and pebbly colluvium covers the glacial and glaciofluvial deposits, there are no substantial head deposits, as proved in a pipeline trench (Barclay, 1989; Gaunt, 1976; *in press*).

River Terrace Deposits

These are confined to the area west of Castleford at the confluence of the rivers Aire and Calder (Giles, 1988). The Second Terrace deposits consist of sand, locally pebbly and clayey, and gravel. Carboniferous sandstone pebbles are predominant, with minor amounts of ironstone, shale, limestone, and a few igneous and quartz pebbles. Some clay layers occur within the deposit, and a thin layer is generally present above. The surface of the terrace, although much affected by mining subsidence, is generally up to about 5 to 6m above the present floodplain. A date of 38,600 years BP has been obtained from the base of the deposits nearby (Gaunt et al., 1971).

First Terrace deposits are less widespread, and confined to patches on the north side of the Aire Valley and in the valley of Sheffield Beck. Their surface lies about 1m above the present floodplain, and they are similar in composition to the Second Terrace deposits.

Peat

Peat occurs at the surface at five localities: (1) A line of sinkholes marking a former surface stream course extends from Burton Salmon to Byram Lake, and peat is present in some of them. The largest spread is at Burton Salmon where about 1.6m of peat and shell marl occur. Pollen analysis has given an age range from Flandrian Zone VIIa to VIIb (Norris et al., 1971). (2) At least 1.3m of organic peaty silt are present at the western end of a large deep enclosed dissolution subsidence hollow [5300 2466]. (3) A small tributary valley of the Aire [c.525 245] incised into the 25-Foot Drift north of Kellingley contains peat and organic silt at least 1.3m thick. (4) At Gale Common an area of peat occupying the central part of a wide shallow depression, perhaps caused by dissolution subsidence, is now buried under made ground. The area shown on the previous geological map was modified in the light of provings in site investigation boreholes drilled prior to the tipping, and then further modified on the basis that peat (and sand) were said to have been removed from below the embankment areas prior to their construction (Taylor et al., 1976). (5) A small peat deposit [5325 2087] mapped near Grant Spring is at least 1.2m thick.

Peat also occurs within alluvial deposits (see below).

Alluvium

The largest tract of alluvium is that which fills the bottom of the Aire and Calder valleys, forming a floodplain that is almost 2km wide north of Castleford, narrows to 0.5km through the Ferrybridge gap, and widens to 1km north-east of Knottingley. Minor amounts of alluvium are present in small tributaries of the major rivers. There are numerous abandoned meander channels filled with silty clays and peat in the area of the confluence of the Aire and Calder (Giles, 1988). Downstream, the alluvium comprises a complex of silts, organic silts, clays and sands overlying suballuvial gravels. The gravels may be partly pre-Devensian in age, equivalent to the terrace deposits upstream and to the Older River Gravel below the 25-Foot Drift to the east. The floodplain is much affected by mining subsidence, large areas now lying under permanent lakes, known as ings. Downstream of Ferrybridge the alluvium consists of a coarsening-upwards cycle of stiff grey clay passing up into grey and brown silt and silty sand. There is a natural levée on the north bank of the Aire east-south-east of Ferrybridge, but flood embankments to the east largely confine the overbank flood deposits of silt and fine sand, resulting in a drop in ground level of up to 3m from the depositional area within the embankments to the former floodplain level. At least 2.3m of peat and organic clay occurs at the margin of the floodplain near Kellingley Crook. Similar deposits, lying in abandoned channels, are likely to exist elsewhere.

The maximum recorded thickness of alluvium, including the suballuvial gravels, is at Ferrybridge, where up to 13m comprise 4m of silt and clay above 9m of gravels, and rest on rockhead at 3 to 4m below OD.

Landslip

The natural topography of the study area is low, and there is little landslip activity. Only five small areas were noted during the survey (p.19).

Made Ground

This is described on p.27, and the hazards associated with it on p.17. Map 3 lists the principal occurrences.

STRUCTURE

The structure of the study area is simple, with a regional dip of about 2° north-east in the Permian and Triassic rocks. The underlying Coal Measures lie on the western margin of the Selby trough (Edwards, 1951) and are structurally more complex, but with dips generally less than 4°. Figure 34 shows the structure of the Beeston Coal, Figure 35 that of the Permian and Triassic rocks.

The Coal Measures were folded and faulted in late Carboniferous time during uplift in the Variscan Orogeny. They were subsequently eroded to a more or less level peneplain upon which the Permian strata were laid down. The distribution of beds below the Permian cover is shown on Figure 32 and Map 13. The Variscan faults were reactivated during the Alpine orogeny and affect the Permo-Triassic rocks, but with smaller throws than in the Coal Measures. Anomalous steep dips and gentle folding in the Brotherton Formation are caused by collapse due to dissolution of evaporites in the underlying strata (p.19).

Structure of the Coal Measures

The dominant structural feature is a suite of regularly spaced, north-east trending normal faults 1.5 to 2km apart. Most throw south and dip at 65 to 80°. Parallel antithetic faults, for example the un-named fault south of the South Pontefract Fault, the South Loscoe Fault and the South Stubbs Lane Fault, give rise to narrow grabens. The throws of the main faults are typically 50 to 100m, although they vary considerably over short distances. Lack of data prevents a clear pattern of the variation being seen, but in general the greatest throws are expected close to the intersection with the major east- west faults. The North Pontefract Fault has the largest throw in the study area, 139m in the Silkstone Coal to the south-west of Pontefract [4376 2057]. Mining information and field observations indicate that the faults consist of one main fracture with little or no disturbance of the adjacent strata, as seen in the Fairy Hill Fault in Cornwall Opencast Site [244 238].

East to east-south-east trending faults, the Kippax, North Featherstone, Harewood Park and Cridling Stubbs faults, are major structures, all with a net downthrow to the south. They appear to be earlier than the north-east suite, being truncated or offset by them. They are generally complex fault belts within which reverse faults, similar to that seen in Ackton Opencast Site [4189 2172], may be present. The Harewood Park and Cridling Stubbs faults are relatively low angle structures, with dips of 60 to 70° and 45 to 50° respectively. The North Featherstone and

Kippax faults bound zones of oblique minor faults with throws generally less than 20m, the pattern of faulting indicating a component of lateral movement (see, for example, Edwards et al., 1940, p.143).

In the south-west of the study area a set of north-west trending normal faults seen in Snydale Opencast Site [401 215] are part of the Morley-Campsall Fault Belt, one of the most important fractures in the Yorkshire Coalfield. It was active during early Carboniferous time and probably during deposition of the Coal Measures, and is likely to be a major structure in the pre-Carboniferous basement.

Superimposed on the regional south to south-easterly dip is a set of gentle open folds with roughly north-west trending axial planes and plunges towards the north-west. They are best developed in the Pontefract- Kellingley area, where the dip is generally lower than farther north, and are truncated by the main faults, suggesting that they developed in independent fault-bounded tilt blocks.

An exception to the general pattern of folds is the Normanton Anticline in the south-west of the area, a pericline-like structure that is truncated by the Morley-Campsall Fault Belt at Normanton, west of the study area (Giles, 1988).

Structure of the Permian and Triassic rocks

Most of the major faults that cut the Coal Measures also affect the Permo-Triassic rocks, but their throws are generally much reduced and less than 20m. The Kippax Fault is exceptional, with an estimated throw of 43m down south at Kippax [416 305]. In the Knottingley-Kellingley area there are additional small north-east trending faults in the Permo-Triassic, interpreted as upward splays of Coal Measure faults. In general the faults dip at a high angle, much of the movement being taken up along near-vertical fractures in the limestones. Open joints are a characteristic feature of the Brotherton Formation, arranged in an orthogonal set, the median principal direction at 320° and the minor direction parallel to the main north-east trending faults.

The east to south-east trending faults are complex, braided tracts, some with slivers of mobile, gypsiferous Permian mudstone, for example the Kippax and Cridling Stubbs faults. In places the mudstone appears to be injected along the faults and incorporated into fault breccia, as with the Cridling Stubbs Fault in the quarry at Doveroyd [492 245] and the Carleton Fault in Knottingley [4925 2300].

Superimposed on the gentle north-east regional dip are small flexures. North of Knottingley they are roughly colinear with the gentle folds in the underlying Coal Measures. Between Fairburn and Ledsham a broad anticline overlies a heavily faulted zone in the Coal Measures, probably caused by transcurrent movement on the Kippax Fault.

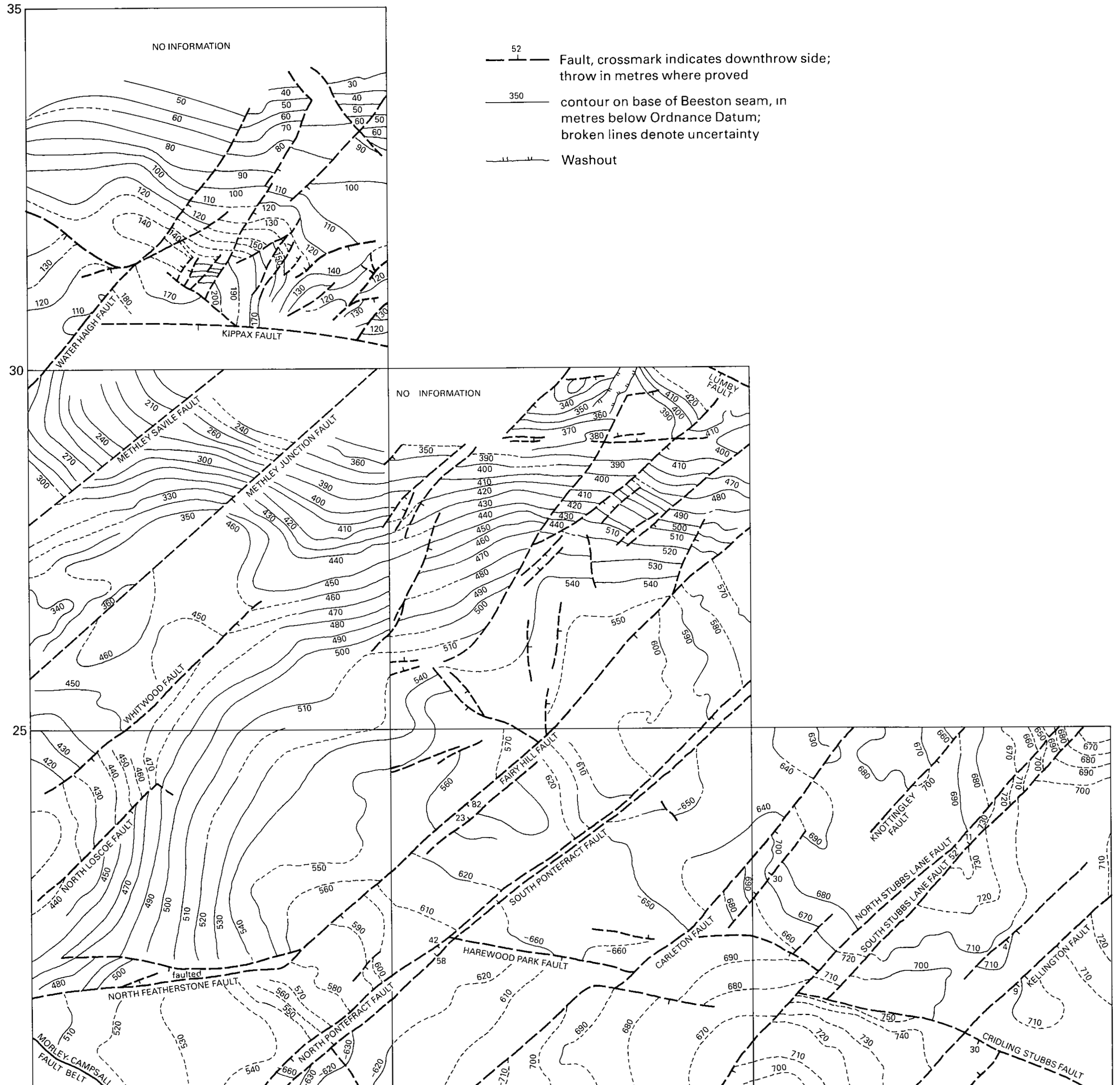


Figure 34 Structure of the Beeston seam

Figure 35 Contours on the base of the Permian

Appendix 2 ENGINEERING GEOLOGY

Geotechnical database

The combination of the geological units into groupings with similar engineering properties was carried out using geotechnical data extracted from site investigation reports on sites within the initial study area (sheets SE 42SW, SE, NE and 52SW). The distribution of these groupings shown on Maps 4 and 5 is based on the new geological maps produced in this study (Maps 1 and 2). As part of the area is rural, coverage of the site investigation reports is geographically restricted. They are mainly of four types:

(1) Construction sites in and around the urban areas
(2) Major road schemes, particularly the M62 Motorway
(3) Those connected with the mining industry, including spoil tip sites
(4) The fuel ash disposal site at Gale Common

The distribution of boreholes assessed is shown on Figure 3. Of these, 1161 have data of sufficient quality to warrant incorporation into the geotechnical database. The engineering geology of the geological units was assessed by analysis of the geotechnical database, supplemented by observations recorded in the site investigation reports on engineering behaviour, problems and hazards.

Summary values of geotechnical parameters are presented in Tables 6,7,9 to 19 and 21 to 23. should be stressed that these give a general guide only, and should not be used in detailed design calculations for the reasons outlined below.

The geotechnical information used to classify geological materials in engineering terms is not necessarily comprehensive or representative of the entire outcrop of any particular formation or deposit. The geographical spread of the geotechnical data is uneven, and for some there is very little data available. The tests for which results are tabulated should have been carried out in accordance with the appropriate British Standard, but spurious results do occur, and were not included in the database. However, a wide range of results has been recorded for nearly all the materials for which a significant number of tests have been carried out. This may reflect variations in geotechnical properties, or in testing procedures, or in the standards to which the tests were carried out. The tabulated statistics give the range of test values encountered and the mean and modal values. They are a useful first approximation to the anticipated engineering properties of the geological materials in the study area.

Geotechnical data were obtained from 4012 borehole samples. Results from the following tests were entered into the database.

(a) In Situ (Field) Tests
1. Standard Penetration Test (SPT)
2. Rock Penetration Test (RPT)
3. Permeability Tests 4. Shear Vane Tests

(b) Laboratory Tests
1. Moisture Content
2. Plasticity Tests (Liquid and Plastic Limits)
3. Bulk and Dry Densities
4. Specific Gravity
5. Particle Size Analysis
6. pH
7. Sulphate Content (of soil or groundwater)
8. Organic Content
9. Triaxial Compression (Quick-Undrained)
10. Uniaxial Compression (Unconfined Compressive Strength)
11. Point Load Tests (Diametral and Axial)
12. Consolidation Tests
13. Compaction Tests
14. California Bearing Ratio (CBR)

For most sample records, only a selection of these geotechnical tests was carried out. Outline descriptions of the tests and measured parameters are presented in Annex A, along with key tables, defining various parameter classes recorded in the summary geotechnical data (Tables 6,7,9 to 19 and 21 to 23).

Following assessment of the site investigation reports, geotechnical test parameters were entered onto a proforma data sheet, checked and collated. These were then keyed into an IBM XT Personal Computer, using a commercial software package. Backup copies of the database are kept by the Engineering Geology Reseach Group of the British Geological Survey. Analysis of the stored data set was carried out using a commercial statistics and graphics software package to provide a statistical assessment of the parameters, including graphical plots. Results were used to collate the summary geotechnical data and to provide a basis for interpretive assessment of the engineering characteristics of each engineering geological group.

The distribution and descriptions of made ground are presented on Map 3. No assessment is made here of the engineering implications of waste disposal sites as the range of fill materials makes them difficult to classify in engineering terms (but see p.17).

For planning purposes the suitability of any potential development site will be dependent not only on the engineering properties of the in situ rocks and soils, but also on the nature and thickness of any made ground.

Engineering Classification of Rocks and Soils

Division of the rocks and soils of the area into groupings of similar engineering characteristics is based on an assessment of recorded geotechnical parameters and lithological characteristics. These groupings do not correspond exactly to the divisions presented on the geological maps. The Coal Measures are divided into Lower, Middle and Upper Coal Measures. These divisions consist of interbedded mudstones, shales, siltstones and sandstones. In engineering geological terms, a two-fold division has been made into sandstones and the dominantly argillaceous ('mudrock') sequences. The two Permian mudstone formations comprise a single engineering geological unit, and likewise the two limestone formations.

Over large parts of the study area, the bedrock is obscured by a variable thickness of Quaternary superficial deposits. A broad distinction has been made, therefore, between the engineering geological characteristics of the bedrocks (Map 4) and those of the superficial deposits (Map 5).

Table 6 Summary geotechnical data for Upper Magnesian Limestone (Brotherton Formation)

IN SITU TESTS

ENGINEERING GEOLOGICAL DESCRIPTION	PENETRATION TESTS: SPT N-VALUE	PENETRATION TESTS: RPT (mm)	PERMEABILITY (m/sec)	VANE SHEAR STRENGTH: UNDISTURBED (kPa)	VANE SHEAR STRENGTH: REMOULDED (kPa)
Pale grey and buff, weak to moderately strong, thinly-bedded, occasionally dolomitic LIMESTONES with thin marl bands.	59	57			
	41	155			
	36	161			
	30.6	80.9			
	5 - >50	25 - 305			

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES: % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS: pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
39	35	35	35	1									
18	37	21	15	2.14									
18	36	21	14										
5.7	10.8	3.5	10.3										
4 - 27	19 - 28	15 - 30	2 - 60										

STRENGTH TESTS

TRIAXIAL: Cu (kPa)	TRIAXIAL: Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2]: DIAM. (MPa)	POINT LOAD (Is 50) [2]: AXIAL (MPa)

CONSOLIDATION AND COMPACTION TESTS

Mv [3] CLASS m^2/MN	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4]: UNSOAKED (%)	C.B.R. [4]: SOAKED (%)

ENGINEERING GEOLOGICAL COMMENTS
Variable rockhead level with possibility of karstic conditions developed locally. Highly weathered zones and solution cavities may cause excessive differential settlements and inadequate bearing capacities for shallow foundations. Ripping or minor blasting required for relatively fresh rocks.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

Table 7 Summary geotechnical data for Lower Magnesian Limestone (Cadeby Formation)

ENGINEERING GEOLOGICAL DESCRIPTION
Off-white to buff, weak to moderately strong, thinly bedded to massive, DOLOMITES and marly LIMESTONES with marls and reef breccia.

IN SITU TESTS

PENETRATION TESTS: SPT N-VALUE	PENETRATION TESTS: RPT (mm)	PERMEABILITY (m/sec)	VANE SHEAR STRENGTH: UNDISTURBED (kPa)	VANE SHEAR STRENGTH: REMOULDED (kPa)
218	305	3		
114	98			
115	77			
69.1	62.9			
6 - >50	12 - 320	$3x10^{-5}$ - $1x10^{-4}$		

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES: % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS: pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
81	24	22	22	24	3	10					5	5	
15	25	22	3	2.01	1.41	2.76					8.1	1	
15	25	22	3	2.02		2.80							
5.1	3.9	3.6	1.2	0.20		0.18							
4 - 34	18 - 35	16 - 29	2 - 6	1.62-2.38	1.39-1.43	2.44 - 2.95					7.5-8.5	1,1	

STRENGTH TESTS

TRIAXIAL: Cu (kPa)	TRIAXIAL: Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2]: DIAM. (MPa)	POINT LOAD (Is 50) [2]: AXIAL (MPa)
4	4	24	7	3
36	13	10.5	0.85	1.62
		7.5		
		9.2		
14 - 55	0 - 23	2.4 - 36	0.6 - 1.6	1.5 - 1.85

CONSOLIDATION AND COMPACTION TESTS

Mv [3] CLASS m^2/MM	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4]: UNSOAKED (%)	C.B.R. [4]: SOAKED (%)
1	1	5	5	7	2
2	3	1.75	14	18	13,19
		1.65-1.96	12 - 16	4 - 34	

ENGINEERING GEOLOGICAL COMMENTS
Variable rockhead level with possibility of karstic conditions developed locally. Highly weathered zones and solution cavities may cause excessive differential settlements and inadequate bearing capacities for shallow foundations. Local presence of artesian groundwater conditions. Subsidence of limestone associated with workings in underlying strata.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

Engineering Classification of the Solid Rocks

The rocks have been divided into four engineering geological groups. The relationship between these and the geological (lithostratigraphical) divisions are shown in Table 3.

The engineering geology groups encompass both engineering rocks and engineering soils. This distinction is based on differences in physical and mechanical properties. Group 1 (Limestones) and Group 2 (Moderately Strong Sandstones) are classes of engineering rock, whereas the 'Friable Sandstones and Dense Sands' of Group 3 have sufficiently different properties to warrant classification as an engineering soil. The Mudrock Group includes those dominantly argillaceous deposits with geotechnical characteristics bordering on those of a 'weak' engineering rock and a 'strong' (overconsolidated) engineering soil. It should be noted that weathering of the engineering rocks (including mudrocks) may cause breakdown and softening of the fresh material into an engineering soil. The variability of the weathering products precludes the identification of distinctive weathering profiles in a study such as this. However, the effects of weathering on the engineering properties of the rocks are described.

Engineering Geology of the Solid Rocks

Limestones

This group includes the limestones of the Brotherton (Upper Magnesian Limestone) Formation and the Cadeby (Lower Magnesian Limestone) Formation. Their lithologies, summarised on p.31, have been variously described in site investigation reports as marly, clayey, silty, sandy, gravelly limestones, calcareous mudstones, marls

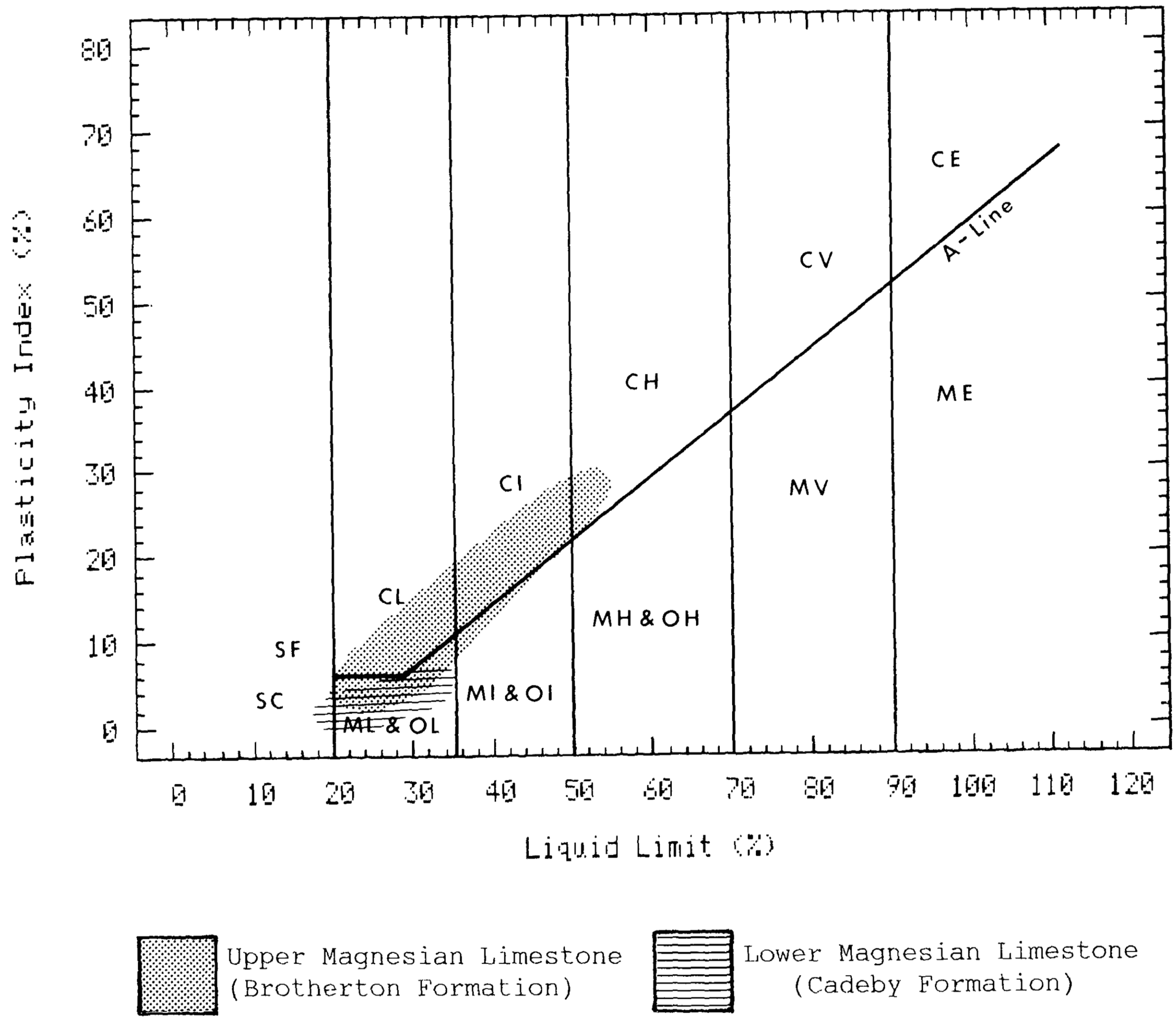


Figure 36 Plasticity diagram for the Magnesian Limestone formations

Table 8 Potential problems in the Magnesian Limestones

GEOTECHNICAL CONSIDERATION	POTENTIAL FOUNDATION PROBLEM
Wide range of measured engineering properties, particularly strength and deformability.	Difficulty in assessing representative values of bearing capacity and anticipated settlements.
High porosities and the presence of voids and cavities. Possible karstic conditions locally developed in rockhead.	Likely to reduce bearing capacity and cause excessive differential settlements below heavy structures. May require ground treatment or special foundation design before placing structures. May cause water inflow problems in excavations.
Local presence of highly weathered zones.	Likely to reduce bearing capacity. May preclude use of shallow foundations except for light structures.
Variable rockhead level and possible presence of infilled solution holes and channels.	Problems in achieving adequate bearing capacity at shallow depth. May result in excessive differential settlements unless deep foundations are used. Piled foundations of variable lengths may be required.
Local presence of artesian groundwater conditions.	Likely to result locally in basal heave of foundation excavations close to limestone/basal sand contact, or lead to stability problems of foundations in weathered rock if taken below water table.
Likelihood of previous or current subsidence of limestone associated with collapse of workings in underlying Coal Measures and Basal Permian Sand (Maps 12a, b). Also subsidence of superficial deposits associated with faulting/fracturing of underlying Magnesian Limestone.	May result in excessive differential settlements. May require treatment before placing foundations.

and calcareous silty sands. This is partly a reflection of the heterogeneity of the rocks due to lithological variation and weathering effects, and partly the non-systematic descriptions of the lithologies by the report writers. The lithological and weathering variations result in a range of engineering properties, summary values of which are shown in Tables 6 and 7.

The limestones dip gently to the east. Bed thicknesses in the Lower Magnesian Limestone generally range from 0.2 m to 0.6 m (medium-bedded), but beds over 2 m (thick-bedded to massive) also occur. The Upper Magnesian Limestone is predominantly thinly bedded, with beds of 0.05 to 0.10 m, but beds up to 0.3 m are fairly common, and thicker beds up to 3m occur at the top. Joint spacings range from between about 60 and 200 mm (closely-spaced) to over 2 m (very widely-spaced), the joints being steep to vertical.

The depth to which weathering extends below rockhead is variable, but zones of moderately to highly weathered rock (with SPT N-values of about 50 or less) have been recorded at 12 to 15 m below the surface. Highly weathered zones are also reported in the vicinity of the water table and at the base of the Lower Magnesian Limestone. The porosity and permeability of limestone generally increases with dolomitisation, but permeability is primarily dependent on the size and concentration of fractures and joints. Three field permeability results for the Lower Magnesian Limestone (ranging from 10^{-5} to 10^{-4} m/sec) indicate a moderately permeable rock mass, but permeability values may be expected to vary widely both areally and with depth. Water percolation along joints and bedding planes results in widening of the discontinuities and the creation of voids and cavities by dissolution, giving karstic rockhead conditions.

The wide range of engineering properties shown in Tables 6 and 7 are principally controlled by rock lithology, with the degree of dolomitisation (and the resultant intergranular solution porosity) being a significant factor in the degree of weathering. The assessment of the engineering properties should therefore include consideration of the range of values quoted for individual tests, as well as the mean and median values.

Standard penetration test (SPT) results have a wide range of N-values, from 5 to well over 50. They show no overall trend of increasing N-values with depth, but the highest values are consistently associated with fresher material, decreasing to below 50 in highly weathered rock.

Plasticity data for the fine grained argillaceous sequences in the Upper Magnesian Limestone (Figure 36) show values falling on or near the A-Line, typical of inorganic clays and silts of low to intermediate plasticity. Data for the Lower Magnesian Limestone group as low plasticity sandy clays and silts. This probably reflects the weathering of the dolomitic limestones to a slightly cohesive silt of low plasticity.

Strength data have been obtained only for the Lower Magnesian Limestone, nearly all the results relating to fresh to slightly weathered dolomite. Unconfined compressive strength values from 24 partially saturated samples range from 2.4 to 36 MPa, and show the dolomitic limestones to be weak to moderately strong, with mean and median values in the moderately weak class. Limited point load data classify the fresh to slightly weathered rock as moderately weak to moderately strong, with a slight anisotropy in strength indicated by diametral and axial tests, probably related to sub-horizontal, thin argillaceous partings. Unconfined compressive strengths obtained for a few samples of slight to moderately weathered 'marly limestone' showed it to fall in the moderately strong class. Rock strength generally decreases with increasing porosity and degree of saturation. However, strength tests carried out on intact material in the laboratory cannot represent the in situ mass rock properties in situ, particularly if the rock is fractured. The influence of discontinuities should therefore be considered in assessment of values of strength and deformability for design purposes.

Design Considerations

i) Foundations

The main factors likely to cause foundation problems in the Magnesian Limestone formations are outlined in Table 8. Combinations of these may present serious problems, particularly where large variations in bearing capacities will cause differential settlements. A limited number of tests of groundwater sulphate content have provided values which fall within Class I of the Building Research Establishment classification for sulphate-bearing soils and groundwaters (Anon, 1975b). However gypsum in the marls overlying the limestones may result in Class 4 sulphate values. It is possible therefore that sulphate-resisting cement may be required locally for foundations, and sulphate levels should be checked during site investigations. Allowable bearing capacities of 500 kPa have generally proved suitable in moderately weathered zones at or near rockhead. Shattered or soft clayey zones should be removed and backfilled with suitable compacted material or concrete. For fresh to slightly weathered rock at depth, allowable bearing capacities of 1000 to possibly 2000 kPa may be used in design.

ii) Slope Stability

The only slope failure observed is west of Townclose Hills [4042 3035], where a combination of faulting, cambering and rotational landslipping affects the basal beds of the Lower Magnesian Limestone. Since the dip of the bedding is low, slope stability problems in engineering works are likely to be confined to rock falls and long-term degradation of rock faces rather than large-scale instability. The most important factors influencing the stability of excavations are the presence of steeply inclined or vertical joints, highly weathered zones, brecciated limestones and weak, highly porous dolomites which are particularly susceptible to weathering on exposure. Groundwater problems may also occur locally where mass permeabilities are high and the water table is at shallow depth. Where water ingress occurs in highly to completely weathered and brecciated limestone or in fault zones, immediate support of excavations may be needed.

Assessment of major road cuts and quarries in the study area indicate that the more resistant fresh to slightly weathered, bedded limestones can maintain stable 70° to near-vertical faces at heights in excess of 10 m where no inclined joint surfaces are present or the cuttings are orientated such that discontinuity-bounded blocks are stable. Slopes of 1:1 are recommended as a preliminary guide for excavations and cuttings in most of the Magnesian Limestones, although re-grading to 1V:2H may be necessary for highly weathered, brecciated or faulted zones and for long-term stability in beds particularly prone to degradation on exposure.

iii) Excavatibility and suitability as fill material

Highly to completely weathered brecciated and shattered rock may be excavated by mechanical scraper or machine shovel; fresh to moderately weathered jointed and fractured rock will require machine ripping. Massive limestone with widely-spaced joints will require pneumatic breakers or minor blasting. Site investigation reports record successful excavation by ripping to at least 10 m depth in well-jointed Upper Magnesian Limestone before minor blasting is required.

Fresh to slightly weathered rock is suitable as fill and is classified as rockfill for compaction purposes. Highly weathered and faulted rock is generally unsuitable as rockfill but may be used as a bulk fill material. The limestones should be assumed to be frost-susceptible for design purposes, and this should be taken into account for calculations of minimum pavement thickness.

Insufficient compaction test data were obtained during the study to provide an assessment of compaction characteristics. For the results obtained, optimum moisture contents ranged from 12 to 16% and maximum dry densities from 1.66 to 1.96 Mg/m3. Unsoaked CBR test results ranged from 4 to 34%, with a mean of 18%.

Moderately Strong Sandstones

These are the sandstones of the Coal Measures. They are greyish brown to yellowish brown, moderately well-jointed, weak to moderately strong, well-graded micaceous sandstones, with some siltstone and mudstone layers and coal partings. The depth and intensity of weathering is variable but complete weathering to a silty or clayey sand may occur down joints and fractures to 6 or 7 m below rockhead. Zones of moderately to highly weathered rock have been recorded to depths of 40 m below ground surface. The degree of weathering is a major factor in controlling engineering behaviour and summary geotechnical properties for fresh to moderately weathered sandstone and highly to completely weathered rock are shown separately in Tables 9 and 10, respectively.

Standard penetration test (SPT) results show a wide range of N-values but are usually well in excess of 50 for fresh to moderately weathered rock. For highly and completely

Table 9 Summary geotechnical data for Coal Measures Sandstone (Fresh to Moderately Weathered)

IN SITU TESTS

ENGINEERING GEOLOGICAL DESCRIPTION	PENETRATION TESTS: SPT N-VALUE	PENETRATION TESTS: RPT (mm)	PERMEABILITY (m/sec)	VANE SHEAR STRENGTH: UNDISTURBED (kPa)	VANE SHEAR STRENGTH: REMOULDED (kPa)
Greyish brown to yellow brown, moderately well-jointed, weak to moderately strong, well-graded, silty micaceous SANDSTONES.	194	252	5		
	100	114			
	88	97			
	53.5	78.2			
	13 ->50	12 - 833	$8x10^{-6}$ - $3x10^{-4}$		

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES: % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS: pH	SO_3 [1] CLASS	ORGANIC CONTENT (%)
48				23	12	9	3	3	3	3	11	17	
12				2.14	1.80	2.64	0	6	90	4	6.7	1	
12				2.10	1.80						6.5		
4.5				0.21	0.18						0.95		
4 - 25				1.65-2.51	1.38-2.08	2.54 - 2.70	0,0,0	2 - 12	75 - 98	0 - 13	5.5-8.6	1	

STRENGTH TESTS

TRIAXIAL: Cu (kPa)	TRIAXIAL: Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2]: DIAM. (MPa)	POINT LOAD (Is 50) [2]: AXIAL (MPa)
14	14	17	37	38
115	16.6	19.4	0.22	0.16
56	16.5	18.9		
109	10.8	6.2	0.08	0.06
33-394	0 - 33	12.2 - 35.1	0.09 - 0.7	0.06 - 0.27

CONSOLIDATION AND COMPACTION TESTS

Mv [3] CLASS m^2/MM	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4]: UNSOAKED (%)	C.B.R. [4]: SOAKED (%)
1	1			2	
1	4			10,12	

ENGINEERING GEOLOGICAL COMMENTS
Moderately strong to moderately weak rock. Generally low compressibilities and immediate settlements but interbedded mudstones will cause local variations in strength and consolidation characteristics. Potential foundation problems associated with shallow coal workings. Ripping or pneumatic tools required for excavation.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

Table 10 Summary geotechnical data for Coal Measures Sandstone (Highly to Completely Weathered)

IN SITU TESTS

ENGINEERING GEOLOGICAL DESCRIPTION		PENETRATION TESTS: SPT N-VALUE	PENETRATION TESTS: RPT (mm)	PERMEABILITY (m/sec)	VANE SHEAR STRENGTH: UNDISTURBED (kPa)	VANE SHEAR STRENGTH: REMOULDED (kPa)
Greyish brown, weak silty SANDSTONES and loose to dense silty, clayey SANDS.	n	33	9			
	$\bar{x}$	35	216			
	M	29				
	σ	21.3				
	RANGE	8 - 84	140-272			

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES: % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS: pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
n	33	23	17	17	12	12		2	2	2	2	11	17	
$\bar{x}$	15	30	21	12	1.94	1.63		0	10	90	0	6.7	1	
M	14	29	21	11	1.98	1.63						6.5		
σ	4.9	8.5	2.6	6.0	0.22	0.14						0.95		
RANGE	9 - 28	16 - 48	15 - 24	6 - 25	1.65-2.51	1.41-1.86		0,0	5 - 14	86 - 95	0,0	5.5-8.6	1	

STRENGTH TESTS

	TRIAXIAL: Cu (kPa)	TRIAXIAL: Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2]: DIAM. (MPa)	POINT LOAD (Is 50) [2]: AXIAL (MPa)
n	7	7			
$\bar{x}$	39	18			
M					
σ					
RANGE	17 - ,90	0 - 36			

CONSOLIDATION AND COMPACTION TESTS

	Mv CLASS [3] m^2/MM	Cv CLASS [3] m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4]: UNSOAKED (%)	C.B.R. [4]: SOAKED (%)
n	8	7			7	
$\bar{x}$	2	4			14	
M						
σ						
RANGE	2 - 3	3 - 4			9 - 20	

ENGINEERING GEOLOGICAL COMMENTS

Variable depth of weathered zone. Often completely weathered to silty, clayey sand within 6 - 7 m of rockhead. Zones of highly weathered rock may be present up to 40 m below ground surface. Generally low compressibilities with high rates of consolidation settlement. Potential foundation problems due to shallow coal workings.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

weathered sandstone near rockhead, N-values are typical of those for medium to dense sands.

In general, increasing weathering grade results in increasing plasticity and moisture content and a decrease in shear strength. Limited field permeabilities obtained for fresh to moderately weathered sandstone range from 10^{-6} to 10^{-4} m/sec, indicative of a slightly to moderately permeable rock mass. These are considered to be fairly representative values but variation across the outcrop will occur depending on degree of weathering, the size and spacing of fractures, and the presence of fault zones.

Unconfined compressive strength values for fresh to moderately weathered sandstone range from 12.5 to 35.1 MPa (for partially saturated samples), classifying the rock as moderately strong. Strengths measured on saturated test samples may be reduced by up to 50%, making the rock moderately weak. Point load test results of similar weathered rock give weak to moderately strong values, with no indication of anisotropic strengths. Values of rock strength will decrease with increased weathering. Also, laboratory tests cannot be representative of the in situ mass rock strength, which will be influenced by the frequency, orientation and infilling of discontinuities.

Design Considerations

i) Foundations

Limited consolidation data show that compressibilities will be low for moderately weathered rock and low to medium for weathered and argillaceous material. However, weathered mudstone and siltstone layers may give rise to differential settlements. A variable thickness (but generally less than 1 m) of head deposits locally covers the sandstone outcrops. This heterogeneous material may also give rise to differential settlements and should be removed prior to placing foundations. Of particular importance for foundation design, are the possible presence of old coal workings at shallow depth below any potential site. Adequate provision should be made in any proposed site investigation to ascertain not only the thickness of the sandstone unit, but the extent and depths of these workings before consideration is given to the use of piled foundations for heavier structures. The Coal Measures rocks are also extensively faulted and the presence of shattered rock in fault zones may give rise to adverse groundwater conditions in addition to differential settlements. Pretreatment of ground may be necessary and site investigations should aim to delineate these problem areas as accurately as possible prior to placing foundations.

Maximum nett safe bearing capacities of 500 kPa have proved suitable for shallow foundations in highly weathered material near rockhead, and 2000 kPa for foundations taken to fresh or slightly weathered rock. Insufficient data have been obtained for an assessment of pile design loads to be made.

Class I sulphate concentrations have been recorded, but Class 2 concrete may be required to combat local acid groundwater conditions indicated by minimum recorded pH values of 5.5.

ii) Slope Stability

No natural slope failures have been recorded in the sandstones. In excavations for construction works the fresh to slightly weathered sandstones may remain stable at steep slope angles, but interbedded siltstones, mudstones and shales will reduce stability, and side slopes of 1V:2H have been recommended for preliminary design purposes. Perched groundwater tables may give rise to high hydrostatic pressures, causing heave at the base of excavations. Dewatering will be required where groundwater seepage is encountered. Excavations in fault zones may require immediate support due to the presence of highly shattered or brecciated rock and clay gouge.

iii) Excavatibility and suitability as fill material

Weathered material may be excavated by mechanical scraping or digging. Fresh to slightly weathered rock may require ripping and, in confined spaces, pneumatic tools for excavation.

Solid sandstone is suitable as embankment fill if care is taken in selection and excavation. Although suitable as bulk fill, use as a high grade fill is not generally recommended due to argillaceous beds. For compaction purposes, the Coal Measures sandstones are classed as a graded granular soil.

Very few test results on compaction properties were obtained and are insufficient to provide a representative assessment of compaction characteristics. Limited CBR values on unsoaked test samples ranged from 9 to 20%, with mean values of 11% and 14% for moderately weathered and highly to completely weathered material respectively.

Friable Sandstones and Dense Sands

This group encompasses the Sherwood Sandstone and Basal Permian Sand. Very few geotechnical test data were obtained for these formations.

Sherwood Sandstone Group

The Sherwood Sandstone outcrop is largely obscured by a variable thickness of superficial deposits. The sandstones are brick-red to orange brown, weakly cemented, cross-bedded, fine to medium grained sandstone, with some thin layers and lenses of red mudstone. Although becoming moderately strong at depth, site investigation records to 12 m below rockhead invariably describe this material as weathered to a weak friable sandstone or loose to very dense sand. Standard penetration test (SPT) results show a general increase of N-values with depth, with values less than 50 occurring in highly weathered material within 5 to 6 m of the ground surface. Insufficient data preclude any meaningful assessment of engineering properties, but they are summarised in Table 11.

Design Considerations

i) Foundations

Weathering grade and relative density of the upper sandstone surface is variable, but maximum nett safe bearing capacities of 500-600 kPa have been quoted for shallow strip foundations, with settlements being very small and rapid. Allowable bearing pressures of 150 kPa are recommended for shallow strip foundations at 0.5 m depth in weathered near-surface material.

The variable thickness of superficial deposits overlying the Sherwood Sandstone generally necessitates the use of piled foundations for heavier structures. Piles would be

Table 11 Summary geotechnical data for Sherwood Sandstone

IN SITU TESTS

ENGINEERING GEOLOGICAL DESCRIPTION		PENETRATION TESTS SPT N-VALUE	PENETRATION TESTS RPT (mm)	PERMEABILITY (m/sec)	VANE SHEAR STRENGTH UNDISTURBED (kPa)	VANE SHEAR STRENGTH REMOULDED (kPa)
Brick-red to orange brown, weakly cemented, friable SANDSTONE and loose to dense SAND.	n	81	45			
	$\bar{x}$	61	187			
	M	51	183			
	σ	30.8	50.8			
	RANGE	5 - > 50	103-294			

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS pH	SO_3 CLASS[1]	ORGANIC CONTENT (%)
n	3	1	1	1	1			1	1	1	1	8	8	
$\bar{x}$	21	58	23	35	1.84			0	12	86	2	7.7		
RANGE	11 - 36											6.6-8.6	1 - 3	

STRENGTH TESTS

	TRIAXIAL Cu (kPa)	TRIAXIAL Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50)[2] DIAM. (MPa)	POINT LOAD (Is 50)[2] AXIAL (MPa)
n	1	1			
$\bar{x}$	19	0			

CONSOLIDATION AND COMPACTION TESTS

	Mv CLASS[3] m^2/MM	Cv CLASS[3] m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R.[4] UNSOAKED (%)	C.B.R.[4] SOAKED (%)
n	1	1				
$\bar{x}$	3	3				

ENGINEERING GEOLOGICAL COMMENTS

Generally weathered to sand within 12 m of rockhead; SPT N-values increasing with depth. Variable thickness of overlying superficial deposits generally require piled foundations set at least 3 pile diameters into sandstone. Consolidation settlements will be small and rapid. Locally high sulphate contents, so care needed in concrete selection.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

Table 12 Summary geotechnical data for Basal Permian Sand

IN SITU TESTS

ENGINEERING GEOLOGICAL DESCRIPTION	PENETRATION TESTS: SPT N-VALUE	PENETRATION TESTS: RPT (mm)	PERMEABILITY (m/sec)	VANE SHEAR STRENGTH: UNDISTURBED (kPa)	VANE SHEAR STRENGTH: REMOULDED (kPa)
Buff to yellow, generally uncemented, soft friable SANDSTONE and medium dense, fine to medium SAND.			3		
			$3x10^{-5}$ x $2x10^{-4}$		

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES: % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS: pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
4				2	2	3	3	3	3	3			
13						2.66	6	10	75	10			
8 - 18				2.0, 2.37	1.64, 1.69	2.65 - 2.70	5 - 8	4 - 20	63 - 87	0 - 28			

STRENGTH TESTS

TRIAXIAL: Cu (kPa)	TRIAXIAL: Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2]: DIAM. (MPa)	POINT LOAD (Is 50) [2]: AXIAL (MPa)
		1		
		7.4		

CONSOLIDATION AND COMPACTION TESTS

Mv [3] CLASS m^2/MN	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4]: UNSOAKED (%)	C.B.R. [4]: SOAKED (%)
				2	
				7	
				3, 10	

ENGINEERING GEOLOGICAL COMMENTS
Moderately permeable. High water inflows, 'running' sand and piping expected in borings and excavations which will require immediate support. Collapse of old sand workings give rise to locally severe foundation problems in overlying limestone strata.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

Table 13 Summary geotechnical data for Coal Measures Mudstones/Shales (Fresh to Slightly Weathered)

ENGINEERING GEOLOGICAL DESCRIPTION
Grey to greyish brown, weak to moderately strong, fissured silty and sandy MUDSTONES.

IN SITU TESTS

PENETRATION TESTS		PERMEABILITY	VANE SHEAR STRENGTH	
SPT N-VALUE	RPT (mm)	(m/sec)	UNDISTURBED (kPa)	REMOULDED (kPa)
160	191			
	135			
138 values >50	121			
	64			
9 - >50	25 - 294			

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
146	97	97	97	36	11	1					9	6	
14	37	23	14	2.12	1.76	2.66					6.9	1	
12	35	23	13	2.14	1.76								
6.6	8.2	3.9	6.5	0.15	0.18								
2 - 51	21 - 26	10 - 32	2 - 40	1.81-2.59	1.57-2.08						4.4-8.0	1	

STRENGTH TESTS

TRIAXIAL Cu (kPa)	Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2] DIAM. (MPa)	AXIAL (MPa)
37	36	7		
106	11.2	11.4		
103	9.5			
47.8	8.2			
17 - 276	0 - 31	5 - 16		

CONSOLIDATION AND COMPACTION TESTS

Mv [3] CLASS m^2/MM	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4] UNSOAKED (%)	SOAKED (%)
4	4	1	1	3	
		1.94	14.0	7	
2 - 5	3 - 4		3 - 11		

ENGINEERING GEOLOGICAL COMMENTS
Fresh to slightly weathered mudrock of low to intermediate plasticity and medium compressibility. Tends to deteriorate and soften when relieved of overburden pressure and on presence of water. Suitable as general fill under controlled compaction conditions. General low permeability but perched water levels associated with sandstone bands.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

Table 14 Summary geotechnical data for Coal Measures Mudstones and Shales (Moderately to Completely Weathered)

ENGINEERING GEOLOGICAL DESCRIPTION
Greyish brown to brown, weak, fissured silty MUDSTONES and firm to stiff silty CLAYS of low to high plasticity.

IN SITU TESTS

	PENETRATION TESTS		PERMEABILITY	VANE SHEAR STRENGTH	
	SPT N-VALUE	RPT (mm)	(m/sec)	UNDISTURBED (kPa)	REMOULDED (kPa)
n	80	74	4	8	
$\bar{x}$	66 50 values > 50	178			
M	62	172			
σ	36.8	70.9			
RANGE	8 - > 50	54 - 380	$2x10^{-7}$ - $1x10^{-4}$	43 - 106	

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES				CHEMICAL TESTS		
								% CLAY	% SILT	% SAND	% GRAVEL	pH	SO_3 [1] CLASS	ORGANIC CONTENT (%)
n	237	127	127	127	41	20	5					9	6	
$\bar{x}$	19	43	25	18	2.03	1.68	2.74					6.9	1	
M	17	41	25	17	2.03	1.74	2.76							
σ	6.6	8.2	4.1	6.5	0.16	0.22	0.05							
RANGE	2 - 53	23 - 70	16 - 40	2 - 41	1.74-2.44	1.21-2.05	2.66 - 2.79					4.4-8.0	1	

STRENGTH TESTS

	TRIAXIAL		UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2]	
	Cu (kPa)	Øu (°)		DIAM. (MPa)	AXIAL (MPa)
n	48	46			
$\bar{x}$	104	7.1			
M	81.5	5.5			
σ	47.8	8.1			
RANGE	14 - 760	0 - 28			

CONSOLIDATION AND COMPACTION TESTS

	Mv [3] CLASS m^2/MM	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4]	
					UNSOAKED (%)	SOAKED (%)
n	11	11	4	4	6	5
$\bar{x}$	2	3	1.9	12	11	3
M	3	3			11	3
σ					2.9	1.5
RANGE	2 - 5	3 - 4	1.87-1.97	10 - 13	6 - 14	1 - 5

ENGINEERING GEOLOGICAL COMMENTS
Depth of weathered mantle variable but frequently occurs to depths in excess of 10 m. Highly weathered zones present at greater depths. Generally medium compressibilities but possibility of very low settlement rates. Heavier loads may require piling to sound rock. May be suitable as general fill, but often too wet to achieve optimum compaction.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

Table 15 Summary geotechnical data for Coal Measures siltstones

IN SITU TESTS

ENGINEERING GEOLOGICAL DESCRIPTION	PENETRATION TESTS SPT N-VALUE	PENETRATION TESTS RPT (mm)	PERMEABILITY (m/sec)	VANE SHEAR STRENGTH UNDISTURBED (kPa)	VANE SHEAR STRENGTH REMOULDED (kPa)
Grey to greyish brown, moderately weak to moderately strong, clayey and sandy SILTSTONES.	33	51			
	68	95			
	50	75			
	44.8	81.5			
	6 - >50	12 - 288			

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
27	15	14	14	3	1	9					5	6	
12	31	21	11	2.25		2.68					7.5	1	
12	30	21	11										
7	7.3	4.6	5.1										
5 - 23	18 - 47	10 - 27	2 - 23	1.92-2.42	1.79	2.58 - 2.83					7 - 8	1	

STRENGTH TESTS

TRIAXIAL Cu (kPa)	TRIAXIAL Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2] DIAM. (MPa)	POINT LOAD (Is 50) AXIAL (MPa)
1	1			
226	0			

CONSOLIDATION AND COMPACTION TESTS

Mv [3] CLASS m^2/MN	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4] UNSOAKED (%)	C.B.R. SOAKED (%)

ENGINEERING GEOLOGICAL COMMENTS

Siltstones occur as interbedded, impersistent layers and lenses within mudstone and sandstone sequences. Variable clay content but of generally low plasticity, increasing with weathering grade. Low compressibilities with low to medium rates of consolidation settlement.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

predominantly end-bearing, and excessive settlement may occur if a layer of loose material is encountered at the pile toe. Driven piles may be expected to carry working stresses of 4-5 MPa of the cross-sectional area of the pile using normal concrete, or 12 MPa for very high quality concrete. Accordingly, working loads of 450-500 kN and 900-1000 kN are suggested for pile diameters of 0.35 m and 0.5 m, respectively.

The variable densities encountered near the surface may necessitate piles being driven further than anticipated in order to achieve a satisfactory set. The variation in level at which the material is sufficiently well-cemented to form a suitable founding stratum should be considered when selecting pile type. Bored piles may be most suitable as their length can be more easily varied. Auger boring through overlying superficial gravels would also be required before placing driven piles. Bored piles would be expected to carry working stresses of 4 MPa of the cross-sectional area of the pile if taken 3 pile diameters into the sandstone. Conventional bored piles may be affected by 'piping' in uncemented material leading to poor performance, and large diameter piles have been suggested to overcome this problem. Large diameter bored piles taken through overlying superficial sands and gravels to at least 2 pile diameters into the sandstone, or where N-values are over 100, are expected to carry working loads of 2000, 3500 and 5500 kN for pile diameters of 0.75 m, 1.0 m and 1.25 m, respectively. Casing is required during boring to support granular material and exclude groundwater. Seepages encountered in bedrock will require cleaning of the bore before concreting. Sulphate contents of groundwater ranging from Class 1 to 3 mean that care should be taken in concrete selection.

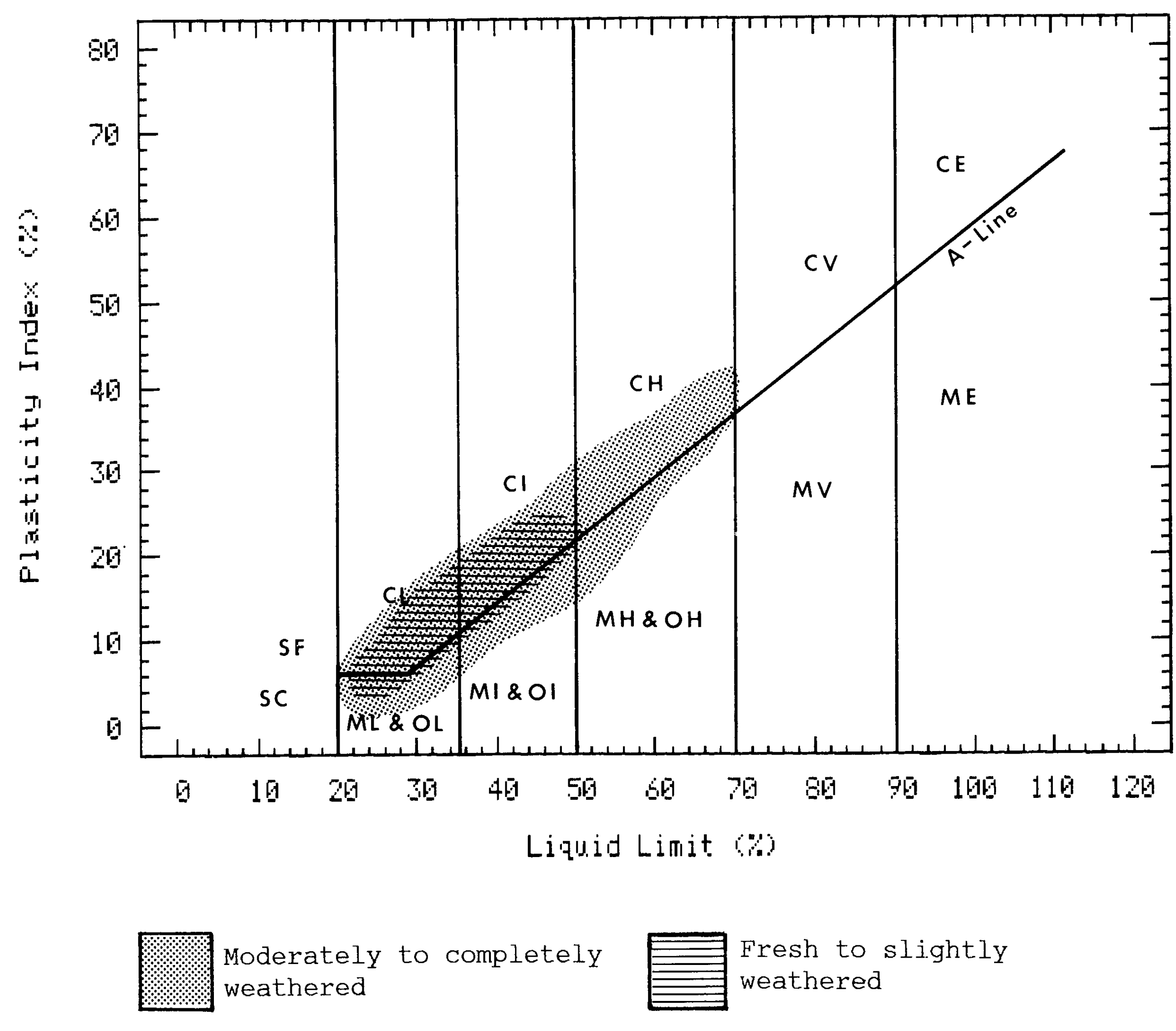


Figure 37 Plasticity diagram for Coal Measures mudrocks

ii) Slope stability

High water flows into excavations in the Sherwood Sandstone are to be expected, and dewatering and immediate support of faces in uncemented material will be required. Cutting slopes of 1V:2H have been recommended for preliminary design.

iii) Excavatibility and suitability as fill material

The Sherwood Sandstone is easily excavated by machine digging or scraping. It may be suitable as fill, and for compaction purposes, is classed as a well-graded, sometimes uniformly graded, granular soil. No test data have been obtained to allow assessment of compaction characteristics.

Basal Permian Sand

This formation consists of buff to yellow, generally uncemented, moderately weak, soft friable sandstone and dense, medium to fine uniform sand. It underlies the Lower Magnesian Limestone and is up to 3 m thick at outcrop. Insufficient test data preclude a meaningful geotechnical assessment, but the limited data collected are presented in Table 12.

Three values of field permeability, ranging from 10^{-5} to 10^{-4} m/sec, classify the sand deposit as moderately permeable. High water ingress, running sand and piping may occur in excavations and borings, so control of groundwater and immediate support of excavation sides will be necessary. Grouting will enhance cementing and inhibit 'washouts' but will not significantly improve strength. Major foundation problems may occur in the overlying Magnesian Limestone due to collapse of old workings in the sand (see Maps 12a,b and pp.00). The extent of these workings make foundation improvement by ground treatment difficult. The sands can easily be excavated by ma-

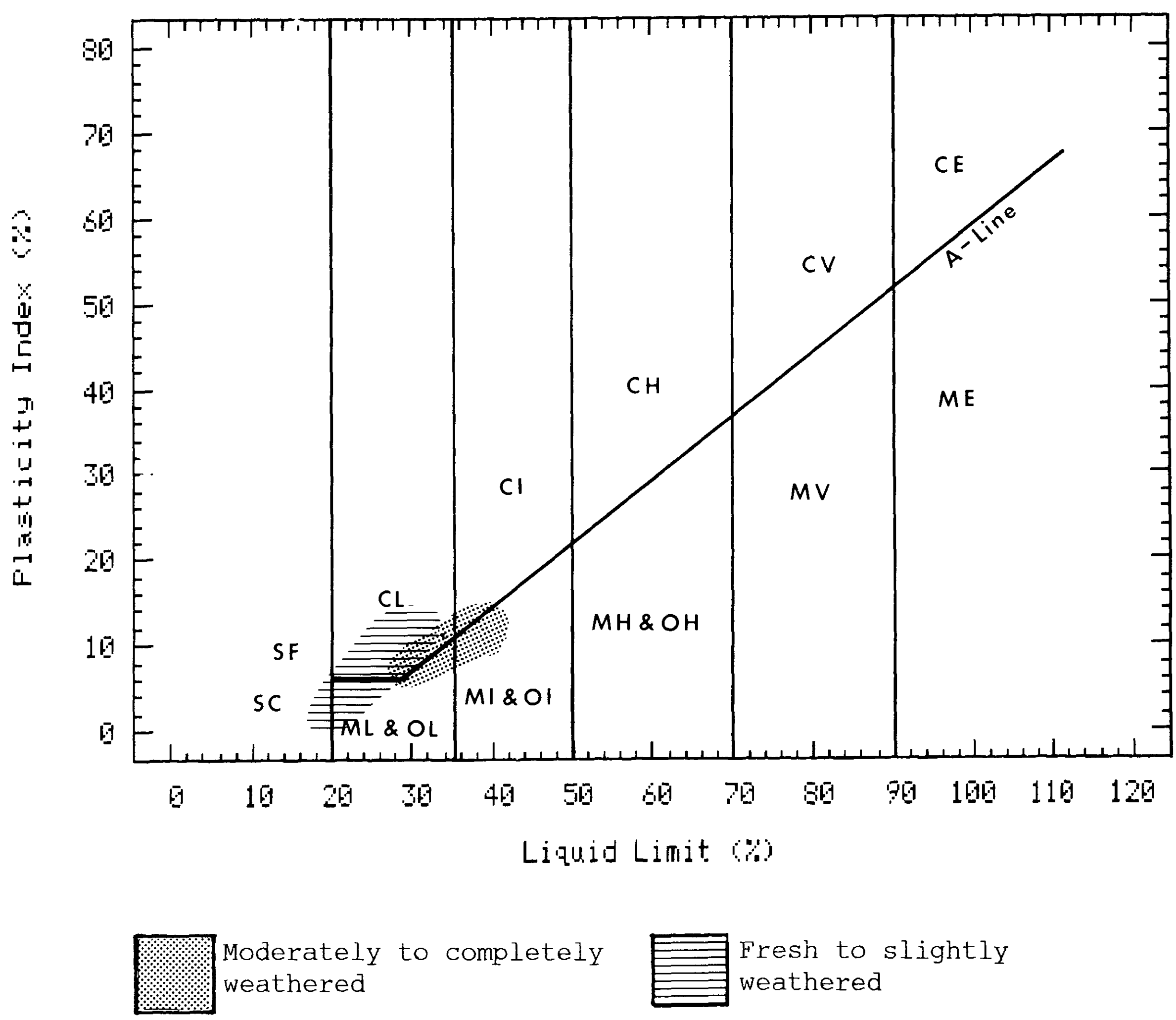


Figure 38 Plasticity diagram for Coal Measures siltstones.

chine digging. No data have been obtained to assess compaction characteristics or suitability as fill.

Mudrocks

This group encompasses those dominantly argillaceous formations with engineering characteristics bordering on those of a 'weak' rock or 'strong' overconsolidated soil. It includes the Coal Measures mudstones, siltstones and seatearths, and the mudstones of the Roxby (Upper Permian Marl) and Edlington (Middle Permian Marl) formations.

Coal Measures Mudrocks

These consist predominantly of grey to greyish brown, moderately fissured, weak to locally moderately strong mudstones, shales, silty mudstones and siltstones. They are particularly prone to breakdown by weathering, and completely weathered firm to stiff, silty clays may occur within 6 m of ground surface. Moderately to highly weathered material, comprising softened mudstone clasts in a silty clay matrix, may occur to depths of about 10 m. Zones of highly weathered mudstone, have been recorded at depths in excess of 50 m, presumably either because of groundwater movement down faults and joints or in an overlying sandstone aquifer, or because of oxidation in old mine workings. The degree of weathering therefore influences engineering behaviour, and, in view of this, summary geotechnical properties of fresh to slightly weathered and moderately to completely weathered Coal Measures mudrocks are presented separately in Tables 13 and 14. Summary geotechnical properties for the siltstones are shown in Table 15.

Standard penetration test (SPT) results show a wide range of N-values which are usually well over 50 for fresh to slightly weathered rock. However, N-values of 40 or less are frequently recorded for slightly weathered weak mudstones.

Plasticity values (Fig. 37) for the moderately to completely weathered mudstones group around the A-line, typical of silty clays and clayey silts of low to high plasticity. For fresh to slightly weathered material, the plasticity values plot as a group typical of low to medium plastic inorganic clays. A plot for the siltstones (Fig. 38) shows them to be of low plasticity, becoming slightly more plastic with increased weathering. In general, the effect of increasing weathering results in increasing plasticity and moisture content and decreasing density and shear strength. Limited consolidation data show the mudrock sequences to be of generally low to medium compressibility, although high to very high consolidation settlements have been recorded locally.

Limited field permeability values for weathered mudstone, ranging from 10^{-7} to 10^{-4} m/sec, classify the rock mass as slightly to moderately permeable, but this may vary depending on weathering grade, fissuring and the presence of interbedded siltstones, sandstones and coals horizons. Waterlogging of ground may occur locally where mudstones are weathered to clay and where mudstone seatearths crop out.

Design Considerations

i) Foundations

Shallow mine workings present a potential foundation problem throughout the Coal Measures outcrop, and any site investigation should ascertain the presence, depth and extent of these. When accurately delineated, piled foundations set in sound rock below the worked level present the safest option for all but the lightest structures, although ground pre-treatment by grout injection has been successfully employed. Working loads of 600 kN are suggested for 0.5 m diameter piles set in sound mudstone. Nett allowable bearing pressures of 50 – 300 kPa are suggested for shallow strip foundations in moderately to completely weathered rock, and 1000 to 2000 kPa at depths greater than 1.5 m in fresh to slightly weathered competent mudstone. Fault zones, comprising shattered rock and clay gouge may present problems in terms of low bearing capacity and excessive differential settlements, and the location of these zones should be part of any site investigation and taken account of in planning and design.

Recorded sulphate contents fall within Class 1, but common measurements of acid groundwater conditions (minimum pH values of 4.4) indicate that care is required in concrete selection.

ii) Slope Stability

Shallow mudflows have been mapped in the valley south of Garforth [4018 3172], at Town Close Hills [4048 3049] and on Park Hill, Pontefract [4430 2227]. In addition, an unmapped area of uneven ground near Ackton [4121 2231] may be underlain by shallow mudflows. Temporary excavations in fresh to moderately weathered mudstone should be stable but slumping in the highly to completely weathered clay mantle is likely. The mudstones are highly prone to deterioration and softening where relieved of overburden pressure and exposed to weathering. Rain and heavy construction traffic will accelerate this process. Side slopes of 1V:2H are recommended for preliminary design of cuttings. Siltstone and sandstone beds may lead to water seepage and accelerated deterioration of cut faces. High groundwater tables may present considerable difficulties in excavations and possible regrading of cut slopes to 1V:4H with suitable drainage will be required.

iii) Excavatibility and suitability as fill material

The mudstones can be readily excavated by mechanical scraping or digging, but ripping or pneumatic breakers may be required at depth or for major excavations. Although successfully used as embankment fill, the material should be placed as soon as possible after excavation and subjected to minimum construction traffic when wet. Soaked and unsoaked CBR test results confirm the sensitivity of mudstone fill to compaction moisture contents. Remoulded undrained shear strengths of 150 to 350 kPa have been quoted in embankment design for material compacted at natural moisture contents between 15 and 22%, but these values may reduce markedly with an increase in moisture content of 2% by dry weight in wet conditions. Checks on 'field' moisture contents should therefore be maintained during construction. Plastic limit versus moisture content plots for in situ material indicate that near-surface, highly weathered mudstone/clays may be classified as cohesive for compaction purposes. Below about 6 to 7 m less weathered mudstones are generally classified as dry cohesive.

Roxby (Upper Permian Marl) and Edlington (Middle Permian Marl) formations

These comprise red brown, green and grey, weak to moderately weak, locally calcareous silty mudstones, with greenish grey siltstone. Gypsum is common as primary, impure grey-mottled beds and secondary white satin spar beds and veins. Descriptions in site investigation reports range from silty, sandy mudstones, marlstones and marls to marly or sandy, silty clays. At outcrop the mudstones are invariably weathered to a firm to hard clay. Weathered clays have been recorded at depths over 20 m. Standard penetration test (SPT) N-values for the Middle Permian Marl show only a slight increase with depth and suggest that it is generally highly weathered throughout, with recorded N-values of below 40 occurring to depths in excess of 10 m.

Field permeability data ranging from 10^{-7} to 10^{-5} m/sec classify the mudstone as slightly permeable, and artesian conditions have been reported locally.

The geotechnical properties, which are similar for the two formations, are shown in Tables 16 and 17. Increasing degree of weathering results in increasing plasticity and moisture content and decreasing strength. Plasticity values (Fig. 39) group near the A-line in the manner characteristic of inorganic clays of low to high plasticity. Compressibilities increase with increasing weathering grade and range from low to high, with low to high rates of consolidation settlements. Undrained cohesion values range from about 15 to 170 kPa and show a general increase with depth and decreasing weathering grade.

Design Considerations

i) Foundations

No major foundation problems should be encountered, but care should be taken in site investigations to delineate fault zones of shattered rock and clay gouge which may cause excessive differential settlements and require ground treatment. The possibility of settlements caused by dissolution of gypsum should also be considered. Artesian water conditions may be present locally, and future coal workings may lead to settlement of structures. Normal consolidation settlements should be complete within the construction period. For heavy structures, the presence of any soft weathered pockets or lenses should be identified and removed before construction. Nett safe bearing capacities of 100-200 kPa are recommended for shallow strip foundations in weathered clay and mudstone near rockhead, increasing to 400-450 kPa at about 3 m depth into weathered material. Nett safe bearing capacities of 600-640 kPa have been recorded for shallow foundations taken to 1.5 m depth in slightly to moderately weathered 'marlstone'.

The Upper Permian Marl is overlain almost everywhere by a variable thickness of superficial deposits and piled foundations are the norm for heavier structures. The granular nature of much of the superficial cover normally requires piles to be driven through pre-augered holes. Casing for all borings through the granular superficial cover will be required to prevent collapse into boreholes. For driven piles set at least 3 pile diameters into the mudstone an end bearing pressure of 3 MPa may be assumed for design. However, hard driving can damage and brecciate the mudstones, possibly affecting long-term performance. Working loads of 500-600 kN have been recommended as the upper bound for 450 mm diameter driven, cast in situ piles. For bored piles, loading criteria of 350, 450 and 600-650 kN for pile diameters of 0.4 m, 0.5 m and 0.6 m, respectively, are suggested (based on allowable end bearing pressures in mudstone of 1.6 MPa and shaft adhesions of 0.45 x undrained shear strength).

For road construction, the mudstone may be cut to formation level with adequate time allowed for moisture content to equilibriate with side drains. Once constructed, in situ CBR tests should be carried out to check deterioration of the mudstone. If necessary, stripping to a lower level combined with increased pavement thicknesses will be required. Measured sulphate contents range from Class 1 to 4, indicating that care is required in concrete selection.

ii) Slope stability

One natural slope failure [5025 2075] has been mapped in the Middle Permian Marl mapped, comprising a series of coalescing shallow earthflows in weathered clays on a south-facing slope of about 4°. The slip debris may contain numerous shear surfaces, along which shear strengths will be reduced towards residual values.

For cuttings in relatively fresh to slightly weathered mudstone side slopes of 1V:2H are generally acceptable, given adequate drainage and top dressing. For more weathered marls and clays, suitable drainage measures will be required to prevent local ponding and deterioration of side slopes. Cutting slopes of 1V:3H are recommended for long-term stability, again with adequate drainage and top dressing. For shallow cuts in highly weathered mudstone and clay, long-term stability may be achieved more economically using side slopes of 1V:2H, with the factor of safety improved by other means such as improved drainage measures and grassing. Removal of unstable fragmented material in faulted and broken ground will be necessary.

iii) Excavatibility and suitability as fill material

The mudstones may be excavated readily by machine scraping or digging. With the exception of highly weathered, high plasticity clays, it is generally suitable as a fill material. Insufficient data have been obtained to properly assess compaction characteristics, but the limited test results indicate that compaction behaviour is markedly affected by increase in moisture content. The mudstone is classed as a cohesive material for compaction purposes and its suitability as compacted fill will depend on preventing an increase of in situ moisture content during construction. In general, undrained shear strengths of remoulded material, recompacted at natural moisture contents (of about 20%), should prove adequate for embankment construction, but a small increase of in situ moisture content may cause an unacceptable reduction in strength values. CBR test results range from about 4 to 10% for material compacted at natural moisture content, but increase markedly to between 35 and 70% for samples compacted at optimum moisture content. The few OMC values obtained in this study range from 12 to 14%.

Table 16 Summary geotechnical data for Upper Permian Marl (Roxby Formation)

ENGINEERING GEOLOGICAL DESCRIPTION
Red brown, green and grey, weak to moderately weak, calcareous silty MUDSTONES, with siltstone and gypsum bands.

IN SITU TESTS

PENETRATION TESTS		PERMEABILITY	VANE SHEAR STRENGTH	
SPT N-VALUE	RPT (mm)	(m/sec)	UNDISTURBED (kPa)	REMOULDED (kPa)
99	57			
48	185			
45	195			
28.1	58.1			
4 - >50	39 - 294			

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
62	54	54	54	7	6						1	1	
21	45	23	22	2.10	1.71						7.0	1	
22	44	23	23										
5.4	10.9	2.9	9.1										
8 - 34	23 - 70	16 - 29	5 - 41	1.98-2.44	1.66-1.79								

STRENGTH TESTS

TRIAXIAL Cu (kPa)	TRIAXIAL Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2] DIAM. (MPa)	POINT LOAD (Is 50) [2] AXIAL (MPa)
13	13			
97	2			
92	0			
37 - 173	0 - 18			

CONSOLIDATION AND COMPACTION TESTS

Mv [3] CLASS m^2/MN	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4] UNSOAKED (%)	C.B.R. [4] SOAKED (%)
2	2	2	2		
3	3	1.87	14		
3,3	3.3	1.86,1.88	14,14		

ENGINEERING GEOLOGICAL COMMENTS
Genrally weathered to firm - hard clay of low to high plasticity. Medium compressibilities with low to moderate rates of consolidation settlement. Presence of soft pockets or lenses may need removal or treatment prior to construction. Tends to deteriorate and soften in presence of water, controlled compaction conditions necessary. Slightly permeable with possible artesian water conditions locally.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

Table 17 Summary geotechnical data for Middle Permian Marl (Edlington Formation)

ENGINEERING GEOLOGICAL DESCRIPTION
Red brown, green and grey, weak to moderately weak, calcareous silty MUDSTONES, with siltstone and gypsum bands.

IN SITU TESTS

	PENETRATION TESTS		PERMEABILITY	VANE SHEAR STRENGTH	
	SPT N-VALUE	RPT (mm)	(m/sec)	UNDISTURBED (kPa)	REMOULDED (kPa)
n	18	10	6		
$\bar{x}$	42	105			
M	24	90			
σ					
RANGE	6 - >50	25 - 294	$5x10^{-7}$ - $2x10^{-5}$		

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES				CHEMICAL TESTS		
								% CLAY	% SILT	% SAND	% GRAVEL	pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
n	75	35	35	35	25	21	1					3	3	
$\bar{x}$	22	48	23	24	2.01	1.61	2.75					7.6	1,4,1	
M	23	48	22	25	2.00	1.62								
σ	4.2	10.9	3.7	8.2	0.17	0.09								
RANGE	4 - 34	23 - 84	17 - 37	2 - 47	1.77-2.69	1.46-1.79						7.2-8.2		

STRENGTH TESTS

	TRIAXIAL		UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2]	
	Cu (kPa)	Øu (°)		DIAM. (MPa)	AXIAL (MPa)
n	28	28	2		
$\bar{x}$	71	3.8	7.85		
M	69	3			
σ	32.9				
RANGE	15.2-130	0 - 17	7.4, 8.3		

CONSOLIDATION AND COMPACTION TESTS

	Mv [3] CLASS m^2/MN	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4]	
					UNSOAKED (%)	SOAKED (%)
n	21	13	1	1	4	
$\bar{x}$	3	3	1.97	12	5	
M	3	3				
σ						
RANGE	1 - 3	2 - 4			4 - 8	

ENGINEERING GEOLOGICAL COMMENTS
Generally weathered to firm - hard clay of low to high plasticity. Medium compressibilities with low to high rates of settlement. Tends to deteriorate in presence of water with consequent decrease in shear strength and bearing capacity. Controlled compaction conditions needed. Care required in concrete selection due to high sulphate contents. Possible artesian water conditions.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

As with the Coal Measures mudrocks, rapid construction loading can cause high positive pore pressures in the lower parts of embankments. These will be slow to dissipate due to the low permeability of these materials, and maximum shear strengths will not be achieved for a considerable time after construction. Under such conditions, stability calculations should be based on undrained shear strengths 'as placed' rather than for equilibrium conditions. If the undrained strength is unacceptably low, stability may be improved by flattening side slopes or the use of berms. Consolidation settlements can be minimised by compacting in thin layers and rates of consolidation settlement increased by the installation of horizontal drainage blankets.

Engineering Geology of the Superficial Deposits

The superficial deposits have been combined into six engineering geological groups, shown in Table 4. The distribution of these groups is shown on Map 5, with made ground shown separately on Map 3.

Made Ground

Material descriptions and the distribution of areas of made ground are presented in Map 3, and discussed on pp.27,29. As an engineering geological group, made ground, also known as fill or backfill, is variable in composition, thickness and geotechnical properties. Materials include chemical, mining and quarry waste, domestic refuse and bulk fill derived from the bedrock formations. Insufficient site investigation data are available to enable a meaningful geotechnical assessment to be carried out. The implications for development on made ground are discussed on p.17, and any proposed development must be preceded by a site investigation to ascertain the composition, thickness and engineering behaviour of the materials.

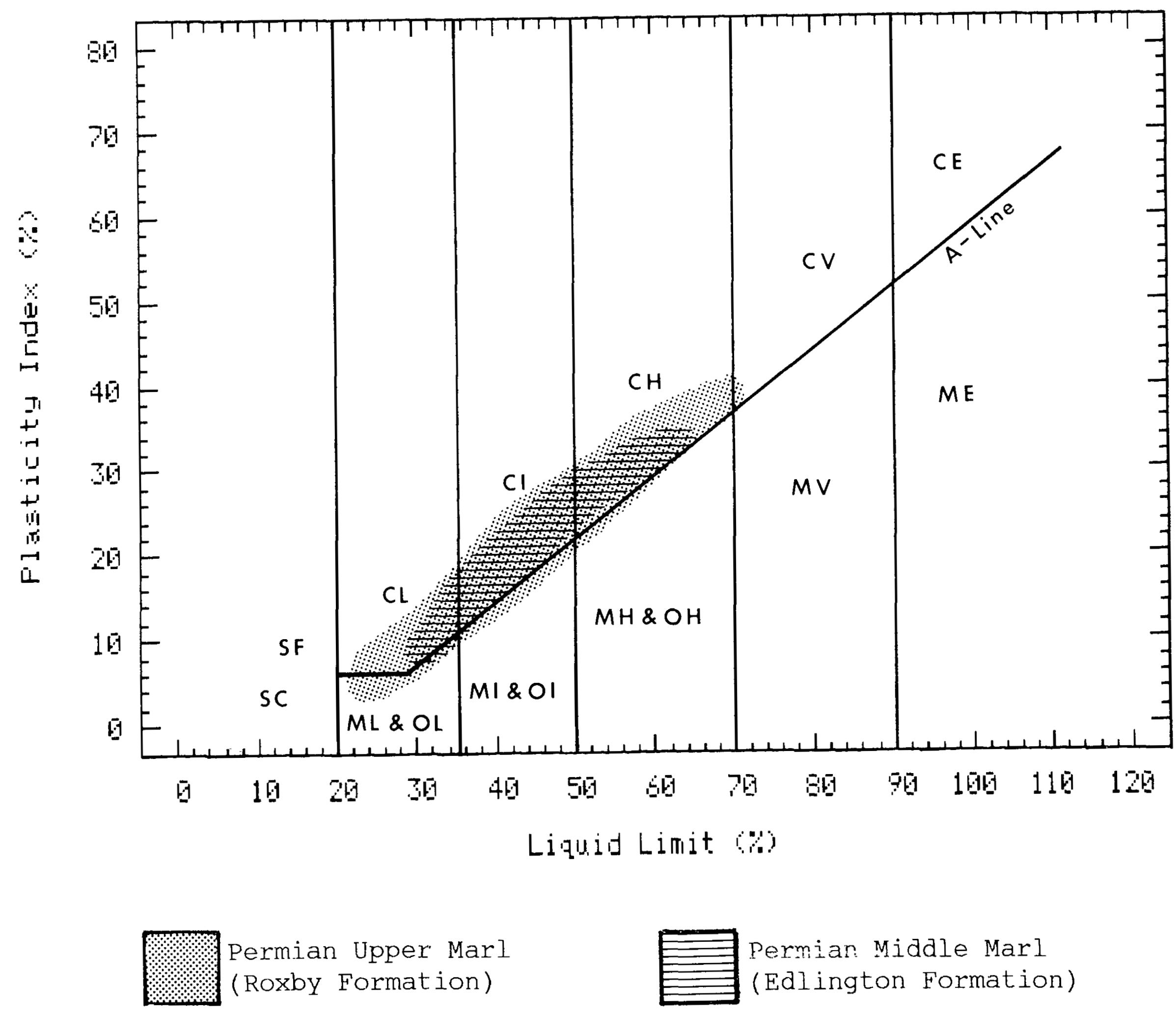


Figure 39 Plasticity diagram for Permian marls

Peat

Peat is confined to a few occurrences overlying glaciolacustrine deposits in the south-east, to patches in sink-holes, and to lenses in river alluvium (p.60). No geotechnical data were obtained. It usually comprises dark brown to black, fibrous or amorphous, soft organic debris and very soft to firm, organic clays. In geotechnical terms, peat is extremely plastic and highly compressible with very low shear strengths. Excavations are very unstable and prone to severe groundwater problems. For the limited occurrences in the area, the peat should be removed prior to construction or piled through to a suitable set in the underlying bedrock or superficial deposits. Where its occurrence at depth is suspected, rapid short-term, slow long-term and potentially large differential settlements should be anticipated in design.

Normally Consolidated/Loose Heterogeneous Deposits

Head

Head deposits are superficial materials derived from bedrock and superficial deposits by the action of periglacial freeze-thaw weathering processes and hillcreep, solifluction and gelifluction. Typically, it is a soft to firm sandy, silty clay with stones, but locally is a gravel. It forms a generally ubiquitous cover on the slopes of the exposed Coal Measures and Permian rocks, usually as a thin veneer less than 1m thick, but greater thicknesses may accumulate at the foot of slopes and in hollows. Its variable composition reflects its local derivation. Thicknesses ranging from less than 1 m to 6 m are recorded in a number of site investigation reports for construction sites, but the distinction between in situ weathered bedrock and head may be difficult, the one grading into the other. The mapped distribution of head generally greater than 1 m is shown on Map 2. It should, however, be assumed to occur elsewhere as a patchy veneer of varying thickness, and its thickness and geotechnical characteristics established prior to design of foundations or cut slopes.

Summary geotechnical properties are shown in Tables 18 and 19. The wide range of values for most of the measured parameters reflects the lithological variation of these deposits. Head overlying the Coal Measures mudrocks can be classified as silty clays of low to very high plasticity (Fig. 40). The influence of the parent material is shown by the distinct grouping of head overlying Coal Measures sandstones in the low to intermediate plasticity range. The deposits on the Permian limestones are of generally lower plasticity and often contain increased silt and sand components in addition to gravel-size limestone clasts. The plasticity chart for these materials (Fig. 41) shows the head matrix developed over the Upper Magnesian Limestone to be silty clays of low to intermediate plasticity, and that over the Lower Magnesian Limestone to be low plasticity silty clays and clayey silts. This distinction is also shown on the plasticity diagram for the in situ limestone bedrock (Fig. 36). A comparison of the plasticity diagrams for the bedrock and overlying head deposits for all the Coal Measures and Permian rocks shows that the head generally has the higher plasticity. The bedrock plasticities normally decrease with decreasing weathering grade. Similarly, head shows more variable but generally higher compressibilities, more variable rates of consolidation settlement, and generally low shear strengths.

Design Consideration

i) Foundations

Differential settlements, soft, highly compressible zones and the ponding of water in depressions (locally caused by mining subsidence) due to the presence of impermeable clays present the main problems to foundation design on head deposits. In general, bedrock lies within 1.5 m of ground surface, and where feasible, the head material should be removed prior to placing foundations, or the loads transferred to the underlying bedrock by piling. For shallow foundations on dominantly clay head, the loading criteria shown in Table 20 should be used as a guide.

Recorded sulphate contents fall in Class 1, but highly acidic groundwater contents with a minimum pH of 4.4 indicate that care is needed in concrete selection.

ii) Slope stability

No natural slope failures have been recorded in head deposits, but the presence of relic shear surfaces (resulting from solifluction and multiple sliding movements during its formation under periglacial conditions) may be present, even on low-angle slopes. Shear strengths on these relic failure surfaces will be at or near residual values. This should be accounted for in slope design calculations. Cutting side slopes of 1V:2H are suggested as a guide for preliminary design in head without shear surfaces.

iii) Excavatibility and suitability as fill material

Head deposits may be easily excavated with normal soft ground excavating plant. Problems may be encountered locally due to ponding of water in depressions due to the presence of impermeable clay head. Head may be suitable for use as bulk fill, but may be locally too wet to achieve satisfactory compaction. Recorded CBR values for samples compacted at natural moisture content range from 2 to 8% for deposits overlying the Coal Measures. Values increase for samples compacted at optimum moisture contents (ranging from 10 to 16%) but reduce considerably as moisture content increases above optimum.

Alluvium

Alluvial deposits are extensive on the floor of the Aire and Calder valleys. They also occur in minor tributary valleys. Extreme heterogeneity on both a regional and local scale result in highly variable geotechnical properties and engineering behaviour. Material composition includes soft to firm, laminated, silty clays and clayey silts, very soft to soft organic clays and peat, and loose to medium dense sands, with impersistent layers, lenses and pockets of sand and silt.

Summary geotechnical properties (Table 21) may be expected to vary markedly laterally and with depth at specific sites. Plasticity data (Fig. 42) show values grouping on or near the A-line, typical of inorganic silts and clays of low to high plasticity, but zones of organic clay and peat (not recorded in the current data) will have very high plasticity. The 'mass' deposit may be expected to exhibit medium to very high compressibilities, with very slow rates of consolidation settlements for soft organic alluvial clays and peat.

Table 18 Summary geotechnical data for head deposits overlying Coal Measures

IN SITU TESTS

ENGINEERING GEOLOGICAL DESCRIPTION	PENETRATION TESTS		PERMEABILITY	VANE SHEAR STRENGTH	
	SPT N-VALUE	RPT (mm)	(m/sec)	UNDISTURBED (kPa)	REMOULDED (kPa)
Soft to firm sandy silty CLAYS, of low to high plasticity, with variable gravel content.	29	16		15	
	50	195		72	
	43	172		72	
	34.9	84.5		21.2	
	5 - >50	96 - 390		32 - 105	

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS pH	SO_3 [1] CLASS	ORGANIC CONTENT (%)
296	110	107	107	105	88	2					36	34	
21	43	23	20	1.96	1.62	2.68, 2.67					6.6	1	
20	42	23	20	1.97	1.62						6.7		
7.03	13.9	4.6	10.7	0.14	0.17						0.91		
6 - 57	19 - 85	15 - 40	1 - 51	1.47-2.31	0.83-2.07						4.4-8.5	1	

STRENGTH TESTS

TRIAXIAL Cu (kPa)	TRIAXIAL Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2] DIAM. (MPa)	POINT LOAD (Is 50) [2] AXIAL (MPa)
120	120			
81.9	8.5			
68	6.0			
66.1	9.2			
4.8-518	0 - 33			

CONSOLIDATION AND COMPACTION TESTS

Mv [3] CLASS m^2/MM	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4] UNSOAKED (%)	C.B.R. [4] SOAKED (%)
26	26	4	4	27	5
		1.93	13	6	3
3	3			6	3
				1.8	1.5
1 - 4	2 - 4	1.81-2.16	10 - 16	2 - 8	2 - 5

ENGINEERING GEOLOGICAL COMMENTS

Variable lithology and thickness give rise to areal variations in geotechnical behaviour. Generally low bearing capacities and variable consolidation characteristics. May contain relict shear surfaces when developed on slopes >3° - 7°, with shear strengths approaching residual values.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

Table 19 Summary geotechnical data for head overlying Magnesian Limestone

ENGINEERING GEOLOGICAL DESCRIPTION
Soft to firm, very sandy, silty CLAYS and clayey SILTS, of low to high plasticity, with variable limestone clasts.

IN SITU TESTS

	PENETRATION TESTS		PERMEABILITY	VANE SHEAR STRENGTH	
	SPT N-VALUE	RPT (mm)	(m/sec)	UNDISTURBED (kPa)	REMOULDED (kPa)
n	14	2			
$\bar{x}$	20	242,200			
M	13				
σ					
RANGE	4 - 62				

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

	MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
n	56	35	34	34	10	13						4	4	
$\bar{x}$	19	33	20	13	1.89	1.6						7.1		
M	20				1.95	1.6							1	
σ	5.1	9.3	4.6	6.8	0.13	0.07								
RANGE	8 - 30	12 - 68	6 - 32	2 - 42	1.6-2.03	1.42-1.73						6.9-7.3	1	

STRENGTH TESTS

	TRIAXIAL Cu (kPa)	TRIAXIAL Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2] DIAM. (MPa)	POINT LOAD (Is 50) [2] AXIAL (MPa)
n	8	8			
$\bar{x}$					
M	58	10			
σ					
RANGE	18 - 100	0 - 33			

CONSOLIDATION AND COMPACTION TESTS

	Mv [3] CLASS m^2/MM	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4] UNSOAKED (%)	C.B.R. [4] SOAKED (%)
n	4	4			7	
$\bar{x}$					11	
M	2,2,3,3	3,3,3,3			10	
σ						
RANGE	2 - 3	3			3 - 24	

ENGINEERING GEOLOGICAL COMMENTS
Variable lithology, thickness and geotechnical properties. Generally low shear strength and bearing capacities with variable consolidation characteristics. Relic shear surfaces may be present where developed on slopes > 3° - 7°.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

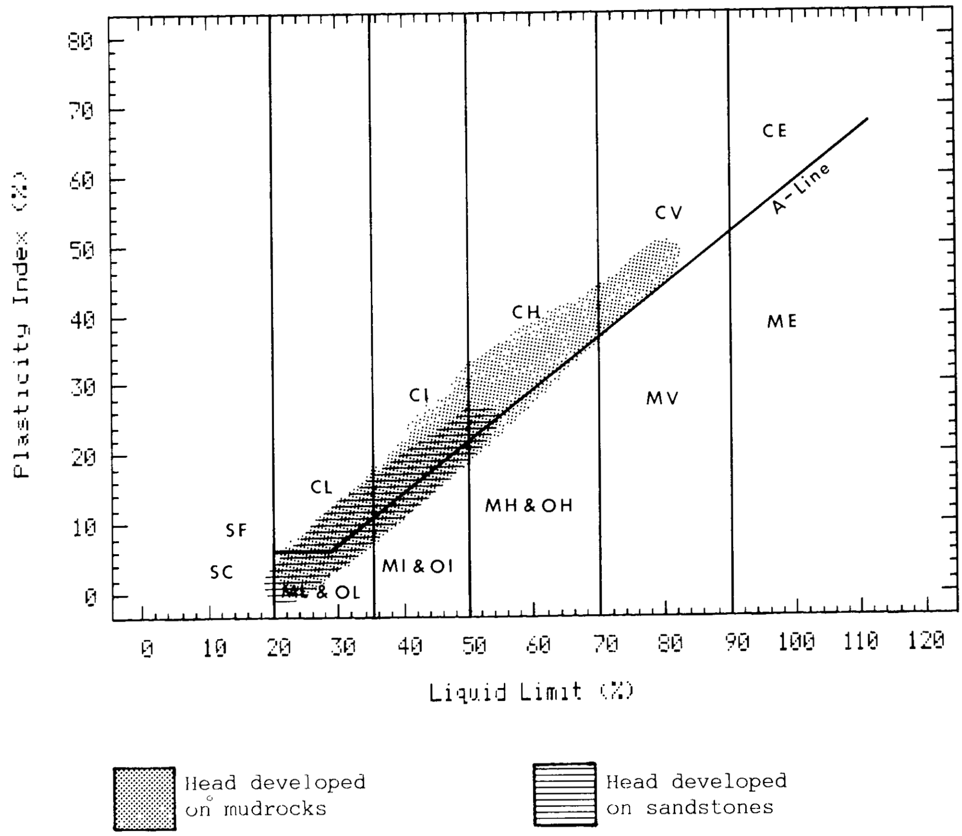


Figure 40 Plasticity diagram for head deposits on Coal Measures

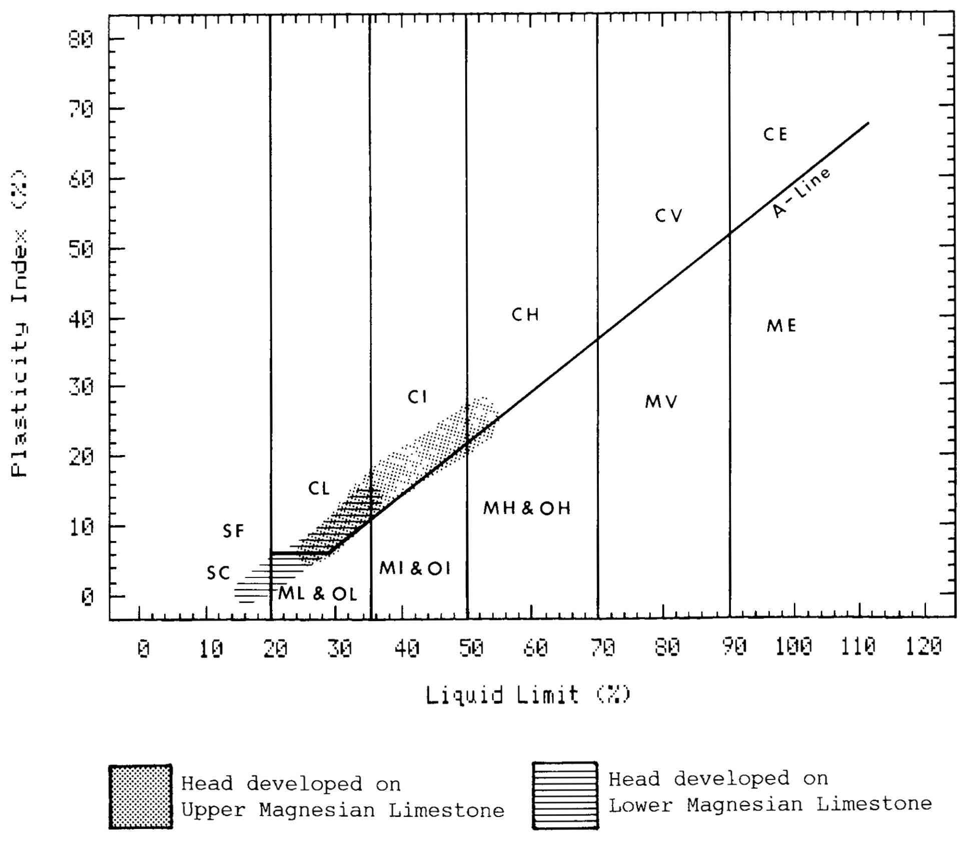


Figure 41 Plasticity diagram for head deposits on Magnesian Limestones

Table 20 Loading criteria for foundations in head

Foundation Type	Depth (m)	Nett Safe Bearing Capacity (kPa)	Factor of Safety	Differential Settlement
0.5m STRIP	1.0	100	3	19 mm
0.5m STRIP	1.0	150	2	29 mm
RAFT	0.5	100	3	40 mm
RAFT	0.5	150	2	60 mm

Standard penetration test (SPT) N-values are consistently well below 40, and reflect the low shear strengths of all the alluvial materials. An increase in strength with depth may, however, take place in individual homogeneous lithological units.

Design Considerations

i) Foundations

The likelihood of excessive differential settlements, water uplift pressures, and low nett allowable bearing capacities of about 50 kPa pose the main problem for foundations. Where limited thicknesses occur, wholesale removal of the alluvial material prior to placing foundations may be an economical option, but thicknesses in excess of 10 m usually require piled foundations, set at a suitable depth in the underlying bedrock, for all but the lightest structures. For piles taken through thicker alluvial deposits, consolidation of clays causing possible 'drag-down' of loaded piles should be anticipated. Recorded groundwater sulphate contents in Class 2 of the BRE classification indicate that care is needed in selection of buried concrete.

Maximum embankment heights of 4 m with 1V:2H side slopes are generally recommended for construction on alluvium. Very low rates of consolidation settlements may be enhanced by staged surcharging. Alternatively, lightweight embankment fill may be used. Monitoring of settlements during construction should be undertaken and the likelihood of differential settlements should be accounted for in pavement design.

ii) Slope stability

Excavations are subject to severe water inflow problems and require immediate support to maintain stability of faces. Running sands may also be encountered in excavations below the water table.

iii) Excavatibility and suitability as fill material

Alluvium is easily excavated using normal soft ground excavating plant, but severe groundwater problems may be encountered during working. It is generally unsuitable as a fill material.

Overconsolidated Heterogeneous Deposits

This group comprises glacially derived boulder clay (till) deposits which occur as irregular sheets and patches.

Geotechnical data, presented in Table 22, have been obtained mainly for till encountered along the route of the M62 Motorway, where it is described as a grey or brown, firm to very stiff, sandy silty clay with sub-angular to rounded gravel clasts, up to 7 m thick. Between the M62 Ferrybridge Service Area and Cridling Stubbs [5200 2150], an upper sandy clay containing a few rounded and fragmented limestone clasts, with common sand pockets near its base overlies a slightly sandy clay with rounded gravel-size clasts derived almost entirely from Coal Measures. A till with a high proportion of sand occurs on the south side of the Aire valley from New Fryston to Ferrybridge, and is shown as sandy till on Map 2.

The till matrix is generally an inorganic silty clay of low to intermediate plasticity, low compressibility and high shear strengths. However, clast content and the presence of sand lenses and pockets will cause local variations in engineering behaviour. High plasticity clays may be encountered locally (Fig. 43).

Design Considerations

i) Foundations

Till should present no major problems for shallow foundations, provided lithological variations are established during site investigations and potential differential settlements accommodated for in design. Insufficient data have been obtained during the study to adequately assess characteristic bearing capacity values.

ii) Slope stability

Ponding of surface water due to generally low permeabilities may occur during construction and may necessitate temporary drainage. Cut slopes of 1V:2.5H are generally recommended for long-term stability.

iii) Excavatibility and suitability as fill material

Till may be easily machine excavated but ponding of surface water may cause problems during working. It may prove suitable as a fill material but insufficient data have been obtained to allow an assessment of expected compaction characteristics.

Pseudo-overconsolidated/Medium Dense Layered and Laminated Deposits

This group comprises deposits laid down in a large lake (Lake Humber) that existed during the last (Devensian) glaciation, and covered the area now known as the Vale of York. The deposits are referred to as the 25-Foot Drift of the Vale of York. Variations in lithology, bed thickness and geotechnical properties of the deposits are partly due to their deposition near the shore of the lake. Geological mapping has distinguished areas of glaciolacustrine sand and glaciolacustrine silt and clay at outcrop (Map 2). However, rapid vertical changes in lithology necessitate consideration of the deposits as a single, complex engineering geological group.

The following generalised section has been proved in site investigation boreholes at Gale Common (Taylor et al., 1976). However, rapid vertical and lateral changes will result in different sequences elsewhere.

		Thickness (m)
Upper Sand –	Sand, brown, medium-dense, medium grained	0 – 2.9
Upper Clay –	Clay, silty and sandy, mottled brown/grey, firm to stiff, fissured, with some tree roots and rootlets	1.0 – 1.6
Lower Clay –	Clay, laminated, dark brown and purple brown, commonly fissured, with impersistent silty laminae, becoming organic locally near base	0.3 – 1.3
Lower Sand –	Sand, silty, pale brown and reddish brown, medium dense, poorly graded, fine- to medium-grained, with common clay laminae	0 – 3.5

This sequence overlies medium dense to dense, fluvial sands and gravels generally between 2 and 6 m thick, but locally up to 7.75 m or greater. The thicker occurrences contain thin silt and clay beds, and, locally a silt layer separates them from the overlying Lower Sand. These deposits, known as Older River Gravels, are not exposed in the study area.

Summary geotechnical data (Table 23) have a wide range of parameter values, reflecting the lithological variations in the sequence. The deposits range from inorganic silts and clays of low to very high plasticity (Fig. 44). The data plot in three clusters, the laminated clays giving the highest (high to very high) plasticities, the mottled, non-laminated upper clays intermediate to high and the dominantly gran-

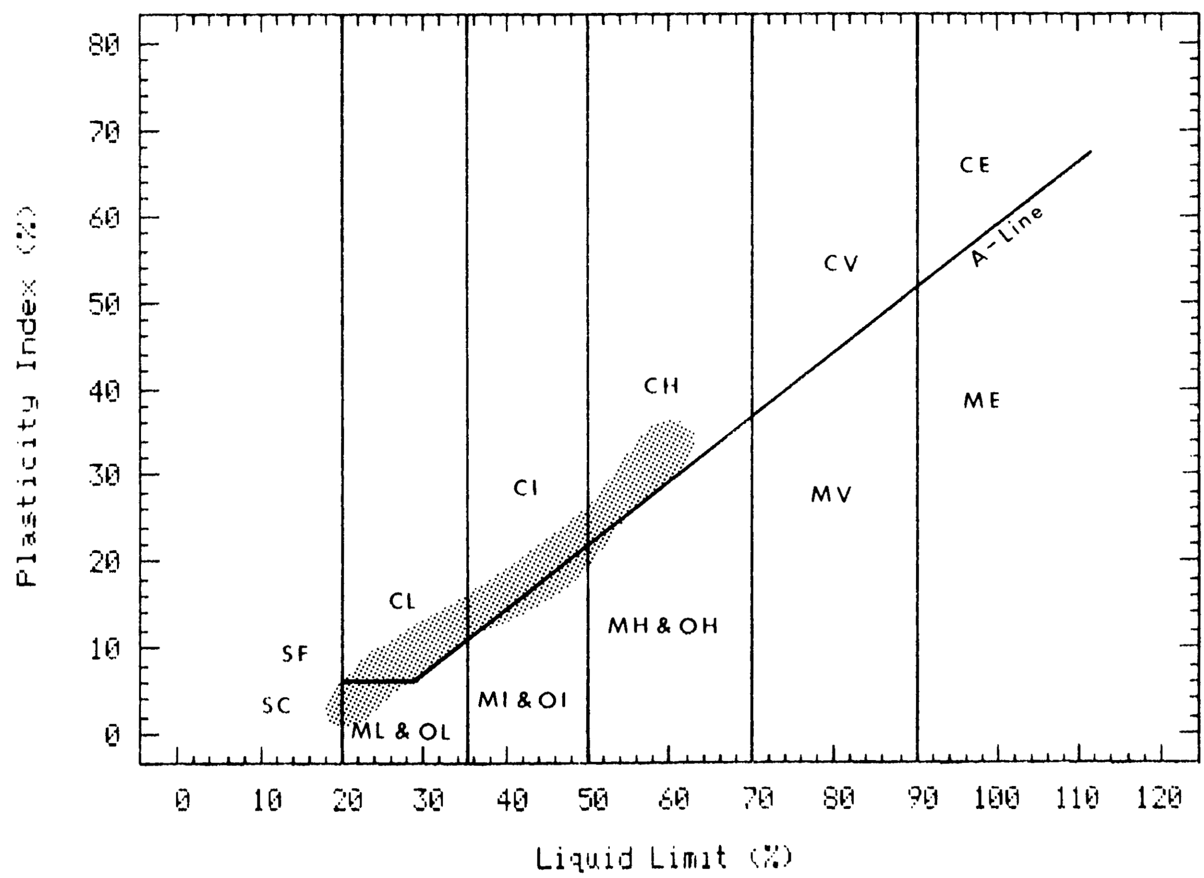


Figure 42 Plasticity diagram for alluvial deposits

IN SITU TESTS

ENGINEERING GEOLOGICAL DESCRIPTION	PENETRATION TESTS: SPT N-VALUE	PENETRATION TESTS: RPT (mm)	PERMEABILITY (m/sec)	VANE SHEAR STRENGTH: UNDISTURBED (kPa)	VANE SHEAR STRENGTH: REMOULDED (kPa)
Very soft to firm, occasionally laminated, silty and organic CLAYS, clayey SILTS and loose to medium dense SANDS with impersistent peat bands.	26				
	13				
	15				
	9.18				
	5 - 45				

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES: % CLAY+SILT	% SAND	% GRAVEL	CHEMICAL TESTS: pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
38	22	22	22	6	6	1	4	8	6		2	
27	40	23	17	1.94	1.54	2.43	15	70	15		2, 2	
26	42	23	16									
7.3	11.06	3.9	8.1									
12 - 45	19 - 58	14 - 31	2 - 35	1.87-2.05	1.43-1.68		3 - 22	12 - 100	2 - 50			

STRENGTH TESTS

TRIAXIAL: Cu (kPa)	TRIAXIAL: Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2]: DIAM. (MPa)	POINT LOAD (Is 50) [2]: AXIAL (MPa)
10	10			
34.6	7.3			
32.8	7.5			
17.5	4.05			
7 - 69	0 - 13			

CONSOLIDATION AND COMPACTION TESTS

Mv [3] CLASS m^2/MN	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4]: UNSOAKED (%)	C.B.R. [4]: SOAKED (%)
2	2				
3,3	3,3			2.8	
				3	
				1 - 5	

ENGINEERING GEOLOGICAL COMMENTS
High compressibility soft silts, clays and peat, with low shear strengths and very low bearing capacities. Generally unsuitable for shallow foundations due to large and variable settlements. High groundwater tables.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

Table 22 Summary geotechnical data for till (boulder clay)

IN SITU TESTS

ENGINEERING GEOLOGICAL DESCRIPTION	PENETRATION TESTS: SPT N-VALUE	PENETRATION TESTS: RPT (mm)	PERMEABILITY (m/sec)	VANE SHEAR STRENGTH: UNDISTURBED (kPa)	VANE SHEAR STRENGTH: REMOULDED (kPa)
Grey or brown, firm to very stiff, sandy silty CLAY, with sub-angular to rounded gravel clasts and occasional cobbles.	26	8			
	35	199			
	35				
	19.8				
	9 - >50	129-283			

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES: % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS: pH	SO_3 CLASS [1]	ORGANIC CONTENT (%)
71	67	67	67	4	1		1	1	1	1	1		
17	40	20	19	2.04	1.66		20	30	20	20	7.0		
16	38	20	19										
46	9.3	3.2	7.0										
3 - 31	19 - 68	16 - 30	3 - 41	1.91-2.18									

STRENGTH TESTS

TRIAXIAL: Cu (kPa)	TRIAXIAL: Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50) [2]: DIAM. (MPa)	POINT LOAD (Is 50) [2]: AXIAL (MPa)
3	3			
122	0			
85-160	0,0			

CONSOLIDATION AND COMPACTION TESTS

Mv [3] CLASS m^2/MM	Cv [3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R. [4]: UNSOAKED (%)	C.B.R. [4]: SOAKED (%)

ENGINEERING GEOLOGICAL COMMENTS

Variable clast content and presence of sand 'pockets' and lenses will influence local engineering characteristics. Matrix clays of generally low to medium plasticity, and low compressibility and permeability. Presents few problems for shallow foundations. Cut slopes of 1V:2.5H with drainage are recommended.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

ular silty and sandy deposits low to intermediate plasticities.

Consolidation test data on the glaciolacustrine clays are particularly pertinent to the engineering geological classification of the deposit in that the markedly flat-topped shape of many of the effective pressure/voids ratio curves (e-log p' plots) indicate overconsolidated clays. Taylor and others (1976) calculated a probable pre-consolidation pressure of 78.5 kPa, implying that 5 to 6 m of overlying sediment had been eroded away. This cannot be reconciled with the geological evidence, and desiccation of the sediments, as shown by the fissures recorded in many excavations, is the most likely explanation for their 'overconsolidated' behaviour. Laboratory test data indicate compressibilities ranging from low to high with low to high rates of consolidation settlement. However, settlement rates measured in the laboratory may be unduly pessimistic due to silt laminations and lenses in the clay mass in situ. Summary permeability values (ranging from 10^{-9} to 10^{-4}) reflect the variation from effectively impermeable clays to moderately permeable granular materials. Mass field permeabilities can be expected to vary markedly at specific sites.

Triaxial compression tests show a large spread of shear strength values, with the laminated clays showing a marked strength anisotropy. In these materials, measured anisotropy in effective friction angle (∅') of the order of 4 to 5 degrees has been interpreted as a function of the preferred orientation of clay minerals adjacent to sub-horizontal silty partings (Taylor et al., 1976). In contrast, the non-laminated, more silty sandy clays have higher effective shear strengths (∅'= 25° – 25.5°) but show virtually no anisotropy in ∅'. The low horizontal shear strength (∅'= 14.5° – 15.0°) of the laminated clay must be accounted for in design calculations, particularly with respect to stability of embankment slopes.

Design Considerations

i) Foundations

Interbedding of contrasting lithologies and impersistent laminations pose the main problem to foundation design. This results in variable consolidation characteristics (due primarily to permeability contrasts), potentially excessive differential settlements, and the likelihood of perched water tables on the virtually impermeable clay layers. It is important that the presence, thickness and on-site geotechnical characteristics of the compressible clays are ascertained prior to design and placing of foundation

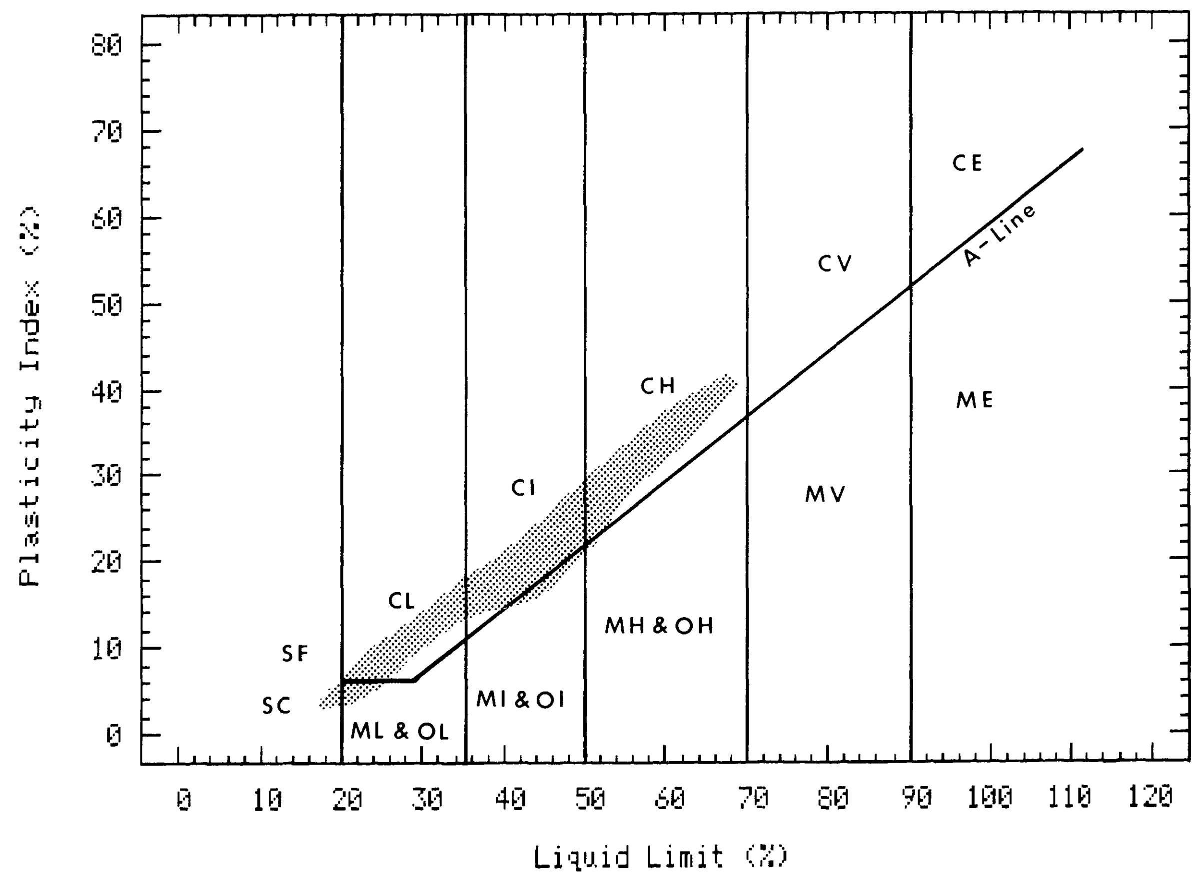


Figure 43 Plasticity diagram for till deposits

Table 23 Summary geotechnical data for glaciolacustrine deposits (25-foot Drift of the Vale of York)

IN SITU TESTS

ENGINEERING GEOLOGICAL DESCRIPTION	PENETRATION TESTS: SPT N-VALUE	PENETRATION TESTS: RPT (mm)	PERMEABILITY (m/sec)	VANE SHEAR STRENGTH: UNDISTURBED (kPa)	VANE SHEAR STRENGTH: REMOULDED (kPa)
Brown, medium dense, medium to fine SANDS, and mottled brown/grey and purple brown massive and laminated, stiff, fissured CLAYS.	560	31	11	10	10
	22	225		38.5	14.2
	17	257	1.5×10^{-6}	39.0	15.0
	15.9	74.8		21.05	8.3
	2 - >50	6 - 300	$1x10^{-9}$ - $6.5x10^{-4}$	6 - 69	4 - 33

FILE FORMAT

	TEST TYPE/ PARAMETER
n = No. of observations	n
$\bar{x}$ = Mean of results	$\bar{x}$
M = Median value	M
σ = Standard Deviation	σ
RANGE = Max. - Min. Values	RANGE

INDEX PARAMETERS

MOISTURE CONTENT (%)	LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	BULK DENSITY (Mg/m^3)	DRY DENSITY (Mg/m^3)	SPECIFIC GRAVITY	PARTICLE SIZE ANALYSES: % CLAY	% SILT	% SAND	% GRAVEL	CHEMICAL TESTS: pH	SO_3[1] CLASS	ORGANIC CONTENT (%)
148	103	95	95	66	50	7	59	59	80	80	11	12	3
26	45	24	24	1.90	1.48	2.6	29	26	40	5	7.1	1	1.6
27	46	24	24	1.88	1.47		17	28	40	0	7.1	1	
9.09	17.1	3.9	13.0	0.07	0.13		26.4	18.9	32.1		0.6		
5 - 40	17 - 74	14 - 31	1 - 46	1.74-2.14	1.27-1.88	2.54 - 2.67	0 - 74	0 - 71	0 - 98	0 - 84	6.2-8.1	1 - 2	1.1-2.08

STRENGTH TESTS

TRIAXIAL: Cu (kPa)	TRIAXIAL: Øu (°)	UNCONFINED COMPRESSIVE STRENGTH (MPa)	POINT LOAD (Is 50)[2]: DIAM. (MPa)	POINT LOAD (Is 50)[2]: AXIAL (MPa)
54	36			
35.6	8.7			
32.0	1.0			
21.9				
7 - 121	0 - 39			

CONSOLIDATION AND COMPACTION TESTS

Mv[3] CLASS m^2/MM	Cv[3] CLASS m^2/yr	MAX. DRY DENSITY (Mg/m^3)	OPTIMUM MOISTURE CONTENT (%)	C.B.R.[4]: UNSOAKED (%)	C.B.R.[4]: SOAKED (%)
45	45	7	7	6	
3	3	1.84	13	6.25	
3	3			5.5	
0.5	0.54				
2 - 4	2 - 4	1.75-1.93	11 - 16	2 - 12	

ENGINEERING GEOLOGICAL COMMENTS
Significant variation in lithology, bed thickness and geotechnical properties. Laminated clays show marked strength anisotropy, with very low horizontal shear strengths. Marked permeability contrasts with potential for large and variable settlements. Pile foundations recommended, set in underlying basal gravels or bedrock.

1 SULPHATE CLASSES DEFINED IN KEY TABLES
2 POINT LOAD (Is 50) VALUES DEFINED IN KEY TABLES
3 CLASSES OF COEFFICIENT OF COMPRESSIBILITY (Mv) AND COEFFICIENT OF CONSOLIDATION (Cv) DEFINED IN KEY TABLES
4 C.B.R. = CALIFORNIA BEARING RATIO

loads. Nett allowable bearing pressures for shallow foundations on the upper sand and non-laminated clay sequences should be of the order of 75 to 120 kPa for 3 – 6 m wide footings (e.g. bridge piers) placed at 1.5 – 3 m depth, with expected settlements of 30 to 70 mm. Bearing capacities do not show consistent variation with depth. For heavier loads, piled foundations taken through the 25-Foot Drift to sets in the basal gravels or underlying bedrock will be required. For driven pile foundations set in the basal gravels design working loads of 220 – 350 kN and 600 – 980 kN are recommended for 0.3 m and 0.5 m diameter piles, respectively. Settlements at these loads are expected to be less than about 25 mm and immediate. Construction joints will be required between piled and unpiled sections of foundations to accommodate potential differential settlements. However, discontinuous clay beds may make the basal gravel an unsuitable medium for pile sets locally, and pile foundations will need to be taken to the underlying bedrock. For sets in the bedrock, the driving of piles through the basal gravels may prove difficult and large diameter bored piles are recommended. Casing of bores to counter 'running' conditions and collapse of granular materials will be necessary. Piled foundations may be subject to a 'dragdown' effect on consolidation of the clay strata. This can set up tensile stresses in piles which may require reinforcement or lining.

Embankment construction should be conducted in stages to allow sufficient time for dissipation of pore pressures in the clays. Rates of consolidation settlements in the field may be more favourable than indicated by laboratory measurements. For a 7.5 m high embankment using a fill density of 2.0 Mg/m3 and two loading stages, periods of settlement of between six and eighteen months have been quoted. Field monitoring of settlements and the installation of piezometers to assess pore pressures during and after construction are recommended, along with drainage blankets of suitable granular material laid at the base of embankments where clays occur at the ground surface. The use of lightweight embankment fill has been successfully employed to minimise excessive settlements.

ii) Slope stability

The main stability problems concern the slopes of embankments constructed on laminated clays. The low horizontal shear strengths of the clays, represented by quoted undrained shear strengths of 19 to 25 kPa and effective friction angles of 14.5° to 15° must be accounted for in design. Safe side slopes of 1V:2H are normally recommended for embankments up to 8.0 m in height on soil

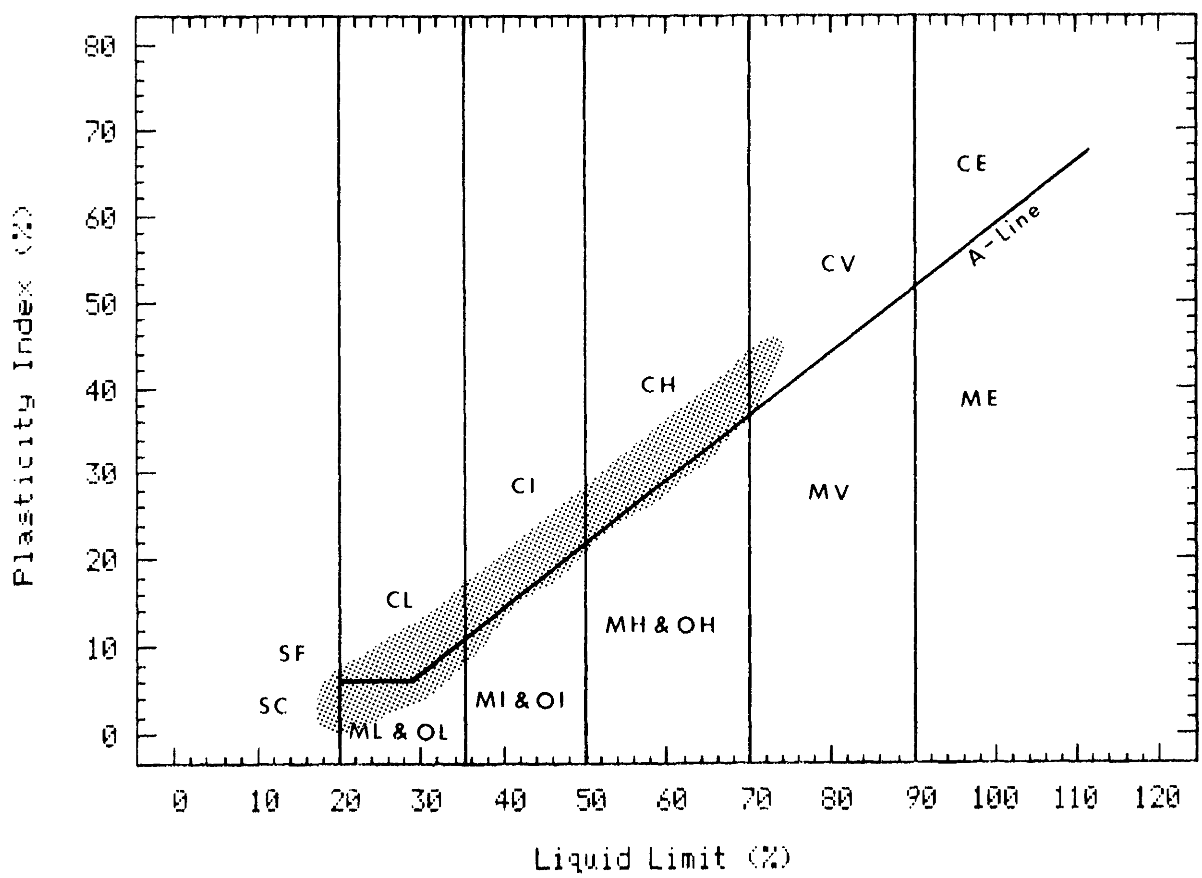


Figure 44 Plasticity diagram for glaciolacustrine clays and silts.

profiles dominated by stiff clays and medium dense sand and gravel. For higher embankments or where loose granular deposits or soft clays are present, these angles will be marginal and regrading or the use of berms may be necessary to maintain stability.

Excavations in granular materials may encounter 'running' conditions and severe seepage problems, requiring dewatering and immediate side support.

ii) Excavatibility and suitability as fill material

Excavation by normal plant should present few problems. However, potentially high water inflows from granular sediments, perched water tables and ponding of water on impermeable clays may be encountered. Shoring of excavations in granular material will be required to ensure safe working conditions.

Insufficient data have been obtained to make an adequate assessment of the glaciolacustrine deposits as fill materials, or to comment on compaction characteristics. In general terms, these deposits may prove suitable as general fill, with the clays (including laminated clays) being classed as a cohesive soil for compaction purposes and the basal sand and gravel sequence as a well graded granular soil. Some of the clays fall in the dry cohesive class and are generally unsuitable as fill. Due to lithological variation, on-site assessment of fill suitability, involving field compaction trials, is necessary. Locally high in situ moisture contents of the clays may present compaction problems if untreated. Compaction during dry weather has been successfully employed in the short term, but the cohesive clay fill must be protected from subsequent wetting. Adequate drainage measures should be incorporated in design and a blinding layer of granular material or grassing used as protection from surface water. Quoted CBR values range from 3 to 7% for silty sandy clays, up to 20% for dominantly sandy lithologies and 30 to 50% for the basal gravels.

Non-cohesive Sand and Gravel Deposits

This group includes those dominantly granular deposits mapped as older littoral gravels, littoral sand and gravel, glacial sand and gravel, glaciofluvial sand and gravel, and river terrace deposits (Map 2). Virtually no geotechnical data have been collected, but descriptions of their lithology, thickness and origin are given on pp.58 to 60.

In general terms, the deposits are medium dense to dense, generally well-sorted, water-bearing sands and gravels of low compressibility and high rates of consolidation settlement. However, subordinate layers and lenses of soft to firm clay and loose sandy silt may give rise to lateral and vertical variation and variable engineering performance locally. The geotechnical characteristics of the buried gravels underlying the 25-Foot Drift deposits, described on p.90, will be similar to these exposed sands and gravels. Excavations will generally require immediate support and may suffer severe water inflows. Casing will be required to prevent collapse of granular material into bores.

ANNEX A

Key Tables defining parameter classes used for summary geotechnical test data presented in text Tables 2–17.

Table A1. Sulphates in Soils and Groundwater

Class	Total SO_4 (%)	SO_3 in 2:1 soil:water extract (g/l)	In Groundwater (parts/100 000)
1	>0.2		<30
2	0.2 – 0.5		30 – 120
3	0.5 – 1.0	1.9 – 3.1	120 – 150
4	1.0 – 2.0	3.1 – 5.6	250 – 500
5	>2	– 5.6	<500

From BRE Digest 174 (1975)

Table A2 Scale of Point Load Strengths.

Term	Point load strength kN/m^2
Extremely strong	>12 000
Very strong	6000 – 12 000
Strong	3000 – 6000
Moderately strong	750 – 3000
Moderately weak	300 – 750
Weak	75 – 300
Very weak	>75

After Anon (1972)

Table A3 (a) Coefficient of Volume Compressibility, Mv

Class	Description of compressibility	Mv (m^2/MN)	Examples
5	Very high	>1.5	Very organic alluvial clays and peats
4	High	0.3 – 1.5	Normally consolidated alluvial clays, e.g. estuarine clays
3	Medium	0.1 – 0.3	Fluvioglacial clays, Lacustrine clays
2	Low	0.05 – 0.1	Boulder clays
1	Very low	>0.05	Heavily overconsolidated 'boulder clays', stiff weathered rocks

After Head (1982)

Table A3 (b) Coefficient of Consolidation, Cv.

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

After Lambe and Whitman (1979)

A4 California Bearing Ratio (CBR) Tests

CBR test results given in summary tables (Tables 2 – 16, in text) show values for soils compacted at natural moisture content.

ANNEX B

GEOTECHNICAL TESTS QUOTED IN THE DATABASE AND THEIR APPLICATIONS

1. FIELD TESTS

The Standard Penetration Test (SPT)

The standard penetration test (SPT) 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. Test details are given in BS 5930:1981 (Anon, 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 penetration test (CPT).

Although this is a field test which is subject to operational errors, the SPT 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 SPT and the bearing capacity of a soil.

The results of the SPT are meaningful up to and including an N-value of 50, corresponding to very dense granular soils and hard cohesive soils. The SPT is also frequently used in harder materials, ie. rocks and heavily overconsolidated soils or 'mudrocks', in which case the test is normally terminated before the shoe has been driven the full 300 mm. Rather than extrapolate the number of blows to represent the full 300 mm of test, the amount of penetration in mm for 50 blows can be quoted. When the results are given in this manner the test is referred to as the Rock Penetration Test (RPT). The relationship between the two methods of quoting the results is tabulated below:

Relative Density/Consistency	SPT	RPT
Very loose/very soft	0 – 5	
Loose/soft	5 – 10	
Medium dense/firm	10 – 30	
Dense/stiff	30 – 50	
Very dense/hard	50	300
Rock/Heavily overconsolidated soils		200 – 100

Permeability

The permeability of a soil is its capacity to allow water to flow through it. It may be measured on laboratory samples or from boreholes. Laboratory tests do not take into account the effect of structural discontinuities in the soil or rock mass in situ and may not, therefore, give a true indication of the permeability of the ground en masse. Pumping tests using boreholes give more representative permeability values.

In field permeability tests, water may be pumped out of a borehole and the effect on the water level in adjacent boreholes monitored or 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 in BS 5930:1981 (Anon, 1981). Sections of borehole may be isolated by sealing with 'packers' in order to measure water flows over selected depth intervals. The data obtained from either method enable the coefficient of permeability (k, metres/second) 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.

Shear Vane Tests

Shear strength parameters obtained from laboratory tests are prone to errors resulting from sample disturbance, giving results that are frequently lower than those obtained from back-analysis. In order to address this problem the shear vane test was developed to determine the undrained shear strength of clays within the very soft to firm consistency range, in situ.

The apparatus comprises four thin rectangular blades arranged radially around a circular shaft to form a cross. Advancing this vane into undisturbed soil and rotating at a constant rate of shear using a torque head allows the torque causing soil failure along the surface of the volume of revolution of the vane to be measured. Undrained shear strength is calculated from the relationship between torque and angular rotation, the vane dimensions and the maximum torque applied. Remoulded shear strength is measured similarly, after remoulding the soil by rapid rotation of the vane and allowing a short time period for pore pressures to dissipate.

The results of the test are intended to give a rapid indication of undrained shear strength and may be used in stability analyses. The results obtained should not, however, be generally considered as a replacement for the more accurate shear strength parameters determined from triaxial or shearbox tests. Further details of the test are given in Carter (1983).

2. INDEX TESTS

Moisture Content

The moisture content of a soil sample is defined as the ratio of the weight of water in the sample to the weight of solids, normally expressed as a percentage, i.e:

$$\text{Moisture content, m} = \frac{\text{weight of water} \times 100\%}{\text{weight of solids}}$$

Standard test procedure is given in BS 1377:1975 (Anon, 1975a). Moisture content is a basic soil property and influences soil behaviour with regard to compaction, plasticity, consolidation and shear strength characteristics.

Atterberg or Consistency Limits (Plasticity Tests)

As moisture is removed from a fine-grained soil it passes through a series of states, i.e. liquid, plastic, semi-solid and solid. The moisture contents of a soil at the points where it passes from one stage to the next are known as 'consistency limits'. These limits are defined as:

Liquid Limit (LL). The minimum moisture content at which the soil will flow under its own weight.

Plastic Limit (PL). The minimum moisture content at which the soil can be rolled into a thread 3 mm diameter without breaking up.

Shrinkage limit. The maximum moisture content at which further loss of moisture does not cause a decrease in the volume of the soil.

The range of moisture content over which the soil is plastic is known as the plasticity index (Ip), and is defined as:

$$Ip = LL - PL$$

Test procedures are given in BS 1377 (Anon, 1975a).

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. A soil may be classified in terms of its plastic behaviour by plotting plasticity index against liquid limit on a standard plasticity (or Casagrande) chart. The consistency limits also give an indication of soil strength and compressibility.

Density

Density of a soil, i.e. the mass per unit volume, may be measured in various ways.

The total or bulk density is the mass of the entire soil element (solids + water) divided by the volume of the entire element.

The dry density is the mass of dry solids divided by the volume of the entire soil element.

The saturated density is the mass of the entire soil element with its pore spaces filled with water (i.e. totally saturated) divided by the volume of the entire soil element.

Density measurements are simple if an undisturbed specimen of known, or easily measured, volume is obtained. If this is not possible in the field, the sand replacement method is used to determine the volume of a hole from which the soil sample is excavated by filling with a measured quantity of dry, uniformly graded sand of known density. Density measurements are usually expressed as Mg/m^3 and full test details are given in BS 1377 (Anon, 1975).

Soil density measurements may be used to assess various earth loads such as soil mass, overburden pressure, surcharge pressure and earth pressure on retaining walls.

Specific Gravity

The specific gravity of a soil is the ratio of the weight of dry solids to the weight of an equal volume of water (i.e. the weight of water displaced by the solids). It is, therefore, a dimensionless parameter. Full test details are given in BS 1377 (Anon, 1975). Specific gravity is a basic soil property and represents an average for the particles of different minerals present in a soil sample. The parameter is used to enable calcuation of other basic soil properties. For example, specific gravity (G), moisture content (m), voids ration (e) and degree of saturation (S) are given by the useful relationship:

$$Gm = Se$$

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 ym 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 passing 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, dried and the contained solids weighed or, alternatively, hydrometer readings of the soil-water suspension are recorded at specific time intervals. 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 BS 1377 (Anon, 1975a).

Particle size distribution is used for classifying soil in engineering terms (BS 5930:Anon, 1981). Particle size distribution curves will give an indication of 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 in situ, but may show similar particle size distribution in a bulk test sample.

3. 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 for at least 12 hours. 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 BS 1377(Anon, 1975a).

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 strongly-acidic cationic exchange resin activated with hydrochloric acid. The groundwater or soil-water washings are collected and titrated against standardised sodium hydroxide solution, using a suitable indicator. From the amount of sodium hydroxide used during titration the quantity of dissolved sulphates can be determined and expressed in terms of SO_3 content, as grams per litre or as parts per 1000000. Full test details are given in BS 1377 (Anon,1975).

It is important that the sulphate content of groundwater and soil is known as ordinary Portland cement deteriorates in the presence of sulphate. Knowledge of sulphate concentrations enables a suitable sulphate resisting or high alumina cement to be used in appropriate concrete mixes for applications below ground level.

Organic Content

A small (0.2 – 5 g) dry, representative sample of soil is weighed and reacted with 10 ml of normal potassium dichromate solution. The potassium dichromate which is left after the organic material has been oxidised is then determined by titration against a standard solution of ferrous sulphate. The organic content of the soil can then be calculated. Details are given in BS 1377 (Anon, 1975a).

Organic silts and clays are weak soils and usually highly compressible. In extremely organic soils, such as peat, very high and rapid compressibility is found and permeability is high. Although weak and permeable, density is low and cuttings in peat may therefore stand better than a clay soil of the same height and slope angle.

4. STRENGTH TESTS

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 general terms, an undisturbed cylindrical specimen (usually 76mm x 38mm) 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, taking care that all air is removed. The confining water pressure in the cell is then maintained at a prescribed constant value while the axial load on the specimen is increased at a constant rate of strain. The test continues until the specimen shears or a maximum vertical stress is reached. Vertical displacement and axial load on the sample are measured during the test. The test is repeated on two further specimens (from the same sampling point) at different confining pressures. From the results obtained from the three tests, a standard graphical construction (based on the Mohr-Coulomb failure criterion) enables the measured principal stresses to be plotted so that the shear strength of the soil can be determined in terms of its cohesive and frictional components (ie. cohesion, C, and angle of internal friction, $\varnothing$).

The test may be carried out with the sample either drained or undrained (with or without pore pressure measurement), and the type of test will depend upon the site conditions and type of engineering works being undertaken.

An unconsolidated-undrained (UU) test is used for foundations on normally consolidated clay soils (where drainage would be slow). The test normally takes only a few minutes, as pore pressures are not allowed to dissipate, and is thus often known as a quick-undrained (QU)test. The strength parameters determined in this test are the total or apparent undrained cohesion and friction values (C_u and $\varnothing_u$, respectively).

In a consolidated-undrained (CU) test, free drainage of the specimen is allowed under the cell pressure for 24 hours before testing (that is, the sample consolidates). The drainage valve is then closed and the load increased rapidly to failure. This test is applicable to situations where a sudden change in load takes place after a period of stable conditions (e.g. as a result of rapid drawdown of water behind an earth dam).

A consolidated-undrained test with pore pressure measurement may also be carried out. In this test, the measurement of pore pressure enables calculation of the effective strength parameters, C' and $\varnothing$' (sometimes referred to as the "true" cohesion and "true" angle of internal friction), in addition to the undrained parameters, C_u and $\varnothing_u$.

A drained (CD) test is suitable for sandy soils or for clay embankments in which drainage blankets have been laid. Free drainage of the sample is allowed during both the consolidation and loading stages of the test, with the sample loading applied at a rate slow enough to allow dissipation of pore pressures. The test conditions enable the determination of the effective strength parameters, C' and $\varnothing$'.

Unconfined Compression Test

This test measures the unconfined (uniaxial) compressive strength of rock samples of regular geometry and is mainly intended for strength classification and characterisation of intact rock.

Test specimens are required to be right circular cylinders having a height:diameter ratio of 2.5-3.0 and a diameter preferably of not less than 54 mm. The sides and ends of the specimen should be smooth and end surface treatment other than machining is not permitted. Samples should be stored and tested in such a way that the natural water content is preserved. If other moisture conditions are used, they should be reported with the test results.

The prepared rock cylinders are placed in a suitable load frame and the load applied continuously at a constant stress rate such that failure will occur within 5 – 10 minutes of loading, alternatively the stress rate should be within the limits of 0.5 – 1.0 MPa/sec. The specimen is loaded to failure and the maximum load recorded. The number of specimens tested should be determined from practical considerations, but at least 5 are preferred. The uniaxial compressive strength is calculated by dividing the maximum load carried by the specimen during the test, by the original cross-sectional area.

Point Load Test

The point load test provides a rapid, economical and reasonably accurate index of rock strength and strength anisotropy, the principles of which have been described by Broch and Franklin (1972) and Bieniawski (1975). The test basically involves loading a sample of rock to failure between two standard-shaped steel cones mounted in a portable hydraulically-operated press. The load at failure is determined from appropriately calibrated pressure gauges and the Point Load Strength (Is) calculated from the relationship:

$Is = P/D^2$, where D is the initial distance between the loading cones holding the sample and P is the maximum pressure recorded on the gauge (i.e. the failure load).

The test is usually carried out on pieces of rock core placed both diametrically and axially between the loading cones to obtain an indication of strength anisotropy. For diametral tests the length:diameter ratio (L/D) of the core should be >1.4; for axial tests the diameter:length ratio (D/L) should be c.1.1 (where D is the axial distance between the cones). The test may also be performed, less accurately, on irregular lumps with D/L ratios of 1.0 – 1.4.

It is usual practice to correct the point load strength (Is) to a standard 50 mm reference diameter using a set of standard curves to give the Point Load Index, $Is_{(50)}$. This index is essentially equivalent to the point load strength multiplied by correction factors for shape and size. The Anisotropy Index (Ia) of the rock may be expressed as:

$$Ia = \frac{Is_{(50)}\ [\text{diametral}]}{Is_{(50)}\ [\text{axial}]}$$

5. CONSOLIDATION and COMPACTION TESTS

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 towards areas of lower pressure at a rate controlled by the soil permeability. The removal of water causes a decrease in volume of the soil, a process known as consolidation.

The consolidation parameters are measured in the laboratory by placing a disc of soil confined in a metal ring, in a water filled cell. A constant normal 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 (m^2/MN), 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 (m^2/year) is also calculated, and is a measure of the rate at which the volume change will take place for a given increase in stress.

Consolidation test results are important for foundation design and calculating the likely settlements that will take place during and after construction. The test results also enable the planning of phased construction stages to allow full consolidation settlement (dissipation of pore pressures) to take place prior to successive load stages.

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 (Proctor) 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 (Anon, 1975a).

The results of the compaction test are used to determine the optimum moisture conditions at which to place a given soil as general or embankment fill.

California Bearing Ratio (CBR)

The California Bearing Ratio test is an empirical test carried out in the laboratory, or in the field, which compares the resistance of a soil to penetration by a standard plunger to the resistance to penetration shown by standard crushed stone:

$$CBR = \frac{\text{Measured force} \times 100\%}{\text{Standard force}}$$

There are, however, various ways of preparing samples for the test. The samples may be either undisturbed or remoulded. Remoulded samples may be compressed into a standard CBR (or Proctor) mould under a static load, or dynamically compacted into it, at the required moisture content, either to achieve a specific density or by using a standard compactive effort. Undisturbed samples may be taken on site in a CBR mould, either from natural ground or from recompacted soil such as an embankment or a road sub-base. Specimens may be tested in the mould as prepared (or as recieved) or after soaking in water for several days.

For soaked CBR tests on remoulded soil at maximum compaction, for example, the test normally involves a series of samples which are compacted in a 152 mm diameter mould at moisture contents around the optimum. 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 CBR 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 (Anon, 1975a).

The CBR value of recompacted soil is very sensitive to variations in moisture content and dry density. Some typical laboratory CBR values for British soils compacted at natural moisture content are indicated below:

Type of soil	Range of PI (%)	Range of CBR* (%)
Clay	40 – 70	1 – 3
Silty clay	about 30	3 – 5
Sandy clay	10 – 20	4 – 7
Silt	0	1 – 2
Sand (poorly graded)	NP	10 – 20
Sand (well graded)	NP	15 – 40
Sandy gravel (well graded)	NP	20 – 60

*Lower values relate to water table depth ≤600 mm below formation level. Upper values to water table >600 mm below formation level. (From TRRL Road Note 29)

In the field test, the plunger is jacked into the ground against the reaction of a heavy lorry. Field values are usually lower than laboratory values and the results of these in situ tests are not directly comparable with laboratory test results. The laboratory test in the CBR mould is recognised as the standard test. The results of the CBR test are used to assess the suitability of soils for use as base, sub-base and sub-grade in road construction.

Appendix 3 HYDROGEOLOGY

Introduction

The district lies within Hydrometric Area 27, administered by the Yorkshire Region of the National Rivers Authority. References to groundwater are given in Edwards and others (1940) and in a survey of water resources published by the Yorkshire Ouse and Hull River Authority (Anon, 1969).

The district is drained by the rivers Aire and Calder. The mean gauged flow of the Aire, as measured at Beal Weir [534 255], just beyond the area boundary, is about 37 cubic metres per second (m^3/sec). The lowest recorded gauged flow was 5.05 m^3/sec in August, 1976, a notable drought year. The base flow (groundwater contribution) is probably only a small part of the total flow.

The mean annual rainfall ranges from about 650mm in the west to less than 640mm in the east. Annual losses due to evaporation and transpiration are of the order of 430mm. The mean annual infiltration rates were estimated by the Yorkshire Water Authority (in Monkhouse and Richards, 1982) to be about 200 mm over the outcrop of the Magnesian Limestones and about 180mm over the Sherwood Sandstone.

Water for public supply comes largely from impoundment reservoirs on moorlands on the Millstone Grit outcrop in the Pennines. Pontefract and its environs are also supplied from boreholes in the Sherwood Sandstone to the east of the study area. Licensed groundwater abstraction within the area totals 4.69 million cubic metres per annum (m^3/a), of which 61 percent is for industrial use (including quarry use and aggregate washing), 32 percent for the generation of electricity (at Ferrybridge power station [470 260]), 6 percent for spray irrigation, and 1 percent or less for other agricultural and for domestic requirements (based on information supplied by the Yorkshire Water Authority). The locations of licensed abstraction sites are shown on Figure 45.

Coal Measures

The Coal Measures strata form a multi-layered aquifer, groundwater being contained in sandstones. There is little connection between the sandstones, except locally by faulting, coal mining and resulting subsidence. The most important sandstone aquifers are the Thornhill Rock and Glass Houghton Rock, although the Haigh Moor Rock and Ackworth Rock are also important hydrogeologically. The matrix of the sandstones is usually sufficiently well cemented to be essentially impermeable, and groundwater is contained in, and flows through joints and fissures. At depths over about 120 m fissure development and permeability is much reduced.

Currently, 12800 m^3/a are licensed for abstraction from the Coal Measures for spray irrigation. Yields from boreholes range from less than 60 cubic metres per day (m^3/d) to more than 1000 m^3/d. The greater the number of sandstones intersected, the greater the yield; large yields can be obtained where the Ackworth Rock is directly overlain by the Brotherton (Lower Magnesian Limestone) Formation, the latter acting as a conduit for replenishment. In the vicinity of working coal mines, groundwater levels are commonly depressed due to mine dewatering. When a mine is closed, groundwater levels rise and the workings become flooded to form a local storage reservoir. However, mine discharges from Prince of Wales [451228] and Kellingley [526237] collieries are relatively small, together amounting to about 3 million m^3/a, and seem to have a negligible effect on groundwater levels in the overlying aquifers.

Boreholes are usually unlined, apart from the topmost few metres, but, sand screens are used to prevent collapse of mudstone beds.

Shallow groundwaters are usually of fair quality with a total hardness in the range 300 to 500 milligrammes per litre (mg/l: as $CaCO_3$) and a chloride ion concentration of less than 100 mg/l (as Cl). Deeper-seated waters (below about 100 m) tend to be more heavily mineralised, with high concentrations of sodium, chloride and sulphate; iron concentration commonly exceeds 5.0 mg/l. Water pumped from mines is, therefore, rarely potable. Similarly, water pumped from flooded mine workings is usually of poor quality, and boreholes in the vicinity of such workings may draw on the storage of mineralised water.

Groundwater is not generally vulnerable to pollution from surface sources, largely because of the protection afforded by the mudstone layers, but shallow wells into sandstone outcrops, particularly in the vicinity of farm buildings, probably require some protection.

Basal Permian Sand

The Basal Permian Sand is too thin to be of hydrogeological importance.

Cadeby (Lower Magnesian Limestone) Formation

The Cadeby Formation is the major aquifer within the study area. Although the matrix of the rock is generally impermeable, groundwater is contained in, and flows through numerous joints, cavities and fissures. Yields of boreholes depend, therefore, on the intersection of these in the saturated zone, failure to do so resulting in a "dry" well. An analysis of borehole performance suggests that the mean yield of a borehole of 300 mm diameter penetrating 30 m of saturated aquifer would be about 800 m^3/d for a drawdown of 10 m. There would be approximately a 20 percent chance that the yield would be less than 190 m^3/d for the same drawdown. There appears to be little difference in borehole performance between the confined and unconfined parts of the aquifer.

Licensed groundwater abstraction amounts to 4.55 million m^3/a, of which 2.89 million m^3/a are for industrial use, 1.50 million m^3/a for electricity generation, and the rest mostly for spray irrigation. There are also a few minor wells for other agricultural and domestic purposes.

Natural rest water levels are generally about 5 to 15 m above Ordnance Datum (OD) but lower in the river valleys. Natural fluctuations of groundwater level have not been monitored in the area, but are unlikely to exceed a range of 5m. Locally, in the vicinity of the larger, continuously pumping wells such as Ferrybridge power station [470260], groundwater levels have been depressed to within 2 or 3 m of OD, but on the cessation of pumping, recovery to natural levels is usually rapid.

Groundwater varies from the calcium bicarbonate to the calcium sulphate type, with some magnesium sulphate waters. The total hardness is generally large with normal values ranging from 450 to 600 mg/l (as $CaCO_3$). The concentration of sulphate varies from less than 100 to more than 340 mg/l (as SO_4), the values closely parallel to those for total hardness. Sulphate concentration appears to be related to the depth of the borehole, with the largest values recorded in boreholes over 60 m. The chloride ion concentration is usually less than 100 mg/l (as Cl). Nitrate concentrations have not exceeded the recommended limit of 50 mg/l (as NO_3) in recorded analyses, but there are insufficient data available to permit a comprehesive assessment. Typical analyses are given in Table 24.

Boreholes constructed into the Cadeby Formation usually stand without support, and lining is ordinarily restricted to a few metres from the surface. Where broken rock is encountered some form of sand screen is required. Overlying beds of the Edlington Formation and drift deposits need to be lined out.

Since the formation is a fissure-type aquifer, groundwater flow may be rapid. Where it crops out and is drift-free or or has a permeable drift cover such as sands and gravels, pollutants can pass quickly from the ground surface to the saturated zone, and be transported laterally with equal

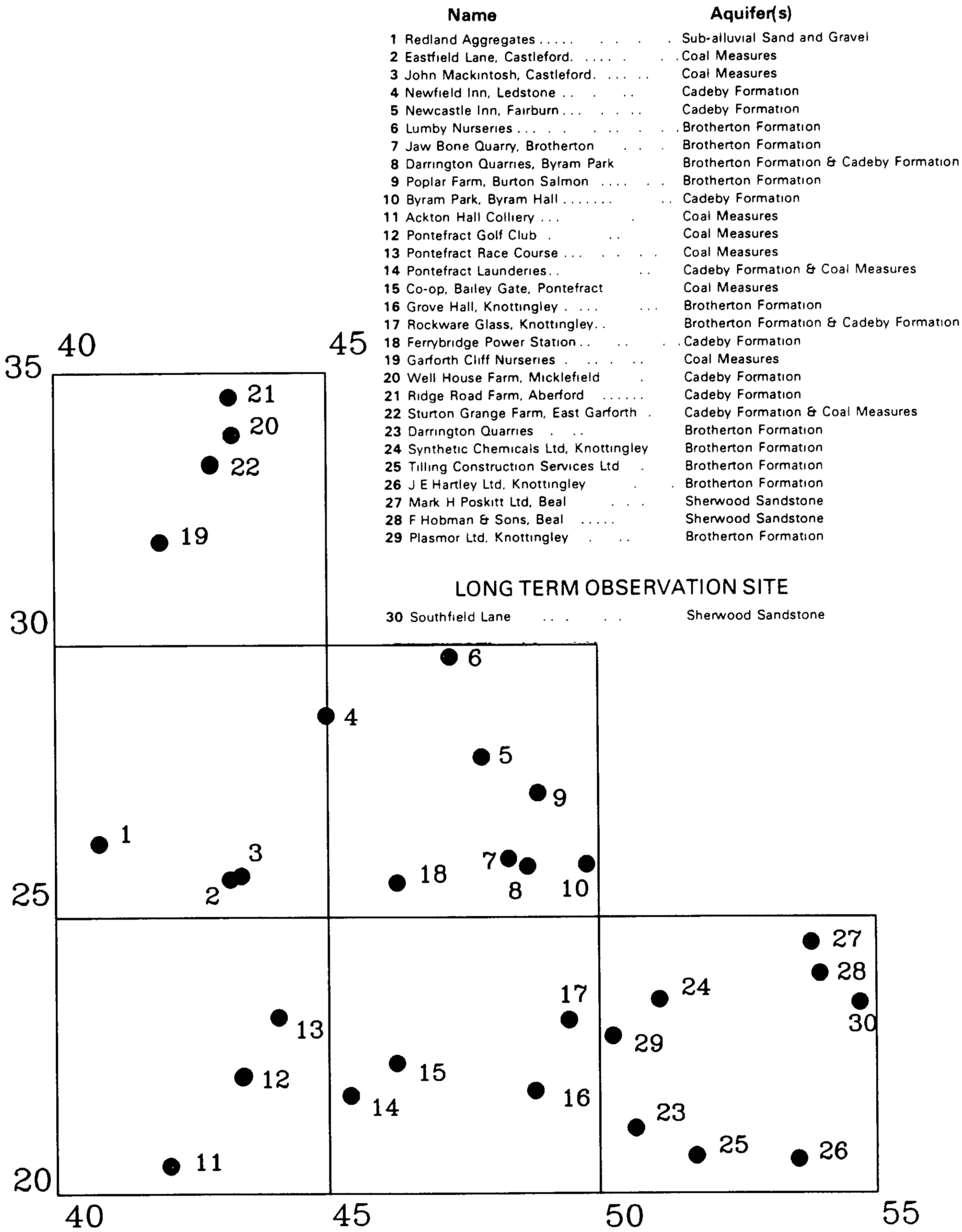


Figure 45 Abstraction sites

facility. This high degree of vulnerability to surface pollution necessitates some measure of protection. Landfill waste disposal sites can yield undesirable leachates, road drainage may carry noxious substances from traffic accidents, and even normal agricultural practices may add their quota of fertilisers and pesticides. The amount of groundwater in storage is suffiently large to ensure adequate dilution of most single polluting events, providing that pumped groundwater sources are about 1 km distant. Continuous input of pollutants can pose more of a problem. Retention of pollutants within the aquifer is a function of the ability of the matrix to retain the undesirable elements and the speed at which groundwater flow may flush them out. In this aquifer, the matrix is largely impermeable and groundwater flow rapid. Consequently, although a polluting incident may be serious, there is some potential for cleansing the aquifer, even if this should take a number of years.

Edlington (Middle Permian Marl) Formation

The Edlington Formation is an aquiclude separating the Upper and Lower Magnesian Limestones. It is uncertain as to how good a barrier it may be since the area is crossed by many faults and the formation contains some permeable beds. It is possible that a high degree of hydraulic continuity may be present between the overlying and underlying aquifers. The evaporites in the formation may have some effect on the groundwater quality in the adjacent limestones.

Brotherton (Upper Magnesian Limestone) Formation

The Brotherton Formation is hydrogeologically similar to the Cadeby Formation, but used much less for groundwater supply. In the outcrop areas, wells are generally sunk to the Cadeby Formation. The formation lacks the cavernous nature of the Cadeby Formation and the presence of collapsed strata above areas of evaporite dissolution suggests lower permeabilities. There are too few data points from which to calculate the level of the potentiometric surface, but rest water levels appear generally to be about 15 m above OD. Groundwater quality seems to be similar to that of the Cadeby Formation, on the evidence of the few analysis available, but with lower values for total hardness and sulphate concentration. Unfortunately, there are too few analyses available to confirm this.

Roxby (Upper Permian Marl) Formation

The Roxby Formation is an aquiclude with anhydrite and gypsum which may contribute to mineralisation of groundwater in the underlying limestone.

Sherwood Sandstone

The Sherwood Sandstone is one of the major aquifers in the United Kingdom; within the study area, its outcrop is of limited extent, and its importance less than that of the limestones. Experience has shown that much of the flow is through fissures even though there is significant intergranular storage. Licensed abstraction is restricted to two wells which together amount to 0.12 million m^3/a. An analysis of borehole performance in the aquifer immediately east of the area, where there are more data available, suggests that the mean yield of a borehole of 300 mm diameter open to 50 m thickness of saturated sandstone would be of the order of 820 m^3/d for a drawdown of 10 m. There would be a 20 percent chance that the yield would be less than 400 m^3/d for the same drawdown. Rest water levels are generally about 10 m above OD in the centre and the west of the outcrop, but seem to fall to near OD in the east, possibly in response to pumping beyond the area boundary. The well hydrograph for the Southfield Lane Borehole for 1978 to 1987 (Fig. 46) shows a fluctuation of about 3 m. However, levels may have been affected by pumping from this well up to the end of 1981.

Table 24 Chemical analyses of groundwater from the Castleford – Pontefract area.

SITE	1	2	3	4	5
Aquifer	SSG	SSG	MgL	MgL	MgL
Date	25 NOV 86	26 MAR 77	25 AUG 77	18 DEC 83	21 MAY 80
pH	7.2	7.4	7.6	7.8	7.5
Total hardness (as $CaCO_3$)	392	340	486	625	532
Carbonate hardness (as $CaCO_3$)	98	132	218	200	260
Calcium (as Ca)	101	88.6	129	90	119
Magnesium (as Mg)	34.1	28.9	40.1	97	81.7
Sodium (as Na)	17	18.75	19	47	16.9
Potassium (as K)	12	3.35	2.4	4.3	2.08
Bicarbonate (as HCO_3)	119.5	161	266	244	317
Sulphate (as SO_4)	158.6	127	221	220	240
Chloride (as Cl)	43	32	25	80	20.6
Nitrate (as NO_3)	129.7	68.6	0.9	nd	25.9

1. Southfield Lane [547236]
2. Mark H Poskitt [538247]
3. Darrington Quarries Ltd [507213]
4. Ferrybridge Power Station [470260
5. Lumby Nursery [473289]

SSG = Sherwood Sandstone Group

MgL = Magnesian Limestone

Data supplied by the Yorkshire Water Authority

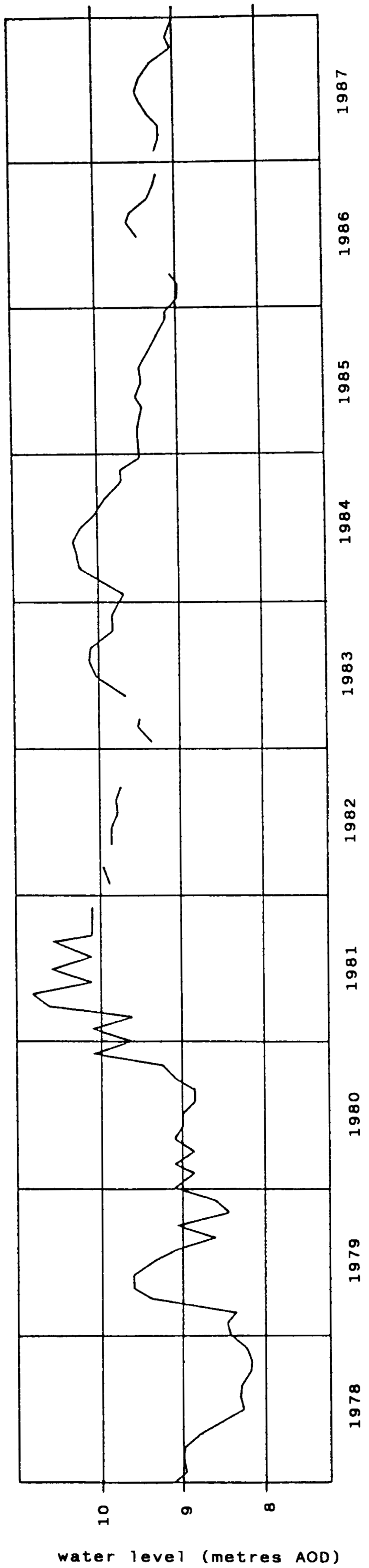


Figure 46 Well hydrograph for Southfields Lane Groundwater Observation Well

Representative analyses are given in Table 24. Water is of the calcium bicarbonate/sulphate type. The total hardness is usually 200 to 400 mg/l (as $CaCO_3$), the recorded concentration of sulphate up to 165 mg/l (as SO_4). The chloride ion concentration is generally less than 40 mg/l (as Cl). Nitrate concentrations may be locally over 50 mg/l (as NO_3) where the outcrop is drift-free or covered by thin and permeable drift, and a concentration of nearly 130 mg/l was recorded at Southfield Lane. High concentrations are usually confined to the uppermost few metres of the saturated zone, rapidly decreasing with depth.

In drift-free areas, or where the outcrop is covered by permeable drift, and where the water table is close to the ground surface, pollutants may quickly reach the saturated zone. Downward percolation of water through the unsaturated zone and lateral groundwater flow are likely to be relatively slow when compared, for example, with the Magnesian Limestones. Although this suggests that pollutants are likely to take a long time to reach abstraction sources, they may be retained for far longer periods. When a pollutant reaches the saturated zone, it may take many years to fall to acceptable values, either by chemical change or slow diffusion and dilution.

Superficial Deposits

The Superficial Deposits are mostly unimportant as groundwater sources. Permeable sands and gravels are mainly thin, with little capacity for storage. The silt and clay deposits of the 25-Foot Drift of the Vale of York tend to reduce infiltration into underlying aquifers. There are extensive deposits of alluvium in the Aire and Calder valleys, but they are permeable only to a limited extent;

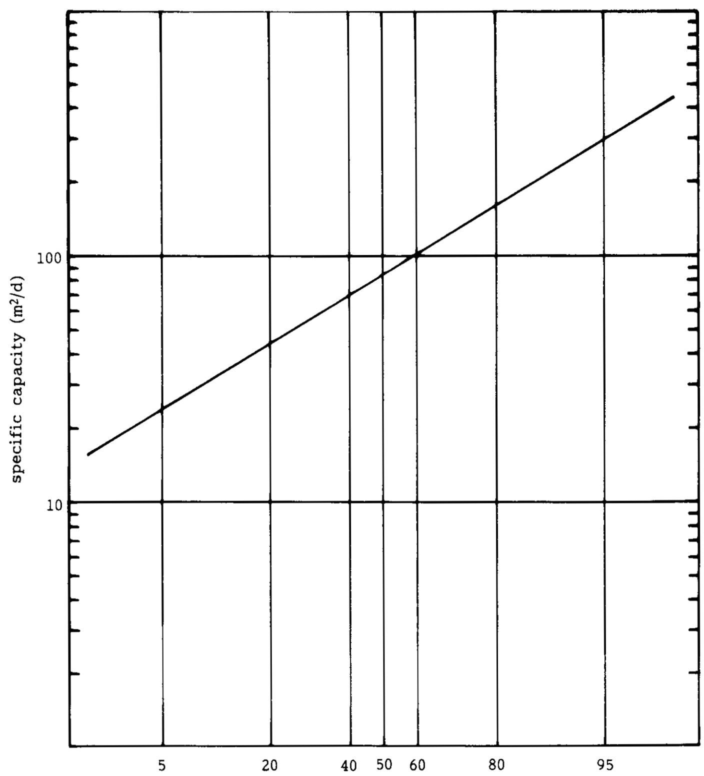


Figure 47 Distribution of specific capacities of boreholes in the Sherwood Sandstone

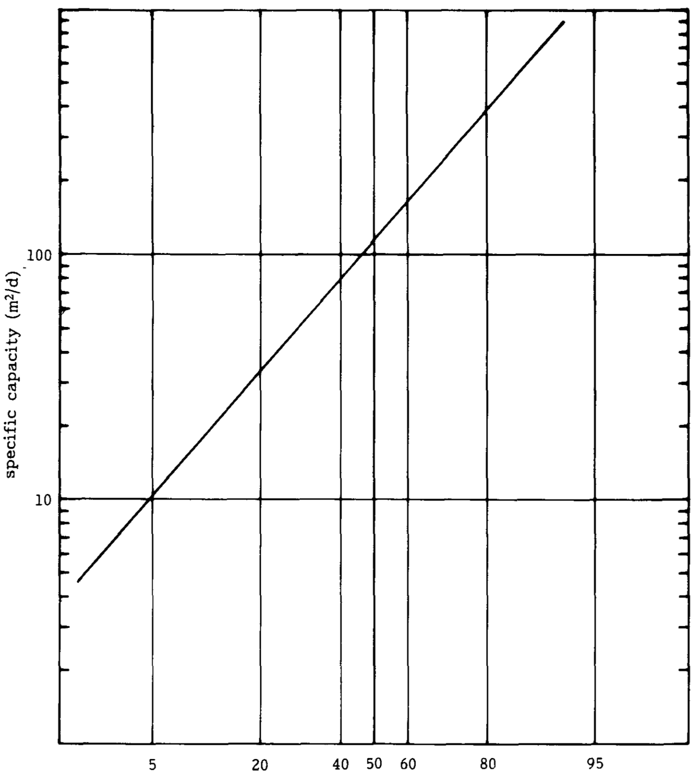


Figure 48 Distribution of specific capacities of boreholes in the Magnesian Limestone

pumping a well in the more permeable beds would be likely to yield river water rather than groundwater.

Borehole yields

The yield of a borehole is dependent on its dimensions and the characteristics of the aquifer. The length of the borehole open to the saturated aquifer (the effective length), its diameter, the depth to which it penetrates the aquifer and the drawdown all have a direct effect upon the yield. Consequently, it is rarely possible to compare borehole yields directly where one or more of these parameters differ. When this is considered with the variations in transmissivity and specific yield (the aquifer characteristics), the prediction of borehole yield becomes complex. A method has been devised to reduce observed data to standard borehole dimensions and use statistical analysis to determine yield probabilities.

When a full pumping test of a borehole is carried out (Anon, 1983), the transmissivity and specific yield (coefficient of storage in a confined aquifer) are determined, together with an estimate of well losses. From these the yield and drawdown may be predicted for a borehole of similar dimensions at any location where the aquifer characteristics are identical. Nonetheless, since aquifer characteristics tend to vary areally, a large number of such tests would be necessary to permit yield predictions, even in a small area. Such tests are costly, and are usually carried out only on a few high-yield sources, generally intended for public supply.

When a borehole is constructed, it is usual for a yield test to be carried out on completion. Pumping usually takes place at a constant rate for a period ranging from a few hours to several days. At the end of the test, the yield and the drawdown are noted. Occasionally, yield and drawdown are measured when the borehole is in service. In general, yield-drawdown tests of this type provide the only available data.

To compare the yields of boreholes, the following information is required for each: pumping rate (m^3/d), rest water level (the level before pumping started, in metres), pumping water level (the level when pumping stopped, in metres), borehole depth (in metres), borehole diameter (in the length open to the aquifer, in millimetres), and the length of plain lining tubes from the ground surface (in metres). Geological conditions must also be noted, such as the thickness of any cover above the aquifer. From these data, two further parameters are calculated. The first is the drawdown, the difference between the rest and pumping water levels (if the pumping rate is not constant, then the drawdown will vary accordingly, and any comparisons with other boreholes will be invalid). The second is the effective length, the depth of the borehole less the length of the lining tubes from the ground surface or the depth of the rest water level, whichever is the greater.

The number of wells taking water from the Sherwood Sandstone within the study area is insufficient for any useful analysis. Accordingly, details were taken from 26 boreholes on sheets SE52 and 53. The specific capacity (yield in m^3/d divided by drawdown (in metres); units m^2/d) was determined for each well. The best fit by regression analysis was obtained between the specific capacity (C) and the effective length (L). A standard length was defined arbitrarily as 50 m. A correction (derived from the relationship established) was then applied to the observed values of specific capacity:

C corrected = C observed x 100/Z
where Z = 7.721 x L0.6547

The corrected specific capacities were then compared in the same manner with the borehole diameters (D). A standard value of 305 mm was used, and a further correction to the specific capacities applied:

C corrected = C corrected effective length x 100/Z
where Z = 6.098 x D0.4870

No discernible relationship was established between specific capacity and depth to rest water level.

A distribution was then determined for the corrected specific capacities which corresponded to the log-normal (Figure 47). The mean was 84.9 m2/d, and the standard deviation of the log-normal distribution was 0.775. The 20% value for the distribution was 44.3 m^3/d, the 80% value 162.7 m^3/d. The range of effective lengths used in these calculations was 10 to 45 m, the range of diameters from 102 to 838 mm.

A similar process was carried out for 35 boreholes in the Magnesian Limestones, using data from sheets SE27, 28, 35 to 37, 42 to 45, and 50 to 52. The standard length was taken as 30 m, the standard diameter as 305 mm. The correction for effective length was determined:

C corrected = C observed x 100/Z
where Z = 3.333 x L

The following correction was determined for diameter:

C corrected = C corrected effective length x 100/Z where Z = 18.856 + 0.249 x D

With the available data, no significant differences were observed between the Magnesian Limestone at outcrop or beneath cover, nor between the Brotherton and Cadeby formations (there were very few usable sites in the former). No discernible relationship could be established between specific capacity and depth to rest water level.

The distribution of specific capacities in boreholes from the Magnesian Limestones is shown in Figure 48. The mean was 113.5 m^3/d, the standard deviation of the log-normal distribution 1.461. The 20% value for the distribution was 33.3 m^3/d, the 80% value 386.4 m^3/d. The effective lengths for the Magnesian Limestones ranged from 4 to 60 m, the diameters from 127 to 533 mm.

From these analyses, it is possible to say that a borehole of 305 mm diameter open to 50 m of saturated Sherwood Sandstone would have a mean yield of the order of 850 m^3/d for a drawdown of 10 m. There would be a 20% probability of the yield being less than 440 m^3/d for the same drawdown. For the Magnesian Limestones, a borehole of 300 mm diameter open to 30 m of the saturated aquifer would have a mean yield of about 1130 m^3/d for a drawdown of 10 m. There would be a 20% probability that the yield would be less than 330 m^3/d for the same drawdown.

REFERENCES

ANON, 1969. Survey of Water Resources. Yorkshire Ouse and Hull River Authority, Leeds.

ANON, 1975a. Methods of Testing For Soils For Engineering Purposes, BS 1377, **British Standards Institution**, London.

ANON, 1975b. Concrete in sulphate-bearing soils and groundwaters, Digest 174, **Building Research Establishment**, Watford.

ANON, 1981. Code of practice for Site Investigations, BS 5930, **British Standards Institution**, London.

ANON, 1983. British Standard Code of practise for test pumping water wells. BS 6316:1983, **British Standards Institution**, London, 44pp.

ATTEWELL, P B and TAYLOR R K (editors) 1984. **Ground movements and their Effects on Structures. (Surrey University Press.)**

BALDWIN, M J and NEWTON, M A. 1988. Basal Permian Sand mines and associated surface movements in the Castleford and Pontefract area of West Yorkshire. 351-357 in **Engineering Geology of Underground Movements**, Geological Society Engineering Geology Special Publication No.5. Bell, F G, Culshaw, M G, Cripps, J C. and Lovell, M A. (editors).

BIENIAWSKI, Z T. 1975. The point load test in engineering practice. **Engineering Geology**, No. 9, 1 -11.

BROCH, E and FRANKLIN, J A. 1972. The point-load strength test. **International Journal of Rock Mechanics and Mineral Science**, No. 9, 669 – 697.

BURTON, P W, MUSSON, R M W and NEILSON, G. 1984. Macroseismic Reports on Historical British Earthquakes 1V: Lancashire and Yorkshire. **British A Geological Survey Global Seismology Unit Report** No 219(b).

CARTER, M. 1983. **Geotechnical Engineering Handbook**. (Pentech Press: London.)

COOPER, A H. 1986. Subsidence and foundering of strata caused by the dissolution of Permian gypsum in the Ripon and Bedale areas, North Yorkshire. 127-139 in **The English Zechstein and related topics**, Geological Society Special Publication No.22. HARWOOD, G M and SMITH, D B (editors).

DEPARTMENT OF THE ENVIRONMENT, 1988. **Review of the Minerals Planning Research Programme**. (London: Department of the Environment.)

EDWARDS, W. 1932. The Mansfield Marine Band in the Castleford District. **Transactions of the Leeds Geological Association**, Vol. 5, 86-92.

EDWARDS, W. 1936. Pleistocene dreikanter in the Vale of York. 8-18 in **Geological Survey of Great Britain Summary of Progress for 1936**, Part II. (London: His Majesty's Stationery Office).

EDWARDS, W. 1951. The concealed coalfield of Yorkshire and Nottinghamshire (3rd edition). **Memoir of the Geological Survey of Great Britain.**

EDWARDS, W. WRAY, D A., and MITCHELL,G H. 1940. Geology of the country around Wakefield. **Memoir of the Geological Survey of Great Britain.**

FURNESS, R R, and KING, S J. 1978. Soils in North Yorkshire IV, Sheet SE 63/73 (Selby). **Soil Survey Record No. 56.**

FYLES, G. 1987. The effects of Permo-Triassic strata and speed of advance on coal mining subsidence. **Royal Institute of Chartered Surveyors Magazine**, Vol. A 5, 125-137.

GARRARD, G F G, and TAYLOR, R K. 1988. Collapse mechanisms of shallow coal mine workings from field measurements. 181-192 in **Engineering Geology of Underground movements**, Geological Society Engineering Geology Special Publication No 5. BELL, F G, CULSHAW, M G, CRIPPS, J C and LOVELL, M A. (editors).

GAUNT, G D. 1976. The Quaternary geology of the southern part of the Vale of York. Unpublished PhD thesis, University of Leeds.

GAUNT, G D. 1981. Quaternary history of the southern part of the Vale of York. 82-97 in **The Quaternary in Britain**. NEALE, J and FLENLEY, J (editors). (Pergamon Press.)

GAUNT, G D. in press. Geology of the country around Goole, Doncaster and the Isle of Axholme. **Memoir of the British Geological Survey**, Sheets 79 and 88 (England and Wales).

GAUNT, G D. , JARVIS, R A, and MATTHEWS, B. 1971. The late Weischelian sequence in the Vale of York. **Proceedings of the Yorkshire Geological Society**, Vol. 38, 281-284.

GILES, J R A. 1987. Geological notes and local details for 1:10 000 sheets: SE42NW (Castleford). **British Geological Survey Open File Report.**

GILES, J R A. 1988. Geology and land-use planning: Morley – Rothwell – Castleford. **British Geological Survey Technical Report** WA/88/33.

GILES, J R A. 1989. Evidence of syn-depositional tectonic activity in the Westphalian A and B of West Yorkshire. 201-206 in **The role of tectonics in Devonian and Carboniferous sedimentation in the British Isles.** ARTHURTON, R S, GUTTERIDGE, P and NOLAN, S C. (editors). Yorkshire Geological Society Occasional Publication No 6.

GOOSSENS, R F and SMITH, E G. 1973. The stratigraphy and structure of the Upper Coal Measures in the exposed Yorkshire Coalfield between Pontefract and South Kirby. **Proceedings of the Yorkshire Geological Society**, Vol 39, 487-514.

GOOSSENS, R F SMITH, E G and CALVER, M A. 1974. Westphalian. 87-114 in **The geology and mineral resources of Yorkshire**. RAYNER, D H, and HEMINGWAY, J E, (editors). Yorkshire Geological Society.

GREEN, A H, RUSSELL, R, DAYKINS, J R, WARD, J C, FOX STRANGWAYS, C, DALTON, W H, and HOLMES, T V. 1878. The Geology of the Yorkshire Coalfield. **Memoirs of the Geological Survey**.

GREGORY, O. 1981. Definition of the problems of disused coal mine shafts. **Conference on disused mine shafts**, Institution of Chartered Surveyors, December 1981.

GUION, P D, and FIELDING, C R. 1988. Westphalian A and B sedimentation in the Pennine Basin, UK. 153-177 in **Sedimentation in a synorogenic basin complex: the**

Upper Carboniferous of north-west Europe. BESLY, B M, and KELLING, G (editors).(Blackie: Glasgow and London.)

HEALY, P R, and HEAD, J M. 1984. Construction over abandoned mine workings. **CIRIA Special Publication 32**, PSA Civil Engineering Technical Guide 34.

HODGKINS, J. 1979. The mining of the Basal Sands of Castleford- Pontefract. **Yorkshire Subterranean Society**, Vol. 2, 39-43.

McCANN, D M, JACKSON, P D and CULSHAW, M G. 1987. The use of geophysical surveying methods in the detection of natural cavities and mineshafts. **Quarterly Journal of Engineering Geology**, Vol. 20, 59-73.

MONKHOUSE, R A and RICHARDS, H J. 1982. Groundwater resources of the United Kingdom. **Commission of European Economic Community**, 252pp. (Th. Schafer: Hanover.)

NORRIS, A, BARTLEY,D D and GAUNT, G D. 1971. An account of the deposit of shell marl at Burton Salmon, West Yorkshire. **The Naturalist**, No. 917, 57-63.

PHILIPS, J. 1828. Geological observations made in the neighbourhood of Ferrybridge in the years 1826-1828. **Philosophical Magazine**, Vol. 4, Series 2, 402.

PRYOR, W A. 1971. Petrology of the Permian Yallow Sands of northeastern England and their North Sea Basin equivalents. **Sedimentary Geology**, Vol. 6, 221-254.

SMALL, R J and CLARKE, M J. 1982. **Slopes and weathering**, 112pp. (Cambridge University Press: Cambridge.)

SMITH, D B. 1968. The Hampole Beds – a significant marker in the Lower Magnesian Limestone of Yorkshire, Derbyshire and Nottinghamshire. **Proceedings of the Yorkshire Geological Society**, Vol. 36, 463-477.

SMITH, D B. 1972. Foundered strata, collapse-breccias and subsidence features of the English Zechstein. 255-269 in **Geology of saline deposits**. Proceedings of the Hanover Symposium, 1968, (Earth sciences,7). (Unesco.)

SMITH, D B. 1974. Permian. 115-144 in **The geology and mineral resources of Yorkshire**. RAYNER, D H, and HEMINGWAY, J E, (editors). Yorkshire Geological Society.

SMITH, D B., HARWOOD, G M, PATTISON, J, and PETTIGREW, T H. A revised nomenclature for Upper Permian strata in eastern England. 9-17 in **The English Zechstein and related topics.** Geological Society Special Publication No. 22.

TAYLOR, R K, BARTON, R, MITCHELL, J E, and COBB, A E. 1976. The engineering geology of Devensian deposits underlying PFA lagoons at Gale Common, Yorkshire. **Quarterly Journal of Engineering Geology**, Vol.9, 195-216.

VERSEY, H C. 1925. The beds underlying the Magnesian Limestone in Yorkshire. **Proceedings of the Yorkshire Geological Society**, Vol.20, 209-212.

WALTON, G and COBB, A E. 1984. Mining Subsidence, 216-242 in **Ground movements and their effects on structures**. ATTEWELL, P B, and TAYLOR, R K. (editors). (Surrey University Press.)

WILLIAMS, G M. The generation and migration of gases in the subsurface. Paper 2.1 in Symposium on **Methane – Facing the Problems,** East Midlands Conference Centre, University Park, Nottingham, 26-28 September 1989.

APPENDIX 4

Statutory authorities and principal sources of data.

British Geological Survey, National Geosciences Data Centre, Keyworth, Nottingham NG12 5GG

The Chief Planning Officer, Planning Department, Wakefield Metropolitan District Council, Chapel Bar, Wakefield, West Yorkshire

The Chief Planning Officer Leeds City Council, Planning Department, Headrow Buildings, The Headrow, Leeds

Chief Planning Officer, County Planning Department, County Hall, Northallerton, North Yorkshire

The Regional Geologist, British Coal, North Yorkshire Area Office, PO Box 13, Allerton Bywater, Castleford, West Yorkshire WF10 2AL

British Coal Opencast Executive, Thorncliff Hall, Thorncliff Park, Chapeltown, Sheffield S30 4PX

British Coal Mines Records Office, Manvers Outstation, Golden Smithies Lane, Wath-upon-Dearne, Rotherham

Typeset by Saxon Printing Limited, Derby