TECHNICAL REPORT WA/88/33

Geology and land-use planning: Morley–Rothwell–Castleford

1:10 000 sheets SE22NE; SE32NW, NE, SE; and SE42NW: Part of 1:50 000 sheet 78 (Wakefield)

J R A Giles

BRITISH GEOLOGICAL SURVEY

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Onshore Geology Series

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1:10 000 sheets SE22NE; SE32NW, NE, SE; and SE42NW: Part of 1:50 000 sheet 78 (Wakefield)

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Geographical index

UK, England, West Yorkshire

Subject index

Land-use planning, thematic maps, Quaternary, Carboniferous, Permian, resources, mining, engineering geology

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

Bibliographic reference

Giles, J R A. 1988. Geology and land-use planning: Morley–Rothwell–Castleford. *British Geological Survey Technical Report* WA/88/33.

Keyworth, Nottingham British Geological Survey 1988

BRITISH GEOLOGICAL SURVEY

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PREFACE

This account describes the geology of the district to the south-east of Leeds covered by the 1:10 000 sheets SE 22 NE, SE 32 NW, NE and SE and SE 42 NW; the area lies within the Wakefield district covered by 1:50 000 geological sheet 78. The district was first surveyed at the six-inch scale by W T Aveline, A H Green, T V Holmes, J Lucas, R Russell and J C Ward, and the maps were published between 1873 and 1878. The district was re-surveyed by W Edwards, G H Mitchell and D A Wray between 1924 and 1935; both surveys were published on maps of the County series.

The present survey was commissioned by the Department of the Environment in order to provide up-to-date geological maps for the area and to identify the implications for land-use planning, development and re-development posed by the geology of the district. Particular attention was paid to sand and gravel resources, and underground mineral workings for both coal and sandstone. Mapping was carried out between 1982 and 1986 by I C Burgess, J R A Giles, C G Godwin, A J Wadge and I T Williamson, with I C Burgess, J I Chisholm and A J Wadge as programme managers.

The ready cooperation of landowners and tenants during the re-survey and the assistance of British Coal Deep Mines and Opencast Executive has been essential to the project. Similarly the help of officials of the West Yorkshire Metropolitan County Council and the Leeds and Wakefield Metropolitan District Councils is gratefully acknowledged.

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Limitations

This report has been produced by the collation and interpretation of geological, geotechnical and related data from a wide variety of sources. The results of this work are contained in the maps and reports listed in Table 1, each giving details of the various sources of the data.

The report aims to provide a general description of the geological factors relevant to land-use planning and development. The data on which it is based are not comprehensive and do vary in quality, and this is inevitably reflected in the report. Local features and conditions may not be represented, and many boundaries shown may be only approximate. The dates of the geological mapping are shown in Table 1 and no information subsequent to these dates has been taken into account. For this reason:-

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

Data used in preparing this report and the associated maps are held in the National Geoscience Data Centre of the British Geological Survey at Keyworth.

Notes

All National Grid references in this report lie in the 100 km square SE. Grid references to specific localities are given to eight figures (accurate to within 10 m); more general locations are given to six figures.

Each borehole or shaft registered with BGS is identified by a four-element code (e.g. SE 42 NW 15). The first two elements define the 10 km square (of the National Grid) in which the borehole is situated; the third element defines the quadrant of that square, and the fourth is the accession number of the borehole. In the text of the report, a borehole or shaft is normally referred to by the last three elements alone (e.g. 42NW15)

CONTENTS

Cover photograph

St Johns Opencast Mine viewed from the southeast

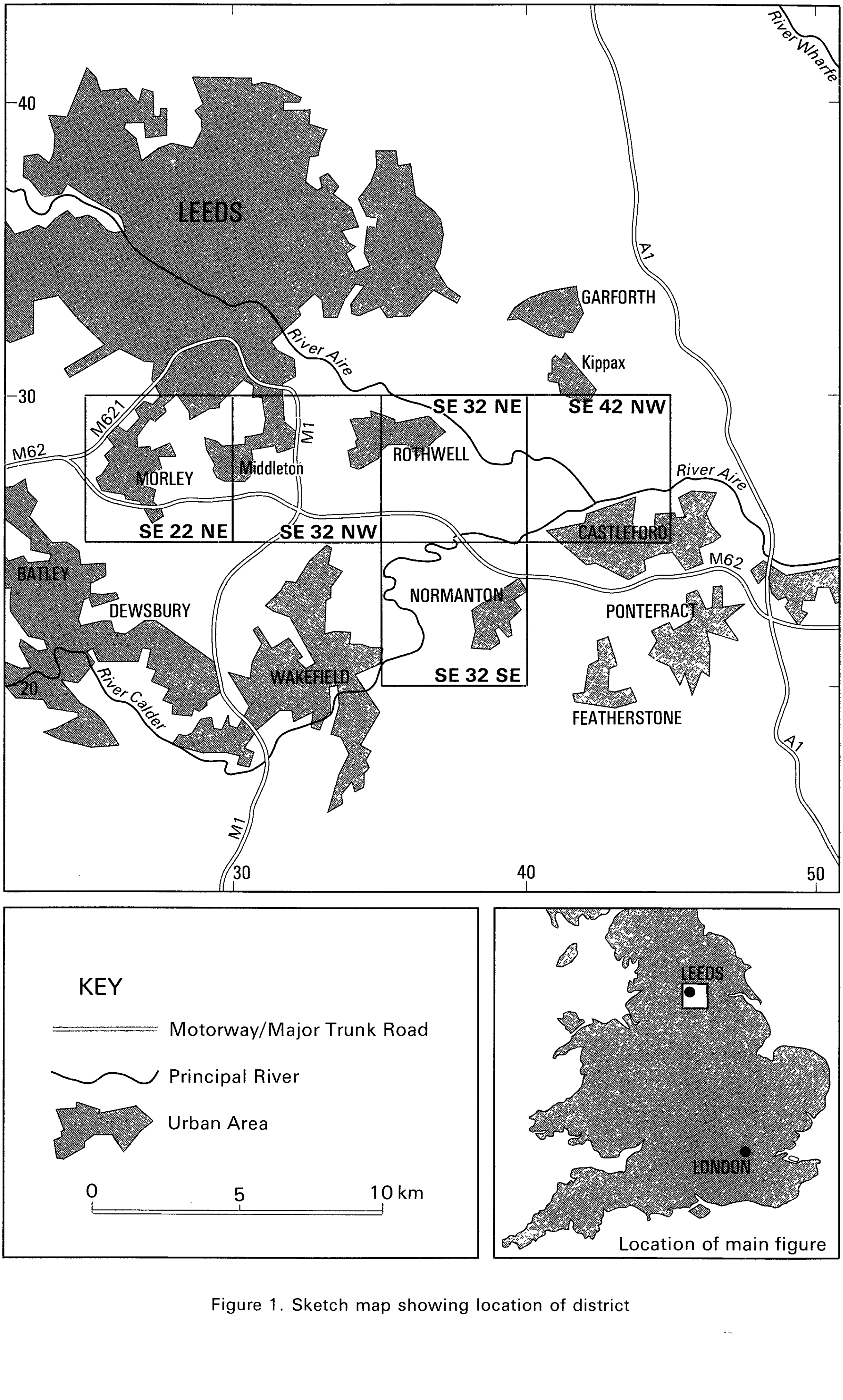


Figure 1. Sketch map showing location of district

EXECUTIVE SUMMARY

This report embodies the result of a study between 1982 and 1986 funded by the Department of the Environment. The study has provided an up-to-date geological map and account of the solid and superficial geology of the study area, and identified and reported on the implications for land-use planning. The study derived its information from two main sources:-

a) archival material comprising mine abandonment plans, opencast mining completion plans, quarry plans, borehole and shaft records, tip plans and data held in the National Geoscience Data Centre at BGS, Keyworth.

b) the detailed field geological survey by BGS surveyors at the scale of 1:10 000.

The re-survey has considerably improved the detail of the geological mapping of the solid and superficial deposits. Several minor coal seams are delimited for the first time and a denuded terrace of the Aire and Calder valleys, lying above the previous highest terrace, is recorded. The detailed Westphalian stratigraphy of the district is described in modern nomenclature.

Land stability and safety

The presence and nature of mining and the accurate assessment of the engineering properties of geological materials and natural slopes are important considerations when assessing land stability and safety.

Although the effects of subsidence from coal and sand mining are considered separately, there are certain parts of the district where both coal and sand mining are within 30 m of the surface.

There are two active collieries in the district: Allerton Bywater and New Sharlston, however, there were many more mines in the past. Much of the district has been mined at depth, the principal seams being the Beeston, Middleton Main, Haigh Moor, Warren House and Stanley Main.

In shallow coal workings, earth pressures may not be sufficient to cause immediate collapse. The rate at which old workings collapse depends upon their depth, the type of extraction pattern, the geological structure and the age of the mining. In addition, new developments or buildings can increase the surface loading and lead to sudden collapse. Since many shallow workings date from the earliest days of coal mining and are not shown on extant records or plans, their presence is difficult to predict and in many cases, is only proved by detailed site investigation. In addition to these shallow mines, numerous abandoned shafts are recorded in the district, although many more unrecorded ones almost certainly exist.

In parts of the district the Basal Permian Sand has been mined. This mining has usually taken the form of adits driven into the deposit from outcrop. The adits opened into pillar-and-stall mines which extended for distances of up to seven hundred metres. During the last two centuries numerous small mines may have exploited the reserves, but only a few plans of the later and more extensive mines survive. Evidence of the existence of mines outside the areas of known mining is furnished by site investigation boreholes and archival sources. The rate at which old workings collapse is very variable; it must not be assumed that all settlement from these mines has ceased. The mining of this deposit was generally at very shallow depth and there is a history of surface collapses associated with the abandoned workings.

The location and treatment of disused shafts and adits, whether from coal or sand mining, clearly affects the safety of a proposed development. Open shafts are a safety hazard and the surface near a shaft may subside or collapse. Various poisonous and explosive gases may be found in unventilated old workings. Finally, old shafts provide artificial channels allowing water to pass from one aquifer to another. If one aquifer becomes polluted, a shaft can act as a path for spreading the pollution to other aquifers.

Slope movements can cause further foundation problems. The escarpment of the Lower Magnesian Limestone to the east of Ledston is cambered and open joints in the bedrock are aligned parallel to the edge of the escarpment. Superficial deposits can also be subject to slippage and down-slope mass-movement.

Head, a poorly consolidated sediment which is generally too thin to map, may be present in substantial thicknesses and can be a hazard to foundations. It is particularly thick along parts of the base of the Lower Magnesian Limestone escarpment, north of the River Aire. In places head may consist of several metres of poorly sorted silts and clays with sand and some gravel. If the toe of such a deposit is excavated the sediment may be remobilised and move down-slope.

Some of the drift deposits may vary in lithology and thickness markedly. For example, the river terrace deposits may show differential compaction under loading, and compressible beds may occur in buried channels.

Made ground and fill may also constrain development. The varied chemical content and compaction of these materials can be hazardous. Backfilled quarries can also give rise to problems; particularly if they are not recognised as former quarries during site investigations.

Mineral and water resources

In planning future developments, it is important to know where the mineral resources are, so that they are not sterilized unnecessarily by building. It may also be possible to extract workable minerals in advance of development.

Much of the district is underlain by coal at shallow depth; amongst the most important seams are the Haigh Moor, Warren House, Stanley Main and the Sharlston Top coals which may provide prime opencast targets where they occur close to the surface.

Over much of the district Coal Measures mudstones and claystones are quarried to supply raw material for brick-making. Certain stratigraphical levels are favoured by the brick companies, such as the measures below the Swinton Pottery Coal around Normanton, although other Coal Measures mudstones and claystones can provide satisfactory raw materials for the process.

In the west of the district the lower and more massive sandstone beds of the Thornhill Rock are quarried for high quality building and ornamental stone.

In the east of the district the Lower Magnesian Limestone has been used in the past as a building stone, and is exploited at various localities elsewhere in West Yorkshire for aggregate, although no extraction is currently taking place in the present district.

Sand and gravel forms a significant resource in the valleys of the Aire and Calder and is currently being exploited north of Dunford House. Extensive resources of sand and gravel remain, although much has been sterilised by colliery waste tipping.

The principal aquifers in the Coal Measures are the major sandstones such as the Thornhill Rock and the Oaks Rock. However, they show considerable lateral and vertical variation and individual beds are commonly restricted by faulting. Resources of water are present in the Lower Magnesian Limestone which has a high secondary permeability. Sand and gravels of fluvial origin in the Aire and Calder valleys are occasionally utilised as a source of water, principally for industrial supply, although much is derived by induced recharge from the rivers.

Geology

The geology is illustrated in a series of five 1:10 000 scale geological maps (published separately). The solid geological maps are summarised in Figure 7 and an accompanying generalised geological sequence is shown in Figure 9. The generalised drift geology is shown in Figure 8. The main geological divisions are the Carboniferous Coal Measures, the Permian and the Quaternary.

The Coal Measures sequence is dominated by claystones, mudstones and siltstones. Thick sandstones, coal seams and rare marine deposits forming 'marine bands', are also present. The total thickness of the Coal Measures in this district is about 1000 m. The succession is divided lithostratigraphically into Lower, Middle and Upper Coal Measures and biostratigraphically into Westphalian A, B and C.

The Permian rocks unconformably overlie the Coal Measures in the east of the district. The Lower Magnesian Limestone constitutes most of the sequence with the thin Basal Permian Sands and Lower Marls beneath and Middle Marls above. The total thickness in this district is some 55 m.

The Quaternary deposits are unconsolidated sediments dominated by sand and gravel, principally of fluvial origin. Clays, silts and peat also occur.

Conclusions and recommendations

Shallow mining, mainly for coal but also for sand and other minerals, is the principal cause of land instability. A specific study is required to investigate the extent of mining-induced instability, particularly that related to sand mining. Significant resources of energy minerals and industrial minerals remain in the district but there is a need for planned extraction to avoid inadvertent sterilisation of one resource during the extraction of another.

INTRODUCTION

This report was commissioned by the Department of the Environment as one of a series of studies to identify and report on the implications for land use planning, development and redevelopment of the local solid and superficial geology. The present study is the first of three in this region, to be followed by similar reports on Castleford-Pontefract to the east and South Central Leeds to the north. The British Geological Survey is undertaking these studies as part of its programme to maintain its coverage of 1:10 000 geological maps of the UK.

The study involved detailed field mapping at a scale of 1:10 000. This was supplemented by the collection and interpretation of geological data from a wide variety of sources. Boreholes provide much of the information; these comprise mineral exploration boreholes, either for coal or sand and gravel, and site investigation boreholes. The total number of boreholes in the district runs into many thousands; records of these are held by the National Geosciences Data Centre at BGS, Keyworth. Geological data also comes from many hundreds of mine plans, mostly for coal, but also for fireclay and Basal Permian Sand, held by British Coal and the Health and Safety Executive. In addition, information is held in the form of maps and notebooks, made by geologists during previous geological surveys in the 1870's and 1930's.

The results of the study are presented in the form of five geological maps, SE 22 NE, SE 32 NW, SE, and NE and SE 42 NW. Each map is accompanied by a report and a series of thematic maps which highlight and illustrate aspects of the geology. All of the maps are at a scale of 1:10 000. Table 1 lists the geological maps, applied maps and reports produced during this project. All the maps are reproduced by the dyeline process and the reports are held on open file. Copies may be obtained from BGS Sales Desks at Keyworth, Edinburgh and London.

Mapped results, of the type presented in this report and the contributory documents, can only help in the most general sense. They can contribute to drafting and evaluating structure and local plan policies. They can alert planners and developers by highlighting particular aspects of the geology of the district. But they cannot replace site-specific studies aimed at evaluating potential resources and hazards. Their object is to make the geological implications of planning and development clear to the non-geologist.

The district lies between the cities of Leeds and Wakefield and the town of Castleford (Figure 1). About half the district comprises the built-up areas of Castleford, Morley, Normanton, Oulton and Rothwell (Figure 2). The remainder is rural in character, being devoted largely to arable farming with some livestock rearing. The M1 and M62 motorways and the canals of the Aire and Calder Navigation, as well as several railway lines that converge on Leeds, cross the district. Widespread coal mining since the late eighteenth century has left its mark on the landscape in the form of extensive waste tips, reclaimed opencast sites and numerous shafts. Two coal mines are still active in the district, Allerton Bywater Colliery and New Sharlston Colliery.

The West Yorkshire Structure Plan designates the areas around Morley and Rothwell as 'areas of search for major residential developments'. However, the district has a long history of exploitation of its natural resources by mining and quarrying, and most of the district has been undermined from near the surface to depths of over 640 m. Subsidence related to deep mining, arbitrarily taken as greater than 30 m, is normally completed soon after the roof supports are withdrawn, but mine workings at shallow depth may stand open for decades or even longer before collapse. This project has delineated areas where shallow coal mining (Figure 3) and sand mining (Figure 4) are likely to have occurred. The identification of such areas should help in the safe and cost effective development and redevelopment of the district.

Mining is the principal cause of land instability in the district but unstable ground can also arise from other causes. The thickness and nature of the superficial deposits vary considerably across the district, and unconsolidated sediments in excess of 16 m thick are recorded in some parts of the Aire and Calder valleys. The floodplains of the valleys are commonly covered by clay and silt with interbedded peat; this last is variable in its compressibility and can be a hazard to construction.

Although the mineral resources of the area have been exploited for nearly 2000 years, considerable resources of sand and gravel, coal, building stone, brick clay and fireclay remain. The identification of these resources during this project should help safeguard them against inadvertent sterilisation.

Past mineral workings have had an adverse effect on the landscape. Large spoil tips are associated

Table 1. Maps and reports prepared during the project.

National Grid Quarter Sheet	Date of Geological Mapping	Author(s) of Report	Thematic Maps 1	2	3	4	5	6	7
SE 22 NE	1982	Burgess, I C	X		X		X	X	
SE 32 NW	1983	Williamson, I T. and Giles, J R A	X		X	X	X		
SE 32 NE	1984	Giles, J R A and Williamson, I T	X	X	X	X	X	X	
SE 32 SE	1985	Giles, J R A and Williamson, I T	X		X	X	X		
SE 42 NW	1986	Giles, J R A	X	X	X	X	X	X	X

The types of thematic maps available are:-

1. Distribution of Drift Deposits
2. Thickness of Drift Deposits
3. Distribution of Made Ground
4. Borehole Locations
5. Underground and Opencast Coal Mining
6. Sand and Gravel Resource Map
7. Underground Sand Mining

Table 2. Geological information relevant to Structure Plan policies.

Structure Plan Policy	Summary of Policy	Relevant Geological Information
H11	Morley and Rothwell to expand for residential purposes	Geological map; thematic maps showing distribution of sand and gravel, constructional materials, drift distribution and thickness, distribution of made ground and location of underground and opencast coal mining.
N1	Environmental improvement areas around Normanton and Castleford	Thematic map showing the extent and distribution of man-made ground
N26	Avoidance of damage from mining subsidence	Thematic maps showing the distribution of shallow coal and sand mining
N35	Where coal occurs in association with other minerals, both should be worked	Geological map and thematic maps showing distribution of sand and gravel and construction materials
N38	Proven mineral deposits will generally be protected	Geological map showing distribution of rocks and thematic maps showing distribution of sand and and constructional materials
N41	The effect of land-fill sites on ground- and mine-water	Geological map showing probable paths of pollution plumes

with the sites of former collieries. Many disused quarries are backfilled with the various man-made deposits, which make up made ground. They are generally variable in their chemical content and state of compaction. Documentation on their extent and nature is imprecise and incomplete. As part of this survey, made ground was recorded, mapped and classified into several categories. Some of the areas most adversely affected by dereliction due to old mineral workings and spoil tipping lie around the towns of Normanton and Castleford. These areas are identified in the Structure Plan as 'Environmental Improvement Priority areas'.

The implementation of many Structure Plan policies is made easier by a better understanding of the geology. Some examples are listed in Table 2.

LAND STABILITY AND SAFETY

The consequences of mining, principally for coal and sand, upon land stability are considered below. In addition, the problems associated with slope stability, poorly consolidated ground and the presence of buried channels are discussed.

Mining

The Carboniferous and Permian strata of West Yorkshire contain several economically valuable minerals, some of which have been quarried and a few of the most valuable have been mined. Mining has been mainly directed at coal but Basal Permian Sand and Coal Measures sandstones, ironstones and mudstone-seatearths have also been mined. The distribution of coal and sand mining is illustrated in Figure 3 and 4.

Coal Mining

Coal has been mined in West Yorkshire since Roman times. Mining appears to have ceased during the 'Dark Ages', as no mention is made of it in the Doomsday Book. By the thirteenth century, there is documentary evidence of a widespread, but very small-scale, coal industry. Initially, mining was restricted to 'bell pits'; this was succeeded in the fifteenth or sixteenth century by the 'pillar-and-stall' system. Longwall mining was developed in the late seventeenth century and is still the method employed today. It has become progressively more mechanised, particularly since the nationalisation of the industry. A list of the main collieries entrances forms Annex 1. Large-scale opencast mining is entirely a product of the twentieth century.

Each of these mining methods imposes constraints on the development and re-development of the affected areas. Table 3 lists the seams in the district in stratigraphical order and shows which have been mined and by what method.

In digging a bell pit or beehive pit, a shaft, usually about 1 m across was sunk through the overlying strata to the coal at a maximum depth of about 10 m. The coal was then worked all around the shaft until the unsupported roof became unsafe. Another pit was then sunk adjacent to the first and the process repeated. The excavated area of coal was roughly circular and 3 to 6 m across. Although crude, the system recovered a high percentage of the seam with careful management. Because of the depth limitation, only narrow strips close to the outcrop could be mined and the potential reserves available to the method were small.

Of the mining methods used in the present district bell pit mining affects the smallest area. Hardly any reliable plans of this type of working survive, but it seems that it was confined to only a few seams (Table 4) and more particularly is known from only a few areas. It cannot be safely assumed that ancient bell-pit workings have collapsed and are satisfactorily compacted. In many cases, bell pits were only partly backfilled and the present state of compaction is far from good. Taylor (1968) cited a case history involving the difficulty of detecting partially collapsed bell pits at Heath Estate, Leeds [SE 283 308].

During the fifteenth and sixteenth centuries, the pillar-and-stall method of mining was developed to gain access to deeper reserves of coal. The system involves driving two sets of roadways which mutually intersect at right angles. As the roadways run out from the shaft bottom or adit into the seam, unmined pillars are left to support the roof. An example of pillar-and-stall working in the Sharlston Muck Coal, exposed in the St Johns Opencast Coal Mine, is shown in Plate 1. As the depth increases, larger pillars are required to support the roof, and hence a smaller percentage of the coal is recovered. The method is self-limiting since, with increasing depth, the mine eventually becomes uneconomic. In West Yorkshire, the economic limit to the method seems to have been about 30 m, although ventilation, pumping and transport may also have set limits in some cases.

Table 3. Worked coals arranged in stratigraphical order with the style of working shown. The division between shallow and deep mining is taken at 30 m.

Seam	British Coal seam index	Style of working			
		opencast mining	shallow mining		deep long-wall mining
			bell pit	pillar-and-stall	
Shafton	BU			X	
Sharlston Top	BS	X	X	X	X
Sharlston Muck	BR	X	X	X	X
Sharlston Low	BQ	X	X	X	X
Sharlston Yard	BP	X		X	
Houghton Thin	BN	X		X	X
Wheatworth	BL	X		X	
Swinton Pottery	BK	X			
Newhill	BJ			X	
Meltonfield	BH	X	X	X	
Two Foot	BG				X
Abdy	BE				X
Stanley Main	BBD	X	X	X	X
Kent's Thin	BA	X			
Kent's Thick	AZ	X	X	X	X
Warren House	AWY	X	X	X	X
Low Barnsley	AV	X		X	X
Dunsil	AUX	X			
Beck Bottom Stone	AU	X		X	
27 Yard	AS	X			
Swallow Wood	AR	X			
Haigh Moor	APQ	X	X	X	X
Lidget	AN				X
Flockton Thick	AK	X	X	X	X
Flockton Thin	AJ	X		X	X
1st Brown Metal	AH	X	X		X
2nd Brown Metal	AG	X	X		X
3rd Brown Metal	AF	X	X		X
Middleton Little	AE	X			X
Middleton Main	ACD	X		X	X
Wheatley Lime	AB	X			
Middleton 11 Yard	AA	X		X	X
Blocking	Z				X
Top Beeston	UX	X		X	X
Low Beeston	T				X
Crow	N				X
Black Bed	M				X
Better Bed	K				X

Table 4. The location of known areas of bell-pit mining. Other unknown areas probably exist. The NGR cited is the approximate centre of the affected area.

Seam	Location	NGR
Sharlston Top	Warmfield Common	[378 207]
Sharlston Muck	Warmfield Common	[378 207]
Sharlston Muck	Goosehill	[371 219]
Sharlston Low	Warmfield Common	[378 207]
Sharlston Yard	Streethouse	[399 211]
Meltonfield	Ledston	[437 283]
Kent's Thick	Almshouse Wood	[380 271]
Warren House	Great Preston	[404 294]
Warren House	Lee Moor	[345 257]
Haigh Moor	Carlton	[339 266]
Haigh Moor	Carlton	[346 276]
Flockton Thick	Belle Isle	[318 296]
Flockton Thick	Rothwell Haigh	[335 296]
Flockton Thick	Dean Hall	[251 283]
1st Brown Metal	Middleton Wood	[302 290]
2nd Brown Metal	Middleton Wood	[302 290]
3rd Brown Metal	Middleton Wood	[302 290]
Middleton Little	Beeston Park Side	[296 292]
Middleton Main	Beeston Park Side	[296 292]
Middleton Main	Gilead House	[254 293]
Blocking	Hill Top Farm	[261 294]

Shallow pillar-and-stall workings cause serious foundation problems. Unlike deeper mine workings they did not collapse when mining ceased, since the earth pressures at such shallow depths were not sufficient. The roof supports become weaker with time, however, and loading by new construction can lead to sudden failure. Site investigations may be only of limited use in identifying this type of working as much of the coal is left undisturbed in pillars. If too few boreholes are drilled or if they are drilled on a regular grid they may only find the solid coal in pillars and miss the voids.

Piggott and Eynon (1978) noted three principal mechanisms of failure of shallow mine workings:-

i) collapse of roof beds spanning adjacent pillars

ii) pillar failure

iii) squeeze of floor or roof strata

Sudden collapse of the beds spanning the stalls is the major cause of ground instability problems in this district. The void propagates upwards under the combined influences of gravity and weathering, until the whole void becomes choke-filled with debris, or some highly competent bed is reached. If the void reaches the surface, it forms a crown hole. Piggott and Eynon (1978) showed empirically that the maximum height of collapse in British Coal measures is commonly up to 6 times the height of the mine void but may, exceptionally, exceed 10 times the height.

It is possible that the slow deterioration of pillars may take place after many years but generally pillar failure is rare in shallow coal working, provided that the original pillar geometry was sufficient to support the roof. Piggott and Eynon (1978) commented that the pillars left by ancient mining were usually much greater in cross-section than was required to support the over-lying strata. However, failure may occur where pillars are very small or have been robbed at a later date. Pillars may also collapse long after mining has ceased when piles place highly concentrated loads directly on to old pillars. It is essential to consider old shallow mine workings especially when developments have deep foundations or concentrated loadings.

Piggott and Eynon (1978) identified the squeeze of floor or roof strata as a major cause of failure of shallow coal workings. In such cases, the strength of the coal pillars is such that the earth pressures are transferred to the floor or roof strata and their bearing capacity becomes a critical factor. If the pillar is strong enough to carry the load, it will be 'punched' into the roof or floor measures, particularly where former workings are flooded or low strength seatearths underlie the coal.

The longwall mining method was developed during the late seventeenth century in Shropshire and is now the general method of mining in the UK. Two parallel headings, typically about 200 m apart, are driven from a main development road. Between these headings the coal is excavated. As the face is advanced the roof behind the working face is allowed to collapse.

Much has been published on subsidence induced by longwall mining. Generally the amount of subsidence is a function of depth, the width of the panel mined and the thickness of strata removed. Subsidence occurs rapidly after mining and is usually complete about a year after extraction, although a small amount of residual subsidence may occur over the next few years.

In the twentieth century, the development of mechanical earth-movers has made large-scale, opencast mining practical. The initial sites developed during the early 1940s were seldom excavated deeper than 20 m, but since then the economic limit to excavation has increased to more than 100 m. A list of the opencast sites within the district is given in Annex 2.

The sites of former opencast mining are subject to a period of settlement after backfilling. At the end of the settlement period, the site may be re-developed, but there may be special problems in building large structures or structures with high foundation loadings on such sites.

Natural movements along faults, can cause subsidence but such movements are extremely rare; most faults were caused by earth movements long ago. It is much more common for faults to be reactivated by mining subsidence, especially when coal extraction has been limited to one side of a fault. In these cases, all the movements due to coal extraction beneath is taken up on the fault plane. The effect of such subsidence on a building is shown in Plate 2. Such subsidence tends to be most intense when workings approach the fault from the upthrow side. These effects should be carefully considered when planning sites which straddle faults. Generally, the faults are not single fractures, but consist of a series of sub-parallel fractures forming a complex fault zone which may be tens of metres wide.

Faults may also juxtapose lithologies with differing geotechnical properties and differential compaction may occur under high loads. Also, rocks that have been faulted may be internally fractured and consequently weaker than where unaffected by faults.

Sand Mining

In parts of the present district, the Basal Permian Sand has been mined as foundry sand, glass sand and building sand at various times since at least the late seventeenth century. This mining was usually by means of adits driven into the deposit from outcrop, opening into pillar-and-stall mines at depth (Plate 3). Extensive mining continued into the present century at the largest mine known in the district, Wheldale Sand Mine [4490 2640], which is estimated to have some 32 km of tunnels extending for 700 m from the mine mouths. The mining of the deposit is thought to be restricted to within thirty metres of the surface. During two hundred years of sand mining numerous small mines may have exploited the deposit, but only a few plans of these survive. Plans of the larger workings such as the Wheldale and Ledston have been preserved. Evidence of the existence of mines outside the areas of known mining is furnished by site investigation boreholes and indirect archival references, but the extent of such workings is not accurately known.

The rate and method of collapse of old sand workings depends upon a number of factors, and settlement cannot be assumed to have ceased, even with the most ancient of workings. There is a history of subsidence associated with the abandoned workings in certain parts of the district probably caused by the collapse of the roof beds spanning the voids. For example, north of Pannel Hill, above the old Ledston Sand Mine, numerous circular depressions indicate where adjacent voids have collapsed.

Subsidence associated with shallow sand mines is controlled by the size and spacing of the pillars left during mining and the strength of the roof rock, which in turn is controlled by the joint-spacing and the thickness of the beds in the overlying Magnesian Limestone. In the Redhill area of Castleford collapse of the roof rock spanning mine voids is a more common failure mechanism than pillar collapse (Baldwin and

Newton 1987). These authors noted a series of hairline stress fractures along the edge of, and parallel to, roadways. These fractures, in some cases, been opened by solution but in general were tight and closed.

The ground water conditions are also an important factor. As the Lower Magnesian Limestone forms a pronounced escarpment, the Basal Permian Sand is normally above the water table over much of the district. In certain circumstances, locally perched water tables may develop which allow water to gather in old sand workings and weaken the pillars which support the roof. Any engineering operations which might create local perched water tables, such as the use of a grout curtain, should be carefully considered for their effects on the local ground water conditions.

Figure 4 shows the outcrop of the Basal Permian Sand and divides the area underlain by Permian deposits into:

1. those areas under which Basal Permian Sand is not likely to have been mined
2. those areas under which Basal Permian Sand has possibly been mined.

The boundaries between the two areas is taken 700 m from the crop of the Basal Permian Sand, since this is the extent of the largest local mine, Wheldale Sand Mine.

The 700 m cautionary zone is divided into three:

1. Proven sand mining: areas where mine plans exist to show the extent and style of the sand mining.
2. Suspected sand mining: areas where archival evidence suggests that mining was formerly carried out, but the documents do not indicate the extent or style of mining. Such records include, for example, boreholes that encounter voids in the Basal Permian Sand, old trade directories which give some indication of the activities of former mining companies and official returns from companies which indicate how many men they employed underground.
3. Possible sand mining: this category includes all other areas within the 700 m cautionary zone in which mining is not known or suspected. In the Red Hill area of Castleford, this zone terminates against a fault which throws down the Basal Permian Sand to depths below which mining is unlikely.

Other Mining

In addition to coal and sand, several other minerals have been mined locally on a small scale. These include Coal Measures sandstone, ironstone and fireclay. The last was used as a refractory clay. The methods used to mine these minerals were essentially those used to mine coal and, in many cases, they were mined in conjunction with coal. For example, ironstone was mined at shallow depth in Middleton Park Wood from bell pits whilst the Thornhill Rock was mined in Rothwell from adits. Fireclay was deep-mined in this district, probably by the longwall method, and also extracted at a number of opencast coal mines.

Shafts and Adits

The location and treatment of disused shafts and adits clearly affects the safety of a proposed development. There are the following specific hazards:

i) A fall into an old shaft almost always causes injury or in many cases death. Death can also be caused by drowning in flooded workings, suffocation by carbon dioxide or poisoning by toxic gas.

ii) The surface near a shaft may subside or collapse. If the shaft lining has deteriorated, the collapse may not be confined to the diameter of the shaft but may spread to form a crater. The diameter of the crater is a function of the depth to competent strata and the angle of repose of the incompetent strata that collapses. Collapses may also occur beneath competent strata in a shaft; these may not immediately affect the surface but the collapse may reduce the load-bearing capacity of the ground around the shaft.

    Old mine shafts may collapse because of changes in ground water levels, additional surface loadings due to new structures or tipping, vibration from traffic, mining subsidence or blasting. The collapse of one shaft may cause nearby shafts, linked by underground workings, to become unstable.

iii) Various gases may be found in unventilated old workings. These include carbon dioxide and nitrogen, which may comprise an oxygen-deficient atmosphere and cause asphyxiation, methane, which is explosive in mixtures with air of between 5% and 15%, and finally carbon monoxide and hydrogen sulphide, which are poisonous.

Old shafts provide artificial channels allowing water to pass from one aquifer to another. If one aquifer becomes polluted, a shaft can act as a path for spreading the pollution to other aquifers.

Slope stability

Slope movements, either as landslips or cambering, can cause foundation problems. Landslips are rare in the district as the majority of natural slopes are well below their maximum angle of repose and will probably remain stable unless they are artificially oversteepened. Landslips are only known at the following localities:

1. an area of made ground [3148 2593] near Ardsley East
2. an area of colliery waste [3580 2969] near the former Rothwell Colliery
3. at the base of the Magnesian Limestone escarpment near Castleford [4446 2628]
4. in Coal Measures mudstone at Gled Hill [3634 2050]

On the north side of the River Aire, between Kippax and Castleford, an unusually thick deposit of head (page 37) is present at the base of the Magnesian Limestone escarpment. It consists of several metres of poorly sorted silts and clays with sand and some gravel. If the toe of the deposit is excavated, for example in a road cutting, and drainage of the sediment were seriously impeded, the deposit may become mobile and move downslope.

Cambering is found on the sides of valleys where competent beds such as sandstone or limestone are interbedded with, or overlie, incompetent beds such as mudstone. The incompetent beds flow outwards causing the competent beds to warp down the valley side. This occurs along the Magnesian Limestone escarpment east of Ledston where there are open joints aligned parallel to the edge of the escarpment. Cambering is also found north of Elm Farm where thin sandstones in a thick sequence of mudstone are cambered at outcrop.

Poorly consolidated ground

Drift deposits may show marked lateral variation in their lithology and thickness and also in their compaction properties under loading. For example, in the alluvial sediments of the Aire and Calder valleys, buried lenses of peat and organic silt are commonly found within sand and gravel. The contrast in compressiblity of the adjacent sediments is very marked. Where structures are proposed on drift deposits, site investigations should assess the bearing capacity of the ground, particularly at points where highly concentrated foundation loads may occur.

Head covers much of the area mapped as exposed solid strata. It is normally thin but may thicken markedly where it fills rockhead depressions. It is mapped only where it is particularly thick. Relict shear planes in the deposit can make it much weaker than weathered in situ material and site investigations should test for these.

Made ground covers a considerable part of the area. The deposits are variable in their composition, chemistry, compressibility and thickness, and detailed site investigations are necessary where development is proposed on them. Seven categories are distinguished on Figure 5.

i) Landscaped Ground comprises areas of recreation, recent housing development, schools and industrial estates where the original ground surface has been modified by earth-moving operations. Such areas may have a patchy cover of made ground, generally less than 1.5m, and it is virtually impossible to determine the accurate distribution of such deposits without a comprehensive investigation.

ii) Made Ground, Undifferentiated includes major road and railway embankments, stockpiles of coal or sand and gravel, and other general constructional areas. Within any development area such deposits can be widespread. Detailed site investigations may be needed to determine the extent of such deposits, since it is not always practical to delineate them accurately by mapping.

iii) Back-filled Quarries are former excavations for sandstone, clay, limestone and sand and gravel subsequently filled in. Commonly, there are no clear surface indications of their extent or, in a few cases, of their presence. In most instances, archival material is available but in general, there is no information on the nature or state of compaction of the fill material. Many unlocated back-filled quarries are probably present, particularly beneath extensive areas of made ground.

iv) Back-filled Opencast Coal Sites, landscaped and restored, are numerous in the area (Figure 6). They are accurately recorded on abandonment plans.

v) Colliery Waste Tips are conspicuous features of the district. They consist mainly of inert material but there may be a considerable proportion of coal and pyritous sediments. The latter can be hazardous during oxidation, since this reaction is strongly exothermic. Unless the tips are carefully constructed to allow the heat to dissipate, they can ignite spontaneously and give off toxic gases. Modern tips are generally built with this hazard in mind. Some of the larger tips have been landscaped and redeveloped; Whitwood Golf Course near Castleford is a good example. The material may be locally unstable, and small areas of landslipping on coal tips have been noted.

vi) General Refuse Tips comprising domestic and industrial refuse contain a wide admixture of materials which may, upon burial, produce problems of instability and emit methane gas. Archival data have proved inadequate in delimiting all the waste tips and it is inevitable that some have not been located.

vii) Active Opencast Coal Workings and Waste Tips: The St Aidans Extension Opencast Site is working at the time of publication, and mounds of discard and spoil surrounding the site contain all the lithologies in the sequence down to the Dunsil Seam. Some alluvial deposits may also be incorporated into the tips. By the nature of opencast operations, some of these tips may be temporary, whereas others may become more permanent features of the landscape.

Buried channels

The drift deposits obscure the rockhead surface and boreholes across the district show that channels and depressions in rockhead may be completely masked. For example, an old river channel to the north of Methley contains more than 16 m of fluvial sediments. Closely spaced boreholes show that the channel is asymmetrical, having a very steep northern side. Such thick deposits may influence the design of foundations.

The buried channels are not confined to the present river valleys. For example, a channel filled with glacial sediments crosses the interfluve between the Aire and Calder valleys south of Oulton. This steep-sided depression was originally a drainage channel formed during a past glaciation, but is now entirely filled with till. Other channels may occur beneath glacial sediments in other parts of the district.

MINERAL AND WATER RESOURCES

Mineral resources

Much of the past and present wealth of the district has been derived from the underlying rocks which represent a substantial natural asset and, if carefully exploited, can continue to provide wealth in the future. The economic products which have been exploited in the past or are being currently extracted, are described below. In addition, a brief note on the hydrocarbon potential is included.

Coal

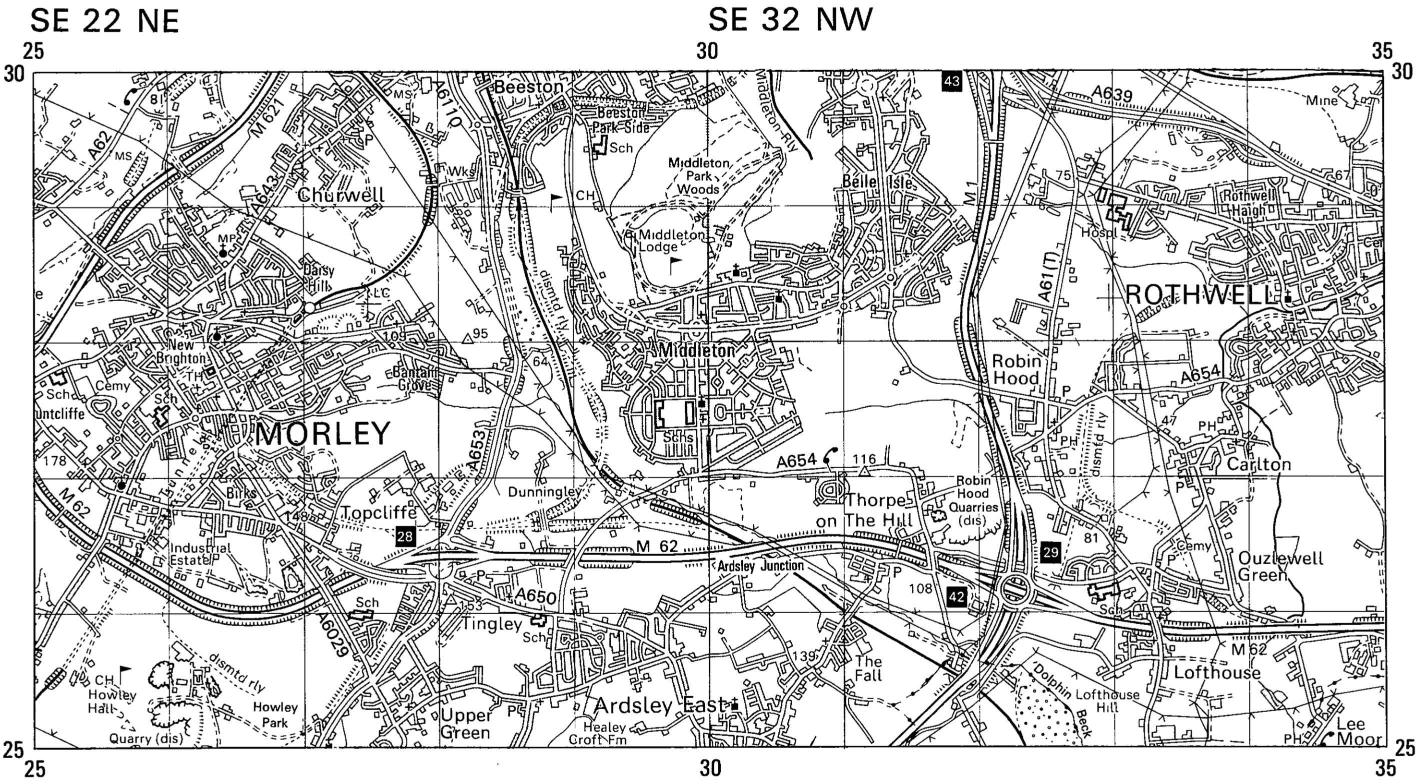
The production of coal continues in the district at two deep mines, Allerton Bywater and New Sharlston. The larger of these is Allerton Bywater Colliery which has substantial reserves of coal. Active opencast mining occurs at two sites, St Aidans Extension and St Johns.

Almost the entire district has been mined underground at some stage in the search for coal. Pillars of coal have been left beneath some localities sensitive to subsidence such as settlements, canals, rivers and shafts. Numerous shafts, backfilled opencast coal sites, shallow mines, deep mines and several large waste tips are a legacy of the exploitation of coal.

Opencast mining has been very extensive in the past. At its beginnings in the 1940's, many seams were worked close to crop beneath thin overburden. Progressive improvements in the methods and scale of excavations now allow working of deeper seams, beneath considerable thicknesses of overburden. Active opencast prospecting continues in the district, with the possibility of further extraction.

Minestone

Extensive areas of colliery spoil lie around the sites of active and former collieries. Some of this spoil is now sold as 'minestone', which can be processed to meet the specifications for a wide variety of uses including the construction of embankments, river and sea defences, land reclamation and brick making.



Fireclay and Pottery Clay

Fireclay is widely used as a refractory material. Some of the mudstone-seatearths lying beneath coals have been exploited as a fireclay. In particular, the seatearth of the Better Bed was formerly worked over a wide area to the south-east of Leeds. The Better Bed Fireclay was mined at Middleton Broom Colliery, where a variety of terra cotta and ceramics were made in the pottery that adjoined the colliery (Edwards and others 1940). The mudstone-seatearth of the Stanley Main was worked at the Dungeon Lane II opencast site. The seatearth of the Swinton Pottery Coal has been widely used as a refractory material as well as a pottery clay. Former quarries in this bed are found to the west of Castleford and active quarries are in production around Normanton.

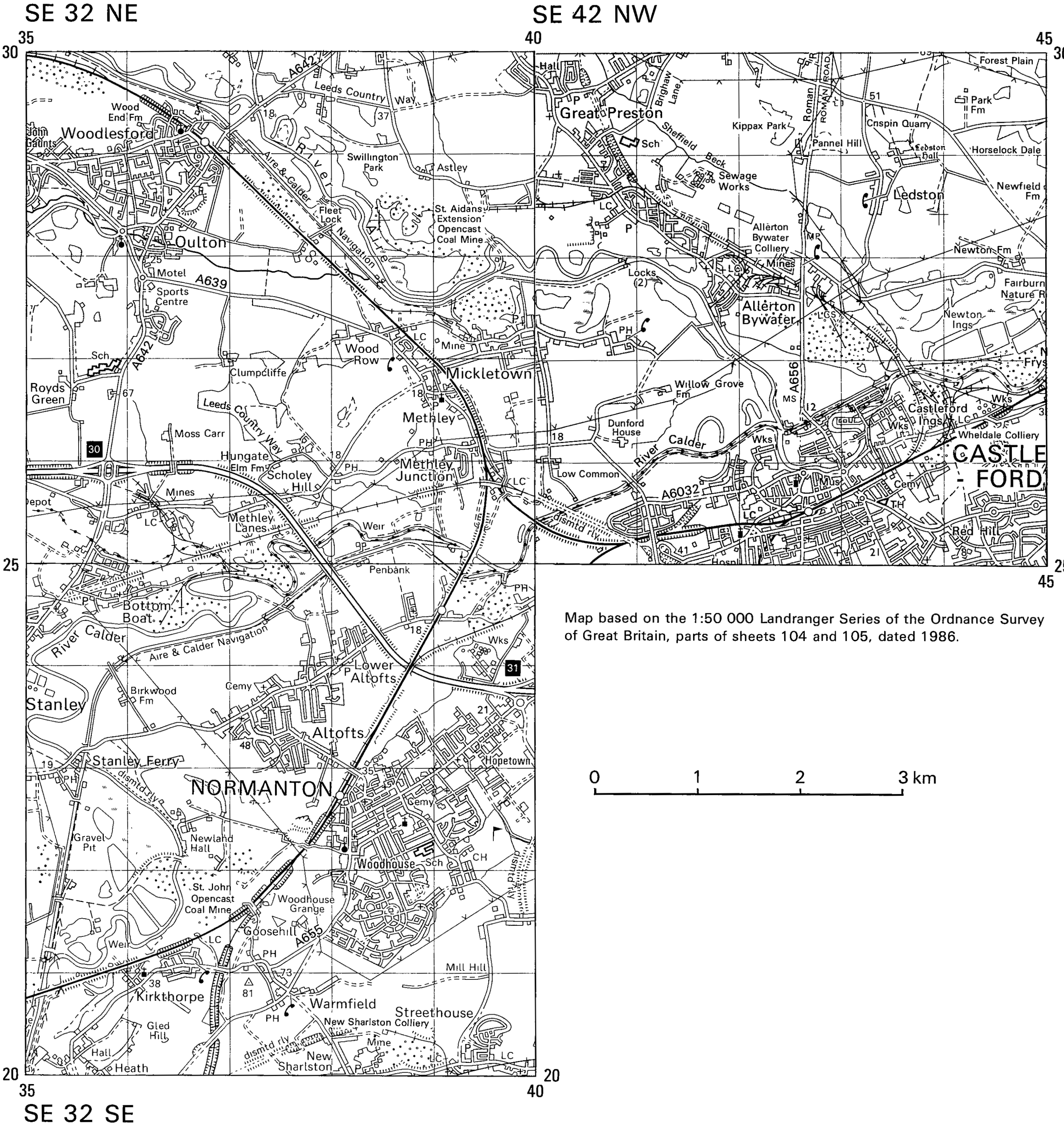
Ironstone

Sideritic ironstones are found above a number of coal seams, and at one time were widely exploited locally but ironstones of this type are too thin and impersistent, and contain too little iron, to be economic ores at the present day. Of particular importance were the ironstones associated with the Black Bed, Middleton Main, Middleton Little and Flockton Thick coals. The mudstones above the Black Bed were worked around Churwell and Beeston for the ironstone nodules they contained. Shallow pits in Middleton Park Wood were reputedly dug for ironstone at about the horizon of the Middleton Little. Some working took place at West Ardsley in the Shelly Ironstone, just above the Flockton Thick.

Mudstone and Claystone

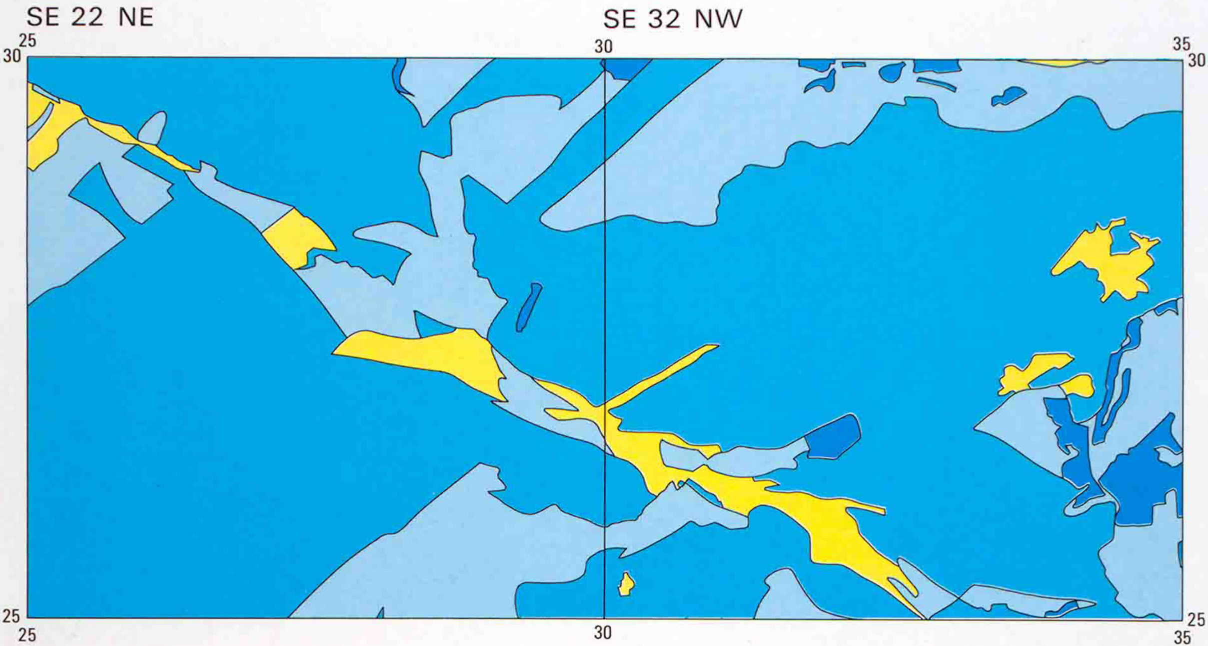
Almost all the mudstones and claystones in the Coal Measures can be used for brick-making and the numerous, small, disused brickworks across the district testify to their widespread use in the past. However, modern constructional requirements for strong bricks of consistent chemical composition have tended to concentrate brick-making into large pits.

Active brick pits are confined to areas around Howley Park, quarrying the upper shaly facies of the Thornhill Rock, and to areas to the the west of Normanton, working the measures above and below the Swinton Pottery Coal. Former brick pits around Castleford also used these measures.



Map based on the 1:50 000 Landranger Series of the Ordnance Survey of Great Britain, parts of sheets 104 and 105, dated 1986.

Figure 2. Locality map of the district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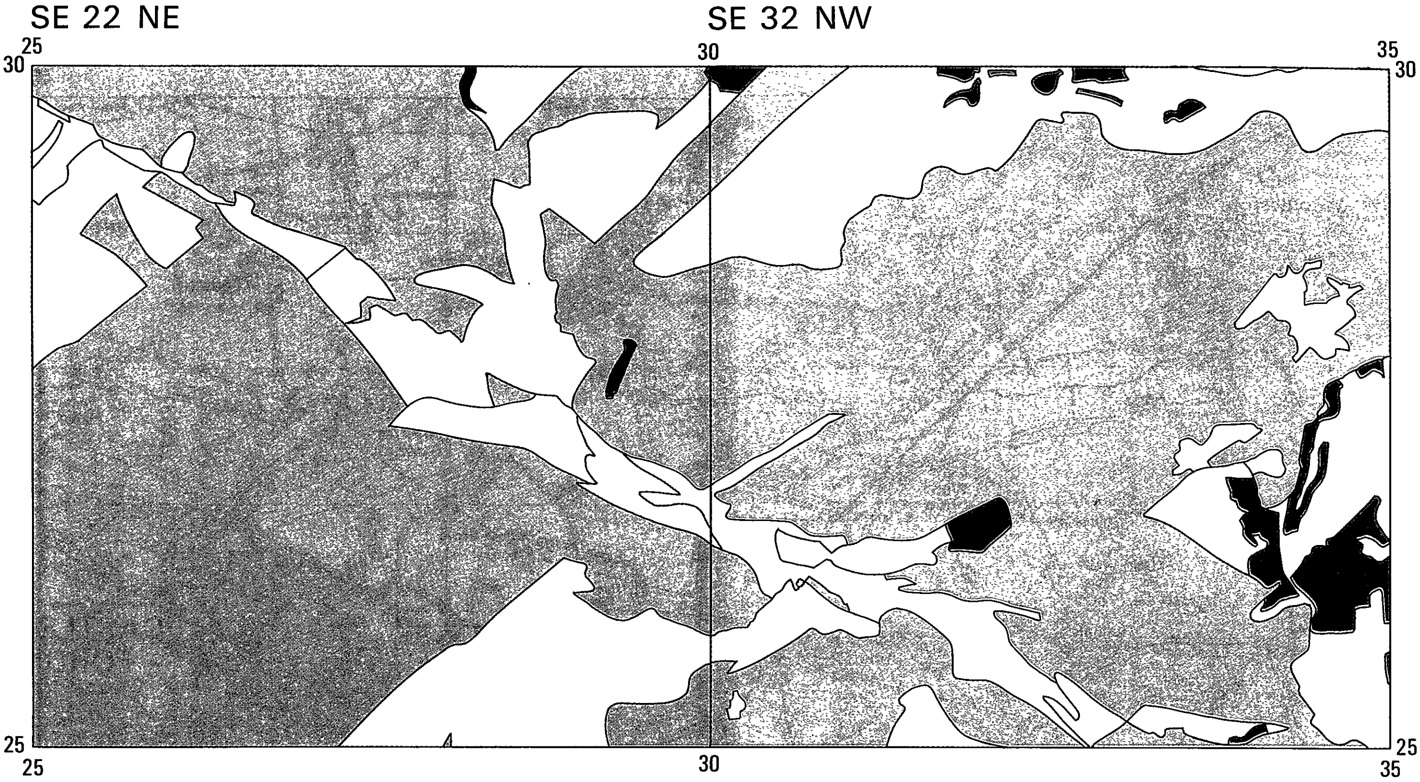


Sandstone

Most of the substantial sandstones in the Coal Measures have been worked for local use as building stone in the past. The most widely exploited is the Thornhill Rock which was extensively quarried, and even locally mined, around Morley, Rothwell and Oulton. It is still quarried south of Morley today.

Basal Permian Sand

The sand was widely exploited in the past for use as a moulding sand for casting iron, as a raw material for glass making and as a building sand. It was either quarried, in conjunction with the overlying Lower Magnesian Limestone, or mined by adits from the surface. The mining commenced before there was a statutory requirement to record the nature and extent of underground workings, so there are only mine plans for the more recent mines, such as Wheldale [4491 2640] and Ledston [4294 2949]. The sand is no longer used as its quality is to low for most modern industrial processes.

Limestone

The Lower Magnesian Limestone is largely confined to the east of the district and its thickness has been proved in only three boreholes. No commercial resource survey has been carried out, and no data are available concerning changes in thickness or variations in the mechanical and physical properties of the rock.

With the limited data available, it is not practical to attempt even an indicative assessment of the resource (Bureau of Mines and Geological Survey, 1980).

The limestone has been used for two main purposes: firstly, for agricultural lime, particularly on the outliers of limestone at Pannel Hill and at Great Preston, and secondly, as a local building stone. There are many disused quarries around Ledston but none are currently working. Extensive modern quarries are operating to the east and north of the district.

Gypsum

A gypsum bed within the Permian Middle Marl was formerly quarried at Park Farm, probably for local use.

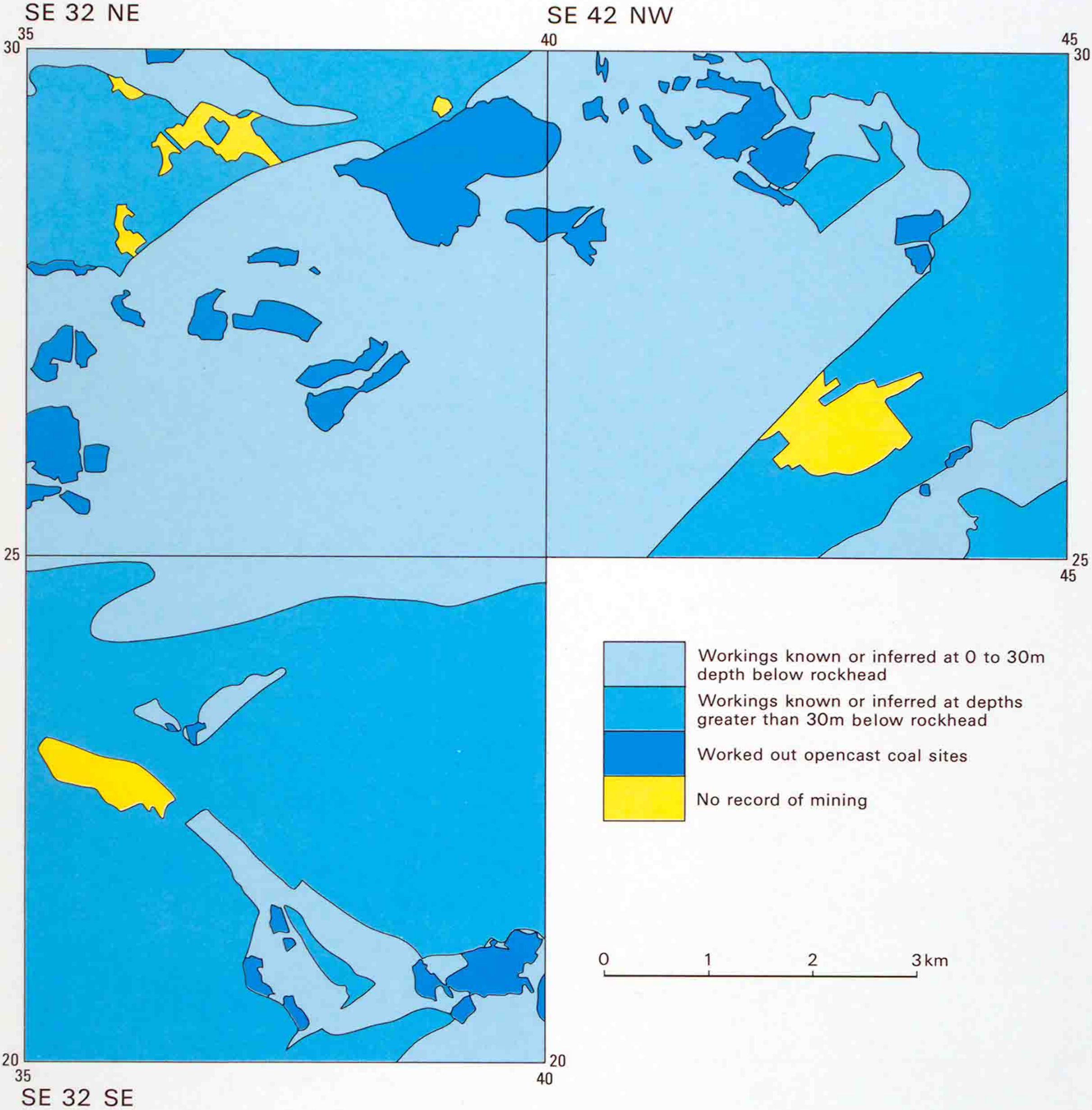


Figure 3. Distribution of coal mining

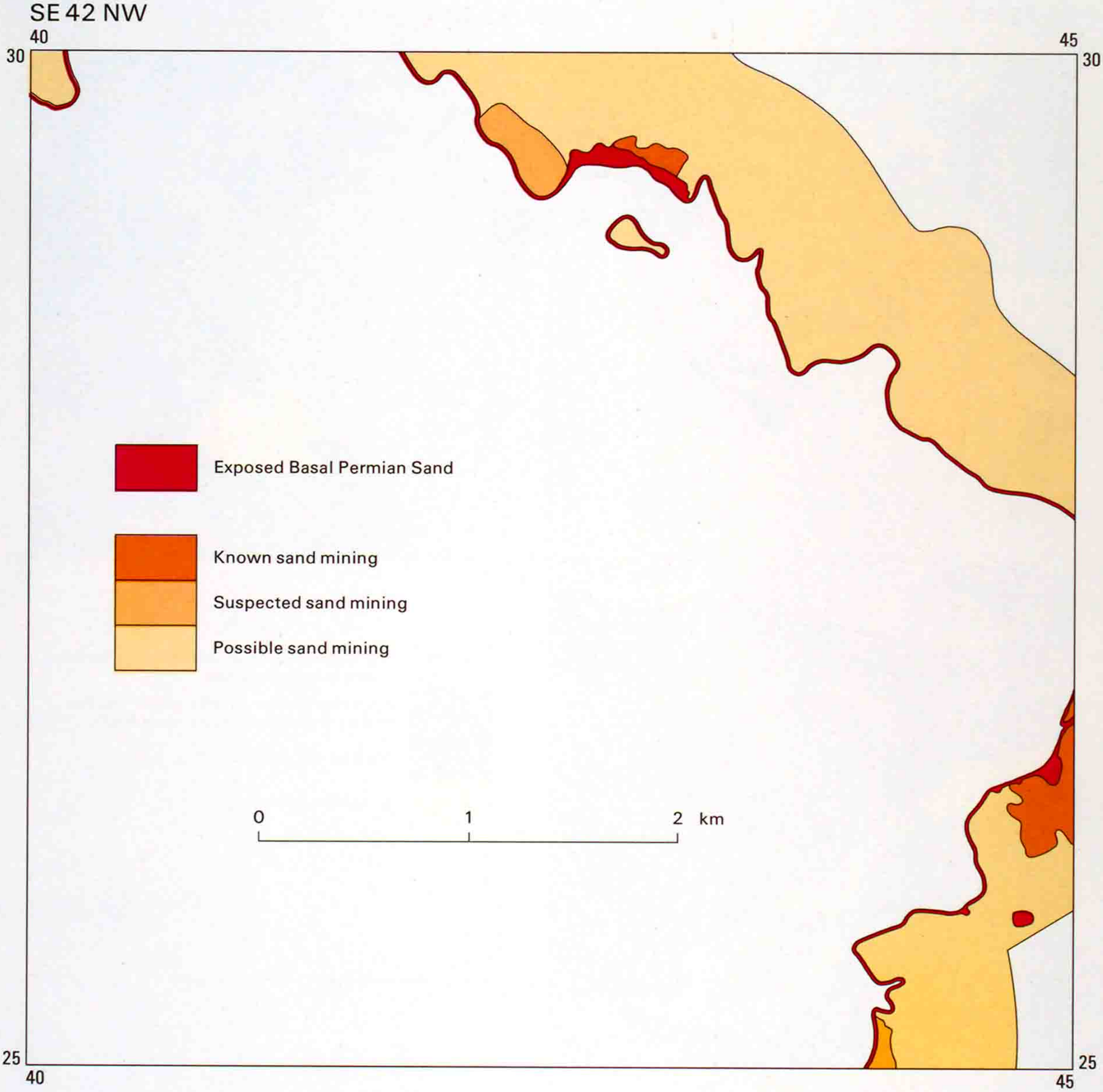
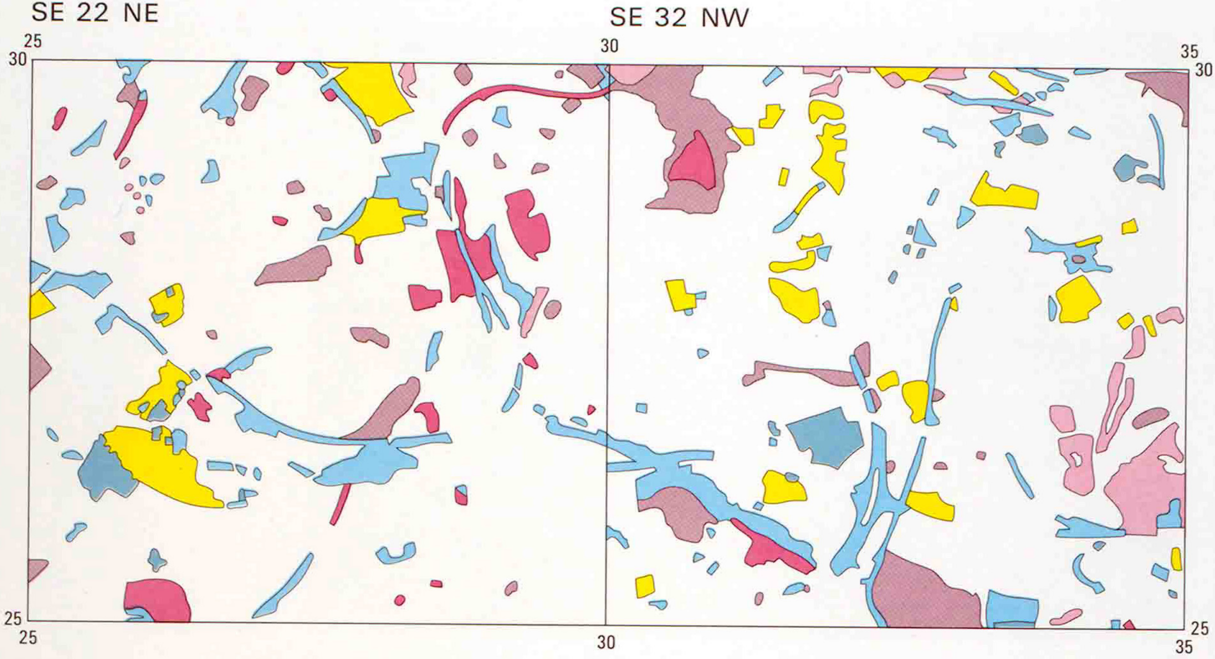


Figure 4. Distribution of sand mining

Plate 1 Pillar-and-stall working in the Sharlston Muck Coal, exposed in St Johns Opencast Coal Mine

Plate 2 The effect of subsidence on a building caused by mine-induced reactivation of a fault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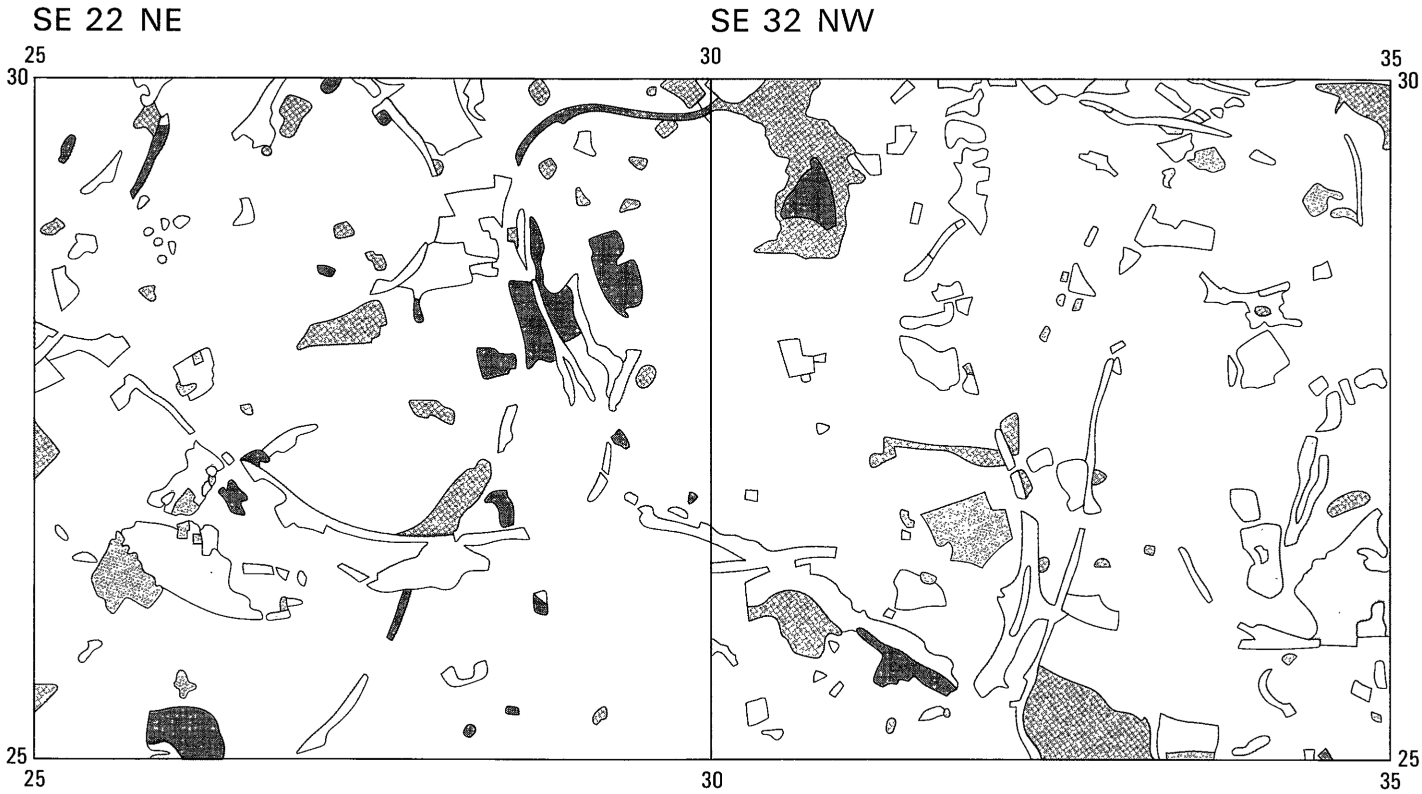


Hydrocarbons

Speculative structure contour maps of the district, based on shafts, boreholes and mine-plan data, indicate several upfolds or anticlines of the kind which may serve as traps for oil or gas. Seismic surveys have recently been conducted to investigate these structures in detail and to identify further potential hydrocarbon traps at depth. To date, no hydrocarbon prospecting boreholes have been drilled, but to the east, early Westphalian and Namurian sandstones are known to be hydrocarbon reservoir rocks.

Sand and Gravel

Extensive sand and gravel resources are present in parts of the district and were assessed as part of the present project (Annex 3). The potentially workable sand and gravel is mainly confined to fluvial deposits in the major river valleys. Small amounts of sand and gravel of glacial origin are also present.

Extensive quarrying of the resource has already occurred, particularly in the Calder Valley to the east of Wakefield and continues at Dunford House near Castleford.

A substantial resource of sand and gravel remains, estimated at about 86 million cubic metres.

Water resources

The principal aquifers of the Coal Measures are the main sandstones such as the Thornhill Rock or Oaks Rock. They are normally fine-grained, and intergranular permeabilities are low, but movement of water is possible along joints, bedding planes and faults. The mudstones have very low permeabilites and act as aquicludes.

The quality of groundwater in Coal Measures sandstones varies considerably, and down-dip variation is often detectible. At outcrop it is typically hard; down-gradient the sulphate content usually increases and the water becomes excessively hard, eventually grading into brackish or even saline water. The total dissolved solids content imposes restrictions on the use of groundwater for public supply, but sodium, chloride, sulphate and iron concentrations may also be unacceptable. Infiltration is restricted to small surface outcrop areas and groundwater storage is limited by lateral changes in the thickness of sandstones and faulting. Consequently good yields may not be sustained for long.

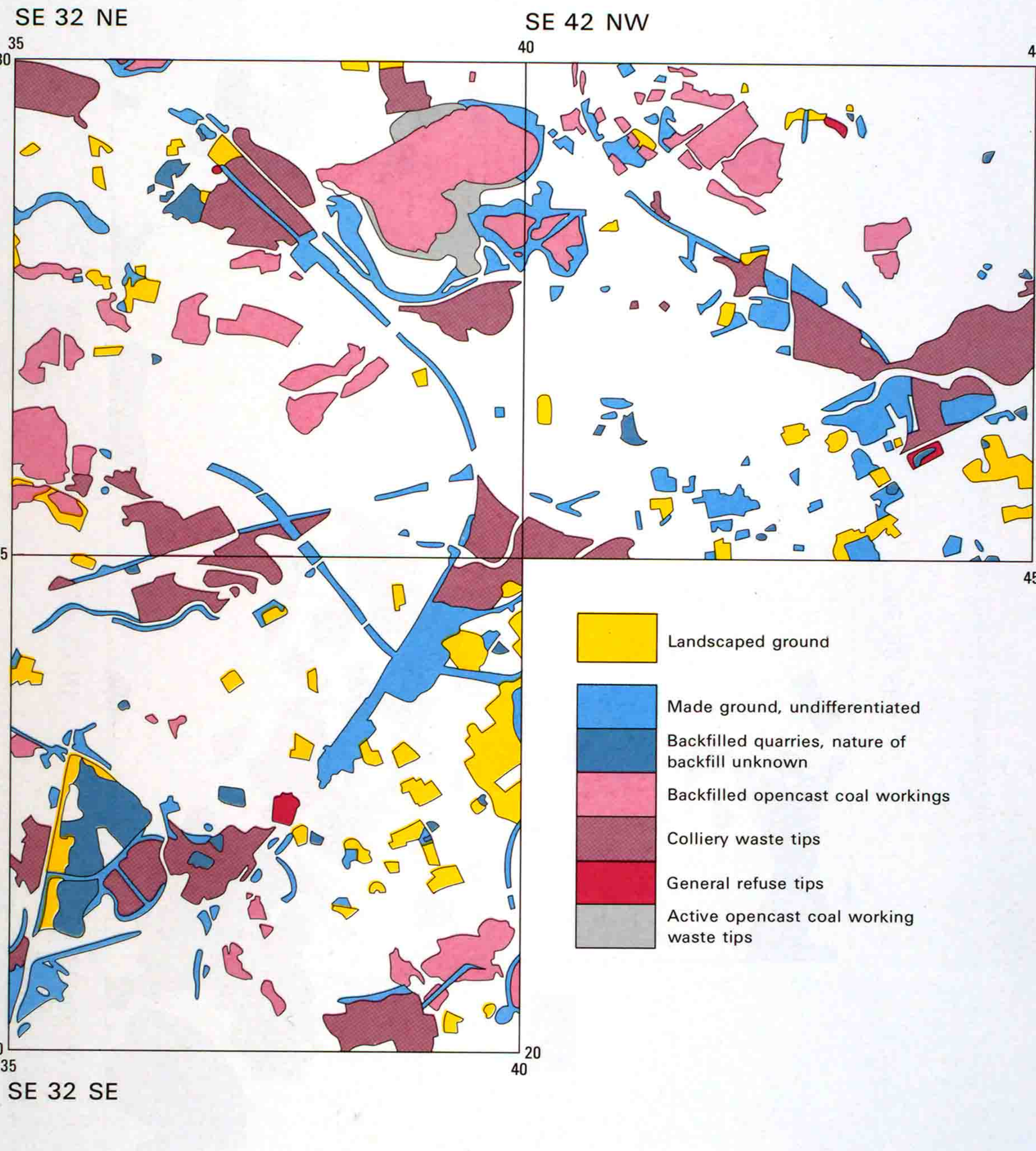


Figure 5. Distribution of made ground

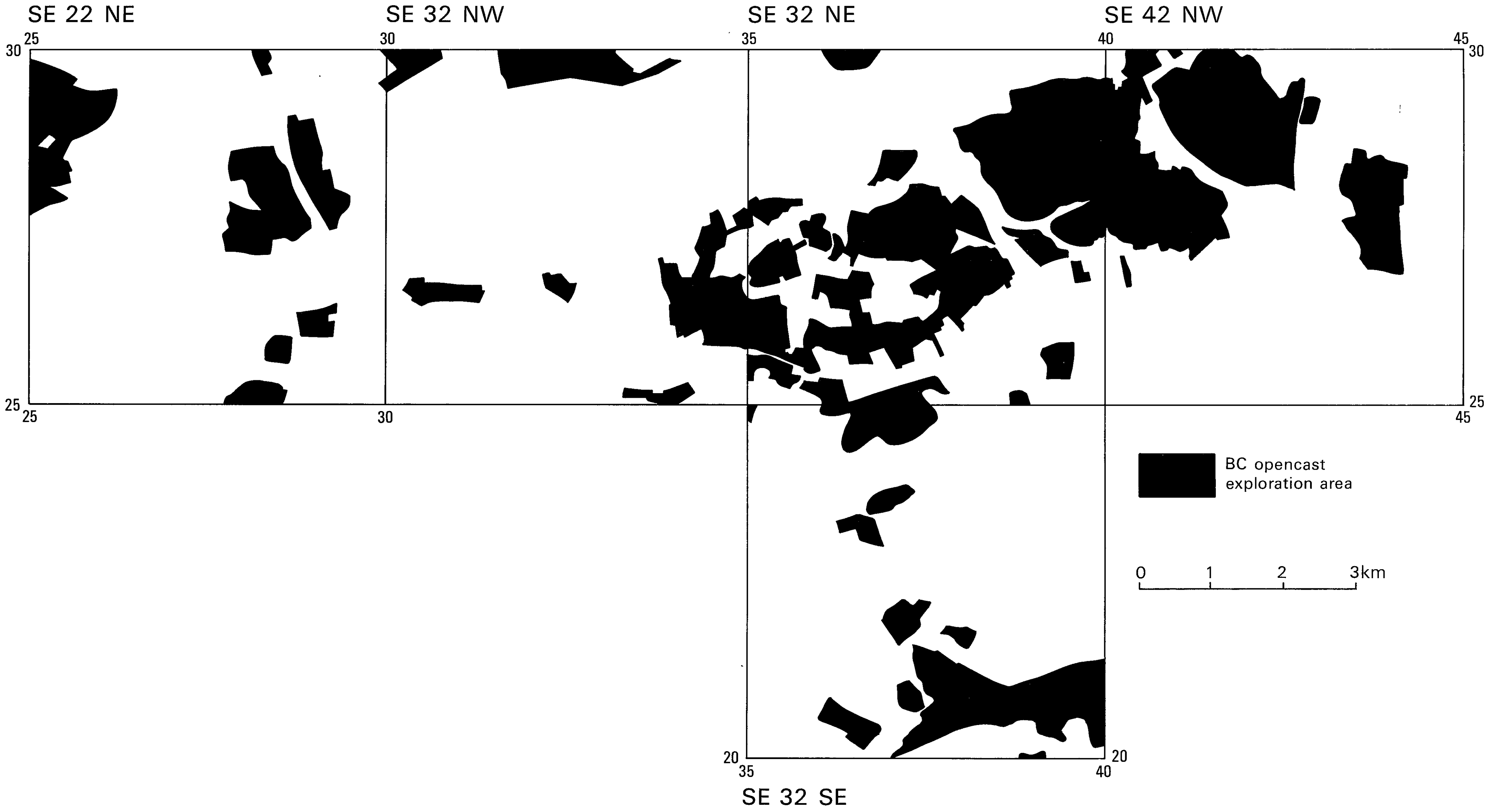
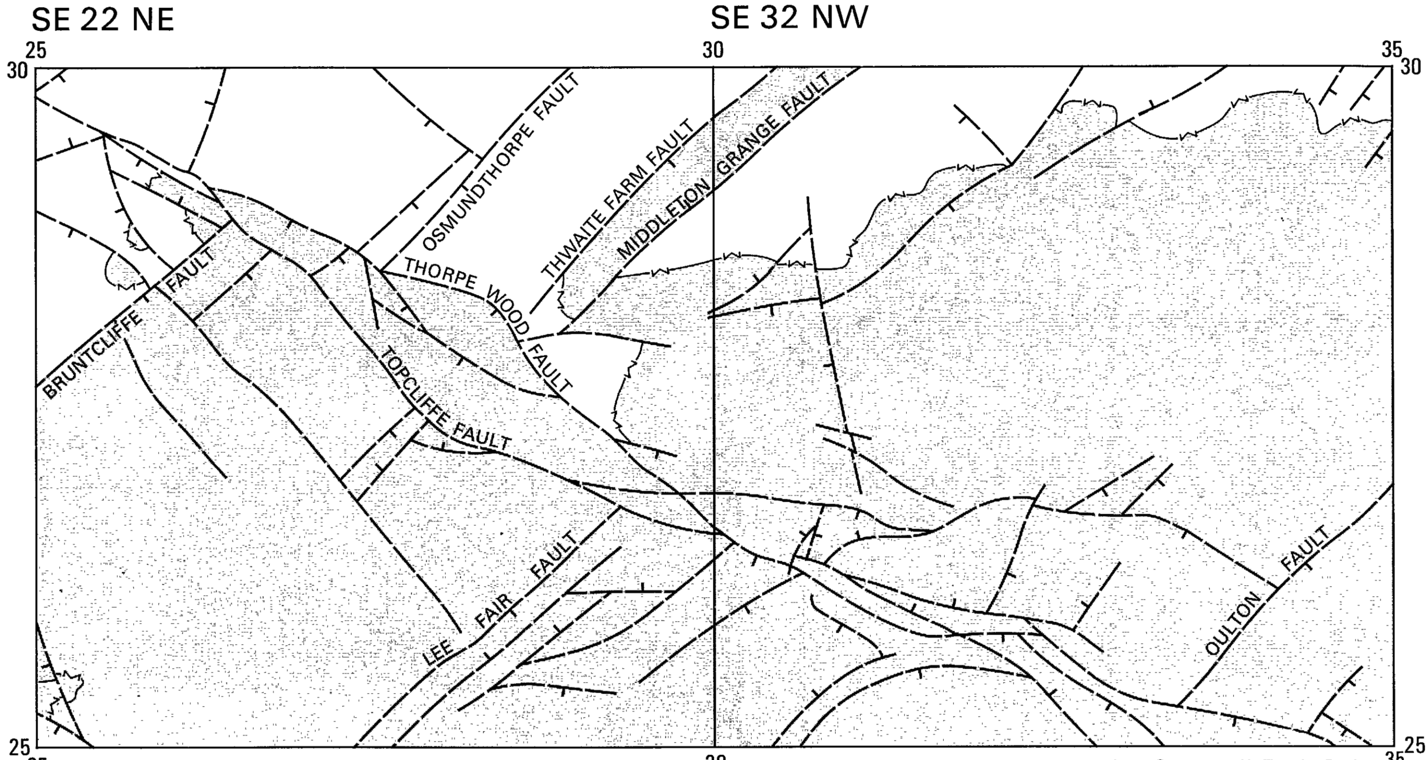


Figure 6. Distribution of BC Opencast exploration areas

Plate 3 Pillar-and-stall mine in Basal Permian Sand (courtesy of John Hodgkins)

Plate 4 Sharlston Group of Coals exposed in Goose Hill Railway Cutting. Figure is standing in shaft of old bell-pit



Morley-Campsall Fault Belt

Large volumes of water are abstracted in mine drainage but are not generally used.

The Lower Magnesian Limestone has a high secondary permeability and groundwater moves mainly through fissures, although there may also be intergranular storage and movement within the dolomites. The water is naturally hard and deteriorates where the limestone is overlain by the Middle Marls; the gypsum in the Marls greatly increases the sulphate content.

Water from the alluvium and terrace deposits of the Aire and Calder is occasionally utilised where it is partly derived from induced recharge from the rivers. The quality of the water varies considerably and is prone to pollution. On the floodplain, there is generally a layer of silt, clay and peat, about 3.5 m thick, which has a low permeability and restricts groundwater recharge by rainwater.

Generally, licensed abstractions of groundwater tend to be for industrial use rather than public supply.

GEOLOGY

Rocks of the Carboniferous Coal Measures and Permian rocks crop out in the district. They are overlain in part by superficial deposits of Quaternary age.

Coal measures

The geology of the district is illustrated in Figures 7 and 8 and the geological sequence is summarised in Figure 9. The Westphalian stages A, B and C have been identified within the Coal Measures sequence, the base of each stage being a specific marine band (Stubblefield and Trotter, 1957). The beds are mainly gently dipping and slightly folded, with steeper dips common near faults. To a large extent the solid rocks are obscured by a mantle of soil, superficial deposits, including head and fluvial sediments, made ground and waste tips. The few exposures of the Coal Measures which remain are largely confined to disused quarries and other artificial sections.

Details of coal sections were given by Green and others (1878) and Edwards and others (1940) and are not repeated in this report. Throughout, the term 'seam' means the combined thickness of coal and dirt partings, whereas 'leaf' refers to coal between dirt partings.

Lithology

The sediments were deposited in a range of deltaic, fluvial and lacustrine environments subject to sporadic marine incursions. A number of facies can be grouped into associations, which are interpreted as representing the main

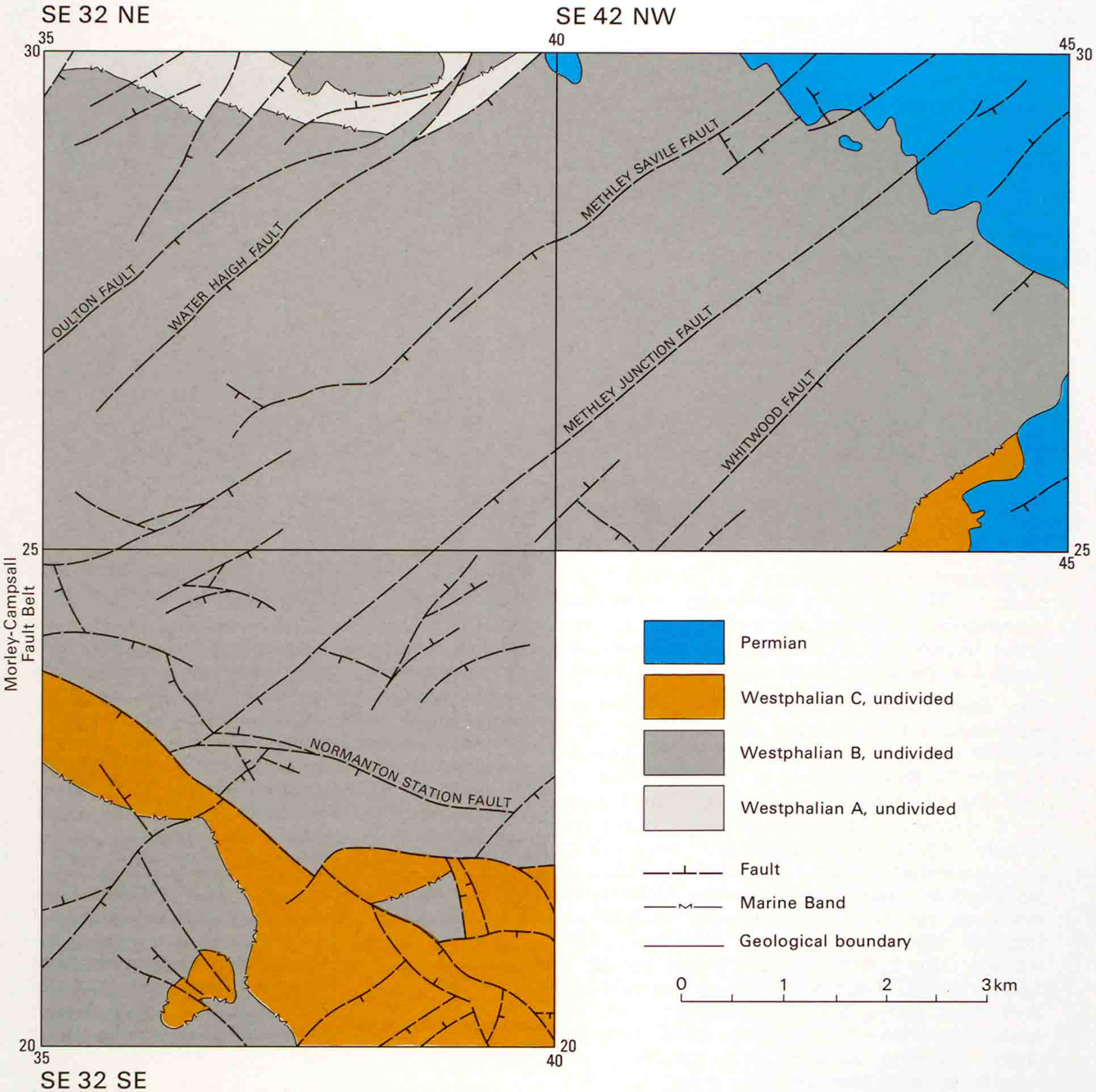
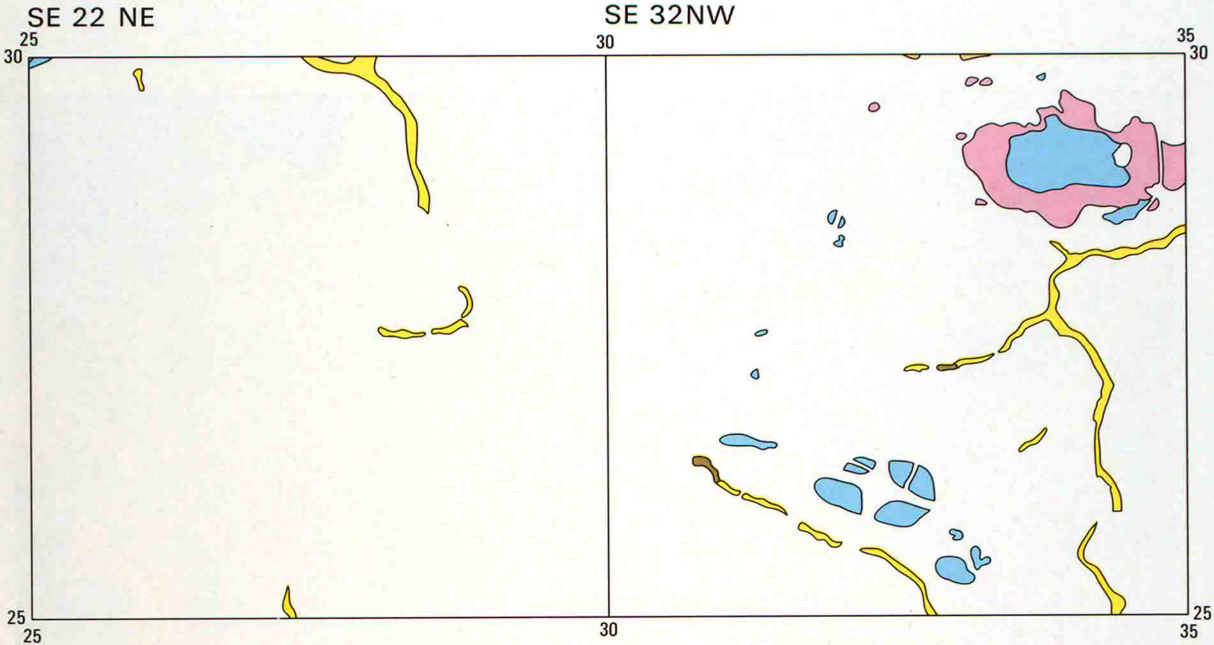


Figure 7. Simplified map of solid geology



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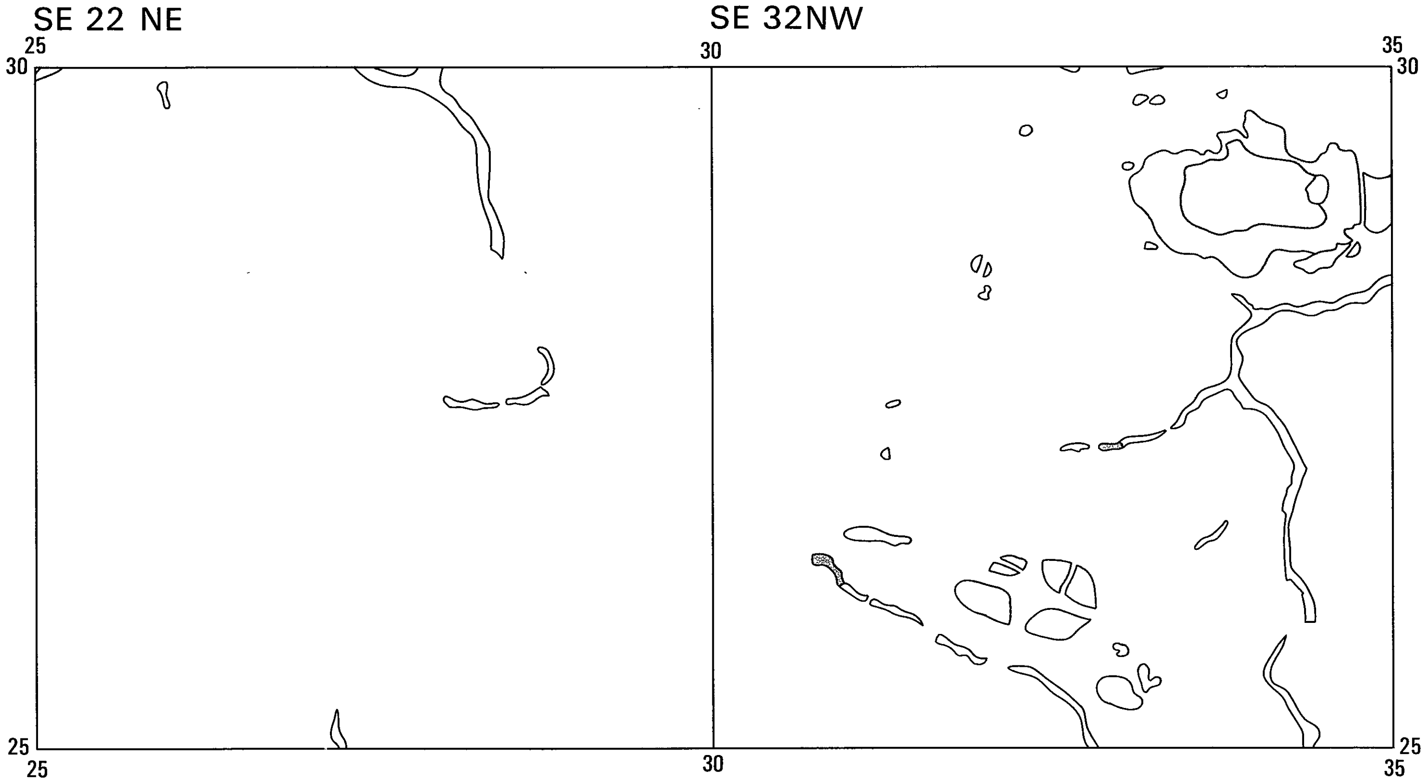

depositional environments of a subaerial delta plain. These are distributary channels, interdistributary lakes, peat swamps and crevasse splays (Figure 10). In addition, marine incursions resulted in shallow prodelta marine environments.

The most common rock types are claystones, mudstones, silty mudstones and siltstones. They weather rapidly on exposure, even when covered by drift. This is due to the oxidation of fine-grained, disseminated pyrite contained in the rocks (Taylor 1988). Sedimentary structures include ripple cross-lamination, wave ripple cross-lamination and lenticular bedding; bioturbation and soft-sediment deformation structures are common. Ironstone nodules are found in association with these lithologies. They are generally barren of body fossils except in discrete bands. The terms claystone and mudstone have been taken to be synonymous with old mining terms such as bind, drub, blaes, metal and shale. Likewise, siltstone is synonymous with stone bind, fakey blaes and slaty stone.

The sandstones are normally fine-grained and are grey where fresh. However, weathering causes oxidation of the contained iron turning the sandstones brown. Coarser grained lenses of intraformational breccias of angular mudstone and ironstone clasts, are channel-lag deposits and occur in the thicker sandstones. The sandstones range up to many metres in thickness. They include named sandstones such as the Thornhill Rock and Oaks Rock. The bedding varies from massive to flaggy. Sedimentary structures include flat laminations, ripple cross-lamination, trough cross-bedding, flaser and lenticular bedding. Bioturbation and soft-sediment deformation structures are also common. Plant remains are the dominant fossil, occuring mainly in comminuted plant debris on the bedding surface of the more micaceous sandstones. The old mining terms cank, freestone, galliard, post, rag and stone appear to be synonymous with sandstone.

The seatearths include all grades of sediment from claystone to sandstone, but are generally unbedded mudstones containing rootlets. They normally lie directly beneath coals, but some are laterally more extensive than the associated seam. The equivalent old mining terms are clunch, earth, fireclay, ganister, spavin, stone clunch and stone spavin.

Coal is formally defined as a readily combustible rock containing more than 50 percent by weight, and more than 70 percent by volume, of carbonaceous material. The main coals are laterally extensive, although their thickness and composition changes. The coals of the district are bituminous, and generally increase in rank southwards (Wandlass, 1960).

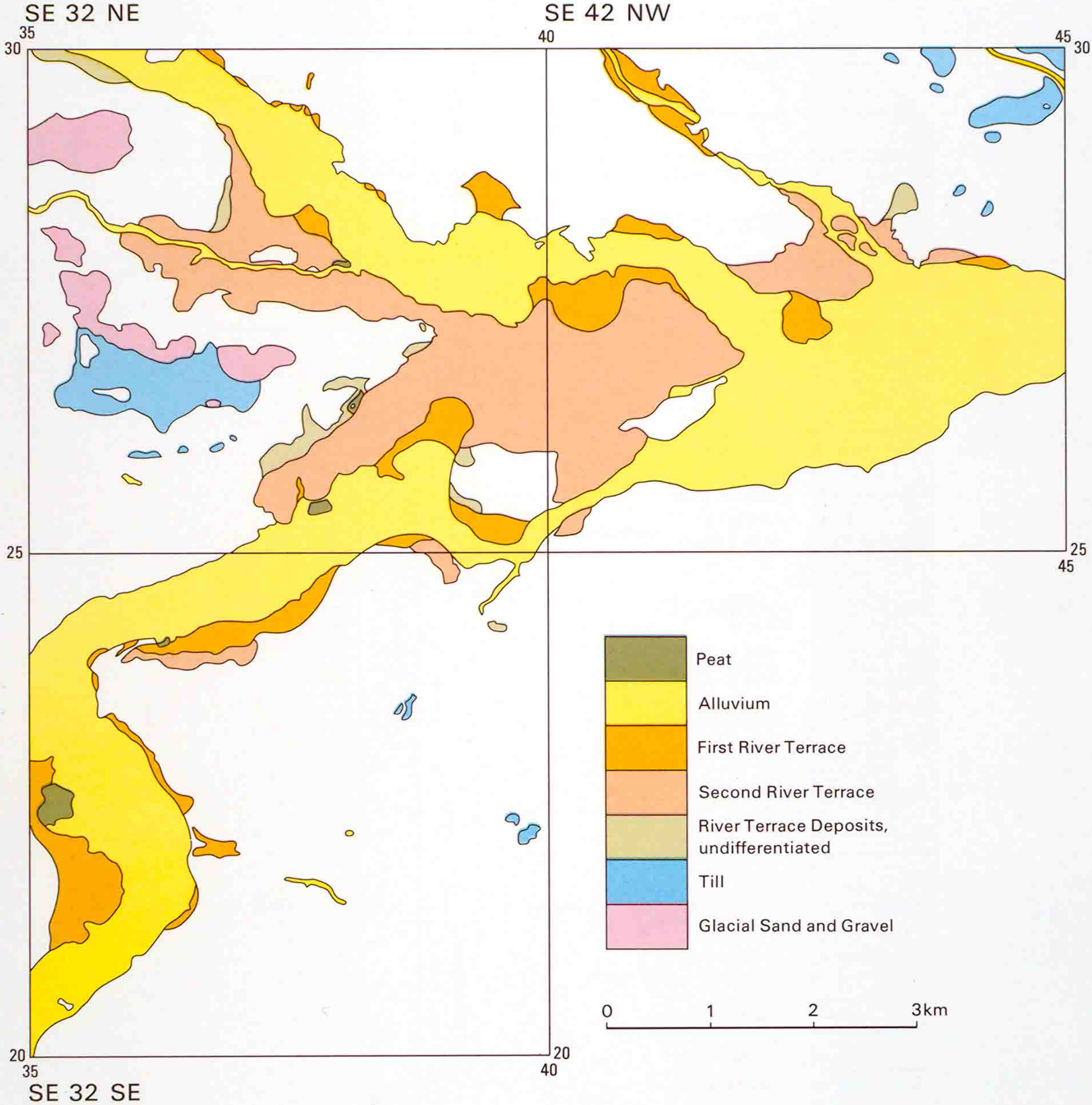

Figure 8. Simplified map of drift geology

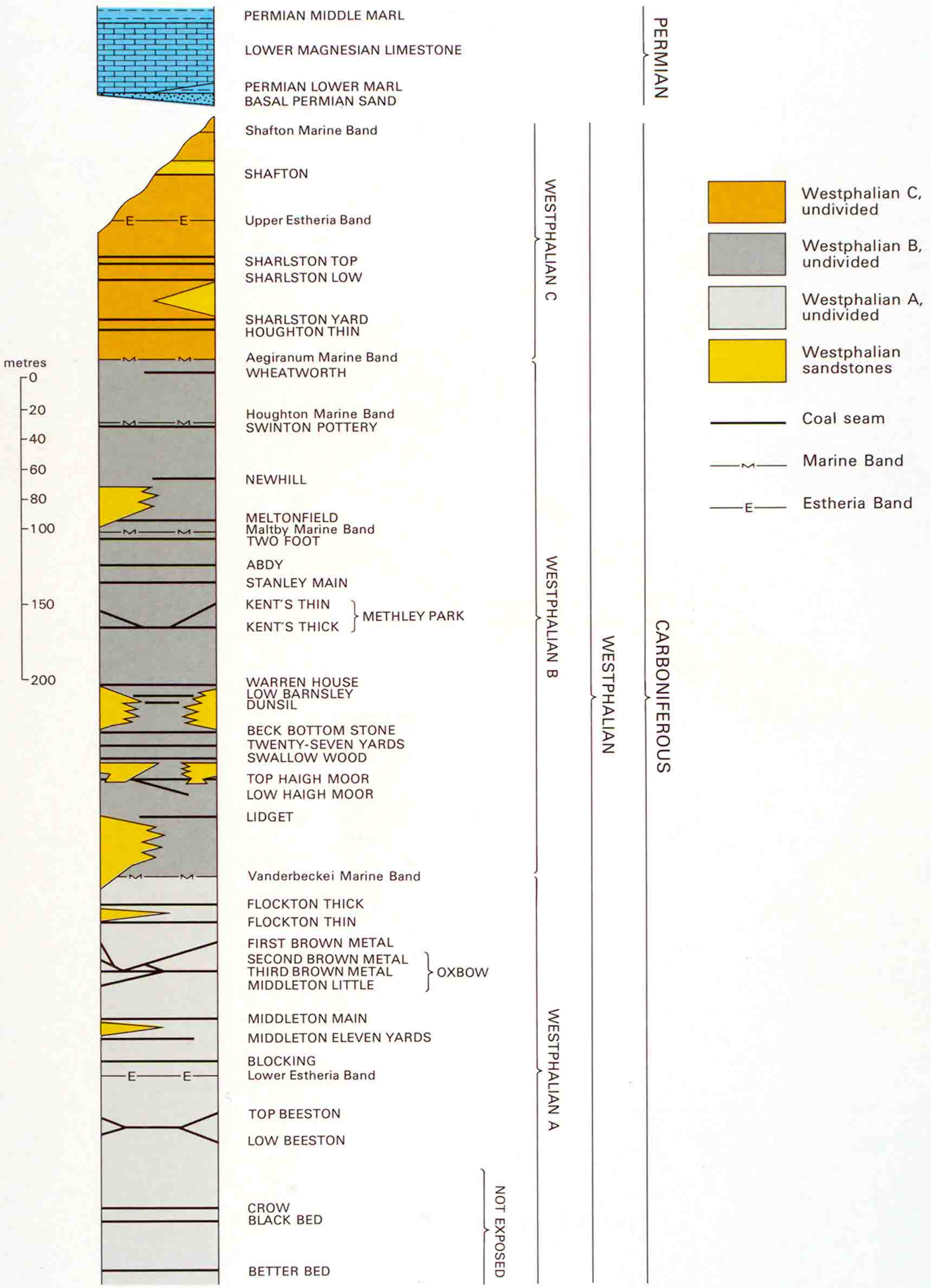

Figure 9. Generalised vertical section

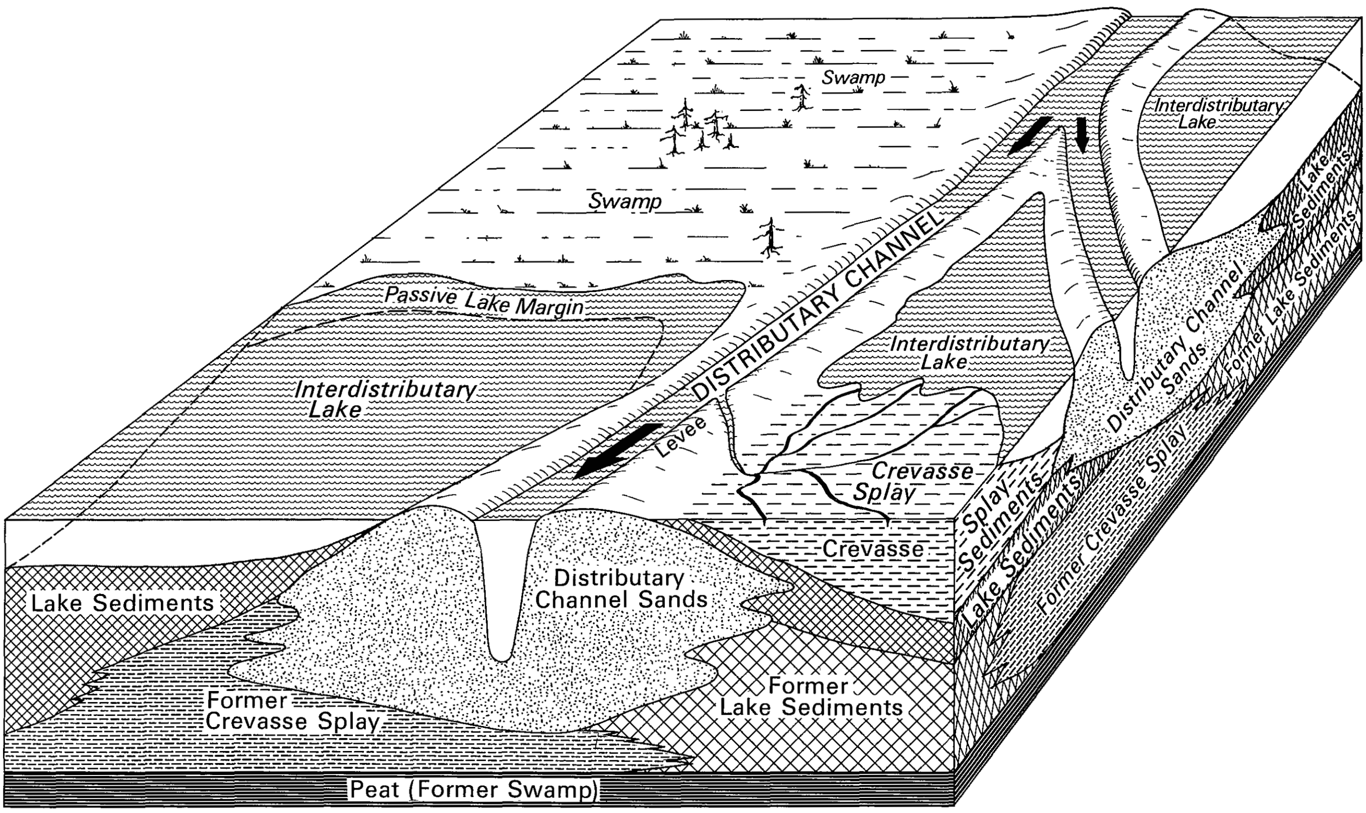

Figure 10. Generalised diagram illustrating the relationships of the major Westphalian depositional environments

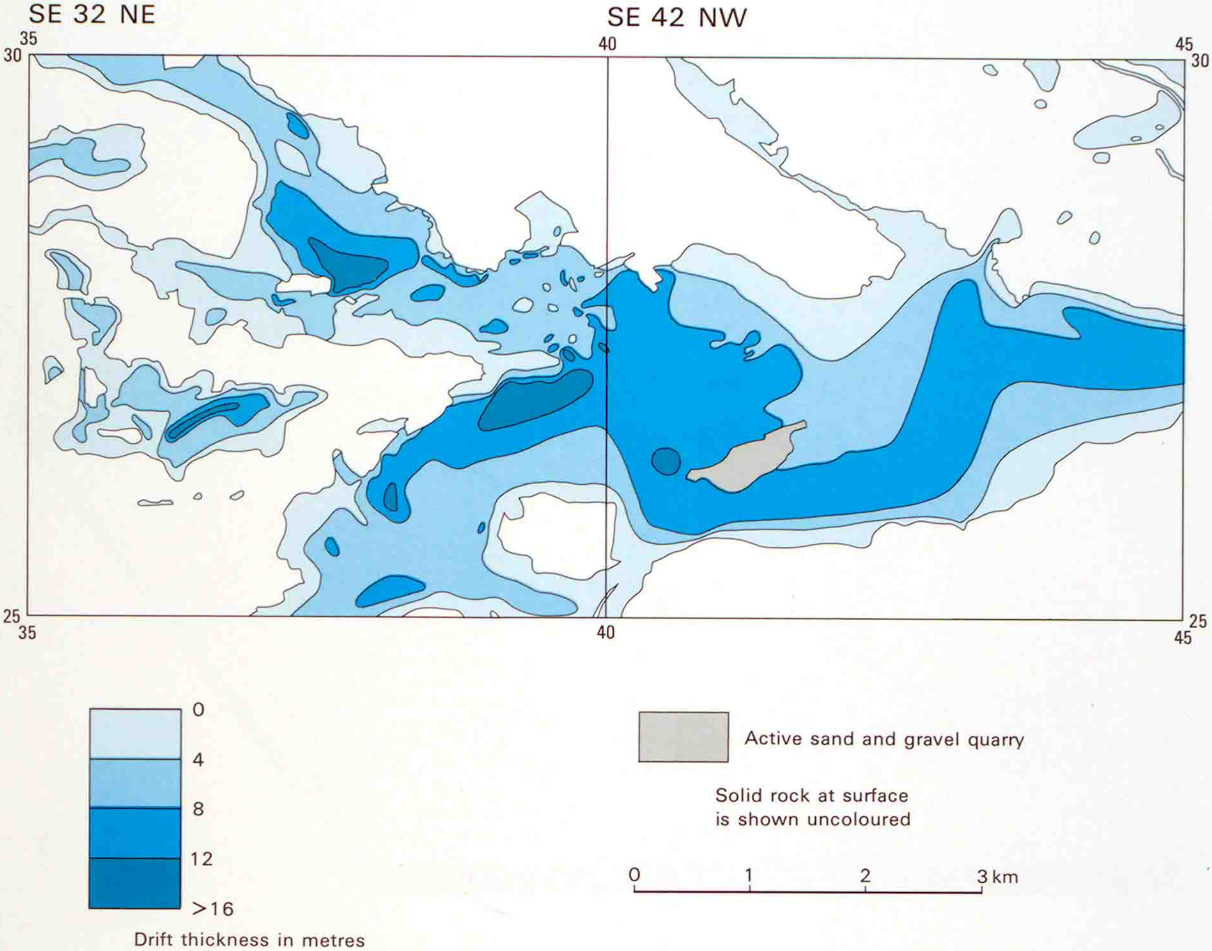

Figure 11. Thickness of drift deposits

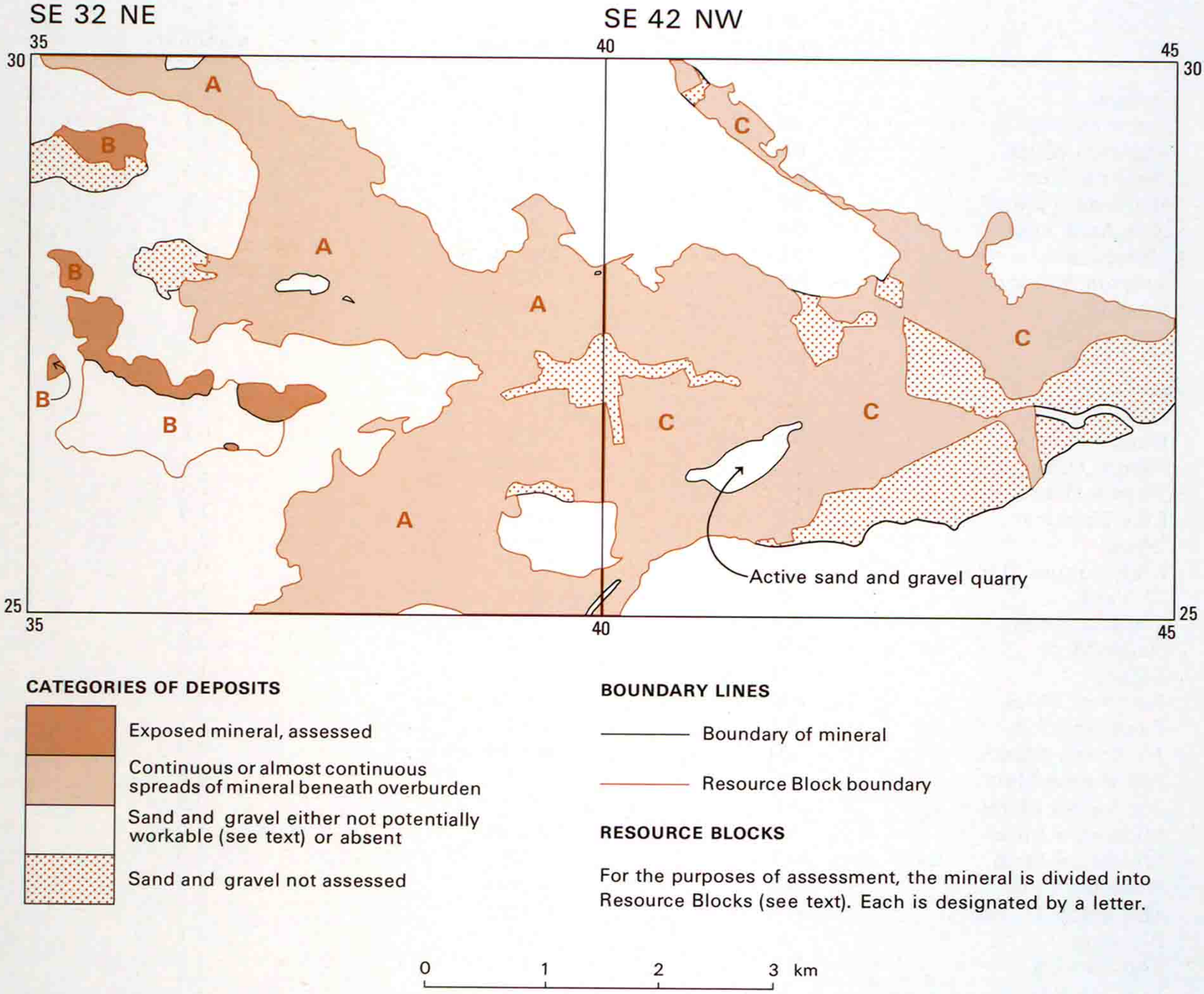

Figure 12. Distribution of sand and gravel resources

Table 5. Coals arranged in stratigraphical order showing the minimum and maximum thickness recorded in boreholes and shafts in the district.

Seam	British Coal seam index	Seam thickness (including dirt partings)	
		minimum	maximum
Shafton	BU	0.9	1.3
Sharlston Top	BS	0.5	1.1
Sharlston Muck	BR	0.4	1.7
Sharlston Low	BQ	0.8	1.1
Sharlston Yard	BP	0.5	1.0
Houghton Thin	BN	0.4	1.4
Wheatworth	BL	absent	1.6
Swinton Pottery	BK	0.2	1.0
Newhill	BJ	absent	1.4
Meltonfield	BH	0.3	2.7
Two Foot	BG	0.4	1.1
Abdy	BE	0.6	1.4
Stanley Main	BBD	1.2	5.0
Kent's Thin	BA	0.3	0.8
Kent's Thick	AZ	absent	3.5
Warren House	AWY	0.7	2.5
Low Barnsley	AV	absent	1.9
Dunsil	AUX	absent	2.1
Beck Bottom Stone	AU	0.1	0.8
27 Yard	AS	0.1	1.3
Swallow Wood	AR	0.1	0.9
Haigh Moor	APQ	0.8	3.5
Lidget	AN	absent	1.3
Flockton Thick	AK	absent	2.2
Flockton Thin	AJ	0.3	4.2
1st Brown Metal	AH	absent	2.4
2nd Brown Metal	AG	0.3	0.8
3rd Brown Metal	AF	0.2	0.6
Middleton Little	AE	absent	3.5
Middleton Main	ACD	0.9	3.0
Wheatley Lime	AB	absent	1.2
Middleton 11 Yard	AA	absent	2.0
Blocking	Z	0.2	2.1
Top Beeston	UX	0.7	1.6
Low Beeston	T	0.4	2.1
Crow	N	0.1	1.0
Black Bed	M	0.2	0.8
Better Bed	K	0.1	0.3

Tonsteins are dense mudstones, usually less than 6 centimetres thick, containing kaolinite aggregates and crystals. Although rare, they are laterally extensive and isochronous. They are considered to be kaolinised ash-fall tuff or reworked volcanic detritus (Williamson, 1970).

A few limestones are present, but they are thin and discontinuous. Eagar and Rayner (1952) recorded a 0.15 m 'shelly limestone' (probably an impure bio-sparite) from the former Westgate Brick Works [3140 2040]. Trueman (1954, pp 27) commented that, 'slabs of mussel bands contain so much carbonate of lime, with varying amounts of carbonate of iron (chalybite), that they form limestone-like masses'. Such limestones, locally called 'cank', are recorded in a number of colliery shafts such as New Sharlston, Parkhill and Glass Houghton.

Ironstone, mainly in the form of impure siderite, is ubiquitous. It mostly occurs as nodules, bands and lenses of clay ironstone within mudstones. Some beds, such as the Black Bed Ironstone, contain sufficient iron to have been worked as an iron ore in the past.

Oolitic ironstones also occur. Dean (1935) records a variable oolitic ironstone, up to 0.25 m thick in Robin Hood Quarry at the horizon of the Swallow Wood Coal.

Stratigraphy

Coal seams of West Yorkshire range in thickness up to five metres, including dirt partings. The seams vary in thickness laterally, the minimum and maximum thicknesses of the named seams being shown in Table 5.

The base of the *Lower Coal Measures* is defined by the Subcrenatum Marine Band. These measures are exposed in the north-west of the district around Beeston and Churwell.

In this district little is known about the measures between the subcrenatum Marine Band and the Better Bed Coal, although further north where they consist of two main units; the Ganister Coals and the Elland Flags, together comprising 180 to 200 m in thickness. To the south of the district in South Kirby No 1 Borehole [4546 1092], the equivalent beds are about 300 m thick.

Between the Better Bed and the Beeston, there are 90 m of strata dominated by claystones, mudstones and siltstone with coals and ironstone. The Better Bed is underlain by a mudstone-seatearth which was mined as a refractory clay along with the coal. Two other coals, the Black Bed and Crow have also been mined. Immediately above the former is the sideritic Black Bed Ironstone which was also mined.

The Beeston (also known as the Churwell in the west of the district) consist of two main leaves, the Top and Low, which may be separated by up to 12.8 m of sandstone and claystone. The Top Beeston is between 0.7 m and 1.6 m thick and mined under much of the district.

The Beeston and Middleton Main are separated by 70 m of claystone, mudstone and siltstone with sandstone and coal. About 35 m above the Beeston is the Low Estheria Band which has been identified in St John's No 2 Underground Borehole [3666 1944]. Two economically valuable coals, the Blocking and Middleton Eleven Yard, are found in the measures above the Estheria Band and both are very variable in thickness. The Slack Bank Rock lies between the Middleton Eleven Yard and Middleton Main. It is absent from much of the district but where it is present it has a channel form (Giles and Williamson 1985; Figure 3).

The Middleton Main, also known as the West Yorkshire Silkstone, varies in thickness from 0.9 m to 3.0 m. It consists of two leaves separated by a thin dirt parting but may be divided into three or four leaves. It has been mined over much of the district.

The measures between the Middleton Main Coal the Vanderbeckei Marine Band are 94 m thick. This monotonous sequence of claystone, mudstone and siltstone is broken only by coals and and a sandstone. The main feature of the lower part of these strata is the complex pattern of the Brown Metal/Middleton Little coals as they split and rejoin. Over much of the area they are thin and impersistent but where several are united the combined seam has been mined. A tonstein is recorded in the roof of the 2nd Brown Metal. The Flockton Thin and Thick coals lie above them and are separated by up to 12 m of strata which contain the Emley Rock. It crops out in Middleton Park Woods where it is a pale brown, cross-bedded, fine- to medium- grained sandstone.

A total of 370 m of *Middle Coal Measures* strata are recorded in this district. The base is defined by the Vanderbeckei Marine Band, but this has not been identified in this district, although its horizon can be readily determined within the local succession.

Between the Marine Band this and the Haigh Moor there are 62 m of measures, including the Thornhill Rock which is a distributary channel sandstone. Where it is present it is up to 45 m thick but it is absent in parts of the district. It consists of a coarse, massive or cross-bedded sandstone that is quarried as a building stone south of Morley. It has an erosive base which cuts down through the Vanderbeckei Marine Band into the Lower Coal Measures strata beneath. Where the Thornhill Rock does not reach its maximum thickness or is absent the Lidget Coal is developed. This seam has been mined from New Sharlston Colliery.

The Haigh Moor Coal consists of two main leaves that are separated by up to 14.6 m of mudrock but they may join to form a seam up to 3.5 m thick. The seam is washed out by the overlying Haigh Moor Rock in a number of places. The seam has been extensively mined.

The Haigh Moor and Warren House are separated by 62 m and contain two distributary channel sandstones, the Haigh Moor Rock and the Horbury Rock. The former is up to 16 m thick and erosively cuts down at its base and causes wash-outs in the Haigh Moor. A sequence of claystone and mudstone with three thin, laterally persistent, coals separates the two sandstones. Up to 37 m of fine- to medium-grained cross-bedded sandstone forms the Horbury Rock. It crop out at Ardsley East and east of Ouzlewell Green but is absent from the area south and east of Oulton. In this area two local seams develop, the Dunsil and the Low Barnsley, both of which are mined at St Aidans' Opencast Site.

The Warren House varies from 0.7 to 2.5 m in thickness and has between 2 and 7 leaves. It is exposed in the cutting just north of the former Kippax Railway Station [4050 2964] where it is 2.3 m thick and contains two dirt partings 0.13 and 0.48 m thick.

Between the Warren House and the Maltby Marine Band are 100 m of claystones, mudstones and siltstones with five coal seams. No thick sandstones are present in the sequence. The lowest two coals, the Kent's Thick and Kent's Thin, join in the area between the Oulton and Water Haigh faults to form the Methley Park Coal. The Stanley Main Coal is best developed near Normanton, where it was extensively mined, but southward the increasing thickness of dirt partings make it less valuable. The Abdy and Two Foot are both laterally persistent seams, neither of exceed 1.4 m in thickness.

The Maltby Marine Band was identified in the roof measures of the Two Foot Coal at Welbeck Lane Borehole [3585 2159] and comprised 0.58 m of black, silty mudstone with *Lingula.*

Four coals are found in the measures between the Maltby Marine Band and the Aegiranum Marine Band: Meltonfield, Newhill, Swinton Pottery and Wheatworth. They are vary variable in thickness and only small areas of each have been mined. A mudstone-seatearth beneath the Swinton Pottery Coal has been quarried as a refractory clay, and the mudstones above and below this seam have been used for brick making. The Woolley Edge Rock is the only major sandstone. It lies above the Meltonfield except where its erosive base has removed the coal and some of the strata beneath. The rock is up to 30 m thick and normally consists of a fine-grained, trough cross-bedded sandstone. The Houghton Marine Band is found in the roof of the Swinton Pottery Coal. It consists of a 2.4 m of dark grey to black mudstone with *Lingula.*

The Aegiranum Marine Band crops out near Kirkthorpe [3695 2101]. It consists of 1.9 m of dark grey, fossiliferous mudstone interbedded with 0.4 m of fossilerous siltstone.

Above the Aegiranum Marine Band there are a series of claystones, mudstones and siltstones with two thick sandstones and the Houghton Thin Coal, Sharlston Group of Coals and the Shafton Coal. The Sharlston Group of Coals (Plate 4) consists of the Yard, Low, Muck and Top. In this district the Low and Muck are united to form a single seam which contains a tonstein. The Yard and Low seams are separated by the Warmfield Rock, a fine-grained, medium-bedded sandstone up to 30 m thick. Above the Top is the Upper Estheria Band which is a coalfield-wide fossil band. The Shafton consists of a single leaf between 0.9 and 1.3 m thick. It is overlain by a sandstone up to 25 m thick which is in turn overlain by the Shafton Marine Band.

Permian

Permian rocks form a bold escarpment in the east of the district where they unconformably overlie Middle Coal Measures. A total of some 55 metres of Permian strata crop out in the district. The beds have a gentle regional dip of two to three degrees to the east-north-east, except where the strata are affected by faults. Part of the exposed area is mantled by drift deposits such as remanie till and head.

The generalised vertical section (Figure 9) illustrates the sequence of Permian rocks proved in the district. Many details of the Permian rocks of the region are published in Edwards and others (1940).

Classification

A classification for the the Permian rocks of the British Isles was proposed by Smith and others (1974). Smith (1974a) described in detail the application of this proposed British classification to the Yorkshire region. The classification that he suggested for central Yorkshire has been followed in mapping the Castleford district. Subsequently Smith and others (1986) have published a revised nomenclature for the Upper Permian strata of eastern England.

Palaeo-geography

Between the deposition of the youngest Carboniferous and oldest Permian deposits of the district, there was a period of widespread uplift. The earth movements which caused the uplift probably occurred in the late Westphalian and possibly the Stephanian stages of the Carboniferous. By the latter part of Lower Permian times subaerial erosion had reduced many areas to a gently rolling peneplain. Smith (1974a) comments that the sub-Permian surface is almost planar where it cuts across Coal Measures and that it lay close to sea-level at that time. Palaeo-latitude determinations of Permian rocks show that the British Isles were then situated close to the equator. The environment during this extended period of subaerial erosion was that of a semi-arid desert.

At the start of the Upper Permian there was a major marine transgression. The Zechstein Sea, an epicontinental sea, flooded much of eastern England including the Castleford district. Smith (1970) describes the palaeogeography of the British Zechstein in terms of a series of five sedimentary cycles, EZ1 - EZ5. Each cycle commences with a shelf carbonate deposit which grades up into evaporites. Only strata of the lowest EZ1 cycle are found exposed in the Castleford district.

Stratigraphy

Basal Permian Sand In the district the Basal Permian Sand forms an almost continuous deposit which rests unconformably upon the underlying Coal Measures rocks. The Sand consists of well-rounded grains of quartz and rock-fragments, transported primarily by wind, and deposited in the low-lying areas either as a sand sheet or in the form of dunes. The Sand may have been subsequently reworked during the marine transgression the Zechstein Sea, so the final deposition may have been in shallow marine water (Edwards and others 1940; Pryor 1971; Smith 1974a).

The Basal Permian Sand is absent locally, and ranges up to 5.41 m in thickness. It is exposed at a number of localities in the district. The best are in road cuttings which cross the Permian escarpment at Red Hill. Here 1.90 m of soft, very pale orange, thickly bedded sandstone rest directly on the Glass Houghton Rock. A section in the back garden of a private house [4468 2638], exposed 0.50 m of sandstone. In Kippax Park 1.00 m of very pale orange, fine- to medium-grained, friable sandstone was noted. Exposures were formerly more numerous, many of which are recorded in Edwards and others (1940, p 132).

The extensive mining of the Basal Permian Sand is discussed in the Land Stability and Safety Section of this report.

Lower Marls A number of boreholes record a thin calcareous mudstone that rests directly on the Basal Permian Sands and is in turn overlain by the Lower Magnesian Limestone. The maximum recorded thickness in this district was in Ledsham No 16 Borehole [4427 3038], consisting of 2.58 m of grey, calcareous mudstones and thin, muddy limestones. The beds are not exposed at the surface. Smith (1974a) noted that the Lower Marls commonly contain numerous fragments of comminuted plant debris and suggested deposition in a restricted marine shelf environment in a few metres of water.

Lower Magnesian Limestone The Lower Magnesian Limestone (the Cadeby Formation of Smith and others 1986) consists of buff-coloured, sparsely to moderately fossiliferous, oolitic dolomite with scattered bryozoan-algal patch reefs. Where the base is exposed as at Kippax Park and Wheldon Road, the limestones which directly overlie the Basal Permian Sand are very sandy for up to 1.90 m. Smith (1974a) suggested that the formation was deposited on a broad open shelf in no more than a few metres of water. Bryozoan-algal patch reefs with flanking calcareous sediments were formed in deeper water (Smith 1981). Harwood (1986) noted that much of the original detail has been obliterated by dolomitisation.

The Limestone forms a bold escarpment in the east of the district and is widely exposed and recorded in numerous boreholes. Only three boreholes penetrate the full thickness of the Lower Magnesian Limestone in the Castleford area: Sheepcote Wood No 1A Borehole (37.21 m), Ledsham No 16 Borehole (45.65 m) and Ledsham No 35 Borehole (55.14 m).

Middle Marls These beds (the Edlington Formation of Smith and others 1986) occur in a small area around Park Farm and to the north of Forest Plain; their outcrop is marked by greyish red soil. Edwards and others (1940, pp 135) recorded a section at Plaster Pits [4458 2959] where 6.0 m of stiff red marl with pure white, massive gypsum was formerly exposed. At Park Farm an old well recorded 9.14 m of 'red clay' overlying limestone. The Middle Marls were not exposed in the district during the resurvey and no borehole penetrated the full thickness.

Smith (1974a) suggested deposition in a broad coastal plain with an extensive shallow sea to the east.

Structure

The dip of the strata is normally less than three degrees although minor folds and flexures steepen the dip near faults. There is no overall direction of dip across the district, the direction varying from one fault-block to another. The direction and value of dip also change vertically, especially where the dip is so low that the effects of differential compaction of the sediments become significant.

The principal structure of the district is the Morley-Campsall Fault Belt which is part of the northern boundary fault of the Gainsborough Trough. It is a west-north-west trending structure with an overall downthrow to the south, but there has probably been a significant strike-slip component along it. Within the fault belt, dips are highly variable and there is much minor faulting and folding.

Arcuate faults, such as the Normanton Station Fault, branch off Morley-Campsall Fault Belt. Near the fault belt these have throws in the order of 100 m but their throws decrease rapidly away from the Fault Belt.

NE-trending faults, that includes the Oulton, Water Haigh, Methley Savile and Methley Junction faults, also branch off the Fault Belt. These faults throw down to the south-east, with throws up to 120 metres. The throws may decrease rapidly laterally. For example, the Methley Junction Fault has a throw of 118 metres at Low Common, but 5 km to the north-east it dies out. Some faults in the district form pairs. As one fault dies out, another fault develops with the same trend but offset from the first by about one kilometre.

The major faults comprise narrow zones of sub-parallel fractures, as proved by site investigations and seen during quarrying and opencast coal mining.

A second fault set, with minor throws normally less than 2 m, have a north-west trend and are much less extensive vertically and laterally. Because of their impersistence and variability, these minor faults have not been projected to the surface from mine workings unless they are proved independently, for example by opencast prospecting.

Folding is usually in the form of broad open structures, such as the Normanton Anticline.

There is an angular unconformity between the Coal Measures and the Permian strata. Some of the major faults, which have large throws in the Coal Measures, either do not fault the Permian or only have throws of one to two metres. The Methley Junction Fault has a throw of 25 m in the Coal Measures west of Ledston, whereas the throw is less than two metres in the Permian. Locally the Permian is faulted and folded. For example, to the east of Park Farm there is a NE-trending fault which throws down 10 to 20 m to the north-west and has a complementary monoclinal fold.

Joints are common and are best developed in the thicker sandstones of the Coal Measures and the limestones of the Permian. They are normally very steep or vertical, and generally comprise two or more conjugate sets at any one locality. Regionally, however, these vary considerably in trend and no general pattern can be discerned from the sparse data available. The joints near the surface may open into fissures where undermined, as has been recorded at a number of sites which have been cleared prior to development.

Cambering has been recorded at some localities where competent beds of sandstone or limestone cap hills or form pronounced breaks in slope. For example, there are open joints in the Lower Magnesian Limestone aligned parallel to the edge of the escarpment to the east of Ledston.

Superfical deposits

The Quaternary drift deposits comprise Till, Glacial Sand and Gravel, River Terrace Deposits, Alluvium, Peat and Head. Half of the area is covered by mappable drift deposits. The most extensive areas of drift are located in the Aire/Calder valley. Figure 8 shows the distribution of drift deposits and Figure 11 gives isopachytes or contours of drift thickness across the district.

Regional Setting

West Yorkshire was affected by several cold episodes during the Quaternary. Prior to the Ipswichian the region was covered by ice on at least one occasion. Deposits belonging to pre-Ipswichian glaciation show no constructional features, are usually extensively weathered and decalcified and are only preserved as eroded remnants on the interfluves.

Ipswichian inter-glacial deposits are poorly known. Bones of two adults and one juvenile Hippopotamus were found in the terrace deposits of the Aire (Denny, 1854), although the precise location of these finds is not known.

In the glaciation during the Dimlington Stadial (Rose, 1985) ice advanced down the Vale of York briefly as far south as Doncaster but the moraines at York and Escrick represent a more persistent southern limit to the advance. Ice also accumulated on the Pennines producing substantial valley glaciers which flowed down the main Pennine dales.

It is probable that the present district was free of ice for much of the Devensian as the major ice-sheets terminated farther to the north and west. Fluvio-glacial deposits were laid down under periglacial conditions in the major dales during the advance and subsequent retreat, of the glaciers. At the time of maximum glaciation and for a period during the retreat a substantial pro-glacial lake, Lake Humber, covered much of the Vale of York. The initial level of Lake Humber, was at about 30 A.O.D. (Edwards, 1936), and this is marked by isolated patched of shore line gravels along the edge of the Pennines and along the York-Escrick Moraines. The level of Lake Humber subsequently dropped to between 7 and 8 m A.O.D.

Following the climatic improvements at the end of the Devensian and the draining of Lake Humber, meandering rivers systems developed in the major dales, re-sorting and re-depositing the fluvio-glacial deposits.

Till

The till occurs in isolated patches across the district. The thickest deposits are found along the watershed between the Aire and Calder, particularly around Rothwell and to the south of Oulton. Here a number of ditch sections show a yellowish brown, slightly sandy, silty clay with pebbles and sporadic cobbles. The clasts are dominated by locally derived sandstone with lesser amounts of chert and ironstone. Boreholes in this vicinity show the till to be up to 13.4 meters thick. Elsewhere, only very poor sections were seen during the resurvey, but these consistently show a yellowish brown to a pale reddish brown, pebbly clay. The clasts vary across the district from a Carboniferous-dominated suite in the west and centre of the district to a Magnesian Limestone-dominated suite in the east.

Glacial Sand and Gravel

Glacial sand and gravel is found in close association with till between the Aire and Calder. The deposit contains an abundance of pebbles and cobbles of locally derived Carboniferous sandstone and grits, with lesser amounts of ironstone, siltstone, chert, quartz and limestone. Particle size analysis shows the deposit contains between 4 and 24 percent fines, with a mean of 12 percent, mean gradings for both the sand and gravel are 44 percent.

River Terrace Deposits

Much of the drift-covered area comprises the fluvial deposits of the Aire and Calder. Two main river terraces have been recognised; they vary markedly in lithology, both vertically and horizontally, ranging from laminated clays through silts and sands to coarse gravel. They were laid down in complex fluvial and fluvio-lacustrine environments. Near Methley and around Ledston, a higher sand and gravel deposit of uncertain origin has been classified as 'Terrace Deposits, undifferentiated'.

For example, at Rothwell Haigh, north-west of Wood End Farm, sand and gravel with subordinate clay is exposed above the general level of the Alluvium; its relationship to the Second River Terrace is uncertain because it is largely obscured by colliery spoil. Gradings show that the material is a 'very clayey' sandy gravel with a composition essentially similar to the other river terrace deposits.

Opencast coal exploration boreholes in the vicinity of Methley Park and Ledston have proved a deposit of sand and gravel above the level of the Second River Terrace. It has no constructional features but drapes a south-facing slope between 20 and 30 m A.O.D. Glacial sediments in this position would have been removed by solifluction during the Devensian. Although its origin is unclear it is possibly related to the deposits that Edwards (1936) attributed to the high level strand line of Lake Humber.

Small isolated patches of this deposit are also recorded in Swillington Park and south of Methley Junction.

Deposits of the second River Terrace are widespread at the confluence of the Rivers Aire and Calder, to the east of Mickletown. The terrace surface, which was originally planar, is now gently rolling due to mining subsidence. The deposits comprise sand and pebbly sand, which may be 'clayey'or 'very clayey', and sandy gravel. The gravel fraction is dominantly composed of Carboniferous sandstone with lesser amounts of ironstone, shale, limestone and traces of igneous rocks and quartz. The sand and gravel is normally overlain by thin deposits of silt and clay beneath soil. Some beds of clay occur within the sand and gravel, but these are normally thin and discontinuous. The sand and gravel normally rests directly on the bedrock. Despite complications caused by subsidence, the terrace can be traced over a considerable area at a maximum height of 5 to 6 m above the level of the alluvium.

A mammoth tusk found at the base of the Second Terrace gravels at the Oxbow Opencast site, to the north-west of the present district, yields a radio-carbon date of 38,600 +1720 to -1420 years Before Present (Gaunt and others 1970). The deposition of the Second and First terraces is therefore later than this date.

The First River Terrace Deposits are far less extensive than the Second, being confined to a small area to the north of Mickletown and isolated remnants south of Allerton Bywater, around Fleet Lock and to the west of Newton Farm. Although a number of boreholes record the thicknesses of the deposit, only one describes the nature of the sediment. This single record describes the sand and gravel as a 'clayey' pebbly sand. The composition of the gravel fraction is essentially the same as that of the Second Terrace. Subsidence has affected this terrace, flooding a considerable area of outcrop to the north of Mickletown.

First River Terrace Deposits are found along the course of the Sheffield Beck and its north-westwards extension, Kippax Beck. Much the deposit has been either removed as overburden during opencast coal mining or covered by made ground. At some time prior to the publication of the first Ordnance Survey 1:10560 map in 1850 the course of Sheffield Beck, east of Brigshaw Lane, was diverted to the south onto the First Terrace. Just to the north of the 'Playing Fields' on Brigshaw Lane there is a small exposure of this deposit comprising 'clayey' sand and 'clayey' pebbly sand. The dominant pebbles in the gravel are ironstone.

Alluvium

Alluvial deposits occur along the margins of the River Aire and River Calder forming spreads hundred of metres wide. They were formed comparatively recently by deposition in meandering channels. The alluvium is being quarried for sand and gravel north and west of Dunford House. A typical section of the quarry face shows that the alluvium is composed of sandy gravel which may be locally 'clayey'. Borehole evidence from elsewhere in the district records similar sediments. Ninety percent of the gravel fraction is composed of sub-rounded to well-rounded Carboniferous sandstone. The remainder consists of ironstone, quartz, coal and some volcanic and igneous clasts. The deposit is crudely bedded, with widespread imbrication of tabular clasts. The imbrication locally picks out tabular cross bedding, with sets less than a 0.3 m thick. Occasionally tree trunks have been recovered from the gravel.

The floodplain of the Calder, above its confluence with the Aire shows a number of abandoned meanders. These may have been artificially abandoned when the river was straightened to improve it as a navigable waterway. Other, older naturally abandoned meanders have been located in boreholes and in the quarry near Dunford House. One section of the quarry shows a sequence of silty clays with interbedded peat. The peat is rich in woody material and contains identifiable fragments of birch trees. The silty clay and peats fill a cut-off meander channel.

The alluvium has also been affected by subsidence. Large areas of alluvium have been flooded to form permanent shallow lakes known locally as 'Ings'.

Small strips of alluvium occur along minor streams such as Oulton or Sheffield Beck.

Peat

In this district peat is normally associated with alluvium. It is recorded in the quarry north of Dunford House in former courses of abandoned meanders. Other such occurrences should be expected within the alluvial deposits. Peat has formed in enclosed hollows created artificially either by subsidence or engineering works. An example is at Ardsley Junction where the M62 motorway crosses the Dolphin Beck. No data are available on the thicknesses of these minor deposits.

Head

Head is the term applied to deposits formed by the slow downslope movement of material under periglacial conditions of alternate freezing and thawing; some of the material may still be moving today under the action of weathering. Deposits of Head are especially thick at the foot of pronounced escarpments, such as the Permian escarpment in the east of the district; they comprise a mixture of soft clay, sands and angular rock fragments. Similar deposits are found in the bottom of dry valleys on the outcrop of the Magnesian Limestone. One such deposit has been separately mapped at in Horselock Dale.

Head is also present over much of the Coal Measures outcrop where it is commonly a yellow sandy clay lacking in cohesion and stability. It tends to be thicker in hollows and against obstructions or slopes.

The head is generally less than 2 m thick, but may exceed this at the base of the Permian escarpment. It is not possible to indicate its complete distribution due to its thinness and its lack of distinguishing characteristics. Head should be assumed to be present everywhere unless proved otherwise.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that:

1. The main cause of land instability is the existence of former shallow mine workings for coal, sand and, more rarely, other minerals. Where coal was worked at depth, it is reasonable to assume that most of the subsidence occurred a short time after the roof supports were withdrawn. But this unlikely to be true of shallow mining.
2. Land instability may also occur on slopes which are subject to cambering where ground is underlain by poorly consolidated natural sediment such as peat or head. Unconsolidated deposits up to 16 m thick have been recorded in buried rockhead channels beneath the fluvial sediments in the river valleys.
3. Made ground and fill have a varied chemical content and their state of consolidation is commonly unknown. Old quarries that have been backfilled and restored can also give rise to construction problems, particularly if they are not recognised during site investigations.
4. Inadvertent sterilisation of mineral resources can be avoided by a reference to modern geological and thematic maps, from which the distribution of minerals can be deduced. The principal minerals in the district are coal, minestone, fireclay, ironstone, brick clay, sandstone, sand, limestone, gypsum, hydrocarbons and sand and gravel. The sand and gravel resources have been assessed and it is estimated that about 86 million cubic metres are available.
5. The principal aquifers are the major sandstones in the Coal Measures. Occasionally water from the fluvial sand and gravel of the Aire and Calder valleys has been utilised. This is partly derived by induced recharge from the rivers.

We recommend that:

1. Land stability problems associated with the mining of the Basal Permian Sand should be more extensively investigated to refine the categories established in this report.
2. Other minerals found in association with workable opencast coal reserves should also be worked where appropriate, if necessary by phased extraction involving different public bodies and private companies. The object of this recommendation is to prevent the wastage of finite natural resources.
3. The resources of Brick Clay and Lower Magnesian Limestone should be assessed.
4. The results of the study should be taken into account in the planning of land use and in considering development of land in the area.

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GLOSSARY

ALLUVIUM Sediments deposited by a rivers or streams, during relatively recent geological time and deposited on the flood-plain

BIOTURBATION The disturbance of a sediment by living organisms

BRITISH COAL SEAM INDEX A nation-wide coding system for seams developed by British Coal used in the report as a short hand for seam names

CLAST Rock fragment or pebble in a sedimentary rock

CROSS-BEDDING The internal layering of a bed of sediment, characterised by inclined minor beds disposed at various angles to the principle bedding planes.

DEVENSIAN The part of the Quaternary during which the Britain last glaciated

DIRT A collective name for non-coal material found between leaves of coal within a seam, usually a mudstone or mudstone-seatearth.

DISTRICT The area covered by this report.

DRIFT Unconsolidated sediments deposited during the Quaternary

DOLOMITIC A term used to describe limestones containing more than 15% magnesian carbonate

FACIES The combined total of the features of a rock including such things as lithology, fossil content, sedimentary structures etc

HEAD Unconsolidated sediment produced by a mixture of mass-movement processes including solifluction and slope wash, and commonly characterised by weak shear strengths

INTERFLUVES High ground between stream or rivers of the same drainage basin

IPSWICHIAN The temparate period prior to the Devensian

ISOCHRONOUS Belonging to the same time, being of the same age

ISOPACHYTES Lines of equal thickness of sediment

LACUSTRINE Relating to lakes

LENTICULAR BEDDING A sedimentary structure in which lenses of one sediment are enclosed in another sediment

OOLITE A subspherical particle commonly of calcium carbonate, that has grown by accretion around a nucleus

RANK A system of classifying coal based on the energy released during combustion

REMANIE TILL The remains of a now extensively weathered and eroded which are only preserved in isolated patches or marked by erratic pebbles in the soil

RESERVES The economically exploitable part of a resource

RESOURCE The total amount of potentially workable mineral

SOLIFLUCTION A process where sediment is transported down slope under the influence of alternate freezing and thawing

STADIAL A term used to refer to geologically short cold periods during the Quaternary

TILL Sediment deposited by glacier; commonly a stiff clay

UNCONFORMITY A surface between two groups of rocks which marks a period of non-deposition or erosion

ANNEX 1: MAIN COLLIERIES

Tables showing the major collieries, National Grid Reference of a mine entrances and seams worked by British Coal Seam Index (see table 3 for codes). The * indicates that the mine was producing coal on the 1st January 1988.

Colliery	Grid reference of mine entrance	Seams worked (British Coal seam index)
Aberford Road	[3589 2488]	APQ, AWY
Allerton Bywater*	[4215 2788]	UX, ACD, AE, APQ
Allerton Main	[3979 2897]	M, UX, AA, ACD, AE, AWY
Allerton West	[3875 2826]	APQ
Beeston Manor	[2830 2870]	M, T, UX
Bruntcliffe	[2503 2731]	M, T, UX, Z, ACD, AE, AH, AK
Churwell	[2692 2982]	M, T, UX
Dean Hall	[2583 2842]	ACB, AE, AG, AH, AJ
Dartmouth	[2724 2889]	T
East Ardsley	[3056 2586]	UX, AA, AB, ACD, AE, AJ
Ebor	[3146 2926]	ACD
Fleakingley Beck	[3898 2943]	UX, ACD,
Foxhole	[3748 2540]	APQ,
Glass Houghton	[4307 2438]	UX, ACD, AK, APQ, AWY, BBD
Glasshouse	[2987 2745]	ACD
Great Preston	[4004 2970]	APQ
Goodhope	[3977 2322]	ACD, BBD
Harthill	[2535 2932]	K, T, ACD, AE, AJ
Howley Park	[2504 2547]	T, UX, AB, ACD, AE, AH, AJ, AK
Kippax	[4126 2868]	APQ,
Ledston Luck	[4293 3082]	AJ, AK,
Lingwell Gate	[3175 2536]	APQ
Lofthouse	[3252 2474]	UX, Z, AA, ACD, AE, AJ
Lofthouse Park	[3332 2513]	BBD
Lowther	[4058 2856]	APQ
Methley Junction	[3963 2565]	UX, ACD,
Methley Savile	[3923 2730]	UX, AA, ACD, AE, AK, APQ
Middleton	[3082 2909]	K, M, N, UX, Z, ACD, AE, AG, AH, AJ
Mill Shaw	[2786 3012]	M
Morley Main	[2703 2803]	UX, ACD, AE, AJ, AK
New Hall	[3189 2884]	UX, AA, ACD, AE
Newmarket Silkstone	[3620 2567]	UX, Z, AA, ACD, AE, AJ, APQ, AWY, AK, BE
Newmarket Spencer	[3504 2616]	APQ, AWY
Newmarket Swithens	[3463 2694]	APQ
New Sharlston*	[3839 2020]	UX, Z, ACD, AN, APQ, AWY, AZ, BBD, BE
Newton	[4494 2777]	AWY, BBD
Newton Abbey	[4500 2733]	BBD
Park Hill	[3516 2178]	ACD, APQ, AV, AWY, AZ, BBD, BE
Philadelphia	[2593 2953]	UX

Colliery	Grid reference of mine entrance	Seams worked (British Coal seam index)
Primrose Hill	[3874 2972]	M, N, UX, AA, ACD, AE
Red Hill	[4435 2515]	BN
Robin Hood	[3241 2722]	AE, UX, AA, ACD, AE, AJ
Rothwell	[3474 2982]	M, N, T, UX, Z, AA, ACD, AE, AJ, APQ
St. John's	[3742 2217]	Z, UX, AA, ACD, APQ, BBD, BE, BG
Stanley Ferry	[3515 2301]	BBD
Street House	[3980 2018]	BBD, BE
Snydale	[4079 2017]	APQ, AWY, BBD, BE
Swillington Park	[3811 2892]	APQ
Tanhouse	[2727 3004]	UX, T
Water Haigh	[3731 2829]	Z, UX, AA, AB, ACD, AE, AK
West Ardsley	[2786 2663]	UX, AA, AB, ACD, AJ, AK
West End		UX
West Riding	[3894 2417]	M, UX, AA, ACD, AJ, APQ, AWY, BE, BBD
Wheldale	[4413 2626]	UX, ACD, AE, AK, APQ, AWY, unamed
Whitwood	[4059 2485]	UX, ACD, AA, AE, AH, AK, APQ, AWY, BBD
Woodlesford	[3607 2986]	UX, ACD

ANNEX 2: OPENCAST COAL SITES

Tables showing the Opencast Coal Mines, British Coal site number, National Grid Reference (NGR) and coal seams worked. The * indicates that the site was active on 1st January 1988.

Site	Site number	NGR	Coal seams worked
Astley and Extension	671A/678A	[388 283]	Kent's Thick
Bell Hill	780A	[328 299]	Flockton Thick, Flockton Thin
Birkwood Common	Unnumbered		
Coney Warren	108	[347 262]	Kent's Thick, Warren House
Dungeon Lane	612	[355 270]	Stanley Main
Gap Lane	721	[374 206]	Sharlston Yard, Houghton Thin
Great Preston	253	[405 298]	Warren House, Dunsil
Healdfield	Unnumbered	[439 260]	Wheatworth
Hill Top Farm	Unnumbered	[366 232]	Stanley Main
Hungate	639/639A	[381 267]	Kent's Thick
Lockwood	948	[301 299]	Middleton Main, Middleton 11 Yd
Lofthouse Park	056	[340 251]	Stanley Main

Site	Site number	NGR	Coal seams worked
Lowther North and Extension	829/829A	[403 282]	Kent's Thick, Warren House, Low Barnsley, Dunsil
Methley Park	514/514A	[377 272]	Kent's Thick
Millshaw	049	[282 299]	Beeston
Nabs End	511	[293 277]	Flockton Thick
Newmarket Farm	Unnumbered	[356 254]	Kent's Thick
Newton Lane	730/730A	[435 282]	Meltonfield
Oulton Hall	575A	[360 273]	Kent's Thick
Oulton Park	Unnumbered	[353 278]	Haigh Moor
Ouzlewell Green	289A	[343 270]	Swallow Wood, Haigh Moor
Owl Wood	637A/738A	[418 292]	Kent's Thick, Warren House, Beck Bottom Stone, 27 Yard, Swallow Wood, Haigh Moor
Red Lane	337	[400 206]	Sharlston Muck, Sharlston Low
Roman Station Farm	092/092A	[355 255]	Kent's Thick
Royds Green and Extension	033	[347 264]	Kent's Thick
Royds Hall	Unnumbered	[357 259]	Kent's Thick
Snydale	217	[395 210]	Sharlston Top, Sharlston Muck, Sharlston Low, Sharlston Yard, Houghton Thin
St. Aidans and Extension *	181	[390 290]	Kent's Thick, Warren House, Low Barnsley, Dunsil
St Johns *	949	[371 219]	Sharlston Top, Sharlston Muck, Sharlston Low,
Watkinson Terrace	520/520A	[404 294]	Warren House

ANNEX 3: SAND AND GRAVEL RESOURCE ASSESSMENT

As part of the present project, the local sand and gravel deposits have been the subject of a resource assessment, as described below. This is concerned with the estimation of resources, which include deposits that are not currently exploitable but have a foreseeable use, rather than reserves, which can only be assessed in the light of current, locally prevailing, economic considerations. Clearly, neither the economic nor the social factors used to decide whether a deposit may be workable in the future can be predicted; they are likely to change with time. Deposits not currently economically workable may be exploited as demand increases, as higher-grade alternative material becomes scarce, or as improved processing techniques are applied to them. The improved knowledge of the main physical properties of the resource and their variability, which this survey seeks to provide, will add significantly to the factual background against which planning policies can be decided (Archer, 1969; Thurrell, 1971, 1981; Harris and others, 1974).

The survey provides information at the 'indicated' level. 'Indicated' assessments 'are computed partly from specific measurements, samples or production data and partly from projection for a reasonable distance on geologic evidence. The sites available for inspection, measurement, and sampling are too widely or otherwise inappropriately spaced to permit the mineral bodies to be outlined completely or the grade established throughout'. (Bureau of Mines and Geological Survey 1980).

It follows that the whereabouts of reserves must still be established and their size and quality proved by the customary detailed exploration and evaluation undertaken by industry. However, the information provided by this survey should assist in the selection of possible sites suitable, in geological terms, for further investigation. The following arbitrary physical criteria have been adopted:

1. The deposit should average at least 1m in thickness.
2. The ratio of overburden to sand and gravel should be no more than 3:1.
3. The proportion of fines (particles passing a 0.625 mm B. S. sieve) should not exceed 40 percent.
4. The deposit should lie within 25 m of the surface, this being taken as the likely maximum working depth under most circumstances. It follows from the second criterion that boreholes are drilled no deeper than 18 m if no sand and gravel has been proved.

A deposit of sand and gravel that broadly meets these criteria is regarded as 'potentially workable' and is described and assessed as 'mineral' in this report.

Pre-Pleistocene rocks, which are usually consolidated and devoid of potentially workable sand and gravel, are referred to as 'bedrock'; 'waste' is any material other than bedrock or mineral; 'overburden' is waste that occurs between the surface and an underlying body of mineral.

For the particular needs of assessing sand and gravel resources, a grain-size classification based on the geometric scale 1/16 mm, 1/4 mm, 1 mm, 4 mm, 16 mm, 64 mm has been adopted. The boundaries between fines (that is, the clay and silt fractions) and sand, and sand and gravel grade material, are placed at 1/16 mm and 4 mm respectively (Giles, 1982, Appendix C).

The volume and other characteristics of the mineral are assessed within resource blocks, each of which, ideally contains approximately ten square kilometres of sand and gravel. No account is taken of any factors, for example roads, villages or land of high agricultural or landscape value, which might stand in the way of sand and gravel being exploited, although towns are excluded. The estimated total volume therefore bears no simple relationship to the amount that could be extracted in practice.

It must be emphasised that the assessment applies to the resource block as a whole; valid conclusions cannot be drawn about mineral in parts of a block, except in the immediate vicinity of the actual sample points.

The geology of the solid and drift deposits are described in the stratigraphical section of this report.

Composition of the sand and gravel resources

The unconsolidated aggregate resources of the district consist of glacial and fluvial sand and gravel. Details of boreholes and gradings from these deposits are presented in Giles & Williamson (1985) or are commercially confidential but the information has been collated and interpreted, and is presented below in general terms.

Glacial Sand and Gravel

Potentially workable glacial sand and gravel has an overall mean grading of 12% fines, 44% sand and 44% gravel. However, the deposit exhibits considerable variation: borehole and section mean gradings range from 'very clayey' sandy gravel to gravel.

The gravel fractions are mainly coarse and the clasts are predominantly rounded to angular. Carboniferous sandstone commonly accounts for over 90% of the gravel, but cherts and ironstone may be significant components: subordinate constituents include siltstone, mudstone and quartz. Aggregate impact values BS 812 (British Standards Institution, 1975) for composite samples yielded an average value of 41. The sand fraction is mainly medium with subordinate amounts of fine and coarse. The sand is generally subangular to rounded quartz with lithic grains, the latter dominating the coarse grades. Fines consist of yellowish brown silt and clay.

Fluvial Sand and Gravel

River Terrace Deposits (Undifferentiated), Second River Terrace Deposits, First River Terrace Deposits and Alluvium are considered under this heading. The potentially workable fluvial deposits range from 'very clayey' pebbly sand to gravel. The mean grading for the deposits is 12% fines, 55% sand and 33% gravel. The fines are composed of silts and clays. The sand is composed of angular to rounded quartz with lithic grains, the latter of which comprise a greater percentage of the coarse fraction. The modal sand grade is medium with significant amounts of coarse. The gravel is normally fine and composed of rounded to subangular Carboniferous sandstone which commonly forms more than 90% of the clasts. Minor amounts of siltstone, mudstone, chert, quartz, ironstone and coal together form the remaining 10%. Aggregate Impact Values for composite samples range between 40 and 42.

Mineral Resource Information

The summary sand and gravel resource map presented in Figure 12 is a reduced composite of the original 1:10 000 scale Thematic Geology Maps prepared by Giles and Williamson (1985) and Giles (1987). Site-specific data is not shown on Figure 12 since the scale of the figure is too small. The non-confidential data may be examined by application to the National Geoscience Data Centre, British Geological Survey, Keyworth, Nottingham.

The mineral-bearing ground in the district is divided into resource blocks (Giles 1982, Appendix A). Within each resource block the mineral is subdivided into areas where it is exposed, that is, where the overburden averages less than 1 m in thickness, and areas where it is present in continuous (or almost continuous) spreads beneath overburden.

Areas where bedrock crops out, where boreholes indicate the absence of sand and gravel beneath cover, and where sand and gravel beneath cover is not thought to be potentially workable are unornamented on the map. In such cases, it has been assumed that the mineral is absent except in infrequent and relatively minor patches that can neither be outlined nor assessed quantitatively in the context of this survey. Areas of unassessed sand and gravel, for example in built-up areas, are indicated by a stipple.

The area of mineral-bearing ground is measured, where possible, from the mapped geological boundary lines. The whole of the area is considered as mineral-bearing, even though it may include small areas where sand and gravel is not present or is not potentially workable.

Results

The statistical results are summarised in Table 6. The statistical methods used are outlined in Giles (1982, Appendix B).

For the three resource blocks, assessed at the indicative level, the accuracy of the results at the 95 percent probability level (that is, on average nineteen out of every twenty sets of limits constructed in this way contain the true value for the volume of mineral) is between 15 and 53 percent. However, the true volume is more likely to be nearer the figure estimated than either of the limits. Moreover, it is probable that roughly the same percentage limits would apply for the statistical estimate of mineral volume within a very much smaller parcel of ground (say 100 hectares) containing similar sand and gravel deposits, if the results from the same number of sample points were used in the calculation. Thus, if closer limits are needed for a quotation of reserves, data from more sample points would be required, even if the area were quite small. It must be emphasised that the quoted volume of mineral has no simple relationship to the amount that could be extracted in practice, as no allowance has been made in the calculation for any restraints (such as existing buildings and roads) on the use of the land for mineral workings.

Notes on the resource block

Geological criteria have been used to designate the boundaries of the resource blocks. Blocks A and C include all the fluvial sand and gravel of the various river terrace deposits and alluvium, whilst Block B contains the glacial sand and gravel.

Several large colliery spoil tips rest directly on fluvial sand and gravel in Blocks A and C. The additional thickness of material, if treated as overburden, may render the sand and gravel beneath as not 'potentially workable'. However, the colliery spoil tips may be considered as a minestone resource, although no formal minestone resource study has been published. Arbitrary decisions have been made during the present work as to whether the sand and gravel beneath a spoil tip was included in the resource assessment. This depended primarily upon the size of the deposit and the nature of the spoil.

Block A

The assessment of this block uses information from two boreholes specially drilled for the purpose (Giles and Williamson 1985), three records of natural sections and information from 19 borehole records in the BGS archives; 12 of which are held commercially in confidence. These data record a range of mineral thicknesses between 0.8 m and 13.4 m, with a mean value of 4.3 m. In five records the total mineral thickness was not proved. Consequently any estimate of sand and gravel resources based on this data set will be conservative. The mean grading for the block is 12% fines, 44% sand and 44% gravel.

There are several small, largely overgrown, quarries which formerly exploited the fluvial deposits for local use and have made no significant inroads into the resource. No commercial sand and gravel extraction from within the resource block is known, although substantial areas have been extracted, largely as overburden, during opencast coal mining. St Aidans Extension Opencast coal site is currently removing large areas of fluvial sand and gravel south of the former hamlet of Astley.

The volume of potentially workable sand and gravel resources of this block is 40.8 million m^3 ± 31%.

Block B

The resources in this block comprise only a small fraction of the mineral on the resource sheet. However, they are geologically distinct and are treated separately. The glacial sand and gravel is closely associated with the till. Together they form spreads on the interfluves between the Aire and Calder, masking the former topography. Opencast prospecting boreholes suggested that the glacial sand and gravel extends beneath the till. Two boreholes (Giles and Williamson 1985) were drilled to see if this is so. Both boreholes proved thick till which was, in part, very pebbly, which could have been interpreted as sand and gravel, in the returns from a shell and auger rig, by an inexperienced operator.

The resource has been exploited in a number of localities by small-scale quarries for local use. In addition, several opencast sites have removed glacial sand and gravel, as overburden.

The resources are estimated using results from the two boreholes drilled for the purpose, seven collected sections and a number of confidential boreholes including opencast prospecting boreholes. These record a mean thickness of 2.4 m of sand and gravel. However, as none of the collected sections recorded the full thickness of the deposit, this is a conservative estimate. The volume of sand and gravel is 2.2 million m^3 ± 53%. The large confidence limits reflect the degree of uncertainty in assessing this block. The mean grading is 12% fines, 55% sand and 33% gravel.

Block C

Geological criteria have been used to designate the boundary of the resource block. The block is composed entirely of fluvial sand and gravel of the various river terrace deposits and alluvium. The assessment of the block used information from BGS archives. This included site investigation boreholes, several resource surveys of the deposits by commercial concerns and selected British Coal opencast exploration boreholes. A total of 71 boreholes were used.

One large quarry currently exploits the resources. Other much smaller quarries may have extracted small areas of sand and gravel for local use, but no records exist of their former extent or depth. British Coal opencast sites have removed significant areas of sand and gravel during excavations for coal, for example at the Lowther

Table 6. The sand and gravel resources of the district: statistical assessment.

	Block Area		Mean Thickness		Volume of sand and gravel	Limits at the 95% probability level
	Block	Mineral	Overburden	Mineral		
	km^2	km^2	m	m	$m^3 x 10^6$	$m^3 x 10^6$
A	9.8	9.5	4.3	4.3	40.8	31
B	2.2	0.9	2.4	2.4	2.2	53
C	8.5	8.5	2.5	5.1	43.4	15

North and Extension Site. In addition, large areas of this resource block are underlain by potential opencast coal resources, several areas of which have been prospected in the past.

Several large colliery spoil tips rest on alluvium. These areas have been excluded from the resource block and have not been assessed. However, the situation could change if parts of these tips were used as minestone in the future.

The mean overburden thickness is 2.5 m with a range of between 0.15 m and 6.70 m. Waste partings are recorded in a number of boreholes and these range in thickness from 0.15 m to 2.89 m, and are normally composed of soft clay or silts. The sand and gravel has a mean thickness of 5.1 m and a range of between 0.30 m and 14.63 m. Several boreholes in the resource block record peat, silt and clay instead of sand and gravel.

The volume of potentially workable sand and gravel resources in this block is 43.4 million $metres^3$ ± 15 percent.