BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WA/91/28

Onshore Geology Series

South-west Essex–M25 corridor

Applied geology for planning and development

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Cover illustration

Map of the area covered by the survey

Geographical index

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Preface

This report describes the results of a three and a half year project to investigate the geology of south-west Essex and part of the London Borough of Havering falling within the M25 'corridor'. The study was commissioned by the Department of the Environment and jointly funded by the Department and the British Geological Survey.

Since the completion of the M25 London Orbital Road the area has been the focus of much commercial, industrial and residential development. This will almost certainly continue, aided by the recent opening of the new road bridge across the River Thames at West Thurrock, to alleviate the long delays often associated with the heavily congested Dartford Tunnel. The route of the proposed Channel Tunnel rail link also passes nearby, and thus the area will be ideally situated for the collection and distribution of exported and imported goods. There will thus be a continuing requirement for good quality building land, and local mineral resources for the construction industry. These needs will inevitably conflict with the requirement to protect the areas of 'green belt' surrounding the urban developments.

This study provides up-to-date geological maps, including a number of thematic maps, each outlining a specific aspect of the geology, together with specialist reports, as a basis for safe and cost-effective planning and development, for assessing and safeguarding mineral and other exploitable resources, and for land use planning in terms of conservation requirements.

Geological surveys of the districts around Brentwood, Billericay, Upminster, Laindon (Basildon) and Grays have been completed for the following 1:10 000 sheets: TQ 57 NE; TQ 58 NE, SE; TQ 59 SE; TQ 67 NW, NE; TQ 68 NW, NE, SW, SE; TQ 69 SW, SE. The area reported on falls mainly within the 1:50 000 Geological Sheets for the country around Romford (257), Southend and Foulness (258/259) and Dartford (271) but also includes a small part of the Chatham (272) sheet.

The area was surveyed previously on the six-inch to one-mile scale by H G Dines, F H Edmunds and T I Pocock between 1902 and 1923, with later amendments in the south by R J Wyatt in 1966. The area lying within the Southend and Foulness sheet (258/259) was resurveyed at the same scale by R D Lake and C R Bristow in 1972.

The recent 1:10 000 resurvey was carried out by A. Smith, B S P Moorlock, M C McKeown, R A Ellison and R D Lake as shown below:

TQ 57 NE, BSPM; TQ 58 NE, AS; TQ 58 SE, BSPM; TQ 59 SE, RAE/MCM; TQ 67 NW, BSPM; TQ 67 NE, AS/MCM; TQ 68 NW, AS; TQ 68 NE, AS; TQ 68 SW, AS/BSPM/MCM; TQ 68 SE, AS; TQ 69 SW, AS/MCM; TQ 69 SE, MCM/RDL/BSMP. Land to the south of the River Thames on the southernmost sheets was not surveyed.

The assistance of landowners, Local Authorities, public utilities, quarry operators, geotechnical consultants and others who have allowed access to land and have generously provided information including numerous borehole records is gratefully acknowledged.

LIMITATIONS

Where representative sections of the different rock types are cited in the text, the onus is on persons wishing to visit the site to first obtain permission from the landowner.

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

Executive summary

This study was commissioned by the Department of the Environment and funded jointly by the Department and the British Geological Survey (BGS). Its principal aim was to produce a synthesis of geological information relevant to the planning of land use and development in south-west Essex and that part of the London Borough of Havering adjacent to the M25 London Orbital Road. This report was written specifically for those involved in planning and development. Geological terms have been kept to a minimum, but for those that are necessary a glossary is appended. Much of the information is provided by a series of thematic maps, each one highlighting a specific aspect of the geology. For those requiring a greater depth of geological background, additional sources of information relevant to the area are indicated.

The study area is approximately 280 km^2 in size. It stretches from Brentwood in the north to the River Thames in the south and takes in what is commonly referred to as the M25 corridor. In addition to Brentwood it includes the major towns of Billericay, Upminster, Grays and the western part of Basildon.

The area is covered by the British Geological Survey 1:50 000 sheets for Romford (257), Southend and Foulness (258/259), Dartford (271) and Chatham (272).

Much of the land lies below 40 m OD, but rises in the north and north-east, reaching a maximum of about 120 m OD just south of Basildon. Apart from the River Thames, the main drainage is via the Mar Dyke, a small stream which flows south through the central part of the district; the River Crouch drains the north-east, and the River Ingrebourne the north-west.

The economy of the area is mixed, with agriculture predominating in the central part, whereas industry is concentrated around the major towns, along the River Thames, and increasingly so in estates adjacent to the M25 motorway. Despite a general decrease in river trade, Tilbury remains one of Britain's biggest ports, with facilities for handling container shipments and other commodities. Much of the former extensive extraction of chalk, clay, and sand and gravel has now ceased, with many of the former workings occupied by housing and trading estates.

As the main objective is to provide geological information relevant to planners and developers, this report concentrates on four main aspects; (*i*) geological hazards which include both natural hazards such as landslips, and those related to former quarrying and mining; (*ii*) the engineering characteristics of the various deposits at or near to the surface, and the related engineering problems associated with the deposits; (*iii*) the hydrogeological characteristics of the area, its water resources and problems of aquifer protection, for example with respect to waste disposal; (*iv*) the nature and extent of mineral resources.

The information used to compile this report was acquired in two ways. Firstly a complete resurvey of the study area was undertaken on the ground, recording details of exposures, auger-holes and surface features, at a scale of 1:10 000. Information gathered from previous surveys held in the BGS archives has been especially valuable in areas subsequently built over where present day evidence is meagre. Aerial photographs obtained immediately prior to field-work were used in conjunction with the topographic base maps.

Secondly data were sought from various others sources, including regional and local government, Anglian Water, the Central Electricity Generating Board, the Port of London Authority, the Ministry of Transport, museums and libraries, and numerous geological and geotechnical consultants. These data were mainly in the form of site investigation reports, with logs of boreholes or trial pits, and the results of geotechnical tests. Much of the additional information obtained is confidential and therefore direct reference to it cannot be made in this report. Other information has been obtained from a wide search of the geological literature.

The data from the field survey and secondary sources have been combined to produce a series of twelve 1:10 000 scale geological maps and reports giving local details of the deposits.

Geological hazards

Several geological hazards or constraints on development have been recognised in the area. Each is described separately. Firstly the causes and effects are explained; secondly the rock or soil types, and hence the areas at risk, are identified; and lastly an indication of typical precautionary measures is given.

The major hazards all involve ground instability and include landslips, subsidence, ground heave, compressible strata and unstable excavations.

Landslips result from the mass movements of ground down unstable slopes under the action of gravity. Both major rotational failures and shallow translational movements occur and may be triggered by many factors such as the erection of new buildings, excavations, changes in the drainage or the removal of trees.

Within the study area landslips occur principally on the Claygate Beds, and to a lesser extent on the London Clay, particularly on hillslopes steeper than 7°, and commonly also involve the superficial veneer of Head which has pre-existing shear planes or weaknesses. Thus they are found in the northern part of the area including the outskirts of Brentwood, Billericay and Laindon where also there is increasing pressure for development.

Although it is possible to build on landslips or at-risk slopes, the engineering solutions inevitably increase the cost of development and it is preferable to use such difficult ground for open space parks, nature reserves or leisure activities.

Subsidence results from the collapse of the ground into shallow mining chambers (known as Deneholes) and natural solution cavities in the Chalk in the southern part of the area.

Open holes or depressions may be created at the surface or the problem may be recognised by the structural damage to buildings caused by settlement. Not only is the land underlain directly by Chalk at risk but also the land underlain by the overlying Thanet Beds and river terrace gravels, and possibly also the Woolwich and Reading Beds.

Subsidence into an existing void may be triggered by construction works or traffic vibration and can propagate upwards through the overlying strata for 20 m or more. Although locations of many of the man-made Deneholes are recorded, many other occurrences almost certainly remain undetected or undocumented. A thorough site-investigation in at-risk areas is therefore essential, employing suitable modern geophysical techniques, prior to any development taking place.

Ground heave is the movement of the ground, caused here by the marked shrinkage and swelling of shrinkable clay as it is alternately dried and wetted.

Although the movement may be slight, heave is capable of doing considerable structural damage to buildings as seen during the severe drought of 1976 which caused widespread settlement cracks in walls and foundations. Differential movements, where one part of a building is subject to heave and another part is not, often do the most damage and are caused by variation across a site, for example the presence of an old pond, ditch or vegetation. Tree roots dry out a site and these when cleared prior to development allow the clay to swell back again, perhaps resulting in damage many years later.

Ground heave is a problem over all of the London Clay outcrop, much of the Claygate Beds and the superficial Head deposits derived from these formations. Modern construction practise based on a detailed site-investigation, including the history of the site, should avoid most of the problems.

Compressible strata allow poorly designed buildings to settle by excessive amounts with resulting structural damage. The problem is most pronounced where uncompacted saturated peat is compressed by an additional load such as a new building so that as water is squeezed out the ground level drops. Similar problems affect soft saturated alluvial silts and clays, particularly if they are also peaty, as well as artificial ground in landfill sites and areas of made ground.

The main areas at risk are the coastal plain where the thick deposits of Estuarine Alluvium contain several layers of peat, and the alluvial tract along the Mar Dyke valley. The problem can be overcome by detailed site-investigation and good design which typically requires the use of rafted or piled foundations.

Unstable excavations are a potential problem over much of the area, affecting almost all the superficial and bedrock formations somewhere according to the lithology and the groundwater conditions. Particular care has to be taken when digging holes because of the danger of side-wall collapse.

The Estuarine Alluvium is most at risk with its saturated cohesionless sand and plastic clay sediments and the digging of trenches requires extensive use of sheet piles.

The factors above all concern instability. In addition there are a number of other geological hazards of a varied nature.

High groundwater levels cause trenches to flood with water and saturated sediment which may cause the trench walls to collapse. These difficulties which make excavations more dangerous and costly may be found in both superficial deposits and bedrock formations throughout the area according to the local geology, hydrogeology and the surface drainage pattern.

The problem is most widespread on the Estuarine Alluvium of the coastal plain and the Alluvium along the lower part of the Mar Dyke but it is also found on the Claygate Beds which commonly have perched water tables issuing as springs.

Providing that an adequate site-investigation is carried out which records water strikes in boreholes and rest-water levels on completion the potential problems should be foreseeable and therefore preventable by the use of sheet piles and pumping.

Flooding is a potential problem for the extensive coastal plain in the south and the low-lying ground along the Mar Dyke. In the past these areas were avoided by agriculture and developments alike, but the improvements to drainage have transformed these former marshes into arable fields and there is now increasing pressure to build on them.

The seawall defences along the Thames have been raised in conjunction with the building upstream of the Thames Barrier to offer protection in the event of an unusually high surge tide, but there is increasing concern that the problem may be compounded by a general rise in sea level associated with 'Global Warming' or the 'Greenhouse Effect'.

The consequent long term risk of inundation of low coastal areas makes it ever more important for a strategic viewpoint to be taken to ensure that new developments are free from this risk.

Derelict worked ground is particularly widespread in the borough of Thurrock in the southern half of the area. Here there are many former chalk quarries which remain as deep holes in the ground surrounded by vertical faces. Situated on the important Chalk aquifer, which needs protecting from pollution, these holes were not backfilled because of the lack of a suitable cheap inert fill available in large volumes. As a consequence they were simply abandoned with no attempt made at restoration. The shallower disused sand and gravel pits are easier to backfill but many have been only crudely reinstated and remain derelict.

More effort has recently gone into land reclamation and some of the chalk quarries are now being developed for housing, most notably the Chafford Hundred site near Grays.

Landfill sites and landfill gas pose two types of problem to development: firstly there are the engineering aspects of building on heterogeneous and unconsolidated material; secondly the waste or its products may be dangerous and require specialised treatment. Furthermore potentially harmful gases and leachates may seep out of the landfill and affect an area larger than the site itself.

Each site needs to be assessed separately as no two will be the same. The need to protect aquifers and therefore the water supply from pollution by toxic waste is obvious. More recently the problem of inflammable landfill gases, produced by the decay of putrescible waste, has been recognised and official guidance issued on its control. The design of landfill sites needs to take careful account of the local geology and hydrogeology in order to protect the environment.

Sulphate in groundwater attacks and weakens concrete foundations. This is widespread problem, though not a major one, for development in the area. The sulphate ions are derived from gypsum which is common across the extensive weathered outcrop of London Clay and the Head deposits derived from it.

The problem is readily solved by using sulphate resistant cement or other techniques according to the results of the site-investigation.

Mineral Resources

The former large-scale extraction of a variety of bulk minerals has blighted much of the southern half of the study area.

Chalk - cement manufacture - agricultural lime

Chalk for use in the manufacture of cement has been quarried extensively from large workings in the Purfleet-Grays area, but production ceased several years ago because of exhaustion after most of the quarries had reached both their maximum areal extent and maximum depth. Subsequently many of the quarries have either been, or are in the process of being, redeveloped as industrial, trading or residential estates. Chalk for agricultural lime was being dug at the time of the survey, at Purfleet and at West Thurrock, from two quarries, both scheduled for closure in the near future.

The cement-making industry is now centred south of the Thames, in Kent, and it is extremely unlikely that the relatively small areas of chalk remaining at outcrop in the Purfleet-Grays area would be considered for future extraction.

Chalk has been dug from numerous underground chambers, known as 'deneholes' or 'daneholes', reached by vertical shafts through as much as 20 m of the overlying terrace gravels and Thanet Beds. On reaching the chalk a number of chambers, usually arranged in a double trefoil pattern, were excavated. There has been much discussion regarding the reason for digging the chambers, with grain stores and hiding places having been suggested, but perhaps the most likely explanation is that they were dug as a source of lime for spreading on the acid soils developed on the overlying terrace gravels and sands of the Thanet Beds. Another suggestion is that they were dug as a source of whiting.

Clay - cement manufacture

London Clay, for use in the manufacture of cement, was dug formerly from pits at Aveley, but is currently worked about 5 km to the east at South Ockendon. Both these areas lie within the lower part of the London Clay where the chemical composition of the clay, particularly the Al_2O_3/SiO_2 ratio, is suitable for cement making. The lower part of the London Clay elsewhere in the area will almost certainly be of similar composition, but the suitability of clay in the higher parts of the formation is not known.

Clay - brick and tiles

Bricks and tiles have been made from a variety of deposits in the area, including the Woolwich and Reading Beds, the London Clay, the Claygate Beds, Till, Glaciolacustrine Deposits, Interglacial Deposits, Head and Alluvium. The town of Grays developed around the brick making industry, and in the nineteenth century about 500 men were employed there making bricks for Martello Towers. When the Interglacial Deposits or 'brickearth' became exhausted the industry ceased. Elsewhere in the area, brickmaking has been on a limited scale, though tiles were formerly manufactured at Aveley from material dug locally from the Woolwich and Reading Beds.

Although the London Clay has been dug locally for brick making, it is unlikely that it will be considered on a commercial scale in the foreseeable future, the manufacturers of bricks preferring the partially self-firing Oxford Clay available in the Bedford and Peterborough areas.

Sands

In the south sands have been dug from both the Thanet Beds and the overlying Woolwich and Reading Beds. These formations have a combined average thickness of about 40 m. In both formations the sands are silty and fine-grained, but those of the Woolwich and Reading Beds have a noticeably higher clay content with thin seams of clay present. The Thanet Beds are pebble-free except in the uppermost metre or so, whereas the Woolwich and Reading Beds contain pebbles of rounded black flints, commonly concentrated into thin gravel lenses or more continuous beds. At Orsett Cock an unusually thick development of gravel occurs and is worked commercially. The sands of the Woolwich and Reading Beds, have only a limited use, mainly as fill for road embankments and disused workings. Many of the pits worked for sand first exploited the overlying terrace gravels. At the time of survey six sand pits were in operation but extensive areas of Thanet Beds and Woolwich and Reading Beds remain, particularly between Grays and Stanford-le-Hope. These areas could provide useful resources from borrow pits should a local need arise.

In the north the Bagshot Beds occupy much of the higher ground. These sands are predominantly fine-grained and contain seams of clay. Much of their outcrop has either been built over or occupies areas of high scenic beauty. The sands have been worked in the past on only a limited scale, mainly for individual farm use. They have a maximum presumed thickness in the area of about 15 m.

Gravels

River terrace gravels have been dug extensively in the southern half of the district, where in many places only the ground beneath roads remains unworked. Large spreads of gravel have been sterilised by the towns of Grays and Chadwell St Mary, and by the more recent construction of the London-overspill town of South Ockendon.

Large areas of terrace gravels remain unworked but information regarding their composition and thickness is generally lacking or of a confidential nature.

Gravels have also been dug at shallow depth beneath Estuarine Alluvium near East Tilbury, and are also present beneath similar deposits to the south of Grays and farther west at West Thurrock, but there lie at a depth of about 15 m below the surface, and thus are unlikely to be commercially viable, at least in the near future.

Glaciofluvial Sand and Gravel occurs as isolated patches, commonly intimately associated with Till (boulder clay), in the north of the study area. In thickness and composition these gravels are much more variable than the river terrace gravels. They may also contain pebbles of chalk, beneath the decalcified weathered top, which renders them unsuitable for some purposes.

The glaciofluvial gravels have been worked on a small scale, mostly just for farm use, although some larger workings are present to the south of Brentwood.

As noted above, the Woolwich and Reading Beds are locally gravelly and are currently being exploited for gravel at the Orsett Cock Pit, just south of the A13 trunk road.

Landfill gas (65% methane/35% carbon dioxide)

Landfill gas produced on a site at Aveley is collected via a network of pipes, compressed and pumped some 5 km to the Purfleet Board Mills on the north bank of the River Thames. The gas, which is used to fuel a steam-raising boiler, is supplied at a discount compared with natural gas, to encourage its use. A landfill site at Mucking Marshes in the extreme east of the study area is currently being developed with the commercial production of gas in mind. Elsewhere the uncontrolled production of landfill gas is a potential hazard rather than a resource.

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ACCOMPANYING MAPS

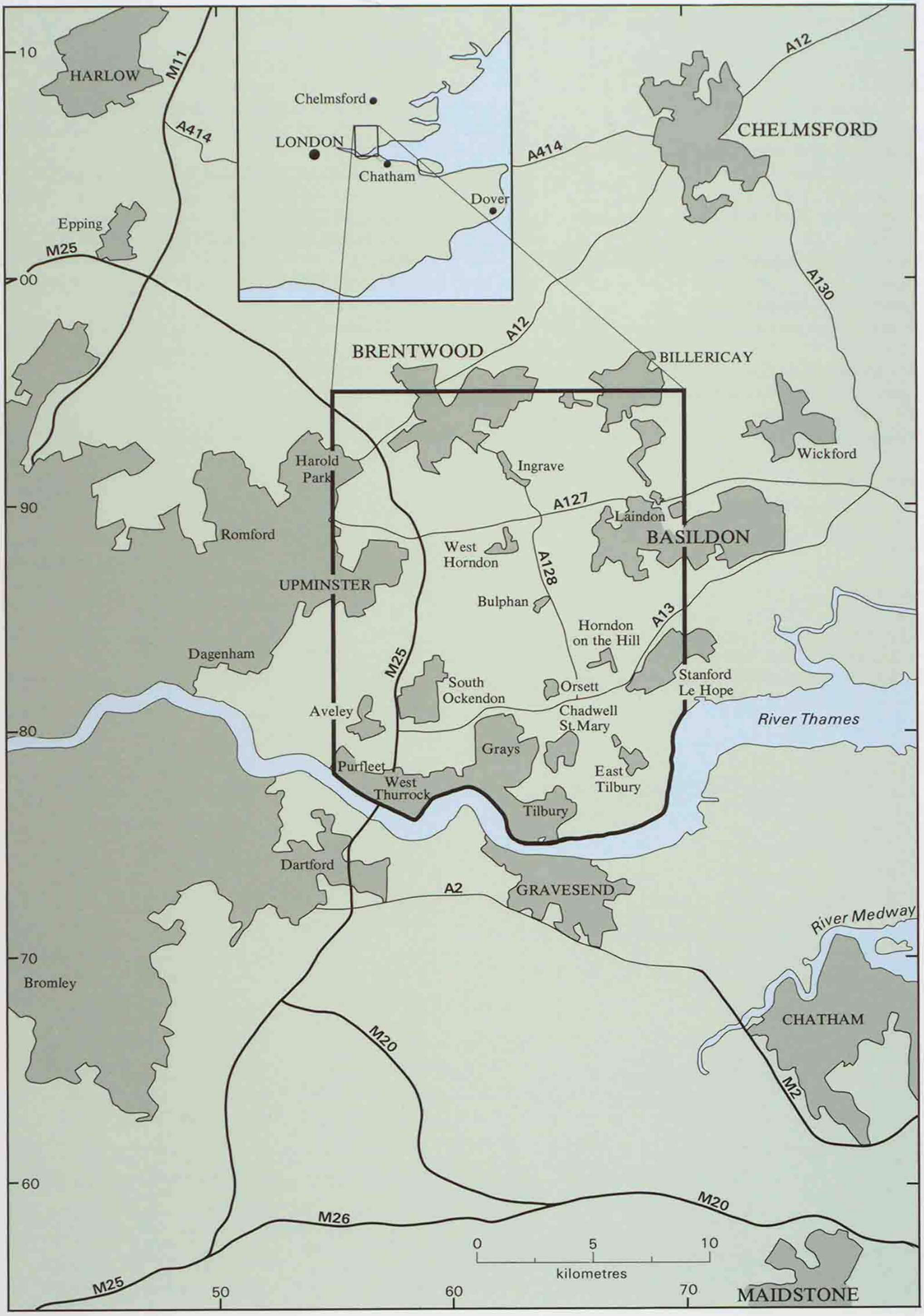


Figure 1 Sketch map showing location of study area

1 Introduction

1.1 OBJECTIVES

The data summarised in this report were obtained during a three and a half year programme of work commissioned by the Department of the Environment and jointly funded by the Department and the British Geological Survey (BGS). The objectives of the study have been to provide up-to-date geological maps, including a number of specific theme maps, and specialists reports, as a basis for safe and cost-effective planning for development, for assessing and safeguarding mineral and other exploitable resources, and for land use-planning in terms of conservation requirements.

This report has been written specifically for planners and developers. Geological terms have therefore been kept to a minimum, but for those that are necessary a glossary is appended. For those requiring a more detailed geological account of the area, a list of additional BGS reports and maps can be found in Appendix 1.

1.2 THE USE OF THIS REPORT

It must be stressed that the information provided in this report and on the various maps has been obtained from a variety of sources. It is interpretive,and based on data which are of variable quality and distributed unevenly. Consequently the report and maps should be used for preliminary investigations only. They must not be considered as a substitute for on-site investigations. Rather they should be used as a reference source providing regional and background information to assist in the interpretation of a specific site.

It is strongly recommended that the report and maps be used in conjunction with each other. This report also contains references to other more detailed sources of information, for example the BGS archives of non-confidential boreholes, and other data, including most importantly the 1:10 000 geological standards, technical reports, and the original field maps which are the fundamental source on which much of this report is based.

1.3 THE STUDY AREA

The study area (Figure 1) falls mainly within south-west Essex, but also includes the eastern part of the London Borough of Havering, formerly within the Greater London Council. To the north the area is bounded by the towns of Brentwood and Billericay; to the west by Upminster and Purfleet; to the east by the western outskirts of Basildon and Stanford-le-Hope, and to the southby Grays and the River Thames. The small towns of Aveley, South Ockendon, West Thurrock and Tilbury also lie within the study area. The distribution of the towns and the administrative planning districts is shown in Figure 2.

Since the completion of the M25 London Orbital Road, the area has been the focus of much commercial, industrial and residential development. This will almost certainly continue, aided by the construction of a new road bridge across the River Thames at West Thurrock to alleviate the delays often associated with the heavily congested Dartford Tunnel. The area is also well suited geographically for access to the Channel Tunnel, due to be completed in the early 1990s.

There will thus be a continuing requirement for good quality building land and local mineral resources for the construction industry. These needs will almost certainly conflict with the protection of the 'green belt' areas surrounding the urban developments.

1.4 PHYSICAL GEOGRAPHY AND GEOMORPHOLOGY

The area abuts on to the north bank of the River Thames. Most of the area lies within the catchment of the Mar Dyke (Figure 3), a relatively small river, which flows southwards through the central area, then changes to a west-south-westerly course before entering the River Thames to the north of Purfleet. The only other significant streams are the River Crouch which flows eastwards between Billericay and Basildon and the River Ingrebourne in the north-west. In the south, sands and gravels deposited by the River Thames, when it flowed at higher levels than at present, now form a sequence of river terraces producing a stepped topography rising from the present flood plain to over 40 m OD.

To the south of South Ockendon the Mar Dyke occupies a deep gorge-like channel cut into bedrock. Hereabouts the position of the valley is controlled by the Purfleet Pericline, a broad dome-shaped fold bringing the relatively hard and resistant Upper Chalk to the surface in its core. Upstream the central part of the area is dominated by the Mar Dyke valley which broadens above the relatively soft and easily eroded outcrop of the London Clay, with extensive tracts of alluvial deposits, in places over 1 km wide, forming a flat base to the valley. Large areas of land surrounding the stream lie at a height of less than 10 m OD and are subject to flooding, especially following periods of rain when the ground has been saturated from previous rainfall.

To the north and east of the Mar Dyke valley, the land rises onto the outcrop of the Claygate Beds, a sequence of interbedded sands and clays, where landslipping is a common phenomenon. The highest ground occurs at Westley Heights near Basildon (118 m OD), Brentwood (109 m OD) and at Billericay (over 100 m OD) where sands of the youngest bedrock formation, the Bagshot Beds, are commonly overlain by relatively resistant superficial sands and gravels, and till (boulder clay).

1.5 OUTLINE OF GEOLOGY

The geological sequence is shown in Table 1.

The deposits of the area can be divided into two main groups, the **superficial (Drift) deposits** (Figure 4) and the **bedrock (Solid) formations** (Figure 5). Whereas the bedrock formations were deposited over a period of more than one hundred million years, the superficial deposits have all formed within the last one million years. The bedrock formations are usually arranged in a 'layer cake' sequence making it possible to predict the next layer in the sequence. Within the present area the beds dip generally northwards so that the

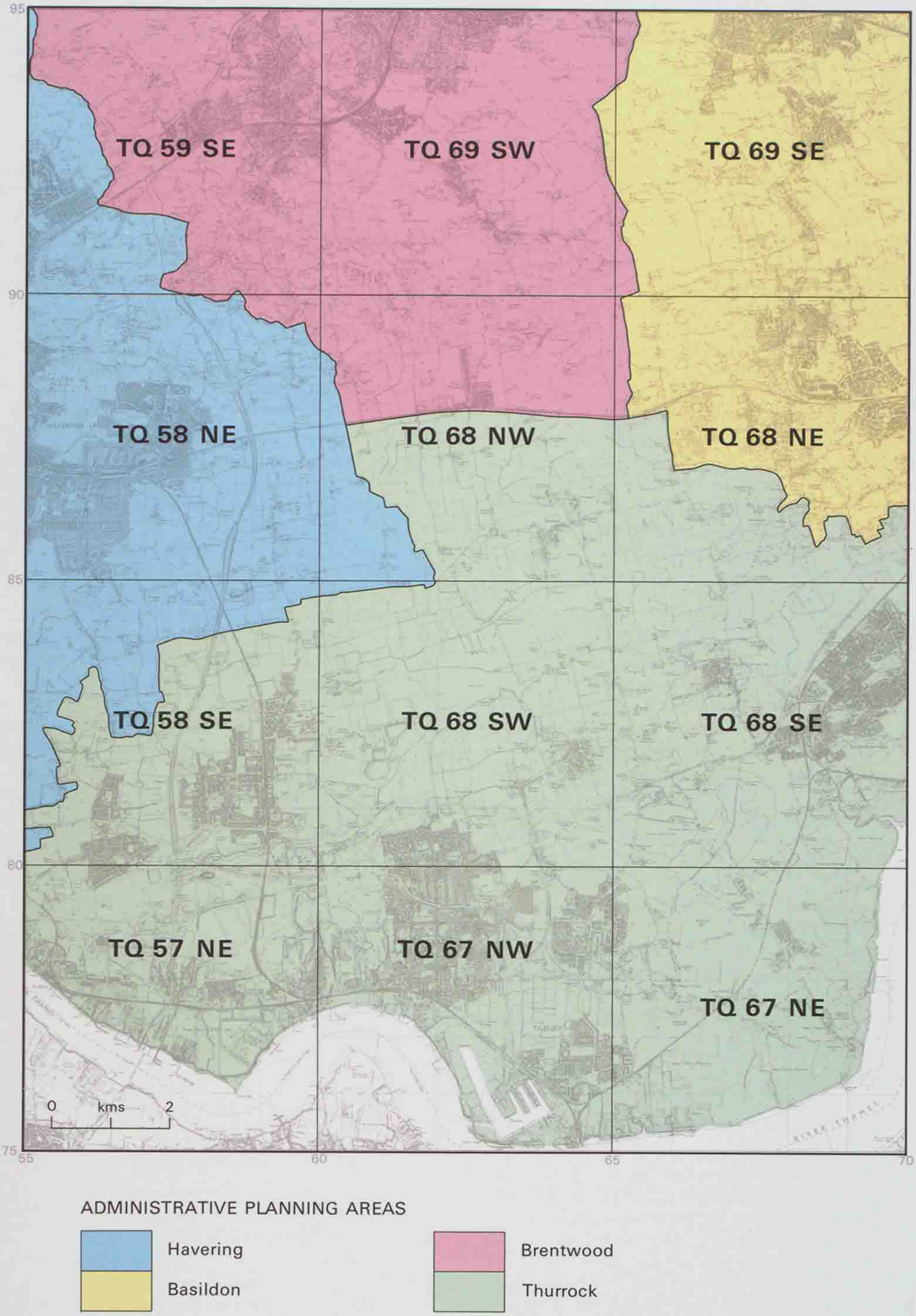


Figure 2 The study area showing administrative planning districts and towns

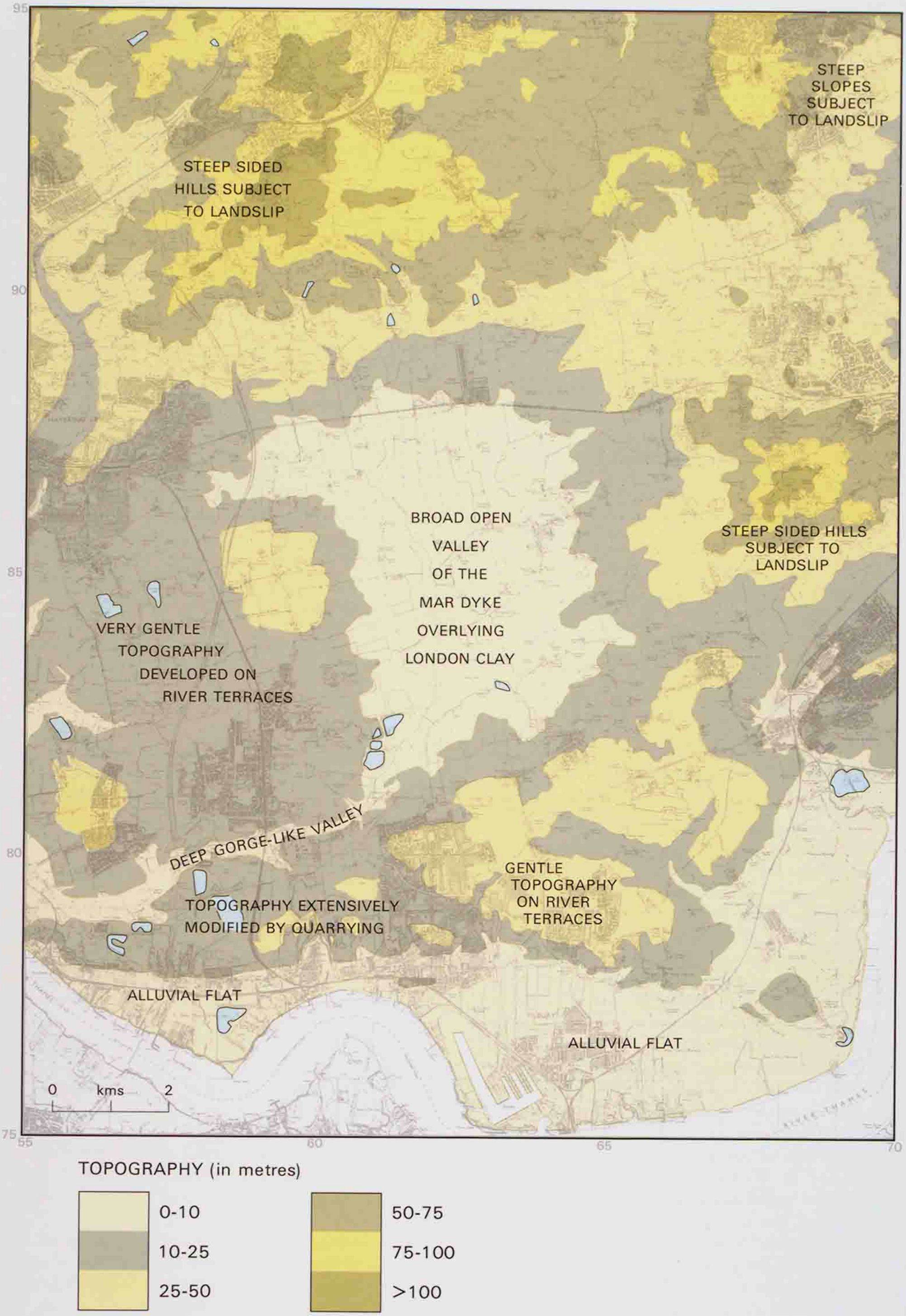


Figure 3 The study area showing topography and main geomorphological features

Table 1 geological sequence

	DISTURBED GROUND	
	Made Ground	
	Worked Ground	
	Landslip	
	SUPERFICIAL DEPOSITS	
QUATERNARY	Peat	
	Alluvium	
	Intertidal Deposits	
	Estuarine Alluvium	
	River Terrace Deposits	
	Head	
	Head Gravel	
	Combe Deposits	
	Interglacial Deposits	
	Glaciofluvial Sand and Gravel	
	Glaciolacustrine Deposits	
	Till (Boulder Clay)	
	Older Head	
	Sand and Gravel of Unknown Age	
	BEDROCK	
TERTIARY	Bagshot Beds	
	Claygate Beds	
	London Clay	
	Oldhaven Beds	
	Woolwich and Reading Beds	
	Thanet Beds	
MESOZOIC	Upper Chalk	
	Middle Chalk	not seen at the surface: proved only in boreholes
	Lower Chalk	
	Upper Greensand	
	Gault	
	Lower Greensand	
	Oxford Clay	

oldest beds seen at the surface are in the south, with the youngest in the north. The superficial deposits include a large variety of sediment types, many of which were deposited on an irregular land surface by a variety of agencies, such as water, wind or ice, and are unstratified or only crudely bedded, and of variable thickness. Because of this their distribution tends to be patchy, and commonly unpredictable at depth where overlain by younger deposits. Their period of deposition was characterised by a series of glacial advances and retreats. Material picked up by the advancing ice sheets was later deposited as till (boulder clay). Torrential streams issuing from the ice sheets deposited glaciofluvial sands and gravels. During warmer interglacial phases, and also after the ice finally retreated from the area, fore-runners of the present rivers eroded and transported the glacial debris and redeposited it on the valley floors as bedded sands and gravels. During this period several changes occurred in the relative levels of the land and sea. With static or rising sea level, accumulation of sand and gravel occurred in the valleys; during periods of relative fall, the rivers cut their channels deeper, leaving the older sands and gravels at higher levels perched on the valley sides, and forming the terrace deposits seen today. In post-glacial and recent times, alluvial sediments and peats have been deposited along the floodplains of rivers and estuaries.

1.6 LAND USE

Despite the presence of several large towns, much of the district, especially the central part, is predominantly agricultural, supporting arable and mixed farming.

In former times much of the area's trade was centred on the River Thames transporting a wide variety of goods. Despite the decline in river trade, Tilbury remains one of Britain's major ports, where the docks, managed by the Port of London Authority, have developed extensive container handling facilities, although other commodities such as grain continue to be handled.

Tankers formerly brought large quantities of oil up the Thames to storage depots between Purfleet and Grays. Many of the depots remain, but most of the oil is now brought in by underground pipeline rather than by river. Following the general decline in river trade, a resurgence in trade for the area has been initiated by the opening of the M25 London Orbital Road which runs through the western part of the district. This has resulted in the development of several large trading and industrial estates near to the motorway, some of which occupy former chalk quarries. Other once derelict chalk quarries in the Grays area are being used for extensive residential developments.

Much of the southern half of the district has been quarried for bulk-mineral resources including chalk, clay, sand and gravel (see below). The resulting holes in the ground have been exploited by several waste disposal companies and the area now receives a large quantity of London's waste and imported waste from overseas. An unfortunate side effect is the large amount of waste dumped illegally along the roadsides in the south, particularly when the licensed tips are closed during wet weather.

A recent consortium planning application to construct a new town at Tillingham Hall, within the Mar Dyke valley, has been rejected.

1.7 MINERAL RESOURCES AND EXTRACTION

The southern part of the district has been blighted by widespread quarrying, much of it now ceased, for chalk and clay used in cement manufacture, and sand and gravel for the construction industry. Grays developed largely as a brickmaking town but the industry is now defunct.

Many of the quarries were abandoned and left derelict or crudely backfilled, resulting in large areas of land suitable only for rough grazing. Within the last few years there has been increasing pressure on the extraction companies to put more effort into reinstatement of the land after mineral extraction has ceased. As a result extensive sand and gravel workings to the north-west of South Ockendon have been backfilled and successfully returned to arable agriculture, with little evidence remaining of former workings.

Most of the chalk in the Grays-Purfleet area has been quarried away to the water table. Likewise, in some areas almost all of the sand and gravel of the river terrace deposits has been excavated, with remnants found only beneath the roads. At the time of survey, sand and gravel was being extracted from six pits.

Clay has been obtained from several deep workings in the area, and at the time of survey London Clay was being dug for cement manufacture from a pit at South Ockendon, from where the clay is slurried and pumped beneath the River Thames to cement works in Kent.

1.8 SOURCES OF INFORMATION USED

A total of 12 1:10 000 geological sheets (Appendix 1) were resurveyed between October 1986 and January 1990 using

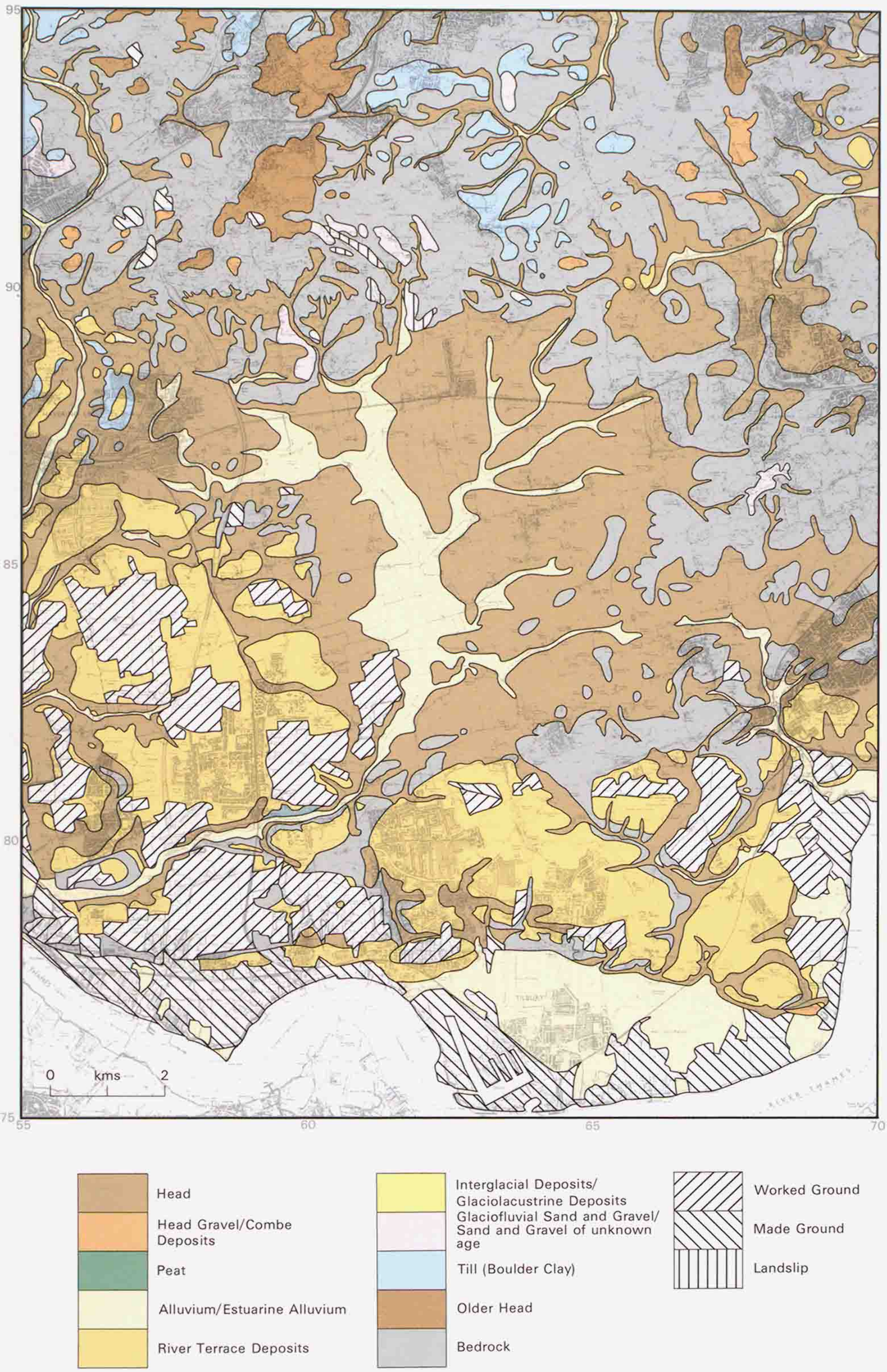


Figure 4 Distribution of the superficial deposits

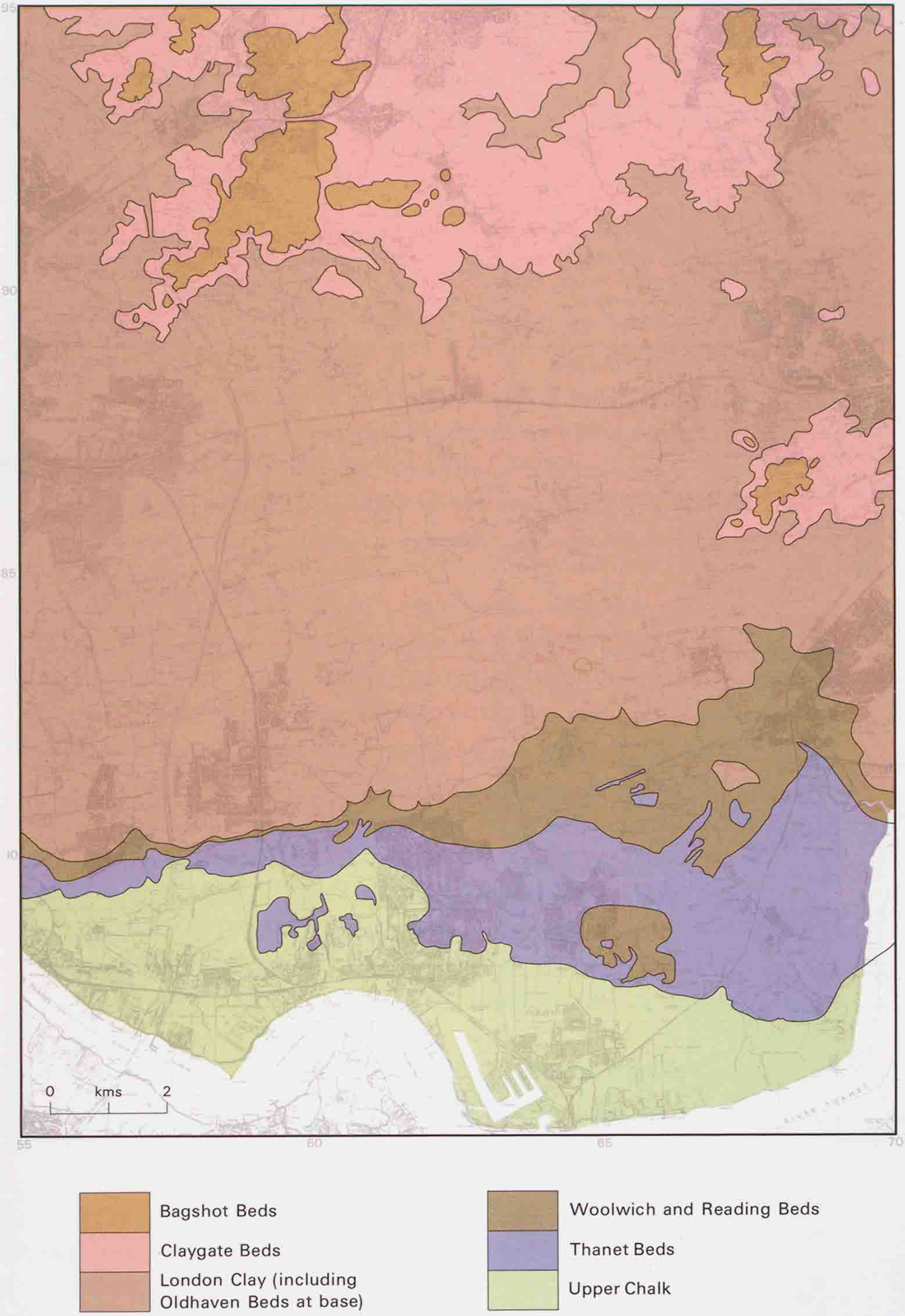


Figure 5 Bedrock geology

Figure 6 The study area showing distribution of boreholes registered in BGS database

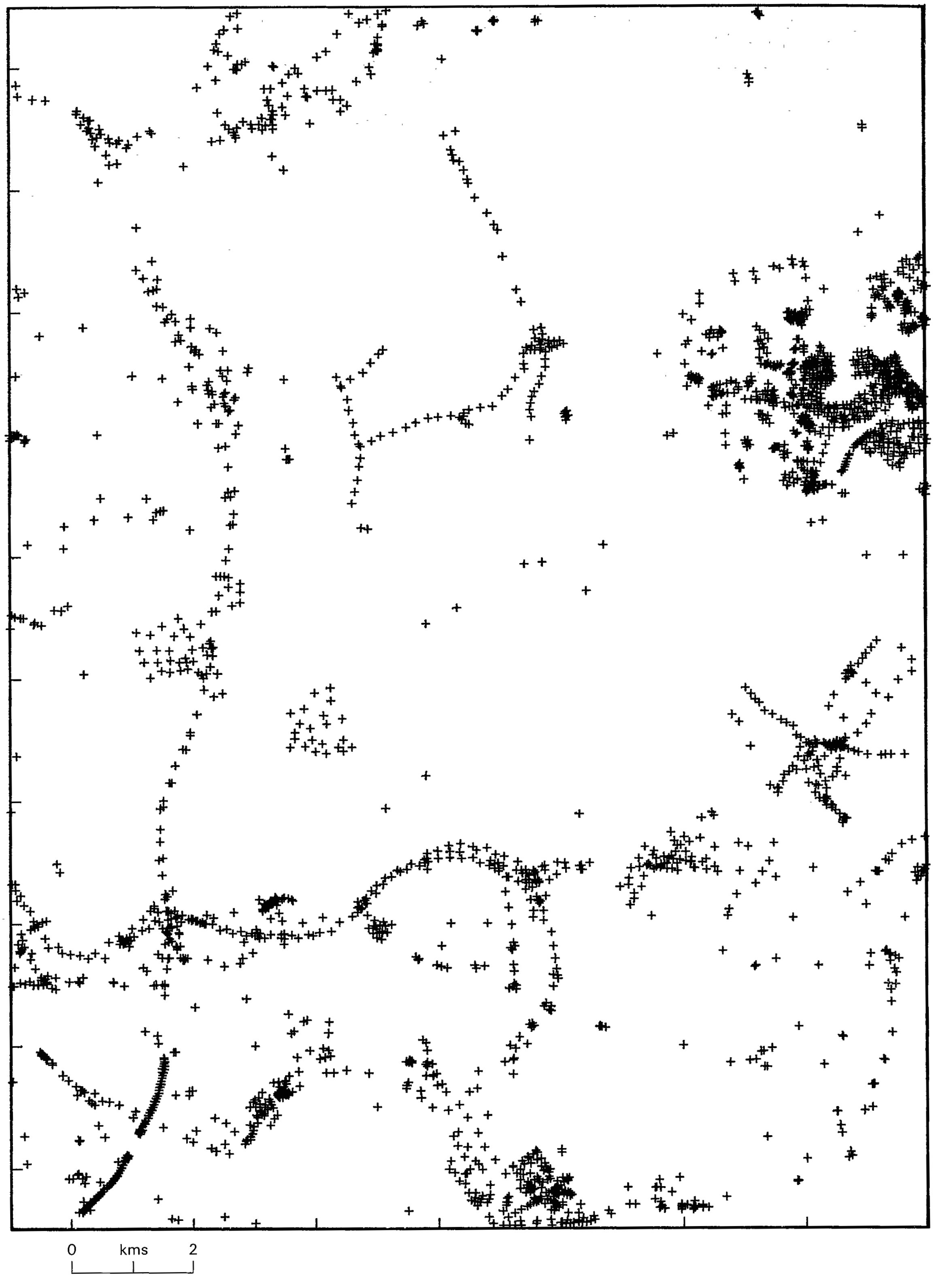


Figure 6 The study area showing distribution of boreholes registered in BGS database

standard BGS mapping techniques. The ground was systematically examined by the use of hand-augered holes and the description of all rock exposures, including measured sections where appropriate.

Exposures of the Upper Chalk were described by Mr C J Wood of Scops Geological Services Ltd. Sections within the London Clay at South Ockendon clay pit have been logged by Mr C King of Palaeoservices Ltd. He has also described borehole cores through the lower London Clay at South Ockendon, kindly donated to BGS by Blue Circle. Discussions with Dr P L Gibbard of Cambridge University, who visited the project area in the company of the BGS team, have led to a much better understanding of the Thames river gravels.

An extensive computerised borehole database (Figure 6) has been established using existing BGS holdings, supplemented by information, much of it confidential, from other sources, obtained during the course of the survey. A separate engineering geology database has been established based upon nearly 12 000 records, with each record generating around 10 data points, thus giving a total of around 120 000 data points.

An Airbourne Thematic Mapper (ATM) multispectral survey was conducted immediately prior to field mapping (McDonald and McKeown, 1988). In addition to this imagery, panchromatic black and white photographs with full-stereoscopic coverage were recorded during the aircraft flights.

As well as information obtained directly from the field survey or the databases, the data obtained during a previous survey of the area between1902 and 1925 by H G Dines, F H Edmunds and T I Pocock have been invaluable, especially in areas subsequently built over where present day evidence is often meagre. For the southern part, additional notes provided by Mr R J Wyatt in 1966, mainly relating to workings, have also been most useful. Examination of early editions of Ordnance Survey maps has revealed the location of former pits and quarries, now backfilled. The Grays Museum has provided additional information about chalk subsidence in the Grays area.

1.9 NOTES TO USERS

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

Boreholes and wells registered with BGS are identified by a four element code (e.g. TQ 67 NE 123). The first two elements refer to the relevant 10 km National Grid square, the third element to the quadrant of that square, and the fourth- to the accession number. In this report boreholes and wells are generally referred to by only the last three elements (e.g. 67 NW 123).

Data used in preparing this report and accompanying maps are lodged in BGS archives at Keyworth, Nottinghamshire. Any enquiries concerning these documents should be directed to the manager of Information Services.

2 Constraints on development

The South-West Essex — M25 Corridor project area situated on the eastern fringe of London, and for the most part on 'Green Belt' land, is coming under increasing pressure from developers, and it is desirable that the geological factors which might constrain this development are examined from a strategic viewpoint which will be of direct relevance to planners. Some of the points raised will also be applicable to individual developments, though their importance is likely to vary from place to place.

Most of the constraints cited in this chapter do not occur randomly, but are closely related to the local geology. Thus from a study of the geology, engineering geology and hydrogeology it is possible to predict areas where problems are likely to be encountered during future development.

The constraints may be split into two main categories:

Firstly there are those referred to as **geological hazards** which present some difficulty to development and need to be taken into account in the design and construction of new buildings. These impose a physical constraint of some sort on development.

Secondly there may be **resources** present such as minerals or water which could be sterilised or adversely affected by new developments. It may be necessary to protect these resources from pollution; or prevent development on them so that they remain available for future exploitation; or perhaps the resource is best utilised so freeing the ground for development.

2.1 GEOLOGICAL HAZARDS

The different types of geological hazards are to a large extent determined by the nature of the different rock types and the soils derived from them. This relationship between geology and hazard is summarised in Table 2. For each hazard the nature of the problem, the areas at risk and precautionary or remedial measures which may be taken are each briefly discussed in turn. The areas at risk for many of the hazards are shown on Map 3.

The notes on precautions only give the more obvious generalised comments and should not be regarded as a substitute for professional advice which should be sought at the planning stage of any development. As a first step the maps produced by this project should be referred to and the relative importance of the various geological constraints, whether hazard or resource, assessed on the basis of this updated information.

2.1.1 Landslip

Nature of the problem Landslips are areas of ground which have moved down a slope as a mass movement of earth under the influence of gravity. Essentially they take place on unstable slopes when the downward force of gravity, or the weight of the ground, exceeds the forces holding the ground in place, or its internal strength. A pre-existing weakness, or a new fracture, is developed, which allows the strata to fail and the earth collapses downslope.

Landslips occur in a number of geological situations affecting a variety of rock and soil types, and the different mechanisms and materials involved in the movement result in different landforms.

In this area large landslips are produced most commonly by the slumping of clays about a curved shear surface involving a rotational movement. These form easily recognised slumped masses with an irregular surface, a crescentic backwall scar above, and a characteristic bulging toe below. A series of adjacent slips gives a scalloped slope, and a succession of slips one above the other forms a stepped or undulating slope.

On a smaller scale some unstable slopes fail on shallow near planar fractures parallel to the ground surface with a translational movement which produces minor rippling or irregularities.

Landslips may be triggered by an increase in the load, a decrease in the load-bearing capacity or an increase in slope which makes it unstable. The additional load may be a new building, a spoil dump, heavy plant or farm machinery or repeated road resurfacing. Alternatively the strength of the strata may be reduced; for example the clay strata within the Claygate Beds become saturated with water from the water-bearing sand units and are weakened by softening or by the increase in pore water pressure. A similar effect may be produced by a local rise in ground-water levels following the clearing of woodland. The removal of trees also reduces the mechanical binding action of the roots and makes at-risk slopes more likely to fail. A slope may also become unstable as a result of stream incision or a man-made excavation which undercuts and increases the angle of the slope, or perhaps removes the toe of an old slip which acted as an anchor. The fine sands within the Claygate Beds, which allow the passage of water through them, may be washed away by the outflow of ground-water at springlines, and so undermine the interbedded clays thereby producing unstable slopes.

Observations of stable and unstable slopes on the London Clay (Hutchinson, 1965a; 1965b; 1967) indicate that the 'ultimate angle of stability' of these slopes against landslipping is about 8° under present climatic and hydrological conditions. Under conditions of unusually high ground-water levels this limiting angle could be reduced slightly.

Head, composed of redeposited weathered London Clay and Claygate Beds, accumulated by downslope solifluction and soil creep, commonly has shear planes already within it, which may be re-activated causing slippage, particularly of the shallow translational variety.

Landslips pose a serious problem to development as they make construction difficult if not impossible and inevitably result in higher building costs. They also make farming more difficult, for modern methods using large machines require large fields with an even surface. As the hedgerows have been removed, however, so the steeper clay slopes have become more unstable and prone to slippage.

Areas at risk In the project area landslips (see Maps 3 and 8) occur mainly on the Claygate Beds and to a lesser extent on the London Clay, pre-eminently at the junction of these two formations, on unstable hillslopes steeper than 7° or 1 in 8. They are found across the northern part of the area along the southern margin of the Claygate Beds and around the Langdon Hills in the east. In addition the Bagshot Beds have slipped in places where they have been left in an unstable sit-

Table 2 Geological hazards

Deposit	Type of Geological Hazard: landslip	solution subsidence	mining subsidence	ground heave	compressible strata	unstable excavation	high ground water	flood	landfill gas	high SO_4	derelict worked ground
Artificial Ground											
Made Ground	C			O	C	O			C	O	
Worked Ground (open or backfilled)	O			O	C		O	O	C	O	C
Superficial Deposits											
Landslip	M			C		C	C			C	
Head	C	P	P	C		C	C	C		C	
Head Gravel						C	C				
Combe Deposit		C	P			C					
Peat					M	C	C			C	
Intertidal Deposit					C	C	C	M		C	
Estuarine Alluvium					C	C	C	M		C	
Alluvium					C	C	C	M			
River gravel		[O]	[O]			C	C	C			
Interglacial Deposit						C	O		[O]		
Glaciolacustrine Deposit						C	O				
Glaciofluvial Sand and Gravel	[P]	[P]				C	O				
Till	[P]	P		P		O	O				
Older Head	[O]					C	O				
Sand and Gravel of Unknown Age	[O]					C	O				
Bedrock											
Bagshot Beds	[O]					C					
Claygate Beds	M			M		M	O			C	
Sand in Claygate Beds	M			[P]		C	O				
London Clay	M			M		M				C	
Oldhaven Beds						C					
Woolwich and Reading Beds		[P]	[P]			C	P		[P]		
Thanet Beds		[C]	[C]			C	P		[P]		
Upper Chalk		C	C				P		[P]		

EXPLANATION

M major }
C common } known hazard with that deposit
O occasional }
P possible hazard with deposit
[ ] indicates that the hazard is a secondary effect rather than a direct effect

uation by slippage of the underlying Claygate Beds and London Clay. Head on the steeper slopes also commonly shows evidence of slipping.

The relationship between slopes steeper than 7° and landslips is clearly shown on Map 8. It can also be seen that the built-up areas of Brentwood, Billericay and Laindon have largely avoided these landslips but as the pressure for more housing rises there is an increasing encroachment onto suspect ground.

Landslips are also found on over-steepened man-made slopes commonly present on the Made Ground of clay embankments and in areas of Worked Ground on the sides of clay pits and cuttings in clay.

Precautions The best precaution in terms of development is to avoid areas which have slipped in the past, or may slip in the future, bearing in mind that changes made to the ground which affect for example the angle of slope, the loading, the load-bearing capacity and the groundwater regime may adversely affect the development site, perhaps inadvertently; a previously stable slope may thus become unstable.

To this end the geological maps should be consulted to check on the occurrence of known slips. The relief of the site should be assessed from contoured maps or surveys and an on-site examination carried out for any evidence of slippage; in addition to hummocky ground this may be revealed by trees and telegraph poles leaning over, fences pushed out of straight lines, cracks in walls and unexpected water seepages.

It may not be possible to avoid building on a slip or potential slip in which case the foundations need to be designed with great care and measures taken to stabilise the slope preventing further movement taking place. A variety of techniques are available which include loading the toe, improving the drainage, planting trees, excavating the slip and replacing with aggregate or putting down deep piles. Specialist advice is needed on such matters.

2.1.2 Solution subsidence

Nature of the problem Subsidence occurs where the calcium carbonate found in some sediments is slowly dissolved in the weakly acidic groundwaters percolating through the rock. These are produced when rainwater combines with carbon dioxide (CO_2) in the air to form carbonic acid.

The solution creates voids which may remain open or become infilled by material falling in from the overlying or surrounding sediments. This infilling may take place as a more or less continuous and barely perceptible concurrent collapse so that an open void is not formed or there may be a sudden collapse into a substantial open chamber which has developed over a long period of time.

These features present a particular hazard when they propagate upwards from unsuspected voids at depth to reach the surface causing a basin-shaped depression or even an open hole to appear. Occasionally this can have dire consequences when holes appear beneath houses or roads. In extreme cases buildings may need to be pulled down as the damage is beyond repair. Subsidence can be triggered by an additional load over the void such as a new building, an embankment, heavy machinery or even rainfall saturating the ground with water. Alternatively the unsupported strata may be weakened by a disturbance of the ground which causes it to cave-in. This may be vibration from road or rail traffic, construction or excavation work.

Solution pipes and cavities are exposed in the faces of some of the chalk quarries in the Grays-Thurrock area. They vary from vertical narrow cylindrical pipes less than about 30 cm across and a few metres deep to irregular shaped cavities several metres in size. Commonly they are filled with pebbly sandy clay or fine-grained sand according to the overlying strata.

Natural cavities are created by percolating groundwaters which tend to exploit initial fractures and bedding planes within the Chalk and as solution continues it is likely that relatively few pipes will be enlarged according to which ones most water funnels down. The distribution and density of pipes is affected by the occurrence of fractures; where the Chalk has many fractures caused by faulting or folding many solution features can be expected. In general though a pattern of scattered pipes of which a few may be greatly enlarged is most probable.

Areas at risk The area most at risk is in the south of the district on the Chalk outcrop including those parts covered by a deposit of Thames river gravel. In addition the outcrop of Thanet Beds to the north is affected by subsidence of these sands together with any Head or river gravel into solution voids in the underlying Chalk. When a subsidence occurs it is often not known whether it is the result of natural solution or of collapse into man-made cavities which are discussed in the following section.

Field observations suggest that the full thickness of the Thanet Beds (20–30 m) can be affected by subsidence and it may possibly extend some way into the overlying Woolwich and Reading Beds.

There is also some risk that the superficial deposits which contain a high chalk content could suffer from subsidence as they are decalcified. Field observations, however, indicate that the chalk clasts contained within the Till, Combe Deposits and Glaciofluvial Sand & Gravel are more likely to be dissolved en masse from the surface downwards so that whilst the deposit loses volume and the surface may sink, the possibility of large cavities forming is slight.

Precautions The available evidence indicates that potential subsidence is a major problem in the Grays–West Thurrock district and no area underlain by Chalk — whether it is at the surface, beneath superficial deposits at rockhead or beneath Thanet Beds — can be regarded as free of solution cavities and therefore safe.

Any building development here should be preceded by a thorough site investigation programme including an initial search of existing records followed by a geophysical survey if appropriate and completed by a series of trial pits or boreholes, or both. It is quite possible for boreholes drilled in one part of a site to miss a nearby vertical solution-pipe. Particular care should be taken if solution effects, for example the piping of superficial gravels down into the chalk, are seen during excavation of the foundations.

Where solution cavities are infilled naturally by sands or gravels it may be possible to build on top of these if the infill is first compacted but where open cavities are detected it will be necessary to pump in a granular fill or similar material before construction continues. In either case special foundations such as a raft, reinforced ring beam or piles will probably be needed because it is difficult to locate all the cavities and then be certain that they have all been totally filled.

2.1.3 Mining subsidence

Nature of the problem The problem of subsidence associated with man-made 'Deneholes' or 'Daneholes' is very similar to the problem of solution subsidence just discussed, indeed it is often impossible to determine which is to blame for a particular collapse if the type of cavity responsible cannot be examined.

Deneholes are underground chambers thought to have been dug for the chalk although there has been much debate over their origin, their age and purpose. It has been suggested by some that they were made for storage, a means of concealing grain from potential enemies.

Commonly they consist of a vertical shaft through up to about 20m of the overlying superficial gravels and Thanet Beds with at the base of this a series of chambers radiating out horizontally for 5 m or so in a double trefoil pattern into the Upper Chalk and sometimes linking up with the chambers of adjacent shafts.

Other man-made cavities are also known which appear to be crude adits into the near-surface chalk. The walls of one of these revealed by the earthmoving for a recent housing development were covered by tool marks clearly demonstrating its artificial origin.

Areas at risk The areas potentially at risk from subsidence into man-made cavities in the Chalk are essentially the same as those for solution cavities noted previously (see Map 3). These include the Chalk outcrop to the north of the coastal alluvium together with the outcrop of Thanet Beds which overlies the Chalk.

In practise the known extent is more restricted (see Map 4). There is a well-documented concentration at Hangman's Wood in Grays (Figure 7) and the information regarding these and all other known subsidences in Grays and West Thurrock has been summarised by Moorlock (1989a, 1989b). A section through a typical Denehole is shown in Figure 7.

There is an apparent concentration of subsidences along the A13 road, though it seems likely that these have been caused by the vibration of heavy traffic here and do not necessarily indicate a greater density of cavities.

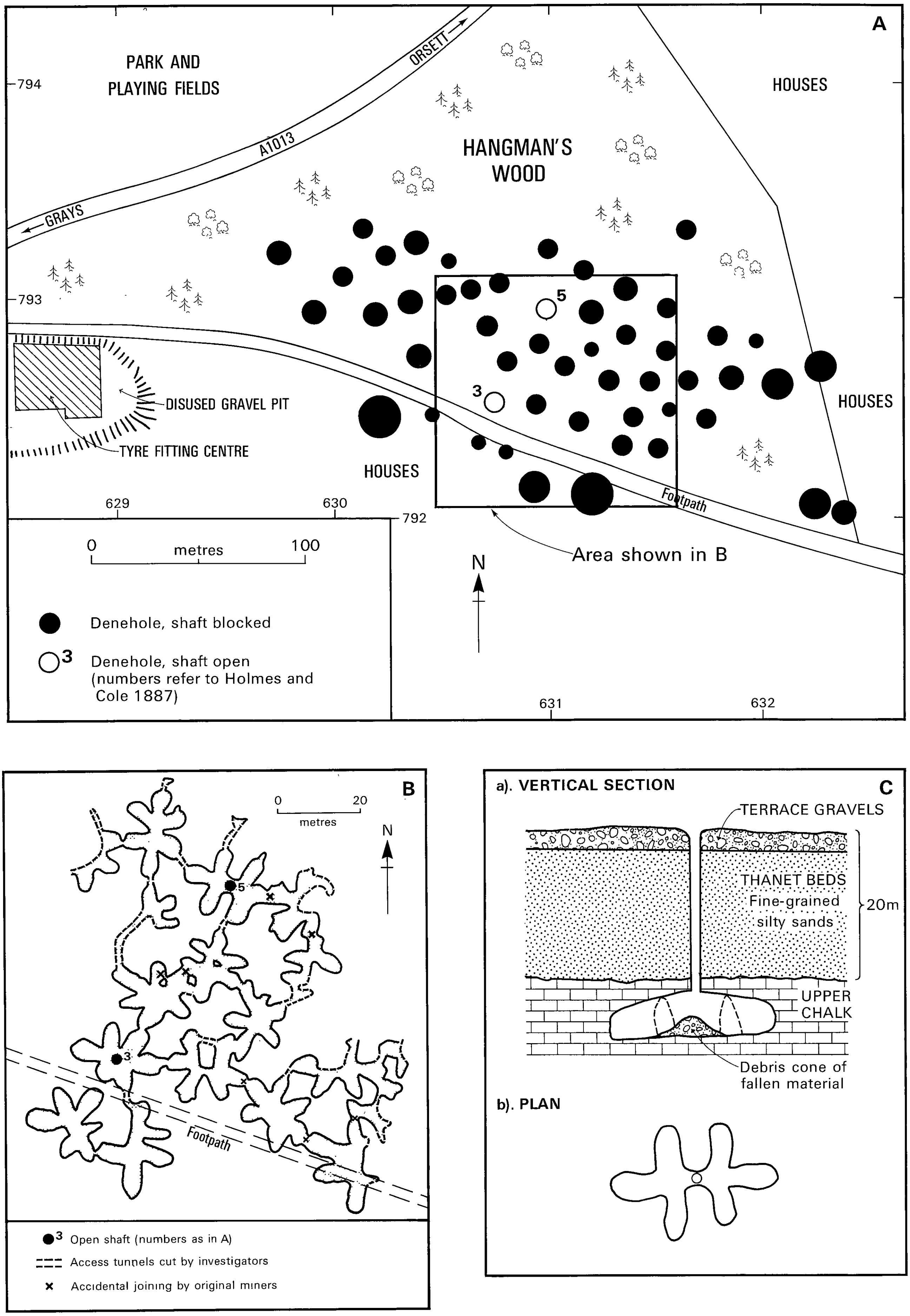


Figure 7 Deneholes at Hangman's Wood, Grays

Precautions The potential problem of subsidence into Deneholes is a major one in the Grays–West Thurrock district and the precautionary notes given previously for solution cavities apply here equally. Given their different origins, however, it is likely that the risks vary slightly from one type to the other.

The distribution and density of solution cavities reflects the pattern of fractures and joints in the rock. With Deneholes the density of cavities can be very high. At Hangman's Wood it seems clear that the maximum amount of chalk was extracted whilst leaving sufficient support to prevent the roof falling in on the miners though it has subsequently caved-in in places.

It may be possible therefore to make some vague predictions about cavity density if the origin of any hole found by site investigation can be determined.

2.1.4 Ground heave

Nature of the problem Ground heave is the movement of the ground caused by the swelling and shrinkage of certain types of clay soil and subsoil as they are subjected to changes in moisture content. This movement is capable of causing considerable damage to buildings erected on susceptible strata and underpinning repairs can be very expensive and not always satisfactory; occasionally in the worst cases demolition and rebuilding may be the only solution. Often problems arise because of differential movements where one part of a building suffers heave caused by swelling and the other does not, with the result that the modern 'brittle' Portland cement fractures under the stress and cracks spread through the walls.

The movement may take place where drains and ponds, trees, shrubs and hedges have been removed. Ground dried out by roots will swell after the vegetation is stripped off, the recovery taking perhaps several years. Conversely, tree roots growing near foundations may dry out wet ground causing shrinkage. Both may cause structural damage.

The capacity of some clayey materials to swell markedly when wet and to shrink when dry is determined by the mineralogy, or the composition, of the clay minerals present. The montmorillonite group of clay minerals, or the smectites, have a layered structure which adsorbs layers of water molecules between the structural layers causing an increase in volume (Deer et al., 1966); a process which can be reversed causing a decrease in volume. The number of layers of water molecules which can be accepted varies in the different smectites and so the shrinkage potential varies also. In the London Clay the extremely expansive smectites make up 20–30% of the clay minerals, whilst micas and kaolinite which form the rest of these sheet-like minerals (Lake et al., 1986) do not adsorb water to the same degree and therefore moderate the shrink and swell effects. Nevertheless the London Clay has a medium to high shrinkage potential (Driscoll, 1983) so that when it dries it shrinks greatly and when it is rehydrated it swells back again.

Areas at risk The London Clay together with the lithologically similar clay units of the Claygate Beds are particularly prone to problems of ground heave (see Map 3).

The London Clay has an extensive outcrop extending from east to west across the central part of the project area, and although much of it is concealed by Head this derived superficial deposit is also subject to heave. In particular much of the new town of Basildon (and Laindon) in the east is built on London Clay and has had major problems with damage to buildings. Along the northern part of the area the Claygate Beds crop out and heave caused by these is a significant factor in Brentwood and Billericay in the north-west and north-east respectively.

The severe drought of 1976 resulted in widespread damage in these at-risk areas and resulted in the building regulations being changed so that typical foundations were deepened from three to four feet (0.9 to 1.2 m).

Precautions Potential problems of ground heave are best avoided by the careful design of the foundations of all buildings where heave is likely to occur. In order to do this effectively it is usually necessary to first carry out a detailed site investigation using trial pits or boreholes to test the ground. Samples may need to be taken for analysis to determine the composition of the bedrock or superficial deposits.

The history of the site should also be researched, by for example examining old maps and photographs as well as making enquiries in order to determine whether or not the site has previously had any trees on it, or ponds or ditches.

At the construction stage the trenches for the footings should also be monitored closely for any signs of ground disturbance and the appropriate measures taken to ensure the stability of the foundations; for example an old infilled pond may have to be completely re-excavated and backfilled with hard- core; a development may have to be modified in order to avoid difficult conditions.

Typically in this area houses are built on deep strip foundations except on more difficult ground where piling techniques, more typical of large office or high-rise blocks, are employed. In this way the building is isolated from nearby ground movements; the building load is borne by strata at a depth which will not undergo changes in moisture content and will therefore not suffer from ground heave. Alternatively, though less common, buildings may be 'floated' on a concrete raft which is able to accommodate slight movements; the building load is evenly spread over a large area and the entire structure is free to move up and down without sustaining any structural damage.

Whilst the high cost of these foundations needs to be considered in the economics of any development it must be remembered that remedial measures such as underpinning may be equally if not more expensive.

2.1.5 Compressible strata

Nature of the problem Major problems of subsidence arise when buildings are erected on highly compressible sediments such as peat which are squashed by the increased load causing the building to settle and sustain damage. Soft unconsolidated water-saturated sediments such as alluvial silt and clay are subject to similar though less pronounced settling problems.

Artificial deposits in the form of made ground or more particularly landfill sites with a high proportion of low-density organic waste pose related engineering difficulties because of poor compaction. In addition there may be voids and the contents can vary much more than natural deposits.

The problem of compressibility is best illustrated by considering peat which consists of the partially decomposed remains of marsh vegetation such as reeds, sedges and rushes, together with some woody fragments. Generally it is dark brown or black consisting almost entirely of organic material with traces of silt and clay. In the study area peat is not seen at the surface very often but it is present in the thick deposits of coastal alluvium where it forms several distinct layers interbedded with soft organic-rich clays and some fine sand. The peat is saturated with water and only slightly compacted so that it occupies a large volume with low density. When the load on it is increased water is squeezed out and the peat becomes more compressed. This causes the ground level to drop and this settling may result in structural damage to buildings.

In the past this effect does not appear to have been a problem in the old housing of Tilbury. This may be because the increased load was relatively little and settling did not take place or the ground may have sunk uniformly without causing significant structural damage. The total thickness of peat revealed by boreholes can be as much as several metres so there is obviously scope for large settlements if it becomes fully compacted.

Like ground heave discussed previously, the problem of compressibility can be most severe where there are differential effects. Where part of a building settles, because for example of peat underlying the foundations at one corner, then the damage may be more extensive than if the building had settled as a whole.

Areas at risk The area most at risk (see Map 3) is the coastal plain in the south and south-east, originally occupied by marshes inundated by water at high tide and shown on the geological map as Estuarine Alluvium. This is partly built on by the West Thurrock industrial estate and power station, and Tilbury, Tilbury docks and power station.

Alluvium along the Mar Dyke (see Map 3) also suffers from compressible sediments, particularly the lower course downstream of North Stifford where it is about 5 m thick and contains peat. The broad near flat Mar Dyke basin in the middle of the study area has former marshy areas still called 'fens' with peaty soil common. There is some evidence here of settling to give slightly uneven ground as the peat has contracted as it has dried out following improvements to the drainage.

Precautions For any proposed building development the potential risk of settlement damage caused by peat needs to be assessed on the basis of the results of site-investigation boreholes and the loading factors that will need to be borne.

The problem can be overcome in a number of ways which basically group into two: firstly the building can be designed to accommodate any settling and secondly the building can be prevented from excessive settlement.

Rafted foundations allow the entire construction to move as a unit thereby avoiding damage. Alternatively piled foundations resting on a stable stratum will isolate the building from movement, or the site may be preloaded by dumping a bed of suitable material such as rubble which will compact the peat layer as well as spreading the load more evenly to reduce settlement caused by the building load.

The particular problems posed by landfill sites require individual assessment by experts. The site-investigation may require trial pits as well as or instead of boreholes in order to determine the composition accurately. The standard ground treatment methods as summarised by Pearce and Thomson (1977) include pre-loading, inundation, rolling and dewatering. Various specialist techniques including vibrofloatation, dynamic consolidation, grouting, explosive compaction and sand drains are also noted.

2.1.6 Unstable excavations

Nature of the problem. Excavations into many of the deposits, both superficial and bedrock, in the study area have unstable sides and particular care has to be taken when digging holes for foundations. This instability is commonly caused by an abundance of groundwater coupled with unconsolidated cohesionless sediments to produce 'running sand' conditions. Also the saturated estuarine clays are highly plastic.

On a larger scale the walls of pits into London Clay are angled at about 30°, which is much steeper than the angle of ultimate stability, as a reasonable compromise between the need to maximise the area worked and the need to avoid major slips.

The pits into terrace gravels, Woolwich & Reading Beds and Thanet Beds are generally worked in dry conditions above the water table and frequently have near vertical faces which are moderately stable but when these same sediments are encountered below the water table in boreholes then they may give running conditions.

Areas at risk Almost all the superficial deposits and bedrock formations in the area, apart from the Chalk, may give rise to unstable excavations in adverse circumstances such as high groundwater conditions. The Estuarine Alluvium with its often-saturated cohesionless sand and plastic clay sediments is most at risk. The risk associated with other deposits varies from low to high and needs to be assessed on an individual basis taking in to account all relevant factors.

Precautions Good building practise should always be followed in the digging of any excavations. This will require, for example, the use where necessary of sheet piles, avoiding loads on the tops of trenches and leaving holes open for as short a time as possible. Information derived from site-investigation boreholes and trial pits should allow for the effective planning of excavation works, whilst conforming with all appropriate safety measures.

2.1.7 High groundwater conditions

Nature of the problem High groundwater conditions can be a major problem for construction works causing flooding of the foundation trenches, or worse washing in sediments from the trench walls, perhaps causing these to collapse. The cost of building may be increased, particularly if such problems were unforseen and the design has to be modified.

Areas at risk Most of the superficial deposits and the bedrock formations suffer from high groundwater conditions somewhere in the study area but the only deposit where the problem could be invariably expected is the Estuarine Alluvium. Elsewhere the groundwater conditions are determined by the relief and drainage and by the type of sediment at a particular place. In a variable and interbedded sand and clay sequence as present in parts of the Bagshot Beds, the Claygate Beds, the London Clay and the Woolwich and Reading Beds there may be localised perched water tables above the main water table. These lenses of saturated strata may flood excavations in apparently well-drained sediments.

In a similar fashion the widespread Head deposits resting on essentially impermeable London Clay commonly have a significant amount of water near the base; indeed for a long time, before the advent of a public water supply and deep boreholes, this source was exploited by many farms using relatively shallow wells.

In the southern part of the area most of the disused chalk quarries stopped above the water table. Now, as water abstraction from boreholes in the London area diminishes and the water table starts to rise again, the bottoms of some of these old workings are threatened with flooding.

Precautions In assessing the risk of high groundwater conditions for any new development the topography should be studied first, and the likely effects of relief and drainage in controlling the flow of surface runoff and the infiltration of water into the ground noted.

The site-investigation boreholes should record water seepages as drilling proceeds together with standing water levels on completion. This information combined with data derived from geological maps can be used to determine the source of any water and therefore how best to deal with it. A small seepage fed by a perched water table may not present much of a problem as it might be expected to diminish with time. A large inflow from an aquifer by contrast would pose a major and persistent problem requiring well planned remedial measures.

On a large site with complex geology, engineering works which alter the level of groundwater at one place may have an adverse effect elsewhere. For example, in an area of perched water tables stacked one on top of the other, excavations which allow water to drain from a high level down to a lower level, might cause unexpected flooding from that lower stratum.

In critical situations such as the building of a power station on the coastal alluvial plain, where the effect of tidal fluctuations or saline intrusion of dense saltwater from the Thames Estuary beneath the fresh water draining off the land also needs to be taken into account, it may be necessary to monitor water levels over a period of time and so gain an understanding of the hydrogeology before construction begins.

In simple situations problems may be solved by pumping trenches dry and by employing additional sheet piles to overcome related problems of 'running sand'. On a large scale project it may be feasible to dewater the ground first by sinking boreholes and pumping water out. Alternatively it may be best to avoid deep foundations by building on a raft or on piles through the suspect ground.

Rising groundwater levels need to be taken into account in the design of new developments planned for old chalk quarries. Detailed predictions of the elevation of the future water table around any potential site should first be obtained from the Thames Water Authority. It may be necessary to raise the floor of the quarry first by a partial backfilling. Such fail-safe solutions are preferable to schemes which require pumping and are prone to break-down.

2.1.8 Flooding

Nature of the problem Flooding is a major potential problem. In the past the at-risk areas were avoided; no one attempted to build on the marshy coastal flat in the south or on the extensive areas of low-lying ground along the Mar Dyke in the middle of the study area.

The greatest threat of flooding formerly came from the Thames. In 1953 a severe storm, caused by a very low depression centred over the North Sea, coincident with high-tide led to extensive flooding and damage along the east coast. Although parts of London were flooded on that occasion it escaped the worst effects. Nevertheless it was realised that the capital had had a lucky escape and the dangers of a storm surge along the Thames were assessed. It was apparent that in the worst circumstances a similar surge funnelled up the narrowing estuary could build up an extremely high tide capable of breaching the existing sea defences. Accordingly the Thames Barrier was built at Woolwich, about 15 km upstream of the study area, to protect the city. In order to prevent the surge simply flooding inland and swamping all the low-lying ground it was also necessary to strengthen the sea defences all the way downstream and this includes the north bank of the Thames which forms the southern margin of the study area.

Inland near to the Mar Dyke the farms were carefully situated upon slight rises which remained above water in all but the worst floods. As drainage of the low ground has been improved to enable arable farming to take place on fields formerly devoted to permanent pasture so the risk of flooding has diminished, indeed without the reminder of predictable annual winter floods there is even a risk of the problem being overlooked — until an exceptional storm overwhelms the drainage network and entire fields are once again submerged

The possible problem that rising groundwater levels pose for the potential development of old chalk quarries has been discussed in the previous section.

Recently the problem of 'Global Warming' or the 'Greenhouse Effect' has come to the fore, attracting a great deal of attention in the scientific literature and in the popular media as environmental issues become increasingly important. The possible causes, indeed the veracity of the theory itself, need not be discussed here. What is important in terms of planning is what will happen, and over what time scale if global warming is taking place, and do these effects need to be taken into account in making strategic decisions over future developments in the study area?

Although opinion over the likely effects differs widely there is a degree of consensus that the sea level has risen about 10–15 cm during the last century and will continue to rise with increasing temperatures because of thermal expansion of the oceans, and the melting of glacier ice and polar sheet ice. Many believe that this will cause the flooding of the world's low- lying coastal areas, where coincidentally many of the largest cities are situated. During the last Interglacial period, a warmer interlude between cold periods marked by glacial advance, the sea level is thought to have been about 6 m higher than at present and one could reasonably suppose that a similar rise could take place in the future. More conservatively, a rise of 0.8–1.65 m has been used as a basis for assessing the effects on low-lying coastal areas (Boorman et al., 1989).

Complicating the situation in the study area is the possibility that much of south-east England is thought to be very slowly sinking. If so this can only increase the risk of flooding in the long term.

Areas at risk As indicated above the main areas at risk are the coastal plains, which were formerly marshes, together with the low-lying inland alluvial flats. Large areas along the Mar Dyke remained under water for several weeks following severe storms in the autumn of 1987.

Map 3 showing areas at risk also shows the 5 m contour to give an idea of the enlarged area potentially at risk with a higher sea level.

Precautions The best precaution is to follow traditional practise and to avoid the at-risk areas for development. Where other factors dictate that building takes place in spite of the possibility of flooding then measures should be incorporated in the design to prevent any damage. Ideally these should be passive and fail-safe. The best example of this would be to first construct a mound of made ground higher than the worst storm flood predicted and to then construct the building upon this. Less costly solutions may employ improved drainage combined, if necessary, with embankments around the site to keep floodwater out. The problem with this is that such measures are prone to fail when they are most needed, for example the drainage may be overwhelmed, and embankments designed to keep water out may also keep it in.

2.1.9 Derelict worked ground

Nature of the problem There are numerous disused bulk mineral workings in the area which remain open or only partially backfilled and have not been reinstated to a beneficial use. They remain as overgrown areas of wasteland which attract illegal waste dumping or fly-tipping which makes them more difficult to restore, and turns them into even worse eyesores, unattractive to potential developers.

Much of this dereliction takes the form of large open chalk quarries ringed by roads and built-up areas on remnants of the original Chalk surface which survive as ribbons of higher ground. Amidst this highly populated area, these holes, up to 25 m deep and surrounded by many kilometres of vertical chalk face, pose particular difficulties for reclamation. If the holes are backfilled up to the original ground level then very large volumes of cheap inert fill must be found locally because the need to protect the Chalk aquifer from pollution largely precludes the use of landfill wastes.

The disused sand and gravel pits and clay pits, although very extensive, present less of a problem because they are for the most part shallower and do not reach the water table.

In a House of Commons Adjournment Debate on the subject in 1973 the MP for the borough of Thurrock, which occupies the southern half of the study area, argued that much of the problem was the legacy of the uncontrolled digging of chalk, sand and gravel, and clay — the three principal components of concrete all found in abundance in Thurrock — during and after the First World War (Essex, 1977).

Areas at risk Land dereliction is a major problem in the south of the area In ?1976 more than 1600 hectares, over 9.5% of the total land area of Thurrock, most of which lies within the study area, were classified as derelict land, compared with a national average of 0.2% (Blunden and Essex, 1977).

In 1988 a submission to the Department of the Environment recorded 300 hectares or 1.8% of land within the borough of Thurrock as derelict excavations and pits. Part of this reduction is probably due to changes in classification but it also reflects the efforts made at land restoration.

The disused workings which remain derelict (see Map 5) are found mainly on the Chalk outcrop around West Thurrock and Grays. Elsewhere there are open pits in the Thanet Beds, the Woolwich and Reading Beds and the London Clay as well as the terrace gravels of the Thames.

Precautions and remedial action Current planning regulations should ensure that new workings are more strictly controlled and therefore do not add to the problem.

The disused sand and gravel workings and old clay pits are often suitable sites for backfilling with landfill wastes, of which there is an abundant supply in the Greater London area. Given careful control valuable resources of methane gas can be generated from these wastes as detailed below.

This approach is not generally suitable for the old chalk quarries because of the need to protect the Chalk aquifer from pollution. The lack of a large supply of inert fill has delayed the restoration of these deep holes. The problem is currently being successfully tackled in West Thurrock at the Chafford Hundred site where an extensive housing development is under way. After clearing and levelling of the site, a layer of Thanet sand is spread over the quarry floor followed by successive layers of chalk. These are obtained from the higher unworked parts of the site and used to raise the level of the quarry floor above the water table and to landscape some of the steep quarry faces.

2.1.10 Landfill sites and landfill gas

Nature of the problem The problems to development posed by landfill sites are twofold. Firstly there is the engineering difficulty of building on heterogeneous and unconsolidated material which was dealt with earlier in section 2.1.5 on compressibility. Secondly the waste materials and the products of their decomposition may be dangerous. Potentially harmful gases and leachates produced by these reactions may escape from the site and affect an area much larger than the landfill site itself.

Each landfill site needs to be assessed individually to determine the range of possible problems as no two will be identical. The many relevant factors include: the geology of the site and surrounding area together with the hydrogeology or groundwater regime; the three-dimensional shape and size of the landfill; the history of the site; the composition of the waste, its construction and compaction; and seepage of waste and its by-products out of the site.

The need to protect the environment, in particular groundwater aquifers from toxic wastes has been appreciated for some time but it is only recently that the dangers of some seemingly innocuous wastes have been realised. The production of landfill gas by the biodegradation of organic matter has attracted much attention following incidents such as the methane gas explosion at Loscoe in Derbyshire in which a house was destroyed (Williams and Aitkenhead, 1991). An official guide on the monitoring and control of landfill gas has been produced by the Inspectorate of Pollution (Department of the Environment, 1989) which has been used as the source of much of the information given below.

Landfill gas is a variable mixture of gases produced when animal and vegetable matter and their derivatives such as timber and paper are decomposed by micro-organisms in anaerobic and moist conditions. The composition of the gas varies with time; initially carbon dioxide predominates with significant amounts of hydrogen but later as methane production increases the typical major constituents are 65% methane and 35% carbon dioxide, together with several minor components. Methane is flammable in concentrations of 5–15% by volume in air, and if not properly managed can give rise to the risk of fire, explosion and asphyxiation as well as killing off vegetation. If the site is not effectively sealed these gases may escape and endanger the surrounding area. Moreover where leachates leak out of the landfill a pollution plume of contaminated water migrating through the ground can carry organic carbon away from the site where under certain conditions it may decompose to produce methane.

It is likely that the production of methane has been increased by modern landfill techniques of rapid infill and compaction which encourage the onset of the anaerobic phase whilst the layered construction and capping now required, prevent the escape of gases to the air. In this way gases may be encouraged to migrate sideways into the surrounding ground where it is permeable, possibly for considerable distances. It is this particular aspect which has caused much recent concern because gases may be able to accumulate in the void space beneath houses near to landfill sites, possibly with disastrous consequences as at Loscoe.

Areas at risk The locations of known landfill sites in the study area are shown on Map 5. Some are constructed on the original ground surface whilst others are used as backfilling for disused bulk mineral workings. All landfill sites are areas of suspect ground from an engineering viewpoint and all should be regarded as a potential source of methane until proven otherwise. In the study area some of the recent landfills have been designed to produce and collect methane with adequate venting of surplus gases. Older sites which produce landfill gases, and do not have facilities to collect and draw these off in a controlled manner, may pose a greater risk.

Precautions Since the Control of Pollution Act of 1974 landfill sites require a licence listing the types of controlled waste which can be deposited, though these categories may change over the lifetime of the landfill. Moreover material may be dumped which the licensing does not permit. It cannot be assumed that the only waste in a landfill is that which has been specified; on the contrary unless a landfill has been under continuous and detailed supervision the only safe assumption is that there may be harmful wastes present.

Former landfills should be monitored and the gas and leachate control systems maintained for as long as necessary. A landfill may not be stabilised for many years, though it may be suitable for agriculture or public open space during this time. Where any development is proposed for a landfill site specialist advice should be sought. Buildings have been safely erected on gas producing landfills by incorporating precautionary measures such as venting systems in the design and construction. Recommendations in Waste Management Paper No. 27 (Department of the Environment, 1989) stress that domestic housing should not be built on gassing landfills and great care must be taken with developments near to such sites in permeable strata until the site has stabilised.

At Sand Lane, Chadwell St Mary, a disused sand and gravel working [650 784] which was infilled with wastes containing putrescible matter has recently been re-excavated and is being backfilled with inert granular waste such as building rubble which will not give rise to problems of compressibility or landfill gas. This site will then be developed for housing.

Williams and Aitkenhead (1989) have emphasised the need to collect adequate information on the geology of proposed landfill sites at an early stage, as knowledge of the basic geology provides the key to understanding the hydrogeology and the direction of further investigations. With this information it is possible to predict the gas and leachate migration pattern for the site under varying conditions and hence design the landfill so that it does not present an environmental hazard. Waste Management Paper No. 26 (Department of the Environment, 1986) provides guidance on the construction of landfills.

2.1.11 High sulphate content

Nature of the problem High concentrations of sulphate in the ground or groundwater can weaken concrete foundations if they are not designed to resist this chemical attack. In the study area the unweathered London Clay contains pyrite (iron sulphide) which commonly in the weathered zone near the surface is oxidised to sulphate ions in solution. Calcium carbonate present in the system may then cause the precipitation of hydrated calcium sulphate as gypsum or selenite crystals.

This change incidentally involves an eightfold increase in volume over the original sulphide and the expansion exerts a pressure on the surrounding ground causing disruption and weakening of the strata which can by itself cause major construction problems in badly affected areas elsewhere (Bell, 1978).

Here, pyrite is only usually encountered in deep excavations or boreholes whilst gypsum derived from it is ubiquitous in the weathered London Clay. This gypsum when itself subjected to weathering produces sulphuric acid and sulphate. Solutions of these in groundwater react with tricalcium aluminate, one of the components of Portland cement which unfortunately cannot be removed, to form calcium sulphoaluminate. This reaction is accompanied by expansion which causes the cement to break down and thereby weakens the concrete used in foundations. The rate of attack is influenced by the permeability of the concrete and the position of the water table. Sulphates can only continue to react with the cement if their solutions continue to infiltrate the structure; concrete above the water table is unlikely to be attacked whilst below it the sulphates may be replenished. Sulphate attack will increase the permeability of the concrete encouraging further attack, and so on.

Areas at risk Concrete foundations are at risk from sulphate attack where the soil or groundwater or both have high sulphate levels. This is the case over most of the London Clay outcrop, the lower part of the Claygate Beds, the clayey Head deposits derived from these formations and the alluvial tract of the Mar Dyke. Together these occupy about two thirds of the study area (see Map 3). Water draining off these areas also has a high sulphate content and may enter some of the older underlying sandy formations such as the Woolwich and Reading Beds in places. For the most part though the flow of high-sulphate waters into these strata is restricted and the problem is much less widespread in the southern part of the area.

Precautions The sulphate content of the groundwater should be tested routinely during site investigations throughout the area. Providing good building practise is followed and the foundations are designed in accordance with the sulphate levels found there should be no problem.

In the past oversize concrete foundations were used where sulphate attack was expected in order to be certain that they retained sufficient strength. In the study area the sulphate levels are not especially high and the use of good quality Portland cement may be adequate. Often though, a sulphate resistant cement may be necessary and these usually have gypsum added. This encourages the reaction with tricalcium aluminate to take place before the cement hardens, thereby preventing the same reaction with sulphate in groundwater later. Additionally the concrete should be well compacted to reduce its permeability, and it can also be protected by an impermeable membrane or bituminous coating.

2.2 RESOURCES

The various mineral resources (see Maps 3, 6 and 7) are described fully in chapter five, here they are briefly considered in terms of the constraints that they impose, or may impose, on development. The constraints may be of an obligatory nature determined by legislation or optional where the planning authorities can choose to take them into account or not according to their overall priorities.

2.2.1 Sand and gravel

There is a heavy demand for sand and gravel from the construction industry in the South-East and consequently pressure to meet much of this from diminishing local supplies. Substantial sand and gravel resources, both in the superficial deposits and the bedrock formations, remain available for exploitation even though extensive areas have been built upon, and therefore sterilised, or have already been worked.

In order to maximise the exploitation of sand and gravel in the area there should be no development on potentially workable deposits until each resource is completely worked out. The distinction between resources which are capable of being worked and may be economic some time in the future and reserves which are proven and exploitable at present should be remembered. It may be necessary therefore to protect deposits for future use which cannot be dug profitably a present.

Wherever an area is disturbed by a quarry or pit all the mineral on that site should be extracted; or failing this no backfilling should take place in order to prevent the remaining potentially workable mineral from sterilisation.

In the past the large spreads of river gravels in the south were worked but the underlying Woolwich and Reading Beds and Thanet Beds which are also sandy formations were mainly ignored. More recently these too have been exploited but there appears to have been little co-ordinated control to ensure that all the available minerals were dug.

There is, however, the obligation to protect the water supply from pollution or likely pollution and to the extent that old gravel workings are used as landfill sites there may well be a conflict of interests. If the maximum amount of mineral is extracted and the resulting deep hole in these permeable strata is used as a landfill site then the risk of polluting the underlying aquifer is increased.

2.2.2 Clay

The main clay resource is the London Clay dug around South Ockendon for use in cement making. Only a small portion of the outcrop suitable for exploitation has been worked so far (see Map 3) and an extensive area remains available, though much of this in the west is concealed beneath river gravels, landfill or the built-up area of South Ockendon.

In the one active pit about 20 m of clay are worked in an efficient manner along a single advancing face so that the demand for new ground is much less than that from shallower sand and gravel pits which often tend to be dug in a more irregular pattern to cope with varying demands.

Much of the London Clay resource forms the floor of the Mar Dyke basin, a low- lying area prone to flooding, where the pressure for development is less than on the surrounding higher and drier ground.

In view of these points and the fact that the London Clay is used as a raw material in an expensive manufacturing process, for which there are other clay substitutes elsewhere, rather than as a product itself there is probably less need to protect the London Clay than the sand and gravel from development.

Providing that an adequate thickness of London Clay is left in the bottom of the London Clay pits to act as an impermeable seal on top of the underlying Woolwich and Reading Beds the old pits often make suitable landfill sites.

2.2.3 Chalk

The area of chalk at outcrop which has not already been worked and which has not been built on is very restricted and realistically there is little need to protect the remaining fragments for future exploitation as a mineral resource because there is not likely to be any.

The Chalk, though, does form a major aquifer and should be protected from pollution as far as possible. Particular care must therefore be taken with any landfill sites to prevent harmful leachates seeping out into the surrounding ground.

2.2.4 Water

Unlike the finite 'use-once, use-up' resources noted above water is a renewable commodity which if correctly managed and protected can be used indefinitely; its use in the public water supply simply forms part of the 'hydrological cycle' which recirculates water continually through the oceans, atmosphere, rivers, ground, plants and animals.

Water is vital to all life and it is therefore of the utmost importance that the supplies are safeguarded.

In the study area a large proportion of the supply comes from groundwater sources, particularly the Chalk aquifer (see Maps 3 and 11), and these need to be protected from pollution if they are to continue in use. Care must be taken to ensure that potentially hazardous leachates from landfill sites do not enter aquifers used for water supply. It may be acceptable, though, to allow leachates from some wastes to enter aquifers providing there is sufficient dilution and breakdown or attenuation of the leachates to render them harmless before they reach nearby abstraction points for supply (Mather and Bromley, 1977).

There is often a conflict of interests between the Waste Disposal Authority and the National Rivers Authority (NRA). The NRA can ask that a proposed disposal licence not be issued or be amended but it is recognised that it is unrealistic for all aquifers to be totally protected from pollution (Gray et al., 1974). The NRA needs to consider all the factors relevant to each site including the economics of waste disposal elsewhere.

2.2.5 Methane

Methane, as a major component of landfill gas, is both a hazard and a resource according to the particular circumstances of its origin. Where its production is controlled it can be a valuable source of energy if it can be sold to a nearby consumer.

The precautions given earlier for landfill gas remain largely applicable here. The landfill sites should not be used for domestic housing until the landfill has stabilised. Whilst best suited for open space recreational areas or agriculture it is possible to build on gassing landfills providing special safety features are incorporated in the design.

2.3 Sites of Special Scientific Interest

There are three SSSIs notified by the Nature Conservancy Council under section 28 of the Wildlife and Countryside Act 1981 because of their geological importance and which deserve protection from development. These are:

Globe Pit SSSI, Grays [625 783]. This site shows the interrelationship of archaeology and geology because of its use in the correlation of the Lower Palaeolithic chronology with the Pleistocene sequence of Thames river terraces.

Purfleet Chalk Quarries SSSI [560 784, 566 785, 569 786]. These quarries with terrace deposits banked against the Chalk provide suitable exposures for work on determining the Thames terrace sequence.

Lion Pit SSSI, South Stifford [597 781]. This site along a disused tramway cutting also has Thames terraces banked against Chalk.

2.4 OTHER FACTORS

There are numerous other constraints, some of which have a geological aspect, which are not dealt with in detail in this report but which are briefly noted below.

Agriculture is strongly influenced by the soil type which is largely determined by the composition of the bedrock or superficial deposit. Some of the recreational areas such as Thorndon Park, Westley Heights and One Tree Hill occur on the higher ground formed by the Claygate Beds and the younger Bagshot Beds. As well as having the most scenic landscape in the area this present usage prevents potential developments from encroaching on to some of the landslips. There are nature reserves, and a number of disused sand and gravel pits have been developed as fishing ponds.

3 Engineering geology

3.1 BEDROCK (SOLID ROCK) AND SUPERFICIAL (DRIFT) DEPOSITS

The two engineering geology maps (Map 9 and Map 10) depict areas in which geotechnical conditions are broadly consistent. However, the maps are only summaries and cannot reflect detailed conditions on a site-specific basis. The maps and the accompanying engineering geological report (Crummy and Culshaw, 1991) present information that provides a better understanding of the general engineering geology of the area so that potential constraints on development (see section 2.1) can be identified and site-specific investigations better designed.

The boundaries between engineering geological units are based on the geological maps produced during the study. Map 9 shows the engineering geology of the bedrock (solid rocks) and Map 10 that of the superficial (drift) deposits. The groupings of materials with similar geotechnical properties were derived, in part, from data extracted from site investigations reports for locations within the study area.

A detailed discussion of the engineering geology and descriptions of the geotechnical tests for which results were analysed are given in the accompanying report by Crummy and Culshaw (1991).

Both engineering geology maps should be examined to obtain an indication of ground conditions in a specific area. It should be noted that for areas shown as being drift-free, a mantle of weathered material and thin superficial deposits may be present. It is also possible that undetected pockets of thicker drift may be present. Map 10 also shows undifferentiated made ground and fill. Additional information on the nature of the fill can be obtained from Maps 4 and 5.

It is emphasised that the engineering geology maps present only a general guide to the ground conditions and that they should not be used, as a substitute for detailed site investigation, to ascertain the conditions prevailing at any specific site. However, the maps will be useful as an aid to better site investigation design by indicating the conditions likely to be found at a given site. They are also a valuable source of general information relevant to planning issues.

Maps 9 and 10 are based, respectively, on the bedrock and superficial geology (Maps 1 and 2). The relationship between the engineering geology units and the bedrock formations and the superficial (drift) deposits are shown in the map margins and tables 3 and 4. These tables also describe the engineering geological characteristics of each of the units. Where information was available, these descriptions include comments on engineering design considerations in relation to foundations, excavatability, suitability as fill material and slope stability. These descriptions are summarised on the map margins. Summary geotechnical data for the units are presented in Tables 1 to 22 of the accompanying engineering geology report (Crummy and Culshaw, 1991).

Table 3 Engineering Geology of Bedrock

Engineering Geological Unit		Geological Unit	Description
1	Very weak to weak limestone	Upper Chalk	Homogeneous, white, generally hard, jointed chalk with occasional flint bands. Joints are tight, becoming more open towards the surface. Weathers from blocky rock of low to intermediate plasticity and very low compressibility when fresh to a very soft, intermediate to high plasticity, medium to high compressibility, putty-like material. Upper surface irregular and solution features may be present in the upper c.20 m. Thickness c.80–100 m.
2	Overconsolidated cohesive soils	London Clay	Stiff to very stiff, overconsolidated, fissured, inorganic, blue-grey, pyritous, high to extremely high plasticity, low to medium compressibility, silty clay with layers of claystone nodules. Weathered clay is brown and may have high sulphate content. Very prone to ground movement due to swelling and shrinkage when moisture conditions are changed. Thickness c.135 m; weathering may extend to c.12 m.
3	Layered overconsolidated cohesive and moderately dense to dense non-cohesive soils	Claygate Beds	Upward coarsening sequence of interbedded moderately dense to dense fine sands and overconsolidated, firm to very stiff, blue-grey (brown when weathered), silty clays and silts of high to very high plasticity and low compressibility. Clays prone to swelling and shrink age on wetting and drying, particularly in surface desiccated zone. Sands may be saturated. 15–20 m thick; weathering observed to c.7 m.
4	Dense to very dense non-cohesive soils	Thanet Beds Woolwich and Reading Beds Oldhaven Beds Bagshot Beds	Dense to very dense, fine to medium, brown sands of very low to medium compressibility. Thanet Beds clayey at base becoming sandy with flint gravel at top; thickness 15–30 . Woolwich and Reading Beds clayey with bands of clay and flint gravel; thickness 8–20 m. Oldhaven Beds <6 m. Bagshot Beds silty, with bands of silty clay; maximum thickness c.15 m.

Table 4 Engineering Geology of Superficial (Drift) Deposits

	Engineering Geological Unit	Geological Unit	Description
1	Fill and made ground	Fill and made ground	Wide variety of materials. Engineering properties likely to be very variable except for engineered fills such as embankments. Methane may be generated from organic material.
2	Organic soils	Peat	Dark brown to black, very soft to firm, highly compressible deposit of decayed vegetation in fibrous and/or amorphous form. Extremely high moisture content (generally waterlogged), extremely high plastic ity. Lenses or layers in the Alluvium. High sulphate contents likely.
3	Normally consolidated cohesive soils	Interglacial Deposits Head Alluvium Estuarine Alluvium Intertidal Deposits	Interglacial Deposits: silty and sandy clays; Head: soft, plastic, low strength, compressible, brown silty and sandy clays; Alluvium, Estuarine Alluvium, Intertidal Deposits: very soft, very plastic, highly compressible, brown (weathered) or blue-grey (unweathered) silty and sandy clays with bands or lenses of sand or gravel, and peat. High sulphate contents may be present (not Interglacial Deposits).
4	Laminated normally consolidated cohesive and non-cohesive soils	Glaciolacustrine Deposits	Complex sequence of variably coloured, interbedded sands, clayey sands and sandy and silty clays. Maximum thickness c.6 m; very lim ited extent.
5	Overconsolidated cohesive soils	Till	Firm to very stiff, moderate to high plasticity, low to moderate compressibility, brown (weathered) blue grey silty and sandy clay with mostly flint gravel. Thickness variable, usually <10 m.
6	Dense to very dense non-cohesive soils	Terrace Gravel Combe Deposits Glaciofluvial Sands and Gravel Head Gravel Older Head Sand and Gravel of Unknown Age	Medium dense to dense, clayey to sandy gravels and clayey and gravelly sands with bands of fine to coarse sand. Gravel predominantly flint. Variable thickness, usually <10 m. Combe Deposits consist of rubbly chalk mixed with flint gravel and sand; maximum thickness c.3 m.
7	Landslip	Landslip	Mass movement deposits usually in London Clay and Claygate Beds and/or Head deposits derived from these. Initiated on slopes >7–8° but may be reactivated on lower slopes. Successive rotational, shallow rotational, translational and non-circular types found in dormant or active state.

3.2 SLOPE STEEPNESS

Slope steepness (Map 8) is an important parameter in planning and development, providing a constraint for some land uses. There is a close relationship between slope steepness and factors such as slope stability, the design of gradients of roads and railways, the use of agricultural machinery and certain types of construction plant, housing density and industrial development. In south-west Essex the steeper slopes (>7–8°), predominantly on the outcrop of the Claygate Beds, are particularly prone to landslip (see section 2.1.1 of this report, and also Crummy and Culshaw (1991)).

4 Hydrogeology

4.1 INTRODUCTION

The average annual rainfall in the area varies from less than 500 mm around Grays to over 600 mm in the northern part of the area; annual potential evapotranspiration is about 435 mm. The two principal aquifers are the Chalk and the sands and gravels of the superficial deposits. The Chalk crops out only in the south but is present at depth beneath the whole area. Superficial deposits cover much of the area but the majority of the sands and gravels occur as terrace deposits along the western margin and bordering the Thames estuary. Therefore the groundwater abstractions are concentrated in the south and west of the district, along with most of the landfill waste disposal sites and the majority of the population.

Map 11 indicates the areal extent of the bedrock formations, with those considered to be aquifers coloured. For clarity the superficial deposits have been omitted. The locations of sources licensed to abstract groundwater are shown with the aquifer, purpose and an indication of the quantity abstracted. Other information shown comprises Chalk groundwater level contours, the position of two isochlors and all known past and present landfill waste disposal sites with planning consent taking non-inert substances. Typical chemical analyses of groundwaters from the main aquifers are given in Table 5.

4.2 BEDROCK FORMATIONS

4.2.1 Chalk

The Chalk forms the principal aquifer although it is overlain by significant thicknesses of Tertiary deposits over most of the area. Porosities vary from 15–40% but because the pores are very small, with most interconnections less than 1 µm in diameter, specific retention is high and primary permeabilities are low at 10^{-3}–10^{-4} m/d. However, these have been increased significantly post-depositionally by high-angle joints and fissures of structural origin and numerous horizontal discontinuities associated with bedding and depositional structures. These are further enlarged by solution in the groundwater weakly acidified by the presence of dissolved carbon dioxide. Flow horizons have, therefore, developed preferentially along areas of highest groundwater flow. These tend to occur along the river valleys, both at outcrop and beneath the younger Tertiary bedrock formations, within 60 m of the ground surface. They are often at or near the water table and occur in discrete horizons at depth, in particular at the base of the Chalk Rock and Melbourn Rock. Where the chalk is beneath a considerable thickness of Tertiary deposits, the fissures tend to be closed, although around Low Street [67 77] this is not the case and flow horizons are abnormally developed at depths of up to 200 m. Where the Thanet Beds are absent, the structure of the top 5 to 10 m of the chalk has been destroyed by subaerial Pleistocene weathering of alternate freezing and thawing and the permeabilities of the resultant putty-like Chalk are minimal.

Yields are consequently very variable, depending on the amount of fissuring encountered, ranging from less than 1 l/s for small-diameter or deep boreholes to over 75 l/s for large-diameter shafts with associated adits. Borehole yields are generally improved by acidisation. A 457 mm diameter borehole at Purfleet [5515 7955] 45.7 m deep yielded 221 l/s from the Chalk, beneath superficial deposits and Thanet Beds, for only 3.3 m drawdown when constructed. Transmissivities at or near outcrop range from less than 5 m^2/d to over 3000 m^2/d with storage coefficients of 1×10^{-3} to 2×10^{-4}. There are licences to abstract 8.1 million m^3/a from the Chalk and overlying Lower London Tertiaries in this area, of which 3.7 million m^3/a is used for public supply.

Records indicate that in the mid- to late-nineteenth century, overflowing artesian conditions existed in the area north of the Thames flood plain, maintained by recharge from the higher ground to the south of the river. However, abstraction caused water levels to fall by several tens of metres to significantly below sea level. With reduced pumping since 1967 and more effective management of the aquifer, levels have risen again, although not to their original height.

At outcrop, water from the Chalk is of the calcium-bicarbonate type and normally of good quality, although in areas of recent recharge nitrates exceed 1 mg/l (as N). However, over large parts of this area the aquifer has been affected by saline intrusion or contaminated by organic matter either naturally from marsh land or from oil spills. Beneath superficial deposits and increasing thicknesses of Tertiary cover, sulphates increase, nitrates decrease, and calcium is replaced by sodium because of cation exchange. Water with a fluoride ion concentration of 4 mg/l was present in a borehole just north of the area [6772 9508] abstracting from both the Thanet Beds and the Chalk. The overpumping which led to the dramatic decline in water levels and extensive dewatering related to the quarry workings has caused saline water from the Thames estuary to be drawn into the aquifer. Salinity levels increased up until 1976, but the decrease in abstractions has halted the encroachment of the saline front, and in some places it has retreated. Also some discharge of water from the Upper Chalk aquifer to the river has recommenced. Currently a recharge mound in the Chalk and Thanet Beds outcrop in the Thurrock area protects the public supply source at Stifford [5926 8008] by stabilising the position of the 100 mg/l isochlor for all except the driest months of the year. Chlorides adjacent to the river are 7000–9000 mg/l but decline rapidly inland, with the saline water overlain by a thin 10–20 m thick layer of fresher water and underlain at more than 100 m by fresher groundwater.

4.2.2 Thanet Beds

The Thanet Beds overlie the Upper Chalk unconformably and are in hydraulic continuity with it. Over the majority of their outcrop the Thanet Beds are partially saturated, apart from the outliers along the southern margin of the outcrop and in a small area north of Chadwell St Mary [655 800]. Boreholes into the sands tend to continue down into the Chalk, utilising both the higher storage coefficients of the Thanet Beds and the higher transmissivities of the Chalk. The sands are layered, leading to significantly higher horizontal than vertical permeabilities. The water is of the calcium sulphate type, with lower bicarbonate but higher sulphate, chloride, magnesium and potassium levels than those encountered in the Chalk.

Table 5 Typical chemical analyses of groundwaters in the SW Essex area

Location	Low Street*	Low Street	West Thurrock#	Merry Meade	Bulpham*	Laindon*	Low Street	Low Street
National Grid Reference	6765 7789		573 780	5996 9433	6470 8618	6848 8818		
Type of Source	Borehole	Borehole	Well	Borehole	Borehole	Borehole	Borehole	Borehole
Aquifer	Chalk	Chalk	Chalk	Thanet Beds	Oldhaven Beds	Oldhaven Beds	Drift	Drift
Date of Analysis	13/12/1983	25/9/1983	2/11/1988	18/8/1913	8/8/1900	4/1898	5/9/1983	30/11/1983
ph	7.2	7.1	7.4	—	—	—	7.5	7.7
Electrical	650	1600	3400	—	—	—	2050	570
Conductivity (µmhos/cm)	—	—	1900	660	8180	785	—	—
Total (mg/l)								
dissolved solids								
Bicarbonate (HCO_3^-) (mg/l)	270	329	365	378	357	366	531	287
Sulphate (SO_4^{2-}) (mg/l)	50	286	240	96	3704	124	86	38
Chloride (Cl^-) (mg/l)	52	216	650	116	1730	155	430	50
Nitrate (NO_3) (mg/l)	0.5	—	65	1.5	10.9	0.9	—	—
Calcium (Ca^{2+}) (mg/l)	90	230	210	6.5	457	8	80	79
Magnesium (Mg^{2+}) (mg/l)	13	13	48	3	848	4.5	10	14
Sodium (Na^+) (mg/l)	29	109	320	251.5	905	284	360	24
Potassium (K^+) (mg/l)	6	17	23	—	—	—	45	6
Iron (total) (mg/l)	—	—	10	—	—	—	—	—
Manganese (total) (mg/l)	—	—	0.73	—	—	—	—	—
Silica (mg/l)	21	13	13	—	333	—	—	19

* National Well Record Collection

National Rivers Authority

4.2.3 Woolwich and Reading Beds

The Woolwich and Reading Beds are important hydrogeologically only in that they tend to confine the groundwater in the underlying strata.

4.2.4 Oldhaven Beds

The Oldhaven Beds comprise up to 6 m of shelly sands with a locally cemented pebble bed at the base. With their limited thickness and outcrop area, they are not capable of providing more than small, local supplies of the order of 0.5 l/s.

4.2.5 London Clay

The main hydrogeological significance of the London Clay is that it confines groundwater in the underlying formations; however, a few small supplies are obtained from springs issuing from the sandier seams and perched water levels occur within the weathered rocks near to the ground surface. Due to the presence of minerals containing sulphur such as selenite and pyrite, within the clay, the sulphate concentrations of these waters can reach 3000 mg/l during periods of dry weather; high sulphate contents in groundwater have a deleterious effect on cement. Chloride contents are also high with values of 250–500 mg/l common, the clays having been deposited under marine conditions.

4.2.6 Claygate Beds

The Claygate Beds comprise between 15 and 30 m of clays, silts and interbedded fine-grained sands. Some springs occur at the base.

4.2.7 Bagshot Beds

Springs are developed at the base of the Bagshot Beds outliers. However, their association with the higher ground means that water drains rapidly from the sands and these strata cannot normally support even small demands, although a 12.0 m deep borehole at Langdon Hill [TQ 6829 8657] sustained a yield of 0.2 l/s for 14 days.

4.3 SUPERFICIAL DEPOSITS

Superficial deposits of variable origin and lithology cover much of the area. There are licences to abstract 2.7 million m^3/a from the superficial deposits in the project area (although 2.5 million m^3/a is used for sand and gravel washing, and a large proportion will therefore be recycled) and they form the second aquifer of the area.

In the north, the Tertiary deposits are overlain by small outcrops of Older Head, Glaciofluvial Sand and Gravel and Till. These are of little hydrogeological significance although the Older Head will limit infiltration into the Bagshot Beds outliers around Brentwood. Further south an early Pleistocene gravel infilling a channel eroded into the Thanet Beds and Upper Chalk forms an important local aquifer. The gravel is at an average depth of 10 m and fully saturated. At Mill House Farm [TQ 6709 7781] it is confined by a 2–5 m thick clay and has a transmissivity of around 300 m^2/d and a storage coefficient in the range 10^{-3}–10^{-4}. The water is sulphate-rich and derived from the Thanet Beds.

The sands and gravels of the Thames terrace deposits together form a series of areally discontinuous multi-layered leaky aquifer units, each with a perched water level, whose flow directions and storage are determined by seasonal recharge patterns and the tidal effects of the estuary. They are saturated to sea level by surface infiltration. Large volumes have been extracted and this, with the associated pumping, has had a major effect on their hydrogeology and that of the underlying Chalk and Thanet Beds. Due to their now patchy nature, yields are generally small and supplies are liable to surface contamination. Quality is very variable, from modern nitrate-rich calcium-bicarbonate groundwaters to calcium-sulphate groundwater and highly saline estuarine waters. Quality improves inland.

The Estuarine Alluvium comprises sandy gravels and clays up to 25 m thick which have a low permeability. Near the Thames the alluvium is in hydraulic continuity with the Chalk and produces mainly saline water.

Head occurs in the central part of the map area, is generally thin and of no hydrogeological importance as it is predominantly underlain by London Clay.

4.4 VULNERABILITY TO POLLUTION

Groundwater is generally less vulnerable to pollution than surface sources because of the filtering and attenuating effects of the unsaturated zone. However, once an aquifer is polluted some persistent substances may remain in it for decades. It is therefore important that aquifers are protected from potential pollutants. There are two main classes of pollution, point and diffuse sources. Point sources include landfills and other waste disposal sites such as sewage treatment works, and storage tanks for silage, fuels, industrial solvents and other chemicals. In the area under consideration there are many landfill sites currently licensed to accept household and commercial and/or industrial wastes. These, together with the many tips that have now closed, represent a significant risk to groundwater quality where they are sited directly on aquifers that are not protected from leachate contamination by overlying fine-grained impermeable material. The amount of leachate produced depends on rainfall, temperature and the permeability and thickness of any cover. The composition of the leachate depends on the age and nature of the infill and on leaching rates. Household and commercial wastes can produce leachates containing bacteria and viruses with dissolved solids contents and biochemical and chemical oxygen demands of many tens of thousands of mg/l. Industrial wastes, either dumped directly or in containers that later leak, may add heavy metals, arsenic, cyanide and other organic compounds. The storage of materials such as fly ash (2 sites in the area) also represents a serious risk to groundwater quality, as do storage tanks that are poorly constructed or in poor repair.

The main source of diffuse pollution in the area is saline intrusion induced by over-abstraction in the past, reducing water levels to significantly below sea level and hence drawing saline water from the Thames estuary into the aquifer. Despite abstraction having declined in the past 20 years, there are still extensive areas where the chloride ion concentration is above 300 mg/l. Although the area under consideration is not primarily agricultural, nitrate and biocides are applied to the land. The use of both these products has increased signficantly since the war. The potential for nitrate applied on the land surface to reach the aquifer depends on the crop, timing of the application, agricultural practice, climate, soil type and presence of any impermeable deposits overlying the aquifer. Leaching losses of 30–50% of the original applications are common, with a consequent increase in the nitrate concentration of both surface waters and groundwaters. The significant quantities of nitrate present in the pore-waters of the unsaturated zones of most aquifers indicate that the nitrate concentrations of groundwaters will continue to rise for some time even if the use of fertilisers is discontinued. Within the area under consideration the most vulnerable aquifers are the Chalk and superficial deposits where they are present at the surface or overlain by permeable material. Locally concentrations already exceed the maximum admissible concentration of 50 mg/l as NO_3 (11.3 mg/l as N) specified in the European Communities Drinking Water Directive (EC 1980). Where the aquifer is overlain by more than a metre or so of clay, nitrate concentrations are generally low (typically less than 1 mg/l as N) and are likely to remain so.

The transport from the soil to the water table of organic biocides, sprayed on the land to control weeds and pests, is likely to be signficantly different from that of nitrate. Little is known about their behaviour within or below the soil zone, but they are known to be adsorbed onto clay minerals, to be biodegradable and to be less readily leached than nitrates. Therefore, aquifers at little risk from nitrate pollution are likely to be protected also from organic biocides, but the converse is not necessarily true.

5 Mineral resources

This chapter outlines the bulk mineral resources of the study area. These include deposits that are not currently exploitable, but may have a foreseeable use, rather than reserves, which can only be assessed in the light of current locally prevailing economic considerations. Clearly, both the economic and social factors used to decide whether a deposit may be workable in the future cannot be predicted; they are likely to change with time. Deposits not currently economically workable may be exploited as demand increases, as higher grade or alternative materials become scarce, or as improved processing techniques are applied to them.

The mineral resources are shown on Map 6 (Bedrock Resources) and Map 7 (Superficial Resources).

On these maps, areas shown as resources do not stop at urban margins but continue beneath the towns which are shown by a superimposed stipple effect. This is intended as an aid to urban development planning where it may be possible to exploit minerals within built-up areas during large-scale developments.

Because much of the information gathered during the study relating to mineral resources is 'commercial in confidence' no attempt has been made to quantify the resources; only their areal extent is shown, together with spot thicknesses where these are available and informative.

A comparison of the two resource maps will show that in many places superficial resources overlie bedrock resources.

5.1 CHALK

5.1.1 Cement manufacture

Until recently the Upper Chalk has been quarried extensively in the Grays-Thurrock area for use in the manufacture of cement, but all extraction has now ceased. By the time of their closure most of the quarries had reached their geographical limits and were also constrained in the vertical sense by the water table which hereabouts lies at about Ordnance Datum (0 m OD).

Many of the former quarries are now being redeveloped as industrial, trading and residential estates; others have been utilised for oil storage. Such developments have virtually sterilised the few remaining areas of chalk above the water table.

With the present day extraction of chalk for cement manufacture now centred to the south of the River Thames in Kent, together with the factors mentioned above, it is unlikely that any major extraction of chalk for cement making will take place in the Grays-Thurrock area within the foreseeable future.

5.1.2 Agricultural lime

At the time of survey (1988) chalk was being dug intermittently for agricultural lime from two quarries, Gibbs Quarry [595 784] at West Thurrock, and Beacon Hill Quarry [558 782] at Purfleet. The area at West Thurrock is scheduled for redevelopment as a residential estate and production may have already ceased. The quarry at Purfleet is also due to be closed within the near future.

Throughout the Grays-Purfleet area, the Upper Chalk has been dug historically from underground chambers, known as 'Deneholes' or 'Daneholes' (see Map 4 and Figure 7). To reach the chalk vertical shafts were dug through as much as 20 m of the overlying terrace gravels and Thanet Beds. On reaching the chalk a series of six chambers, usually arranged in a double trefoil pattern, was excavated. Although there has been considerable debate over the purpose of the deneholes, with both grains stores and hiding places having been suggested, it seems more probable that they were dug as a source of chalk for liming the land. This explanation is perhaps even more plausible when one considers that the soils developed on the terrace gravels or Thanet Beds above are acidic and would benefit from a dressing of lime. It may also be more than a coincidence that most of the deneholes appear to have been dug in the relatively flint-free chalk towards the top of the Upper Chalk thus making excavation easier.

5.2 CLAY

5.2.1 Cement manufacture

London Clay, for use in cement making, where it is mixed with chalk, has been dug formerly from three pits at Aveley, but current extraction is centred about 5 km to the east at South Ockendon, where several pits have been dug. The clay is slurried and pumped beneath the Thames to cement works in Kent. For use in the manufacture of cement, the chemical composition of the clay has to fall within certain well-defined limits, the Al_2O_3/SiO_2 ratio being of particular importance. The London Clay dug from both Aveley and South Ockendon is from near the base of the formation. It is probable that clay dug from a similar stratigraphical position elsewhere along the outcrop will also have a suitable composition. Large areas of London Clay are present to the north of the workings, but these are higher in the formation and until their chemistry has been determined, their suitability for cement making remains unknown. A further constraint on extraction is the necessity during quarrying to retain a seal of clay at the base of the workings to prevent the upward ingress of water under pressure from the sandy formations below.

5.2.2 Brick and tile making

Bricks and tiles have been made historically in the area from a variety of deposits. The most extensive brickyards were at Grays, where in 1880, about 500 men were employed making bricks for Martello Towers, but the interglacial deposits worked for the bricks became exhausted and the industry closed, the only evidence of its former existence being the large area of low-lying, worked out ground underlying much of the central town.

Brick earth was dug from several pits to the north of Upminster. The deposits used appear to have been entirely dug away, but deposits of glacial silt mapped during the present study just to the north may give an indication of their nature.

The Claygate Beds have been worked for brick and tile manufacture from several small pits, notably at Brentwood and Shenfield. Although the London Clay has been worked elsewhere for brick-making, in the present district its use seems to have been restricted to small pits supplying the needs of individual houses or farms during their construction.

Bricks have also been made locally and on a very limited scale from other deposits including Head, Alluvium, Till and the Woolwich and Reading Beds. The latter have been dug from quarries at Aveley for tile-making.

In the foreseeable future it is unlikely that the London Clay will be used for brick-making on a commercial scale in the area, the brick companies preferring the more economical partially self-firing Oxford Clay currently being exploited near Bedford and Peterborough. The Woolwich and Reading Beds could provide a local resource for relatively small-scale specialist tile-making.

5.3 SANDS

Sands have been obtained from the Woolwich and Reading Beds, the Thanet Beds and the Bagshot Beds (Map 6). In the south many of the pits were started as excavations in terrace gravels but were subsequently deepened to include the Woolwich and Reading Beds, where present, and the Thanet Beds below. Grading characteristics of the sandy bedrock formations are shown as histograms in Figure 8.

The Woolwich and Reading Beds and the Thanet Beds consist predominantly of silty fine-grained sands; the main difference between the two formations being the much higher clay content of the Woolwich and Reading Beds. Also the Thanet Beds are pebble-free whereas the Woolwich and Reading Beds contain scattered well-rounded black flint pebbles which locally, for example at Orsett Cock, become concentrated into thick accumulations of gravel.

The fine-grained nature of both the Thanet Beds and the Woolwich and Reading Beds makes them unsuitable for many purposes. Where the clay content of the Woolwich and Reading Beds is high the deposit is usually regarded as waste.

The Thanet Beds and the Woolwich and Reading Beds have a combined average thickness of about 40 m but the uppermost few metres of the Woolwich and Reading Beds, where preserved, commonly consists of shelly clays with beds of litnite and lignitic clays. In the west the Thanet Beds and the overlying Woolwich and Reading Beds have a narrow outcrop in places less than 0.5 km in width along the steep sided valley of the Mar Dyke. The outcrop widens to over 5 km between Grays and Stanford-le-Hope, where the deposits have been worked in several pits. Within this area large tracts of sand remain unworked, much of it overlain by terrace gravels up to 2–3 m thick.

The Bagshot Beds are restricted to the higher ground in the north and east. They also consist predominantly of fine-grained sands, commonly interbedded with thin clay seams. Much of their outcrop is built over by the towns of Brentwood and Billericay, or else occupies areas of great natural beauty. The maximum thickness preserved of the Bagshot Beds is about 15 m. Their extraction has been very limited, local preference being given to the adjacent outcrops of glaciofluvial sand and gravel.

Sands can also be obtained locally by screening of the river terrace sands and gravels. Sands obtained in this way can be produced to the grain-size requirements desired for any particular purpose.

5.4 GRAVELS (BALLAST)

Map 7 shows the areal distribution of gravels within the superficial deposits. Areas where the gravels are within 1 m of the surface are shown in red; areas where gravels may be expected to occur beneath overburden are shown in pink. Deposits where the known thickness is less than 1 m have been omitted, in accord with general BGS practice. The map also shows the extent of former and present-day gravel workings and urban areas where the gravels are effectively sterilised. Gravels are also present locally within the Woolwich and Reading Beds (bedrock), for example at Orsett Cock, where they are currently worked.

Within the study area gravels are present both as isolated patches of glaciofluvial sand and gravel, in the north, and as more extensive areas of river terrace deposits, confined generally to the south and south-west (see Figure 13). Small areas of gravel of unknown age are present in the east but for the purpose of this account can be included in the glaciofluvial gravels. The central part of the area is completely devoid of gravel. In general terms the glaciofluvial gravels can be expected to vary considerably in thickness and grain size over short distances whereas the terrace gravels will be more uniform. Both types are composed essentially of flint pebbles with small quantities of quartzite, vein quartz, sandstone and igneous pebbles also present. Within the glaciofluvial gravels chalk pebbles may be present at depth although none were noted during the field survey. These would render the gravels unsuitable for some purposes.

Grading characteristics of some of the gravels are shown as histograms in Figure 9.

Although it has not been possible to contour the thicknesses of the gravel deposits largely on account of the commercial nature of the borehole data, but also because of the very uneven spread of data available; spot thicknesses are given where available and informative.

The glaciofluvial gravels have been worked on only a limited scale, mostly in small pits for individual farm use, but some larger workings are present to the south of Brentwood. These gravels may occur below, within or above till, and locally may be very clayey and poorly-sorted containing both sand-size particles and cobbles. As mentioned above thicknesses can be expected to be very variable ranging from less than 1 m, perhaps up to 10 m, although the thickness of most deposits would be well below this maximum figure. In areas where glaciofluvial gravels overlie Bagshot Beds both deposits could conceivably be extracted in the same pit.

The terrace gravels, deposted when the River Thames flowed at higher levels than at present, cover much of the southern part of the study area. Several distinct accumulations of gravel have been identified forming a stepped topography from the low-lying ground adjacent to the River Thames up to about 45 m OD inland.

In the west large areas of these gravels have been extracted, in many instances only the gravels beneath the roads remain. Similar extensive workings are also present between Grays and Stanford-le-Hope, and also around East Tilbury.

Over much of the area the gravels are between 2 and 4 m thick but accumulations up to about 10 m occur locally, usually in the form of channels cut into the underlying bedrock. Large areas of gravels have been effectively sterilised beneath the towns of Grays, Chadwell St Mary, South Ockendon and the village of East Tilbury.

With increasing environmental pressures there has been growing concern over the reinstatement of the worked areas. Whilst it has to be said that most of the earlier worked ground was poorly reinstated and remains ground often suitable only for pony grazing, most of the more recent reinstatement has been of high quality with little, if any, evidence remaining of the former quarrying.

National Grid Ref.	Location	Formation	Depth (m)
TQ 5953 9145	WARLEY	BAGSHOT BEDS	
TQ 673 808	BUCKINGHAM ROAD PIT	WOOLWICH AND READING BEDS	
TQ 6965 8241	BGS STANFORD LE HOPE BOREHOLE	WOOLWICH AND READING BEDS	21.35 to 21.45
			22.55 to 22.85
			25.40 to 25.45
			30.35 to 30.65
		THANET BEDS	35.20 to 35.25
			52.95 to 53.05
			55.35 to 55.70

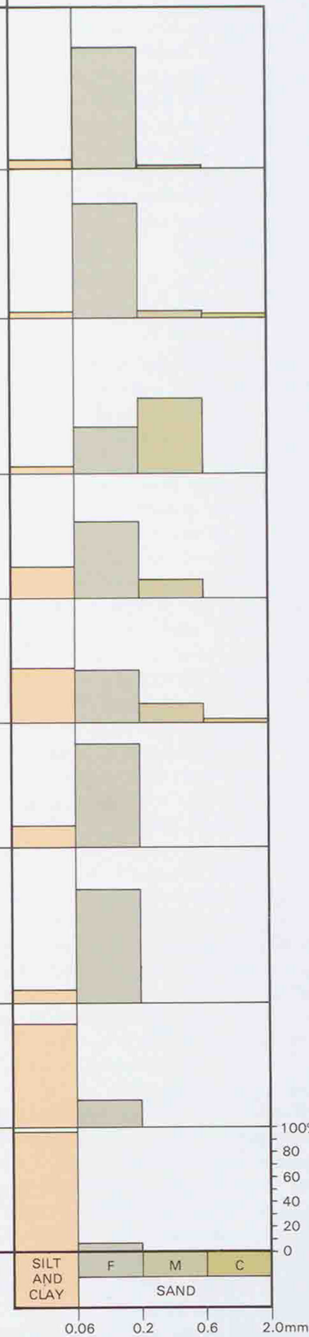


Figure 8 Grading characteristics of selected samples from sandy bedrock formations

National Grid Ref.	Location	Formation	Depth (m)
TQ 5953 9145	WARLEY	BAGSHOT BEDS	
TQ 673 808	BUCKINGHAM ROAD PIT	WOOLWICH AND READING BEDS	
TQ 6965 8241	BGS STANFORD LE HOPE BOREHOLE	WOOLWICH AND READING BEDS	21.35 to 21.45
			22.55 to 22.85
			25.40 to 25.45
			30.35 to 30.65
		THANET BEDS	35.20 to 35.25
			52.95 to 53.05
			55.35 to 55.70

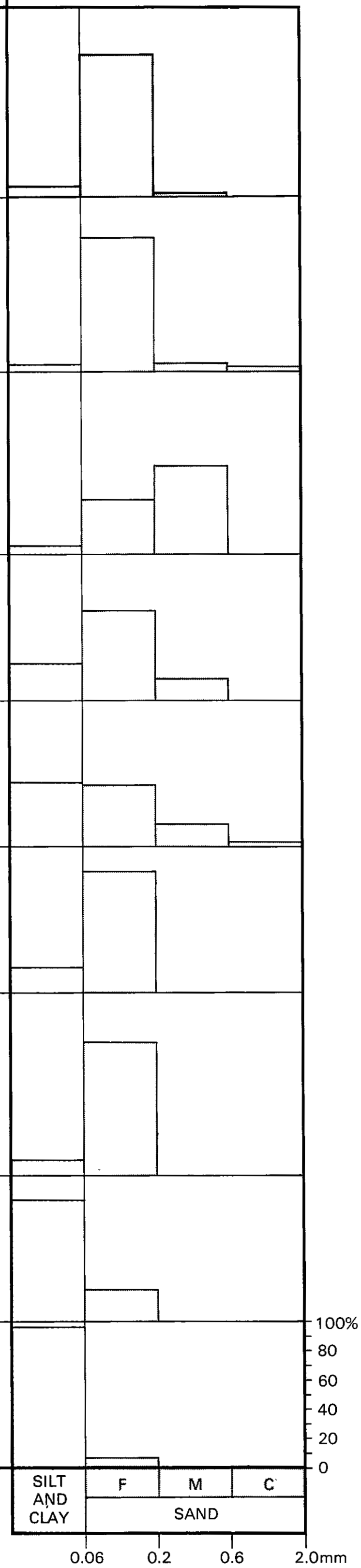


Figure 8 Grading characteristics of selected samples from sandy bedrock formations

Although large tracts of gravel remain unworked, details of their thicknesses and composition commonly remain unknown or only poorly known. Many of the remaining areas of gravel back onto housing bordering the towns.

Gravels in the Grays-Stanford-le-Hope-East Tilbury areas have the added advantage that they overlie Thanet Beds or Woolwich and Reading Beds, and thus future pits could work a combination of these deposits. In the South Ockendon area the terrace gravels overlie London Clay which would be regarded as waste. However, if the gravel workings are ultimately to become landfill sites, then a clay base may be more acceptable than a sandy base which may be in hydraulic continuity with the Chalk, the main aquifer of the area.

National Grid Ref.	Location	Deposit
TQ 688 806	CORY GRAVEL PIT	EAST TILBURY GRAVEL
TQ 5678 7874	WATTS WOOD	CORBETS TEY GRAVEL
TQ 692 782	AYLETTS GRAVEL PIT	MUCKING GRAVEL
TQ 5800 8390	BALDWINS FARM GRAVEL PIT	CORBETS TEY GRAVEL
TQ 5640 8450	BUSH FARM GRAVEL PIT	
TQ 6560 8120	ORSETT COCK QUARRY	ORSETT HEATH GRAVEL
TQ 5950 7870	NORTH END GIBBS QUARRY	
TQ 6590 9015	DUNTON WAYLETTS	TERRACE, undifferentiated
TQ 5953 9145	WARLEY	OLDER HEAD

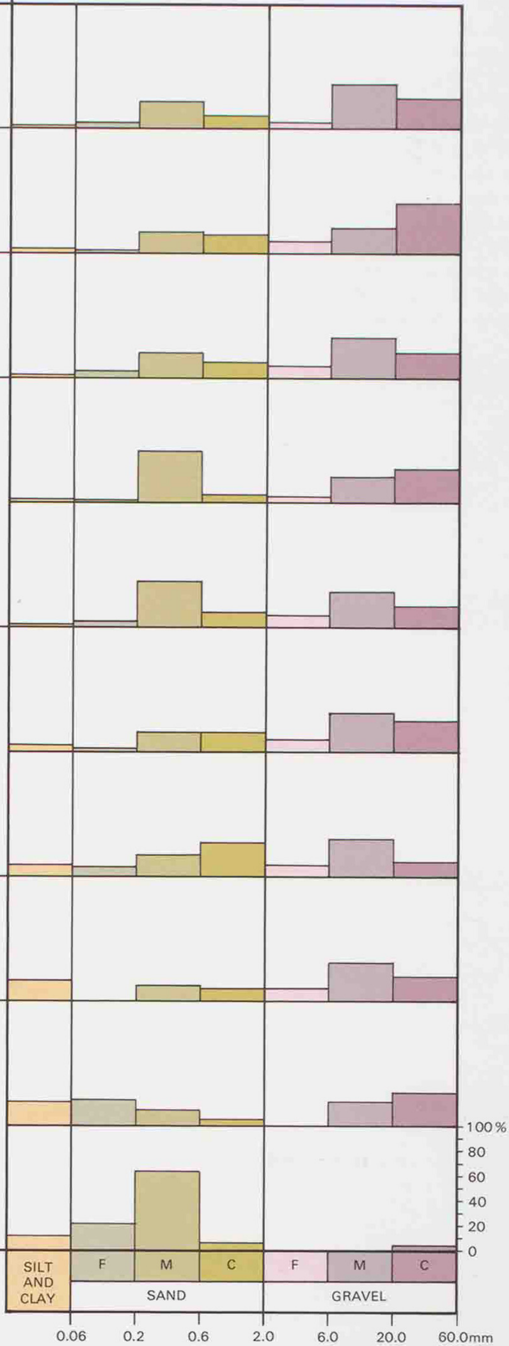


Figure 9 Grading characteristics of selected samples from superficial deposits

National Grid Ref.	Location	Deposit
TQ 688 806	CORY GRAVEL PIT	EAST TILBURY GRAVEL
TQ 5678 7874	WATTS WOOD	CORBETS TEY GRAVEL
TQ 692 782	AYLETTS GRAVEL PIT	MUCKING GRAVEL
TQ 5800 8390	BALDWINS FARM GRAVEL PIT	CORBETS TEY GRAVEL
TQ 5640 8450	BUSH FARM GRAVEL PIT	
TQ 6560 8120	ORSETT COCK QUARRY	ORSETT HEATH GRAVEL
TQ 5950 7870	NORTH END GIBBS QUARRY	
TQ 6590 9015	DUNTON WAYLETTS	TERRACE, undifferentiated
TQ 5953 9145	WARLEY	OLDER HEAD

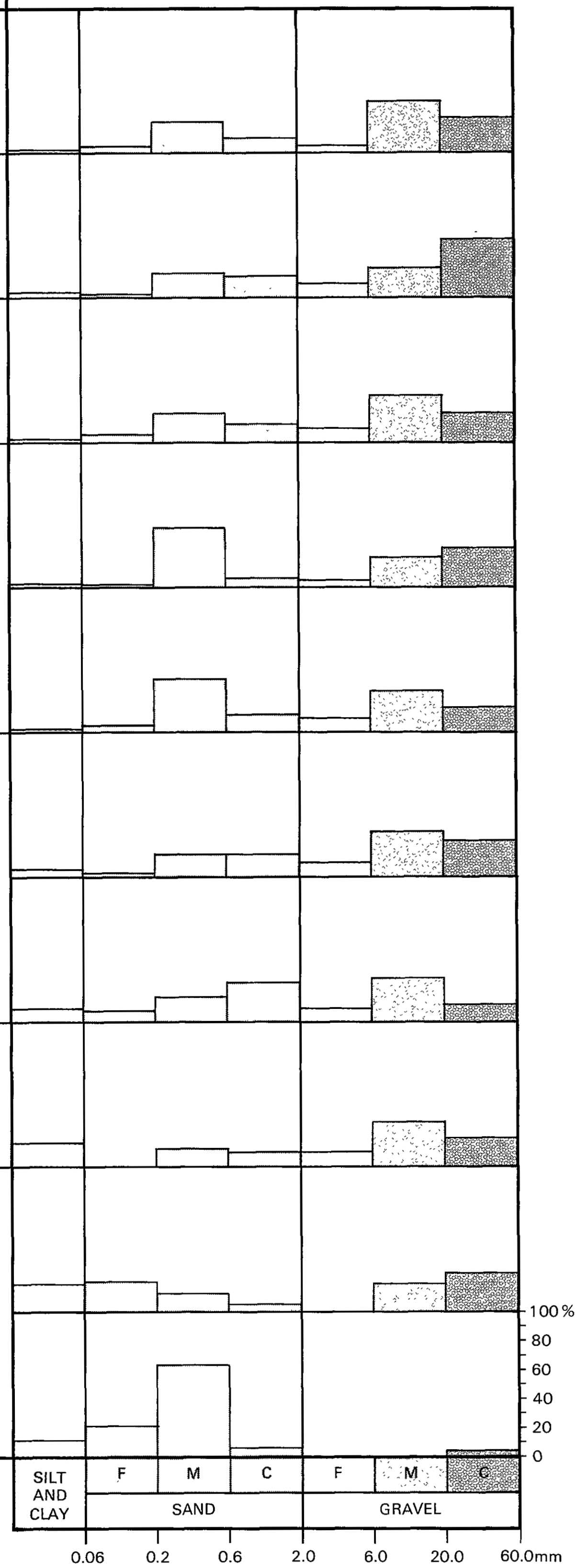


Figure 9 Grading characteristics of selected samples from superficial deposits

5.5 LANDFILL GAS

Within Britain, about 25 million tonnes of household, commercial and industrial waste are disposed of annually, much of this finding its way to landfill sites. Biological processes occur within the dumped material, and when all available oxygen has been used up, a gas is produced consisting of about 65% methane and 35% carbon dioxide. This gas, when extracted, can be processed and used profitably as a fuel.

Gas is currently being produced from a landfill site at Aveley [558 805] formerly operated by the Greater London Council. The site covers an area of 20 hectares and the fill is up to 35 m deep. Between the years of 1972 and 1986, the site received about 250 000 tonnes of household waste a year.

Within the site twenty boreholes lined with perforated plastic pipes connect to a collecting main. After extraction and processing the gas is piped about 5 km to the Purfleet Board Mills for use in a steam-raising water tube boiler. The plant at Aveley commenced production in 1983 and produces about 5 million tonnes of gas per year. The gas is supplied at a discount compared with the cost of natural gas. The costs of conversion to landfill gas fuel can be recovered over as short a period as 1.5 years.

In many landfill sites methane is a hazard rather than a resource. In order for it to become a resource, it is necessary that a potential user be found within the vicinity of the landfill site, otherwise the cost of piping the gas will be prohibitive. The thickness of the fill, its moisture content and the positioning of clay seals within the fill are also important factors in the economic potential of the gas. For these reasons it is advantageous to identify any landfill site as a potential gas resource at an early stage in its development.

Just north of the gas-producing site at Aveley, another large landfill site is currently being backfilled with household waste. This site obviously has the advantage of a ready market for gas, and could also utilise the current pumping equipment, thus cutting costs significantly.

At Mucking Marshes [687 801] a landfill site is currently being constructed with the commercial production of landfill gas in mind. At the time of survey collecting pipes had been inserted. The older areas of landfill in this area are apparently unsuitable due to their thinness, moisture content and lack of clay seals.

6 Geological sequence

The sedimentary deposits of the area can be divided into two main groups, the superficial (Drift) deposits and the Bedrock (Solid) formations. Whereas the bedrock formations in the area were deposited over a period of more than one hundred million years, the superficial deposits have all formed within the last one million years. The bedrock formations are commonly thick, are present over very large areas and they are usually arranged in a 'layered cake' sequence so that it is generally possible to predict the succession. The superficial deposits on the other hand, are commonly thin and variable. They have a patchy restricted distribution with complex relationships reflecting their deposition from water and ice, often upon an irregular land surface. Because of this their sequence is often unpredictable.

The Bedrock formations cropping out in the area are primarily of marine origin. The oldest such unit, the Upper Chalk, was laid down in a warm sea with little sediment influx. At the end of Cretaceous times uplift and erosion took place. Shallow marine or esturine conditions were then re-established and the early Tertiary formations including the Thanet Beds, Woolwich and Reading Beds, and the Oldhaven Beds were deposited. The sea then deepened again and the London Clay was deposited. A renewed shallowing with an increase in sandy sedimentation allowed the transitional Claygate Beds and then the Bagshot Beds to accumulate. There are no younger Tertiary strata in the district.

The Superficial deposits in contrast have been laid down during a brief period of glacial advances and retreats. Material picked up by the advancing ice sheets was later deposited as till (boulder clay). Torrential streams issuing from the ice sheets deposited glaciofluvial sands and gravels. During warmer interglacial phases and also after the ice had finally retreated from the area, fore-runners of the present rivers eroded and transported the glacial debris and redeposited it on the valley floors as bedded sands and gravels. During this period several changes occurred in the relative levels of the land and sea. With static or rising sea level accumulations of sand and gravel occurred in the valleys; during periods of relative fall, the rivers cut their channels deeper, leaving the older sands and gravels at higher levels perched on the valley sides and forming the terrace deposits seen today. In post-glacial and recent times, alluvial sediments and peats have been deposited along the floodplains of rivers and estuaries.

Artificial deposits and areas of worked ground have also been surveyed.

The sequence of superficial deposits and bedrock formations which have been recognised at the surface or proved in boreholes to underlie the study area are shown in Table 1.

6.1 BEDROCK (SOLID) GEOLOGY

The bedrock geology is shown on Map 1.

6.1.1 Concealed strata

Deep boreholes in the area have penetrated up to 250 m of strata below the oldest rocks seen at the surface. Brief details of the formations encountered are as follows:-

Formation	Thickness	Description
Upper Chalk	lowermost 50 m	soft white limestone with flints
Middle Chalk	c.70 m	soft white limestone generally flint free except near top
Lower Chalk	c.50 m	soft impure marly limestone
Upper Greensand	c.5 m	yellow-brown fine-grained sands
Gault	c.55–60 m	blue-grey clay
Lower Greensand	c.5 m	grey-green-brown sandstone
Oxford Clay	>5 m	grey-green silty mudstone

A study of the deep geology of Essex (Allsop and Smith, 1988) based mainly on gravity and magnetic geophysical data, provides information on formations believed to be present beneath those proved in the deepest boreholes in the area.

6.1.2 Upper Chalk

The Upper Chalk is the oldest of the bedrock formations seen at the surface in the district. It underlies the entire study area at depth, but is brought to the surface only in the south (Map 1) by a gentle dome-shaped fold, elongated east to west, known as the Purfleet Pericline. The Upper Chalk has an extensive outcrop between Purfleet in the west and Grays to the east, where until recently it was widely quarried for use in the manufacture of cement. Much of the chalk outcrop is obscured by superficial deposits, particularly by the Estuarine Alluvium of the River Thames floodplain.

The Upper Chalk is a fossiliferous and generally relatively soft white limestone composed mainly of debris from planktonic algae. Within the limestone are courses of nodular and tabular flints which are persistent throughout the area (Figure 10), and together with the rich shelly fauna enable a stratigraphical correlation to be made between the sections in the various quarries.

The Upper Chalk has a well developed system of joints along some of which solution has taken place causing the Thanet Beds or terrace sands and gravels above to collapse to lower levels (see section 2.1.2) The displacement of the courses of flints in some of the quarries indicates the presence of small scale faults.

Only the uppermost 30 m or so of the Upper Chalk is seen at the surface in the area, the remaining 50–70 m have been proved only in boreholes.

REPRESENTATIVE SECTIONS

Purfleet	[567 783]
West Thurrock	[595 785]
Grays	[600 787]

6.1.3 Thanet Beds

The Thanet Beds occur at the surface in the south (Map 1) where they extend between Aveley in the west and East Tilbury in the east. Much of their outcrop is obscured by superficial deposits, mainly river sands and gravels.

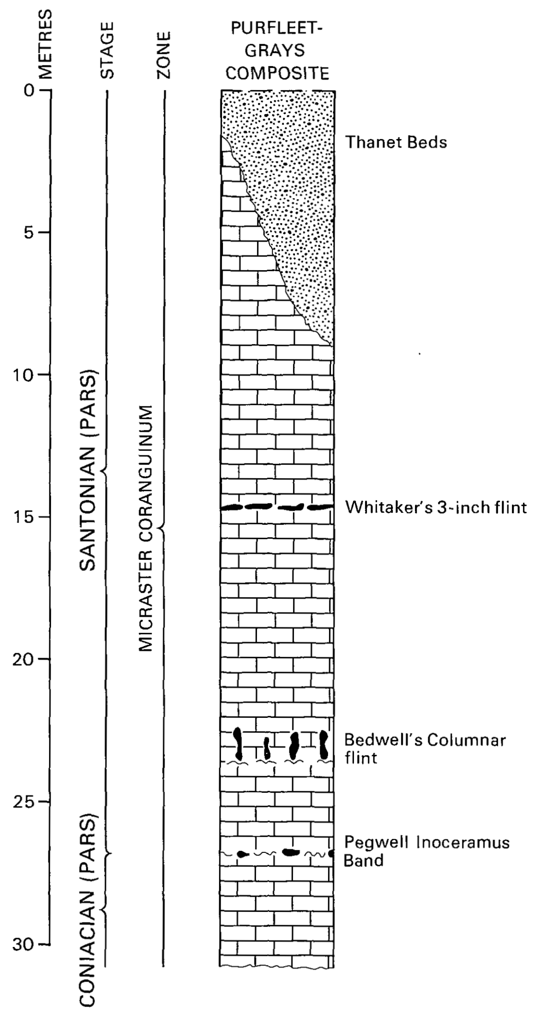


Figure 10 Main flint bands within exposed chalk

The Thanet Beds range in thickness from about 15 m to just over 30 m, although some of the greatest recorded thicknesses may be rather excessive due to the difficulty in distinguishing between the Thanet Beds and the overlying Woolwich and Reading Beds in borehole logs. Where a borehole log records a particularly thick sequence of Thanet Beds and a correspondingly thin sequence of Woolwich and Reading Beds then the borehole log should be regarded as suspect.

The Thanet Beds rest with unconformity upon the Upper Chalk; a period of uplift and erosion separating the two formations.

At the base of the Thanet Beds is the Bullhead Bed, a bed of green-coated generally unworn or only slightly worn nodular flints set in a brown sandy clay matrix. This is typically less than 0.3 m thick when seen in exposures, but in shell and auger boreholes is commonly recorded as being thicker, in some instances up to several metres thick. This is almost certainly in error, and due to some of the large flints remaining in the hole during drilling. The remainder of the formation consists of buff to yellow, glauconitic, clayey silts and fine-grained sands, which tend to become rather less silty and clayey towards the top of the formation. The uppermost 1–2 m are generally much burrowed with irregular burrows up to several centimetres in diameter filled with clayey fine-grained sands, and commonly containing scattered pebbles of well-rounded black flints similar to those occurring in the overlying Woolwich and Reading Beds.

REPRESENTATIVE SECTIONS:

Aveley	[573 800]
Chadwell St Mary	[649 781]

6.1.4 Woolwich and Reading Beds

The Woolwich and Reading Beds overlie the Thanet Beds and crop out between Aveley in the west and Stanford-le-Hope in the east (Map 1). In the west their outcrop is narrow and confined mainly to the steep northern side of the Mar Dyke valley. Farther east the outcrop widens considerably on the much gentler topography to the north-east of Grays. A small outlier almost entirely covered by superficial deposits is centred just east of Chadwell St Mary.

The Woolwich and Reading Beds form a more variable sequence than the Thanet Beds; they consist predominantly of buff-coloured rather clayey and silty fine-grained sands, which contain thin seams of clay and scattered well-rounded pebbles of black flint, which locally become concentrated to form lenses or beds of gravel. A thin gravel is commonly present at the base of the formation. At Orsett Cock [656 811] a gravel up to 9 m thick is developed. Towards the top of the formation, lignites, lignitic clays and grey shelly clays are locally present. At Aveley a thin fuller's earth (bentonite) occurs about 6 m above the base of the formation. The thickness of the Woolwich and Reading Beds varies from about 8 m near Stanford-le-Hope to just over 20 m at Upminster and Brentwood.

REPRESENTATIVE SECTIONS:

Aveley	[573 800]
Orsett Cock (gravel)	[656 811]
Chadwell St Mary	[649 781]

6.1.5 Oldhaven Beds

The Oldhaven Beds are just over 1 m thick near Aveley in the west, but thicken slightly eastwards to about 6 m near Stanford-le-Hope. They comprise orange-brown shelly medium to fine-grained sands locally cemented to form a sandstone. Because the Oldhaven Beds are so thin they have a very narrow outcrop.

REPRESENTATIVE SECTIONS

No sections were visible at the time of survey but blocks of shelly sandstone can be examined at Aveley [572 802] in a disused overgrown quarry.

6.1.6 London Clay

The London Clay, 120–130 m thick, forms an extensive outcrop over much of the central area (Map 1), but it is obscured at the surface by widespread Head (superficial) deposits up to several metres thick.

The lower part of the formation is characterised by blue-grey very silty clays with sandy partings. The silt and sand content decreases upwards through the formation. In the weathered zone the clays become chocolate-brown in colour. Within the clay, grey or pale brown, yellow weathering 'claystones', 'cementstones' and septarian nodules, which are hard pebbles and cobbles of calcareous mudstone, commonly veined with calcite ($CaCO_3$), occur in layers. Gypsum, as finely disseminated grains, and as well formed crystals (selenite) is present in the weathered zone, where it forms by the reaction of sulphate ions, produced by the oxidation of pyrite during weathering, with calcium carbonate present as shell material. At the surface the London Clay is usually strongly fissured, this becoming less noticeable with increasing depth.

REPRESENTATIVE SECTION:
South Ockendon [606 834]

6.1.7 Claygate Beds

The Claygate Beds are restricted to the north of the study area (Map 1), and to the south of Laindon, where their outcrops rise above the more subdued topography of the London Clay. Landslipping on the steeper slopes is widespread.

The Claygate Beds form a transitional formation between the clays of the London Clay and the predominantly sandy Bagshot Beds above. In boreholes which have been well sampled and logged it is possible to define the base of the formation with precision, but problems arise during field mapping. During the survey of the adjacent 1:50 000 Southend sheet the base of the Claygate Beds was taken at the lowest sandy horizon recognisable in the field, and this criterion has been adopted in the present survey.

The Claygate Beds comprise a crudely upward-coarsening repetitive sequence of interbedded silty clays, silts and fine-grained sands. In and around Brentwood it has been possible to map individual sands within the formation but this has not been possible elsewhere. Towards the base of the formation brown clays, in places with a pinkish hue, are interbedded with sands. Because of the difficulties in recognising the base, the presence of major landslips and the scarcity of boreholes which penetrate the full sequence of the Claygate Beds, it is difficult to estimate the thickness of the formation. Generally the available evidence suggests a thickness of between about 15 and 25 m.

REPRESENTATIVE SECTION:
No sections available

6.1.8 Bagshot Beds

The Bagshot Beds are the youngest of the bedrock formations seen at the surface in the area. They cap the higher ground around Brentwood, Billericay and at Westley Heights in the Langdon Hills where their outcrops are characteristically associated with steep slopes overlying the Claygate Beds (Map 1). The maximum thickness preserved is about 15 m in the Brentwood and Billericay areas. The beds comprise mainly yellow to pale brown fine-grained sands, silty in parts, and thinly interbedded with minor grey silty clay. In the Brentwood district some thin pebble beds of well-rounded flint pebbles overlying or possibly interbedded with Bagshot sands recorded in former exposures have been regarded as the Bagshot Pebble Bed but it has been impracticable to map them separately in the recent survey.

REPRESENTATIVE SECTION:
No sections available.

6.2 SUPERFICIAL (DRIFT) DEPOSITS

The distribution of superficial deposits is shown on Map 2.

6.2.1 Sand and Gravel of Unknown Age

Deposits which cap Westley Heights, and two subsidiary hilltops in the Langdon Hills near Basildon were mapped as a bedrock formation, the Bagshot Pebble Bed, on the Old Series one-inch to one-mile sheet published in 1868. On a later edition they were reclassified as Pebble gravel, a superficial deposit. On the Romford (257) one-inch New Series sheet published in 1925, the latter name was retained, but combined with the name 'Warley Gravel'. Other authors have discussed the deposits, some consider them to be superficial, others believe them to be part of the bedrock sequence. Because of the continuing uncertainty over the origin of this deposit, it has been thought best to dispense with the terms Bagshot Pebble Bed and Pebble Gravel until the two can be unequivocally identified and mapped separately.

The deposit is composed of sandy gravel, the gravel component consisting mainly of rounded flint pebbles with scattered pebbles of subangular flints and traces of chert. In sections the gravel can be seen infilling hollows in the surface of the underlying Bagshot Beds (sands). A maximum thickness of only a few metres is indicated.

6.2.2 Older Head

Older Head caps the highest ground in the north of the project area at elevations above 95 m, concealing much of the underlying outcrop of Bagshot Beds, as well as parts of the Claygate Beds. It forms an extensive veneer commonly one to four metres thick, though widespread clayey gravel less than a metre thick in Thorndon Park, which has not been mapped, is probably the remnants of a larger sheet.

The Older Head consists of clayey gravel with predominantly well-rounded flint pebbles in an ochreous and grey mottled sandy clay matrix with pockets of coarse-grained sand in places. There are subordinate sub-angular and nodular flints with minor ammounts of small, white vein-quartz pebbles and 'Bunter' quartzite pebbles. The matrix often has scattered red patches, this reddening or rubification was possibly caused by the formation of soils in temperate conditions, and preserved in the sequence as palaeosols or ancient soils.

The deposit is often cryoturbated with involutions near the surface containing vertically or sub-vertically aligned pebbles. The relationship to the Till is uncertain but Older Head is overlain by chalky Till of assumed Anglian age in the adjacent Epping district (Millward, 1987).

6.2.3 Till (Boulder Clay)

Many patches of glacial Till, formerly known as chalky boulder clay, occur in the Brentwood and Billericay districts in the north. Several patches are also present along the valley sides of the River Ingrebourne to the north of Upminster. Here the Till probably infilled a pre-glacial valley which has been subsequently exhumed by the modern river. These represent the remnants, near the southern margin, of a more continuous sheet of debris deposited by the Anglian ice sheet.

The Till is a heterogeneous deposit consisting mainly of firm to stiff, stony, variably silty and sandy clay.

Unweathered Till samples dug from a depth of one or two metres are pale bluish grey or brown clay with clasts of mainly chalk and flint, with subordinate erratics of 'Bunter' vein-quartz and quartzite, minor Jurassic and Carboniferous limestones and sandstones, and traces of granitic and basaltic igneous rock. The clayey matrix is almost certainly derived from Jurassic as well as Tertiary clays and typically contains a significant proportion of chalk flour. The chalk, however, is leached out of the weathered near-surface deposits by weakly acidic rainfall to leave an ochreous or yellow-brown decalcified pebbly clay with abundant resistant clasts.

The Till is typically less than 3 to 5 m in thickness and although variable is unlikely to exceed 10 m in many places. It may be encountered above, below or within deposits of Glaciofluvial Sand and Gravel.

6.2.4 Glaciolacustrine Deposits

Two small areas just north of Upminster have been tentatively mapped as Glaciolacustrine Deposits. Augering has revealed a complex sequence of interbedded sand, clayey sand, sandy clay and silty clay, variably coloured yellow, ochreous-brown and grey-brown with greenish and lilac hues in part. Evidence from former surveys of the area indicate that the deposits may have a maximum thickness of about 6 m. Adjacent brick pits were probably worked in similar deposits, but the deposits have been entirely excavated.

6.2.5 Glaciofluvial Sand and Gravel

Glaciofluvial Sand and Gravel is restricted mainly to the higher ground in the north where it is commonly associated with outcrops of Till. It may occur above, below or as lenses within the latter. Thicknesses vary markedly over short distances but are typically about 2 to 5 m.

The deposits are composed predominantly of clayey flint gravels and sands, the gravel fraction ranging from angular to rounded. Other pebbles include quartzite, vein quartz and sandstones. Although chalk pebbles have not been noted in the gravels during the survey they may be present at depth, thus limiting the use to which the gravels may be put.

6.2.6 Interglacial Deposits

Interglacial Deposits have been recorded from several localities but have been mapped only within the town of Grays where they were dug extensively for brickearth during the last century. Remnants occur around the margins of the deposits and also beneath some of the major roads which remained unquarried. Little evidence of the deposits was visible at the time of survey. They appear to consist of silty sandy clays and have been dug to a depth of several metres.

6.2.7 River Terrace Deposits

The main River Terrace Deposits occur within a belt up to 8 km wide along the northern side of the River Thames' floodplain (see Figure 11). A sequence of smaller, commonly discrete patches of gravel is present along both sides of the Ingrebourne valley and other patches have been mapped along the Crouch valley.

On the published 1:50 000 257 (Romford) and 271 (Dartford) sheets the Thames terrace deposits are divided into three based mainly upon their relative heights above sea level; Boyn Hill Gravel (high), Taplow Gravel (intermediate) and Floodplain Gravel (low). These gravels were named after, and correlated with, deposits of the Middle Thames to the west of London. The surveyors of the 1:50 000 sheet to the east 258/259 (Southend/Foulness) adopted a numerical system for their terrace deposits from the First (lowest) to the Fourth (highest).

Neither of these systems has proved entirely satisfactory. A numerical system militates against the later recognition of intermediate terraces, which would then require re-numbering or sub-division of the existing numbers, thus causing confusion. Hare (1947) and more recently Bridgland (1983, 1988), Gibbard (1985) and Gibbard et al. (1988), have shown that the correlation between Middle and Lower Thames used on the published maps is incorrect. For this reason it was decided to follow Gibbard et al. (1988) and Bridgland (1988) and use local names for the terrace gravels in SW Essex. This approach allows for the addition of other deposits into the sequence should this become necessary. Indeed two additional gravel units have been added during the course of this study. The correlation between the units used in this report with those used elsewhere is given in Table 6. The East Tilbury Marshes Gravel is not seen naturally within the area, but has been dug from beneath the Estuarine Alluvium in the East Tilbury area. It does not appear on any of the maps.

The gravels are all composed predominantly of flint pebbles together with small quantities of quartzite, vein-quartz, sandstone, chert, and igneous and metamorphic rocks. Lenses and beds of fine- to coarse-grained sand occur within the gravels.

Table 6 Correlation of the Thames terrace deposits

THIS REPORT	FIRST PUBLISHED	MIDDLE THAMES	SOUTHEND/ FOULNESS SHEET	DARTFORD AND ROMFORD SHEET
ORSETT HEATH GRAVEL	BRIDGLAND 1983	BOYN HILL GRAVEL	4	BOYN HILL GRAVEL
GROVES FARM GRAVEL	MOORLOCK 1989	—	—	BOYN HILL GRAVEL
SOUTH OCKENDON HALL GRAVEL	MOORLOCK 1989	—	—	BOYN HILL GRAVEL
CORBETS TEY GRAVEL	GIBBARD 1985	LYNCH HILL GRAVEL	3	TAPLOW GRAVEL
MUCKING GRAVEL	BRIDGLAND 1983	TAPLOW GRAVEL	2	FLOODPLAIN GRAVEL
EAST TILBURY MARSHES GRAVEL	BRIDGLAND 1983	FLOODPLAIN GRAVEL	1	—

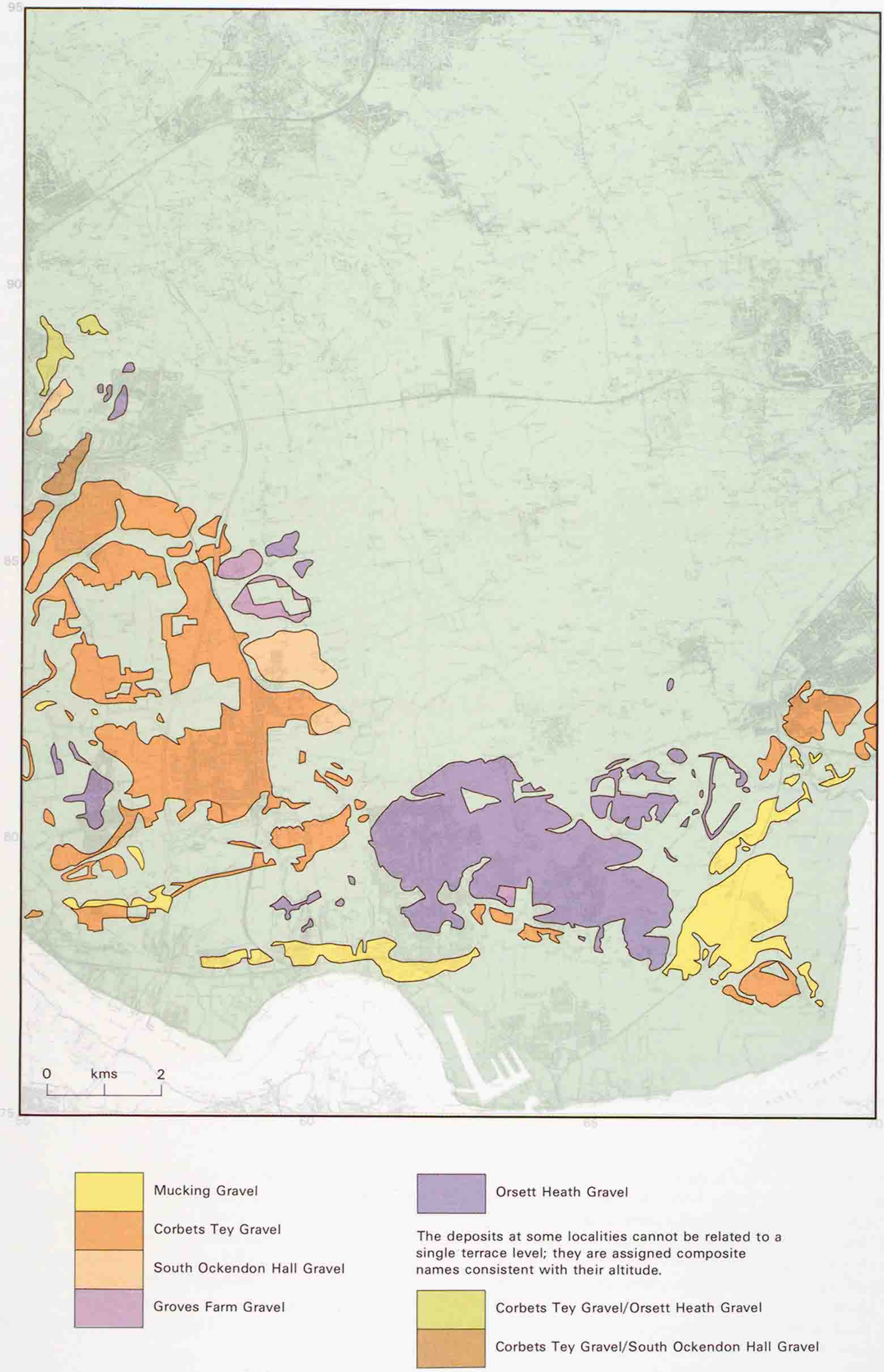
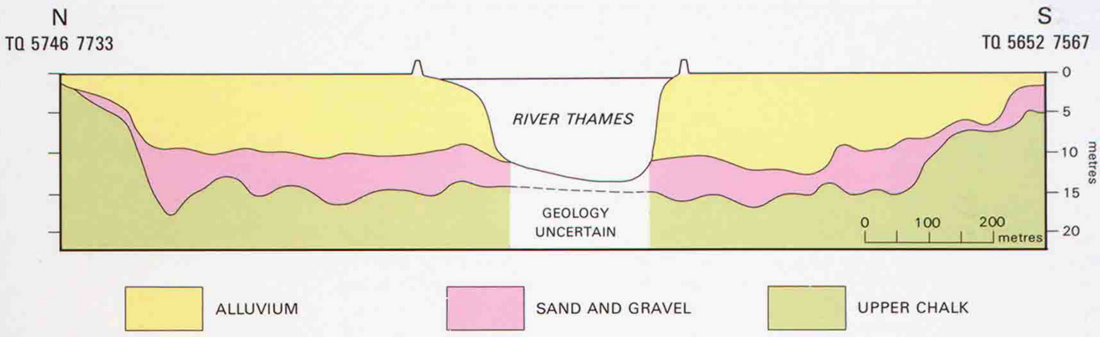


Figure 11 Distribution of the river terrace deposits of the Thames



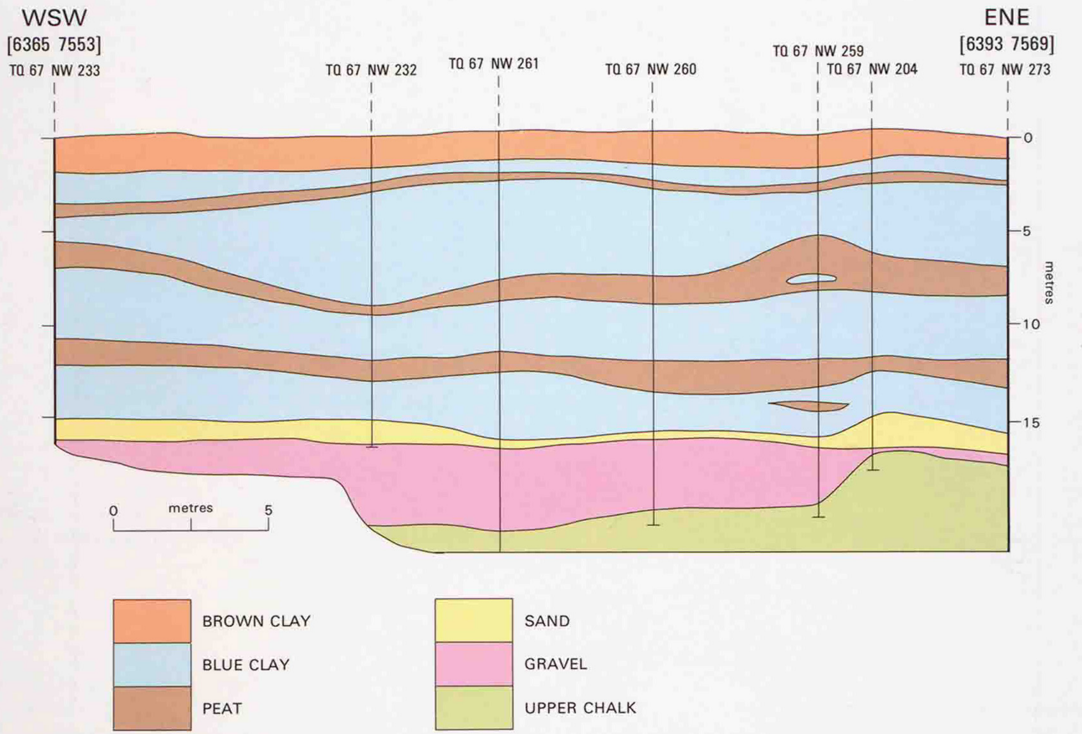
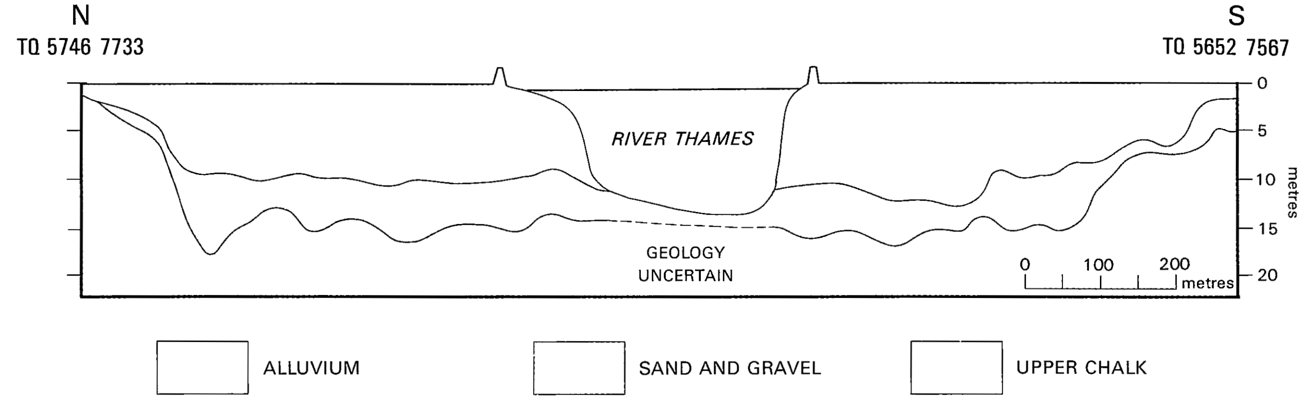


Figure 12 Diagrammatic geological section across the River Thames at West Thurrock, based on borehole data

Figure 13 Diagrammatic geological section through Estuarine Alluvium at Tilbury Docks



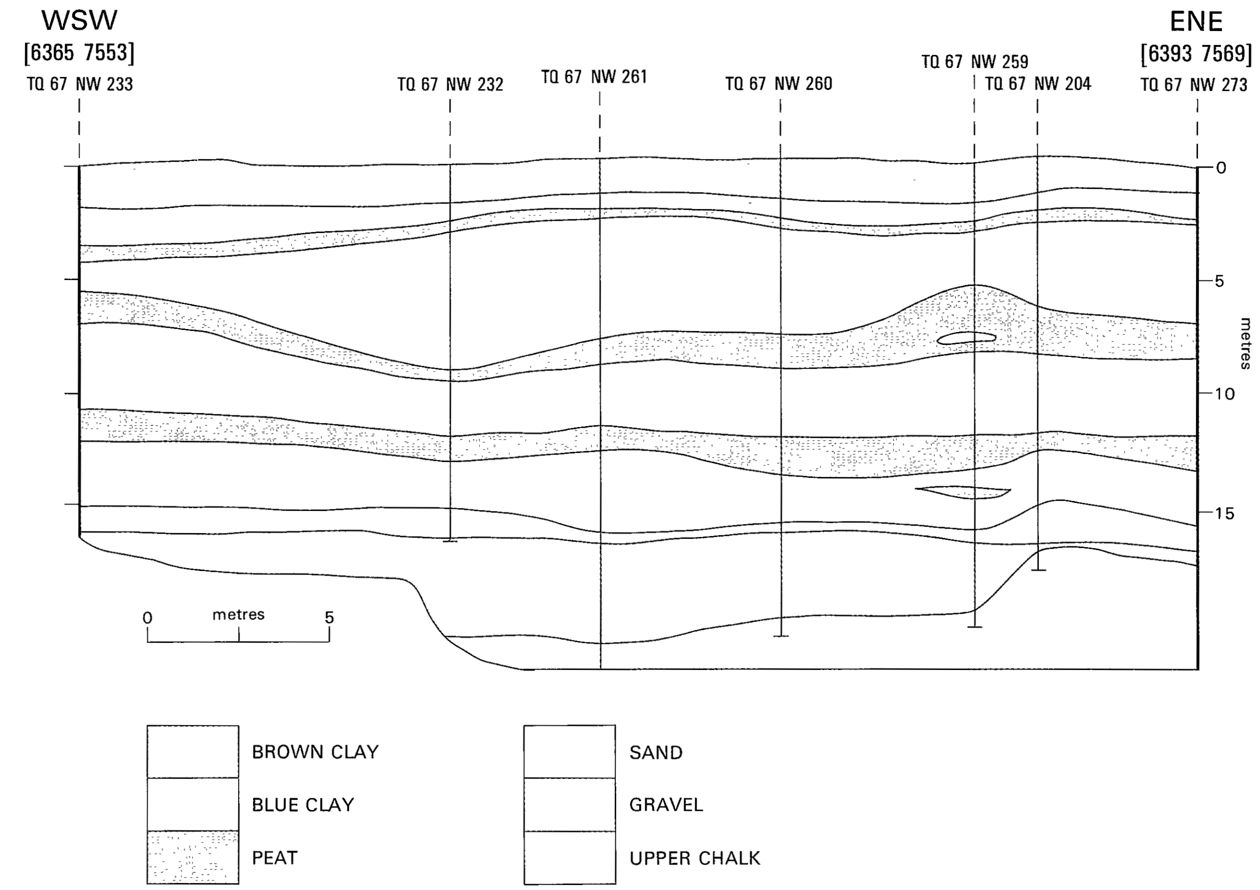


Figure 12 Diagrammatic geological section across the River Thames at West Thurrock, based on borehole data

Figure 13 Diagrammatic geological section through Estuarine Alluvium at Tilbury Docks

Orsett Heath Gravel

The distribution of Orsett Heath Gravel is shown in Figure 11. Small patches occur as far north as Upminster, but the largest spreads underlie much of Grays and Chadwell St Mary. At Aveley and South Stifford only small patches of once more extensive gravel remain following extraction.

The top of the gravels reach a height of about 45 m above OD near Upminster but elsewhere drops to about 20 m OD. Up to 5.5 m of sandy gravel is exposed at the northern end of Gibbs Quarry, South Stifford. At Hangmans Wood [631 793] between 2 and 3 m of gravel is exposed in the upper part of two denehole shafts.

Groves Farm Gravel

A morphological 'flat' at 25–30 m above OD to the north-west of Groves Farm [596 841] near South Ockendon is underlain by gravel. This gravel is at a distinctly lower level than the nearby Orsett Heath Gravel which caps the hill to the north-east, and is higher than the South Ockendon Hall Gravel to the south. Because of this problem of correlation, the gravel is here given a local name. Further research may show it to be part of the Orsett Heath Gravel occupying a channel.

South Ockendon Hall Gravel

This gravel occupies an extensive 'flat' to the north of South Ockendon (Figure 11). The flat is slightly higher than the general level of the Corbets Tey Gravel in the area, and lower than the level of the adjacent Groves Farm Gravel. The gravel is exposed during grave-digging in the churchyard at South Ockendon, where a perched water table within the gravel is evident.

Corbets Tey Gravel
The Corbets Tey Gravel underlies a very extensive 'flat' between Aveley in the south and Upminster in the north (Figure 11). Its surface drops from about 25 m OD in the north to about 15 m OD in the south. The base of the gravel generally lies between 10–15 m OD. Other smaller areas of gravel occur south of Grays, at Stanford-le-Hope, and near East Tilbury. The gravel has been extensively dug.

Mucking Gravel
Between Purfleet and Grays the Mucking Gravel is banked against a steeply rising Chalk surface. The surface of the gravel reaches a height of about 10 m above OD adjacent to the Chalk but drops gently southwards to the level of the flood plain. Farther east the gravel forms an extensive outcrop around Muckingford (Figure 11).

East Tilbury Marshes Gravel
The East Tilbury Marshes Gravel is seen only in excavations between East Tilbury and Stanford-le-Hope where it has been dug from beneath the Estuarine Alluvium.

Other River Gravels
In the north-east Second and Third terraces are mapped along the River Crouch. Elsewhere a few isolated patches of gravel are mapped as Undifferentiated Terrace.

6.2.8 Estuarine Alluvium

Estuarine Alluvium occupies a broad tract of land up to 3 km wide along the north bank of the River Thames from Purfleet to just south of Stanford-le-Hope in the east. Much of the outcrop is obscured by made ground, up to several metres thick, put down as a base for building upon. Most of the alluvial tract lies between 1 and 3 m above OD and prior to the building of the tidal defence well would have been periodically subject to flooding from the sea. A diagrammatic section through the alluvial deposit at West Thurrock is shown in Figure 12.

Typically the alluvium commences at the top with a brown silty clay or silt (Figure 13) which becomes blue-grey with increasing depth. Within the silt and clay are several beds of peat, of which three appear to be persistent throughout much of the outcrop, although the absence of these in some borehole logs may sometimes be due to poor recognition or poor recording of the strata encountered. At the base of the sequence a thin bed of sand is commonly present resting on flint gravel which in turn rests directly on a somewhat uneven surface of Upper Chalk. The complete sequence varies in thickness from several metres to over 20 m in the deepest part of the channel.

6.2.9 Intertidal Deposits

Intertidal Deposits extend outwards from the tidal defence wall into the Thames estuary. The deposits consist of soft unconsolidated brown muds and silts mostly visible only at low water. Comparison of the several editions of the 1:10 000 and 1:10 560 scale maps available shows that the surface form of the deposits is constantly changing and may change dramatically where new piers and jetties are built. At depth the Intertidal Deposits merge with the Estuarine Alluvium, the junction being arbitrary and undetectable in boreholes.

6.2.10 Alluvium

Alluvial deposits floor the bottom of the valleys of the River Ingrebourne, River Crouch, the Mar Dyke and their tributary streams. The deposits vary in thickness from less than one metre in the small tributaries up to several metres in the large valleys. Along river banks the deposits can be seen to comprise very soft blue-grey to ochreous-brown silty clays. The deposits may also contain lenses or more persistent layers of peat, sand or gravel.

6.2.11 Peat

Although Peat occurs extensively within the Estuarine Alluvium and to a lesser degree within the river Alluvium, it has been mapped at the surface at only one locality to the south-east of Brentwood. It is a dark brown to black highly compressible fibrous deposit composed essentially of decayed vegetation.

6.2.12 Combe Deposits

These are chalky head deposits found at outcrop only to the south of East Tilbury, where they mask the low Chalk escarpment over a distance of 500 m in a belt up to 100 m wide. Exposures prove up to 3 m but the maximum thickness of the deposits is not known. They consist of rubbly chalk, irregularly mixed with flint pebbles and sand derived from the river terrace gravels, together with fine-grained sand from the Thanet Beds.

6.2.13 Head Gravel

A few small outcrops of clayey gravel, generally capping low hills or spurs at elevations below that typically associated with the Older Head (95 m) have been mapped as Head Gravel. They are probably derived from the Older Head upslope. The deposit consists of gravel in a matrix that varies depending on the bedrock in the vicinity and immediately upslope.

6.2.14 Head

As originally defined, Head consists of material that has moved downslope by solifluction (mass movement under periglacial conditions), but in this account the definition is broadened to include slope wash material, as in practice it is impossible during field mapping to separate the two types of deposit. Because of its local derivation, Head can be extremely variable, but tends to closely reflect the composition of its source. For example where the Head is derived from London Clay it will be clayey, but where derived from the river terrace deposits it will have a high sand and gravel content. Where the Head has been derived from the Chalk outcrop it will be calcareous.

Head is probably the most extensive of all the deposits mapped in the study area. It is particularly widespread on the outcrop of the London Clay. In most places it is probably less than about 2 m thick, but locally thicker accumulations may be present, especially along valley floors. Although in terms of thickness Head may be considered a relatively unimportant deposit, it can pose serious problems when land is developed. This is due to shear planes which may be present both within and at the base of the deposit. The implications of this are discussed later. It is important to remember that it is current BGS practice to map deposits only where they are a metre or more thick, unless they are particularly important when thinner deposits may be recorded. It follows therefore that thin developments of Head may be present but will not be shown on the map.

6.3.15 Landslip

Landslips occur mainly on the outcrop of the Claygate Beds and to a lesser extent on the London Clay, but are particularly well developed at the junction of the two formations.

Large slips result from the slumping of clays about a curved shear surface and involve rotational movement which produces a crescentic backwall scar, and a characteristic bulging toe to the slip.

Smaller slips fail on shallow near planar fractures parallel to the ground surface, with a translational movement which produces only minor rippling of the ground surface.

Landslips are discussed more fully in section 2.1.1.

6.3 ARTIFICIAL DEPOSITS AND WORKED GROUND

6.3.1 Made Ground

Areas shown on the 1:25 000 general geology map as Made Ground are restricted to situations where material has been placed by human agency on the original ground surface, thereby raising the original level. It does not generally include material infilling former quarries or pits, although there will be instances where unrecorded quarries have been backfilled and the material mounded up above the original surface thereby giving the impression of simple Made Ground.

Areas mapped as Made Ground may contain a wide variety of material ranging from inert, household, industrial and commercial refuse, concrete, fly ash, brick rubble, to bedrock and superficial deposits removed from their natural situation and placed elsewhere. Map 5 shows areas of Artificial Ground, which includes both Made Ground and filled quarries and pits. The degree of fill and type of fill, where known, are shown, together with the current land use of the site.

6.3.2 Worked Ground

The areas worked for bulk minerals are shown on Map 4. The resources include chalk, clay and sand and gravel, dug from both the bedrock and superficial deposits. Some of the workings exploit several deposits, for example a pit may have commenced in river terrace sand and gravel, followed by the underlying Thanet Beds sands, and finally the Upper Chalk below. Many of the workings have been backfilled to varying degrees; others have been left abandoned (see Map 5).

References

ALLSOP, J M, and Smith, N J P. 1988. The deep geology of Essex. *Proceedings of the Geologists' Association*, Vol. 99, 249–260.

BELL, F G (editor). 1978. *Foundation engineering in difficult ground*. 598pp. (London:Butterworth.)

BLUNDEN, J, and ESSEX, J. 1977. The development of a decision making model for the after-use of large-scale quarries and other derelict land. 43–45 in Papers of the Land Reclamation Conference, 1976. (Grays, Essex: Thurrock Borough Council.)

BOORMAN, L A, GOSS-CUSTARD, J D, and MCGRORTY. 1989. Climatic change, rising sea level and the British coast. *Institute of Terrestrial Ecology Research, Publication* No.1.

BRIDGLAND, D R. 1983. The Quaternary fluvial deposits of north Kent and eastern Essex. Unpublished PhD thesis, City of London Polytechnic, 2 vols.

— 1988. The Pleistocene fluvial stratigraphy and palaeogeography of Essex. *Proceedings of the Geologists' Association*, Vol. 94, 291–314.

DEER, W A, HOWIE, R A, and ZUSSMAN, J. 1966. *An introduction to the rock-forming minerals*. (London: Longmans.)

DEPARTMENT of the ENVIRONMENT. 1986. Landfilling wastes. *Waste Management Paper*, No. 26, 205pp. (London: HMSO.)

— 1989. The control of landfill gas. *Waste Management Paper*, No. 27, 56pp. (London: HMSO.)

DRISCOLL, R. 1983. The influence of vegetation on the swelling and shrinking of clay soils in Britain. *Geotechnique*, Vol. 33, 93–105.

ESSEX, J. 1977. Tackling land dereliction in Thurrock. 46-84 *in* Papers of the Land Reclamation Conference, 1976. (Grays, Essex: Thurrock Borough Council.)

GIBBARD, P L. 1985. *Pleistocene history of the Middle Thames Valley*. (Cambridge: Cambridge University Press.)

— WHITEMAN, C A, and BRIDGLAND, D R. 1988. A preliminary report on the stratigraphy of the Lower Thames Valley. *Quaternary Newsletter*, No. 55, 1–8.

GRAY, D A, MATHER, J D, and HARRISON, I B. 1974. Review of groundwater pollution from waste disposal sites in England and Wales, with provisional guidelines for future site selection. *Quarterly Journal of Engineering Geology*, Vol. 7, 181–196.

HARE, F K. 1947. The geomorphology of a part of the Middle Thames. *Proceedings of the Geologists' Association*, Vol. 38. 294–339.

HOLMES, T V, and COLE, W. 1887. Report on the denehole xploration at Hangman's Wood, Grays 1884 and 1887. *Essex Naturalist*, Vol. 1, 248–**000**.

HUTCHINSON, J N. 1965a. The stability of cliffs composed of soft rocks, with particular reference to the coasts of south-east England. Unpublished PhD thesis, University of Cambridge.

— 1965b. A survey of the coastal landslides of Essex and south Suffolk. *Building Research Station Note*, EN 36/65, 104pp.

— 1967. The free degradation of London Clay cliffs. *Proceedings of the Geotechnical Conference, Oslo*, Vol. 1, 113–118.

LAKE, R D, ELLISON, R A, HENSON, M R, and CONWAY, B W. 1986. Geology of the country around Southend and Foulness. *Memoir of the British Geological Survey*, Sheets 258 and 259 (England and Wales).

MATHER, J D, and BROMLEY, J. 1977. Research into leachate generation and attenuation at landfill sites. 377–400 *in* Papers of the Land Reclamation Conference, 1976. (Grays, Essex: Thurrock Borough Council.)

MCDONALD, A J W, and McKeown, M C. 1988. S.W. Essex/ Greater London thematic geological mapping project: evaluation and results of airbourne thematic mapper survey. *Proceedings of the NERC 1986 Airbourne Campaign Workshop, February 1988, Wallingford*, 95–104.

MILLWARD, D, ELLISON, R A, LAKE, R D, and MOORLOCK, B S P. 1987. Geology of the country around Epping. *Memoir of the British Geological Survey*, Sheet 240 (England and Wales).

MOORLOCK, B S P. 1989a. Geology of the West Thurrock district, 1:10 000 sheet TQ 57 NE. *British Geological Survey Technical Report* WA/89/35.

— 1989b. Geology of the Grays district, 1:10 000 sheet TQ 67 NW. *British Geological Survey Technical Report* WA/89/36.

PEARCE, R W, and THOMSON, G H. 1977. Ground treatment processess applicable to land reclamation. 319–341 *in* Papers of the Land Reclamation Conference,.1976. (Grays, Essex: Thurrock Borough Council.)

WILLIAMS, G M, and AITKENHEAD, N. 1991. Lessons from Loscoe: the uncontrolled migration of landfill gas. *Quaterly Journal of Engineering Geology*, Vol. 24, 191–207.

Appendix 1

Availability of reports and maps

This report specifically for those involved with planning and development is one of several written during the present study of S W Essex and the M25 Corridor. The complete list of reports is given below.

1 Applied geology for planning and development
For planners and others who require only an outline of the geology of the area, this report emphasizes those geological factors that might influence development.

This report includes a general geology map and a set of 11 thematic maps all at 1:25 000 scale supplied in a folder.

Bibliographical reference
MOORLOCK, B S P, and SMITH, A. 1991. S W Essex — M25 Corridor — Applied geology for planning and development. *British Geological Survey Technical Report*, WA/91/28.

2 Engineering geology
A separate report giving details of the engineering geology of the area is also available.

Bibliographical reference
CULSHAW, M G, and Crummy, J A. 1991. SW Essex — M25 Corridor: Engineering geology. *British Geological Survey Technical Report*, WN 90/2.

3 Geology
For those requiring a more detailed description of the geology of the area a separate account has been written.

Bibliographical reference
MOORLOCK, B S P, and SMITH, A. 1990. S W Essex — M25 Corridor: Geology. *British Geological Survey Technical Report*, WA/91/27.

Those requiring the maximum local geological detail should consult one or more of the following BGS Technical Reports. Each report describes the geology of an individual 1:10 000 sheet.

Bibliographical reference

MOORLOCK, B S P. 1989. Geology of the West Thurrock district, 1:10 000 sheet TQ 57 NE. *British Geological Survey Technical Report*, WA/89/35.

— 1989. Geology of the Grays district, 1:10 000 sheet TQ 67 NW. *British Geological Survey Technical Report*, WA/89/36.

SMITH, A. 1989. Geology of the East Tilbury district, 1:10 000 sheet TQ 67 NE. *British Geological Survey Technical Report*, WA/89/37.

MOORLOCK, B S P. 1989. Geology of the South Ockendon district, 1:10 000 sheet TQ 58 SE. *British Geological Survey Technical Report*, WA/89/38.

SMITH, A. 1989. Geology of the Orsett district, 1:10 000 sheet TQ 68 SW. *British Geological Survey Technical Report*, WA/89/39.

— 1989. Geology of the Stanford-le-Hope district, 1:10 000 sheet TQ 68 SE. *British Geological Survey Technical Report*, WA/89/40.

— 1989. The geology of the Upminster district, 1:10 000 sheet TQ 58 NE. *British Geological Survey Technical Report*, WA/89/41.

— 1989. The geology of the West Horndon district, 1:10 000 sheet TQ 68 NW. *British Geological Survey Technical Report*, WA/89/42.

— 1989. The geology of the Laindon district, 1:10 000 sheet TQ 68 NE. *British Geological Survey Technical Report*, WA/89/43.

ELLISON, R A. 1990. Geology of the Brentwood district, 1:10 000 sheet TQ 59 SE. *British Geological Survey Technical Report*, WA/90/20.

SMITH, A. 1990. Geology of the Thorndon Park district, 1:10 000 sheet TQ 69 SW. *British Geological Survey Technical Report*, WA/90/23.

MOORLOCK, B S P. 1990. Geology of the Billericay district, 1:10 000 sheet TQ 69 SE. *British Geological Survey Technical Report*, WA/91/26.

4 1:10 000 Maps
Twelve 1:10 000 geological maps have been surveyed and are available for purchase as black and white dye-line copies. These are TQ 57 NE; TQ 58 SE and NE; TQ 59 SE; TQ 67 NW and NE; TQ 68 NW, NE, SW and SE; TQ 69 SW and SE.

The distribution of these maps, together with their names and the number of the accompanying Technical Report describing each district is shown below.

Brentwood TQ 59 SE WA/90/20	Thorndon TQ 69 SW WA/90/23	Billericay TQ 69 SE WA/90/00
Upminster TQ 58 NE WA/89/41	West Horndon TQ 68 NW WA/89/42	Laindon TQ 68 NE WA/89/43
S. Ockendon TQ 58 SE WA/89/38	Orsett TQ 68 SW WA/89/39	S-le-Hope TQ 68 SE WA/89/40
W. Thurrock TQ 57 NE WA/89/35	Grays TQ 67 NW WA/89/36	E. Tilbury TQ 67 NE WA/89/37

Reports and maps are available for purchase from the Sales Desk, British Geological Survey, Keyworth, Nottingham, NG12 5GG.

Appendix 2

List of active workings

The following quarries were operative in 1988:

Name of quarry	Grid reference	Company and address of head office
SAND AND GRAVEL		
Bush Farm	TQ 560 840	RMC St Albans Sand and Gravel Delemere Road Cheshunt Herts. EN8 9SJ
Baldwin's	TQ 575 833	Redland Aggregates Bradgate House Groby Leics. LE6 0FA
East Tilbury	TQ 692 782	Aylett Gravel Co. Ltd. 23a Warley Hill Brentwood Essex CM14 5HR
Mucking Marshes	TQ 685 805	Cory Sand and Ballast Co. Ltd. Windsor House 1270 London Road Norbury London SW16 4XH
Buckingham Hill Road	TQ673 807	Tarmac - Southern 2a Bath Road Newbury Berks. RG13 1JJ
Orsett Cock	TQ 655 812	Southfields Gravel Co. Orsett Cock Orsett Grays Essex
Collingwood	TQ 665 809	Mr K Andrews Collingwood Farm Mucking Heath Orsett Essex
LONDON CLAY		
Ockendon	TQ 614 820	Blue Circle The Shore Northfleet Dartford Kent DA11 9AN
CHALK		
Botany Hill	TQ 557 785	Harmonic Engineering Ltd. London Road Purfleet
Gibbs	TQ 595 785	Pamply and Timms (Grain) Ltd. Wheatshey House Alconbury Huntingdon PE17 5LD

Appendix 3

Glossary

AEROBIC — With oxygen

ALLUVIAL DEPOSITS, ALLUVIUM — Material transported by a river and deposited along the flood plain

ANAEROBIC — Lacking oxygen

ANGLIAN — A period of glaciation over much of Britian

AQUICLUDE — A body of relatively impermeable rock

AQUIFER — A body of rock which yields water by virtue of its permeability

ARGILLACEOUS Descriptive of rocks comprised of clay, mudstone, shale or marl

BASEMENT — Old rocks at depth, usually separated from younger rocks by an unconformity

BASIN — A depression of large size, which may be structural or erosional in origin

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

BEDDING PLANE — surfaces along which the rock is often easy to split

BEDROCK — Rock beneath the soil and superficial deposits, a general term for all rocks older than the Quaternary

BENTHONIC — Pertaining to the sea floor

BIOTURBATION — The disturbance of a sediment by burrowing organisms

BIODEGRADEABLE — Capable of being decomposed by living matter, especially by bacteria

BITUMINOUS — Containing bitumen, a tar-like mixture of hydrocarbons

BOULDER CLAY See TILL

BRICKEARTH — A general term for superficial deposits of varying origin suitable for brickmaking; formerly applied here specifically to certain river, glacial and interglacial deposits

CALCAREOUS — Containing a significant proportion of calcium carbonate

CALCITE — A crystalline variety of calcium carbonate ($CaCO_3$)

CEMENT — Material binding particles of a sediment together

CEMENTSTONE A clayey limestone or calcareous siltstone suitable fo cement making. Commonly occurs as layers of nodules in the London Clay where they are known as CLAYSTONES or SEPTARIAN NODULES

CHERT — A rock composed mainly of very fine crystalline silica (SiO_2)

CLAYSTONE — Stony nodules within the London Clay, see CEMENTSTONE

CONCRETION — A hard, rounded or irregular mass formed by the aggregation of mineral matter precipitated from solution, usually about a nucleus

CONFINED AQUIFER — An aquifer bounded above and below by impermeable strata

CONGLOMERATE — Cemented sedimentary rock containing rounded pebbles set in a finer grained matrix

CROSS-BEDDING — Internal layered structure of a sediment formed by inclined minor bedding planes

CRYOTURBATION — Structure of sediments affected by freezing conditions

CUESTA — An asymmetrical ridge with one long gentle slope (dip slope) conforming to the dip and an opposite steep escarpment slope

DECALCIFIED — Describes soils and rocks from which calcium carbonate has been leached out

DENEHOLE (Danehole) — Vertical shaft dug into chalk opening out into a series of chambers at depth

DETRITAL — Applied to any particles of minerals or rock fragments derived from pre-existing rocks by weathering and erosion

DEVENSIAN — Most recent glaciation in Britain

DIP — The maximum angle of inclination of a bed measured relative to the horizontal

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

ESCARPMENT — The scarp face of a cuesta steeply inclined in the opposite direction to the dip and cutting across the bedding planes

ERRATIC — A rock which has been transported some distance from its source, commonly by moving ice

EUSTATIC — Pertaining to world-wide change in sea-level

EXPOSURE — Place where rocks can be seen *in situ*

FACIES — The sum of all features of a sedimentary rock including grain size, mineral content, sedimentary structures, bedding and fossils from which the environment of deposition can be inferred

FAULT — A fracture in rock along which relative movement has taken place

FLINT — A variety of chert or fine crystalline silica common as nodules in the Chalk and as derived pebbles in younger overlying sediments

FLUVIAL, FLUVIATILE — Pertaining to rivers

FLUVIO-GLACIAL — Pertaining to meltwater streams flowing from ice sheets or glaciers

FORMATION — The fundamental mappable subdivision of a rock sequence with recognisable characteristics, and which differs from adjacent formations

FULLER'S EARTH — A clay rich in the clay mineral montmorillonite and capable of adsorbing oil and grease

GLACIAL — Pertaining to a cold period of ice advance or ice-age

GLACIOFLUVIAL — Pertaining to meltwater streams flowing from ice sheets or glaciers, or to combination of glacial and fluvial action

GLAUCONITE — A green iron silicate mineral found in marine sediments

GRABEN — A down-thrown block between two faults

GYPSUM — Hydrated calcium sulphate

IGNEOUS — Derived from a molten rock (magma)

INTERGLACIAL — Pertaining to a warm period between cold glacial periods

IPSWICHIAN — a relatively warm interglacial period

JOINT — A fracture in a rock with no relative movement between the two sides

LACUSTRINE — Pertaining to lake(s)

LANDFILL GAS — Gas formed from waste decomposing under anaerobic conditions consisting of 65% methane and 35% carbon dioxide

LEACHING — Process of chemical weathering in which some of the minerals in soil are removed in solution by water percolating through

LIGNITE (Brown coal) Organic deposit rich in carbon commonly derived from peat by compaction and slight heating, insufficient to produce coal

LIMONITIC — Containing the iron ore limonite

LITHOLOGY — The general characteristics of a rock

MARCASITE — A form of iron sulphide

MARL — A calcareous clay or mudstone

MICRITIC — Finely grained (limestone)

MIOCENE — A period of geological time from about 25-11my BP

MONTMORILLONITE — A clay mineral belonging to the smectite group which has the property of adsorbing water and oil

OUTCROP — The area over which a particular rock unit occurs at the surface, whether visibly exposed or not

OUTLIER — An outcrop of rock surrounded by older rocks

PERICLINE — Dome, strata dipping away on all sides

PERIGLACIAL — Applied to a region adjacent to an ice sheet in which frost action is an important factor

PLANKTONIC — Organisms which float passively in surface waters

POORLY-SORTED — Consisting of particles of different sizes

PYRITISED — changed into pyrite (a form of iron sulphide)

QUARTZ — Crystalline form of silica (SiO_2)

QUARTZITE — Rock composed predominantly of the mineral quartz (SiO_2)

SELENITE — Crystalline form of gypsum, calcium sulphate ($CaSO_4.2H_2O$)

SEPTARIAN NODULE — A concretion with internal partitions or septa commonly produced by crystalline minerals lining cracks

SMECTITE — A group of clay minerals which have the property of adsorbing water and oil

SOLIFLUCTION (SOLIFLUXION) — The slow downslope movement of superficial material as a result of the alternate freezing and thawing of contained water

STRATIGRAPHY — The study of the order, correlation and relative position of strata

STRATUM (plural STRATA) — Layer of rock

SUPERFICIAL — Applied to unconsolidated deposits occurring at the surface and resting on bedrock, also known as drift deposits

TILL — Unsorted material deposited from an ice sheet (formerly boulder clay) THALASSINOID Burrow type of trace fossil

UNCONFORMITY — A break in the sedimentary sequence represented by missing strata and possibly an angular relationship between the strata above and below

WELL-SORTED — Consisting of particles of similar size