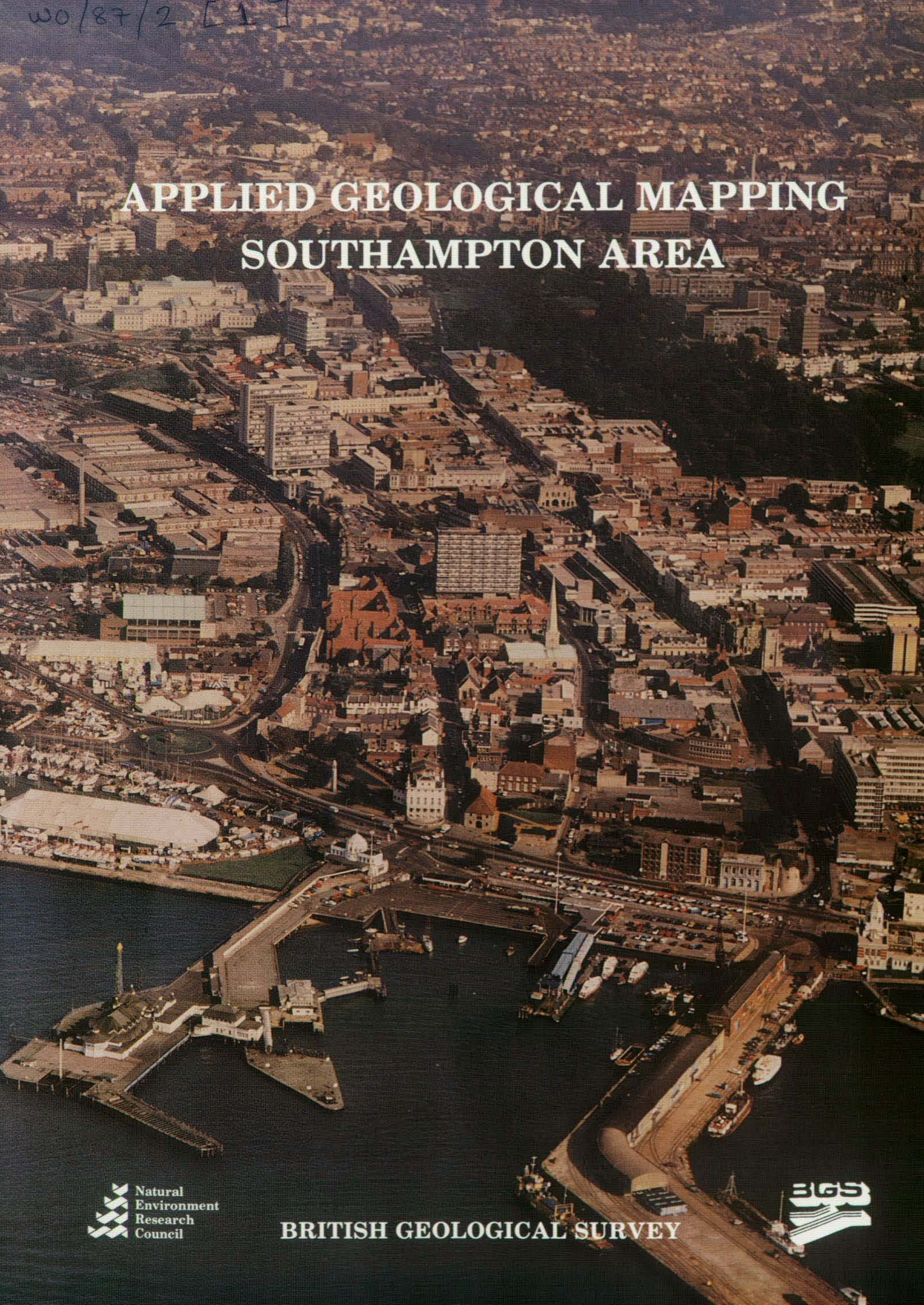
APPLIED GEOLOGICAL MAPPING
SOUTHAMPTON AREA



Natural Environment Research Council

BRITISH GEOLOGICAL SURVEY

BGS

Cover photograph

We see Southampton city centre from the air, looking northwards over the Royal Pier and Mayflower Park (where a boat show is taking place) in the foreground. The low-lying area in the left centre, occupied mainly by industrial buildings, is formed of reclaimed land over Estuarine Alluvium deposits. Most of the rest of the city is built on River Terrace Deposits overlying formations of the Bracklesham Group.

Natural Environment Research Council
BRITISH GEOLOGICAL SURVEY

APPLIED GEOLOGICAL MAPPING SOUTHAMPTON AREA

Area covered by
1:50 000 Geological sheet No. 315 (Southampton)
OS 1:10 000 sheets SU31 and 41, and parts of
SU20, 21, 22, 30, 32, 40, 42, 50, 51 and 52

VOLUME 1: MAIN REPORT AND APPENDIX

The accompanying maps, as listed in the contents, are available separately

R. A. Edwards, R. C. Scrivener and A. Forster

Production of this report was supported by the Department of the Environment but the views expressed in it are not necessarily those of the Department

Bibliographic reference
EDWARDS, R.A., SCRIVENER, R.C. and FORSTER, A. 1987.
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EXETER BRITISH GEOLOGICAL SURVEY 1987

MAIN REPORT AND APPENDIX

VOLUME 1

BGS Research Report ICSO/87/2

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ACCOMPANYING DOCUMENTS

The accompanying maps are available separately. The full set is part of BGS Research Report ICSO/87/2 comprising the following volumes:

2. Maps of solid geology
3. Maps of drift geology
4. Maps of drift thickness
5. Maps of rockhead contours
6. Maps of mineral resources
7. Maps of worked ground
8. Maps of availability of geotechnical test data
9. Maps of engineering geology, slope angle and aquifer distribution
10. Maps of made ground
11. Maps of borehole locations and Sites of Special Scientific Interest

In addition, two other BGS Research Reports describe the computer techniques used in the project and the contents of the database:

LOUDON, T.V. and MENNIM, K.C. 1987
Mapping techniques, using computer storage and presentation, for applied geological mapping of the Southampton area. *Research Report of the British Geological Survey No. ICSO/87/3*

LAXTON, J.L. 1987
Computer databases of geological, borehole and geotechnical information for applied geological mapping of the Southampton area. *Research Report of the British Geological Survey No. ICSO/87/4*

Notes to the user

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

Thus the report and maps are to be regarded as the *best interpretation of the information available at the time of compilation. They should be used for preliminary studies only and are not intended as a substitute for on-site investigations or detailed local searches.* The responsibility for assuring that geological, geotechnical and mineral and water resource data for any given site are as indicated in the maps and in the figures and text of this report must remain solely that of the user.

The possible occurrence of undetected anomalous site conditions should always be anticipated. The indicated occurrences of mineral deposits do not necessarily imply an economic resource. The possible presence of unmapped variable thicknesses of superficial deposits and Made Ground, particularly within the urban area of Southampton, should also be taken into account in any planning procedures.

There is no substitute for the knowledge provided by a detailed site investigation that takes into consideration the extent, nature and location of a proposed development. Therefore the report and maps are intended a) to give guidance on when to seek specialist advice and b) to aid developers in formulating effective investigations.

No information made available after the end of 1986 has been taken into account in this report.

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

Data used in preparing this report and associated maps is lodged at the Exeter office of the British Geological Survey. Any enquiries concerning these documents should be directed to that office. Enquiries concerning the computer techniques or methodology should be directed to the Edinburgh or Keyworth office of the Survey. Enquiries about purchase of the report or maps should be directed to the National Geosciences Data Centre, British Geological Survey, Keyworth, Nottingham NG12 5GG.

PREFACE

This account describes aspects of the geology and provides a set of applied geology maps for the Southampton area covered by the British Geological Survey 1:50 000 Geological sheet No 315 (Southampton), which has recently been revised. The geology of the area is described in detail in the Sheet Memoir (Edwards and Freshney, 1987).

The present study, which was commissioned and partially funded by the Department of the Environment, was concerned with collection and collation of relevant data, and storage by the Geological Survey in a computerised data handling system. The applied geology maps were generated with computer assistance by interrogation of the database.

Data were assembled under the supervision of R. A. Edwards and R. C. Scrivener in the Exeter Office of the Survey. The geotechnical data were analysed from the Keyworth office, by A. Forster. The database and thematic maps were prepared by J. L. Laxton and K. C. Mennim of the Edinburgh office. This report includes significant contributions from J. L. Laxton, R. A. Monkhouse and T. V. Loudon. Assistance in the technical aspects of computer graphics and document processing was given by R. W. McGonigle. The nominated officers were R. J. Wood and subsequently P. J. Bide for the Department of the Environment, and W. G. Henderson and subsequently T. V. Loudon for the British Geological Survey. The work was directed for the Department by R. C. Mabey and for the Survey by B. Kelk.

The co-operation of local and regional authorities and other holders of data is gratefully acknowledged. In particular, we thank Hampshire County Council, New Forest District Council, Fareham District Council, Eastleigh Borough Council and Southampton City for providing additional borehole and testpit data. The Nature Conservancy Council, Lyndhurst, provided maps and details of Sites of Special Scientific Interest within the project area. The Southern Water Authority provided information on licensed abstractions within the study area.

EXECUTIVE SUMMARY

This study was commissioned by the Department of the Environment to develop and apply techniques of applied geological mapping for the purposes of land-use planning and development. It covers the area of the British Geological Survey (BGS) 1:50 000 geological map of Southampton. The study involved the computer manipulation of existing geological, geotechnical, hydrogeological and mineral resource data. The objectives were to develop the methodology, and to provide an archive of information, a set of applied geological maps, and descriptive reports in a form appropriate to all potential users. The computer is a powerful tool for bringing together spatially referenced information from many sources. There was collaboration with the Ordnance Survey and also with the Soil Survey of England and Wales who have been commissioned to undertake a study in the same area.

The particular objectives of this report are to describe the geology of the area, particularly in terms of its implications for land-use planning and development, and to present and describe the applied geological maps of Southampton. Appendices describe the Solid and Drift deposits, the geological history of the area and its structure. There is also a history of mineral working in the area, and an account of the geotechnical tests reported in the database and their applications. The maps themselves are included in Volumes 2 to 11 of this report.

Two other accompanying reports were produced as part of the study. A report by Laxton (1987), describes the organisation of the databases and how they were used in the production of the applied geological maps of the area. The database contents are described in detail for those who may wish to access the databases directly and as a guide to those considering similar projects for the future. The techniques of data presentation and map production are described in a report by Loudon and Mennim (1987), in the light of the advantages and problems in computer storage and presentation of data. The reasons for adopting particular methods and their relevance to longer term objectives are considered.

Geological information is of value in land-use planning and development. Planners are concerned, for example, with preventing the sterilisation of resources, such as sand and gravel; with assessment of geological hazards, foundation conditions and slope stability; with appropriate development of water resources and avoidance of groundwater pollution; and with landfill and the safe disposal of waste. Developers may be concerned with the general background of the distribution of rock types and their geotechnical properties for feasibility studies, and require a lead-in to relevant site investigation reports.

In the Southampton area, the geological aspects affecting planning and development can be categorised as energy and mineral resources, water resources and engineering geology. In the first category, sand and gravel resources are the main concern, although there are resources of brick and tile clay, and chalk which has been worked for agricultural lime. The resources of sand and gravel and locations of workings are shown on the applied geology maps. There are oilfields within 30 km of the area, which is currently being explored for hydrocarbons. Two boreholes have been drilled to evaluate deep aquifers in this area of high heat flow as a potential geothermal energy resource.

In terms of water resources, the Chalk is the most important aquifer, particularly in the northern part of the area, where it is important that the outcrop should be pollutant-free. Tertiary sands provide the other main aquifers. Shallow wells are liable to surface pollution and need careful siting. Water boreholes should not be sited less than 500 m from the shore as prolonged pumping can lead to seawater intrusion.

In engineering terms, the area is divisible into three provinces. Rock (Upper Chalk) presents few engineering problems unless deeply weathered and fractured. Overconsolidated clays and dense sands have a wide range of geotechnical properties, and may give rise to some potential problems related to shrinking and swelling with moisture content changes, running sand, frost heave, settlement, slope instability, etc. Normally consolidated clays and loose sand present greater problems to engineering work because of their low strength and high compressibility. A more detailed classification is given in the engineering geology maps, which also show the location of geotechnical test data sites.

The study area of 553km^2, lying mostly in the county of Hampshire, is shown in Figures 1 and 2. It includes a series of plateaux rising to 129m in the west, the woodland and heathland of the New Forest in the southwest, and lower, undulating landscape in the east. The city of Southampton (population 250 000) is in the southeast of the area, and Fawley, with its large petrochemical complex, lies to the south. Planners

have identified Mid and Southwest Hampshire as areas of planning restraint by virtue of their agricultural, landscape and historical qualities, with much of the New Forest designated as a Site of Special Scientific Interest. South and Northeast Hampshire were identified as growth areas, in which the principal growth sectors are shown in Figure 2.

There are 15 applied geology map types in this report, dealing with aspects of: solid and drift geology; mineral resources; water resources; engineering geology; slope stability; landfill and waste disposal; and data distribution. A description of each map type is included in the report, with extensive notes to clarify their implications for planners and developers. For the convenience of the user, the maps are drawn at 1:25 000 scale with the exception of some summary maps at 1:50 000. There are 62 sheets in total, available as part of the report. Copies of individual maps can be obtained separately.

The main source of data for this study was the field survey by BGS in 1973-80, supplemented by non-BGS borehole and other data held in the BGS archives. Commercial seismic data and data from geothermal and hydrocarbons exploration boreholes were also available to BGS. The results of that resurvey have been incorporated in the published 1:50 000 scale geological map and accompanying memoir (Edwards and Freshney, 1987). The 1:10 000 scale maps prepared at that time have been digitised for the present project and rescaled as the basis for several of the applied geology maps. Additional data have been collected from various sources, including regional, local and water authorities and contractors, and have been added to the archives at BGS, Exeter. Data from the archives including borehole information, particle size, geotechnical and hydrogeological data have been updated and summarised in the database. The databases and the map data were then searched to retrieve the information required for the preparation of the computer-drawn applied geology maps.

The computer systems provide benefits in speed and flexibility for producing specialised applied geology maps. As production tools they could almost certainly be cost-effective. However, although most of the geological databases now fit an established format, developments in the cartographic field are too rapid for a stable production system. It is clear that the important gains still lie in the future, and a continuing major investment will be required to grasp them. Developments in the near future are likely to include links to digital images of published maps and to satellite imagery; the integration and analysis of spatially referenced information on many topics through Geographic Information Systems; and links to three-dimensional spatial models of the geology.

The geology of the area is described in detail in the Appendix. The concealed rocks, known from deep boreholes, comprise Devonian, Triassic, Jurassic and Cretaceous strata. The Cretaceous Upper Chalk is exposed at the surface in small areas to the northwest and northeast of the study area. It is unconformably overlain by 400 m of Tertiary clays and sands, dipping at 1 to 2 degrees to the south. These are overlain by extensive areas of Quaternary deposits, mostly river-laid, with broad coastal spreads of Estuarine Alluvium.

Sets of applied geology maps at 1:25 000 scale have been prepared to show the Solid (pre-Quaternary) geology and the Drift geology and Made Ground. A third set of maps shows Drift thickness, based on field mapping and borehole records. Rockhead contour maps show the form of the rockhead at surface or below the Drift, which is generally thin except in buried river channels.

Mineral resources maps include a set showing the distribution of deposits that are potential sources of sand and gravel, and an assessment of sand and gravel resources in the Fawley area. Possible resources of brick clay are shown at 1:50 000 scale. A set of maps of worked ground includes areas classified as chalk, clay, gravel, sand, and sand and gravel workings.

A map of the distribution of aquifers shows the outcrops of the principal aquifers of the study area, together with the locations of boreholes sunk for water supply. Contours on the base of the Tertiary deposits indicate the depth to the major Chalk aquifer. Much of the water used for public supply is abstracted from the rivers Test and Itchen which derive the greater part of their flow from groundwater discharge from the Upper Chalk. The Chalk is also the most important source of groundwater for wells and boreholes, mostly in the northern part of the district. Aquifers in the Tertiary are of less importance, but are described in the text and some are shown on the map.

Geotechnical data were obtained mostly from commercial site investigation reports, which are irregularly distributed over the area. The maps should be seen as a guide to geotechnical behaviour and not a substitute for detailed site investigation. Up to 19 tests are included in the database but most samples are tested for only a few parameters. The results of the most important tests were analysed and the materials classified in terms of their engineering behaviour.

Engineering geology maps have been prepared to show the distribution of particular types of test data. Maps of the solid deposits show a classification into rock, cohesive, non-cohesive and laminated units. The superficial deposits are largely river and estuarine deposits with lesser amounts of Head. They are classed on the map as cohesive, non-cohesive, mixed and Head. The engineering properties for each class are described in the text, and the maps indicate mean values and ranges of values for the more commonly used geotechnical parameters.

Although landslipping of natural slopes does not appear to be a major problem in the study area, landslip risk should be evaluated carefully in areas where slope angles above 5° coincide with outcrops of the Wittering or Marsh Farm Formations. A map shows the distribution of slope angle and areas classified as landslip. It should be read in conjunction with the maps of solid and drift geology.

Made Ground, particularly infilled land, presents problems in foundation conditions for prospective building developments and has implications for agriculture and forestry. There are also special problems presented by disposal of toxic substances in landfill sites. Maps show three categories of Made Ground - landfill, raised foundations such as embankments, and backfilled sites. The distribution of boreholes held in the BGS archive is shown on a set of maps. The locations of Sites of Special Scientific Interest, which have relevance to planning and development decisions, are also shown.

The report includes a list of references and selected bibliography, a glossary, and appendices outlining the geological history, describing the solid and drift deposits, the history of mineral working in the area, and the relevant geotechnical tests with an account of their applications. Copies of this report, the accompanying reports and maps can be obtained from BGS (NGDC), Keyworth, Nottingham NG12 5GG. The archive data are housed at Exeter and enquiries should be directed to BGS, St Just, 30 Pennsylvania Road, Exeter EX4 6BX.

INTRODUCTION AND OBJECTIVES

The Schedule for the programme of research had the following introduction and list of objectives:

> The study area is defined by the boundaries of the British Geological Survey 1:50 000 Geological Sheet No 315 (Southampton) and comprises parts of OS 1:10 000 sheets SU20, SU21, SU22, SU30, SU31, SU32, SU40, SU41, SU42, SU50, SU51 and SU52.
>
> The area of the study is one of extensive urban and industrial development and redevelopment. The South Hampshire Structure Plan indicates that this is a part of the county where further release of sand and gravel resources might occur. The collation and presentation of data relating to the major industrial area around Fawley will be particularly useful. However there is an urgent need to avoid sterilisation of these resources by other development. Geological maps of the area at 1:10 000 scale have been completed recently and the appropriate Land Survey expertise is available for work on the present task.
>
> The study will involve essentially the computer manipulation of existing geological, geotechnical, hydrogeological and mineral resource data to provide an archive of information, a set of thematic maps and descriptive reports in a form appropriate to all potential users.

The objectives of the study are:-

> (a) to develop a computerised database of geological and related information as a basis for safe, cost-effective planning for development and for exploitation and safeguarding of water resources;
>
> (b) to develop methods of presentation of thematic maps and models from the data by interactive interrogation; and
>
> (c) to present the data as maps and models accompanied by reports describing the techniques and the data.

The results of the study are this report, the computer database of geological, geotechnical and cartographic information, the suite of maps drawn from the database by computer, and the accompanying reports on the database and computer mapping.

APPLIED GEOLOGY MAPS AND THEIR USERS

The DoE, in its programmes of commissioned geological research, has in recent years placed progressively more emphasis on the production of applied geology maps as a way of presenting results, rather than the traditional reports in which the results were placed within a geological framework. The reasons are that carefully designed applied maps are considered by the Department to give a clearer presentation of relevant information to users, including those with little or no geological or geotechnical background.

The principal users at whom the maps are aimed are primarily *planners* who should find them of value for formulating planning policies for development and redevelopment, and *developers* concerned to identify areas where suitable sites might be found. Planners will be concerned, for example, to identify areas of sand and gravel resources to avoid their unnecessary sterilisation by development; similarly to know the location of aquifers to safeguard them from unnecessary development, or pollution by unsuitable waste disposal policies. They will also need to have at hand background geotechnical data in order to assess properly proposals for surface developments and to identify geological hazards to development. Developers need basically two things:

1. general background geotechnical and mineral resource information to undertake feasibility studies of possible sites for civil engineering and building works.

2. a detailed lead-in to the availability of site investigation reports in or near their areas of interest.

GEOLOGICAL IMPLICATIONS FOR PLANNING AND DEVELOPMENT

In this section of the report are set out the main categories in which geological conditions may have an influence on land-use planning and development. Three main categories have been identified, all of which ought to be considered in the making of planning decisions:

Mineral and energy resources

Water resources

Engineering geology

It is emphasised that only general statements are made in this report, in some cases based on limited data, and further investigations are always likely to be necessary to clarify specific problems.

Mineral and energy resources

Under this category in the study area are included the bulk minerals sand and gravel, clay, and chalk, together with hydrocarbons and geothermal energy. However, of the bulk minerals, only the presence of sand and gravel resources are likely to have any significance in the formulation of planning and development decisions.

Clay. Although several formations (shown on Map F) contain substantial resources of brick and tile clay, economic and other considerations mean that renewal of large-scale working of brick clay in the study area is probably unlikely, and the last major brickworks (at Lower Swanwick) closed in 1974. However, the Reading Formation at Michelmarsh, just north of the study area boundary, is still exploited for tile clays. Thus the presence of a brick clay resource in an area will probably not nowadays constitute a major factor in planning decisions.

Chalk. The Chalk outcrop of the study area constitutes a resource of agricultural lime, and has in the past been worked from pits; however none are active at present. Because of the small Chalk outcrop within the study area, the presence of Chalk is unlikely to be a significant factor influencing planning decisions. However, the Chalk does constitute a major aquifer requiring protection (see water resources section, below).

Sand and gravel. River Terrace Deposits and Alluvium of the study area contain the major resources of gravel, while some solid formations contain resources of sand. These resources are shown on Maps E1-E7. Working of sand and gravel continues at present and the locations of workings are shown on Maps G1-G6. Clearly it will be the concern of planners and sand and gravel extraction companies to identify areas of sand and gravel resources to avoid their unnecessary sterilization by development. Potential resources of sand and gravel have been assessed by the Industrial Minerals Assessment Unit (IMAU) of BGS (Mathers, 1982) in the Lymington area and in a belt (which includes the area around Fawley) extending 2km into the Southampton study area. An end-use assessment map (E7) of the eastern sheet covered by the IMAU survey has been produced owing to the particular planning interest of the Fawley area. A description of the map is given elsewhere in this report. Much of the remaining gravel resources contained in the River Terrace Deposits southeast of Southampton, around Romsey and west of Southampton are under pressure from housing or industrial development.

Some of the sand units in the solid formations constitute aquifers requiring protection from pollution (see water resources section, below).

Hydrocarbons

The study area forms part of a wider area currently being prospected for hydrocarbons. The nearest operating oilfield is at Wytch Farm, Dorset, 30 km to the southwest. A second oilfield, about 40 km northeast of Southampton at Humbly Grove near Basingstoke, is currently under development. Recent finds of possible commercial importance include that at Horndean, Sussex, 30 km east of Southampton. The reservoir rocks of most interest in the project area are the Sherwood Sandstone and the Bridport Sands; other possible reservoirs occur in the Middle Jurassic limestones. No significant hydrocarbon shows were recorded in the Marchwood [3991 1118] and Western Esplanade [4156 1202] boreholes, although the Sherwood Sandstone and Bridport Sands there have appreciable porosities and permeabilities. A recent hydrocarbon-exploration borehole at Hoe [3845 1915], between Southampton and Romsey, was dry.

Geothermal energy

The study area lies within an area of high heat flow covering east Dorset and southwest Hampshire. High heat flow combined with the possible presence of aquifers at considerable depth led to the drilling of two boreholes to evaluate geothermal energy resources in the district - one at Marchwood, the other at Western Esplanade near Southampton city centre. The most promising potential aquifer, the Sherwood Sandstone, occurred at shallower depths than had been predicted, but was sufficiently deep to be useful. At Marchwood, pumping tests (Price and Allen, 1982) showed that a pumping rate of 29 litres per second (l/s) was feasible giving a drawdown from 5m down to 370m. It was calculated that after pumping for 20 years at 29 l/s, the drawdown would be 550 metres. The temperature of water at the surface was 71.6°C and the down-hole temperature stabilised at 73.6°C. At the Western Esplanade Borehole (Allen and others, 1983) the borehole was pumped at 19.86 l/s for 33 days with a drawdown to 365 m below ground level. The temperature at surface was 74.9°C and at 1755m was 76°C. Most of the yield comes from thin beds of medium- to coarse-grained sandstone within the Sherwood Sandstone, but these sandstones were only 11m thick in the Western Esplanade Borehole. Thus quite small fault movements could disrupt the reservoir, as could the rapid lithological changes which characterise this type of sedimentation. It is probable that the Sherwood Sandstone becomes thinner and finer grained east of Southampton, thus losing its potential as a geothermal source.

Water resources

The Control of Pollution Act 1974 and the relevant EEC Council Directive (1979) require that groundwater be protected from pollution. In general, pollutants may quickly reach the saturated zone in sandy aquifers where the water table is close to ground surface. It is therefore important that no potential polluting agency should be sited in areas where there is a risk of polluting an aquifer. In areas adjacent to the coast, prolonged pumping from an aquifer may lead to seawater intrusion. Water boreholes should not be sited less than 500m from the shore. The distribution of the main aquifers, along with licensed wells, is shown on Map H.

Chalk is the most important aquifer in the study area. Wells and boreholes in the Chalk are present mainly in the northern part of the area where the formation outcrops or is overlain by only a thin (less than 50m) Tertiary overburden. The use of the Chalk as an aquifer decreases southwards with increasing Tertiary overburden thickness. This is probably due to closure of fissures by overburden pressure, since most groundwater flow in the Chalk occurs through fissures. It is important that the Chalk outcrop (lying mainly north of the study area) should be pollutant-free; pollutants can be carried down-dip (southwards) in the aquifer from outside the area.

The other main aquifers of the area consist of the Whitecliff Sand, Becton Sand, and sands in the Reading Formation. The incoherence of these formations mean that boreholes should be properly designed to avoid silting with consequent deterioration in yield. Shallow wells are liable to surface pollution and need careful siting.

Of the other formations, sandy beds in the London Clay at various levels below the Whitecliff Sand may give small yields (up to $100m^3/d$), but yields may diminish with time. The Bracklesham Group is so varied in lithology that it is difficult to predict yield: the sandier units (e.g. parts of the Marsh Farm Formation west of Southampton) may give $200m^3/d$. However, elsewhere, boreholes are recorded with little or no yield. Except for the Becton Sand, the Barton Group generally contains little usable groundwater, although small supplies are possible from the sandier parts (Chama Sand, and sand in the Barton Clay). Yields in the clayier parts of the Headon Formation are generally very small, although small supplies are possible from the sandier parts of the sequence. Yields from Alluvium and terrace gravels are commonly obtained from the adjacent rivers, and saline water may enter wells where the river is tidal. Shallow wells in the Older River Gravels and River Terrace Deposits are particularly vulnerable to surface pollution, and supplies tend to fail after extended dry periods.

Engineering geology

In engineering terms the project area is divisible into three provinces:-

1 Rock
2 Overconsolidated clays and dense sands
3 Normally consolidated clays and loose sands

Rock

The Upper Chalk, which has small outcrops in the northeast and northwest of the area, is the only rock (in an engineering sense) of any significance in the area. It is a relatively weak limestone, the properties and behaviour of which are well known; it presents few problems to engineering activity when fresh. It may, however, be deeply weathered and fractured, resulting in a loss of strength. Cavities caused by natural solution or mining may also be a problem, but no such cavities have yet been recorded in the study area.

Overconsolidated clays and dense sands

The greater part of the area is underlain by Tertiary deposits of overconsolidated fissured clays, silts and dense sands, which are classed as soils in an engineering sense. The Tertiary deposits are largely the product of cyclical changes in sedimentation and consequently show gradual variations in composition, resulting in a wide range of deposits within the silt, sand, clay spectrum as well as interbedded distinct beds of sand, silt and clay. The geotechnical definition of this material is therefore difficult since the geotechnical properties show a similar wide range of values. The predominantly clay (cohesive) units of the Tertiary sequence are the Reading Formation, Barton Clay, London Clay and Headon Formation. These are overconsolidated stiff to very stiff fissured clays with values of plasticity that range from low to very high. No geotechnical information for the Headon Beds or Reading Formation was found within the area, and their behaviour is assumed.

Engineering problems associated with the clays are slope instability, and foundation problems due to shrinking and swelling with moisture content changes.

The remaining Tertiary deposits are sandy non-cohesive materials which comprise sand and pebble beds within the Reading Formation, Nursling Sand, Portsmouth Sand, Durley Sand, Whitecliff Sand (and pebble beds), Earnley Sand, Selsey Sand, Chama Sand and Becton Sand. These sands range in grain size from coarse to very fine and may include varying amount of silt and clay. They are dense to very dense and, although they may give rise to running sand conditions in excavations and boreholes, they generally offer good foundation conditions and few engineering problems. Some of the finer grained sands may be prone to frost heave in freezing conditions above the water table.

The Marsh Farm and Wittering formations consist of interbedded to laminated medium dense to dense sand and clay which form a distinct engineering unit. The sandy layers act as efficient pathways for water to move in and out of the deposit. This causes the material to consolidate rapidly under load and soften rapidly when the load is removed. Bearing capacity is variable, and structures may suffer a high degree of settlement. Superficial materials on the Tertiary deposits consist mainly of River Terrace sand and gravel which is loose to dense and offers good foundation conditions with few problems; these deposits may carry water and need support in excavations.

Normally consolidated clays and loose sands

The riverine and estuarine alluvium of the River Test, River Itchen and Southampton Water are generally soft to very soft, silty, sandy, normally consolidated, locally organic clays, silts and sands. These materials present a number of problems to engineering work because of their low strength and high compressibility. Excavations will require support, and structures may suffer excessive settlement. The dessicated top of the alluvium may bear the weight of site machinery but if the surface layer is disrupted traffic may become bogged down.

The maps (Maps J and K) describing the engineering geology of solid and superficial materials use a more detailed classification based on the geologically mapped lithostratigraphical units and their engineering behaviour determined from the geotechnical database of values from site investigation reports.

Slope stability

Landslipping of natural slopes does not appear to be a potential problem in the study area. However, it would be prudent to assess the potential for slope stability for any development involving slopes greater than 5° which coincide with cohesive materials, particularly London Clay, Barton Clay, Headon Formation, and Reading Formation. Landslip risk should be carefully evaluated in areas where higher than 5° slope angle coincides with outcrops of Wittering or Marsh Farm formations, particularly if these formations are overlain by or are near to River Terrace Deposits. The distribution of both slope angle and landslips is shown on Map L.

GEOGRAPHICAL AND PLANNING BACKGROUND

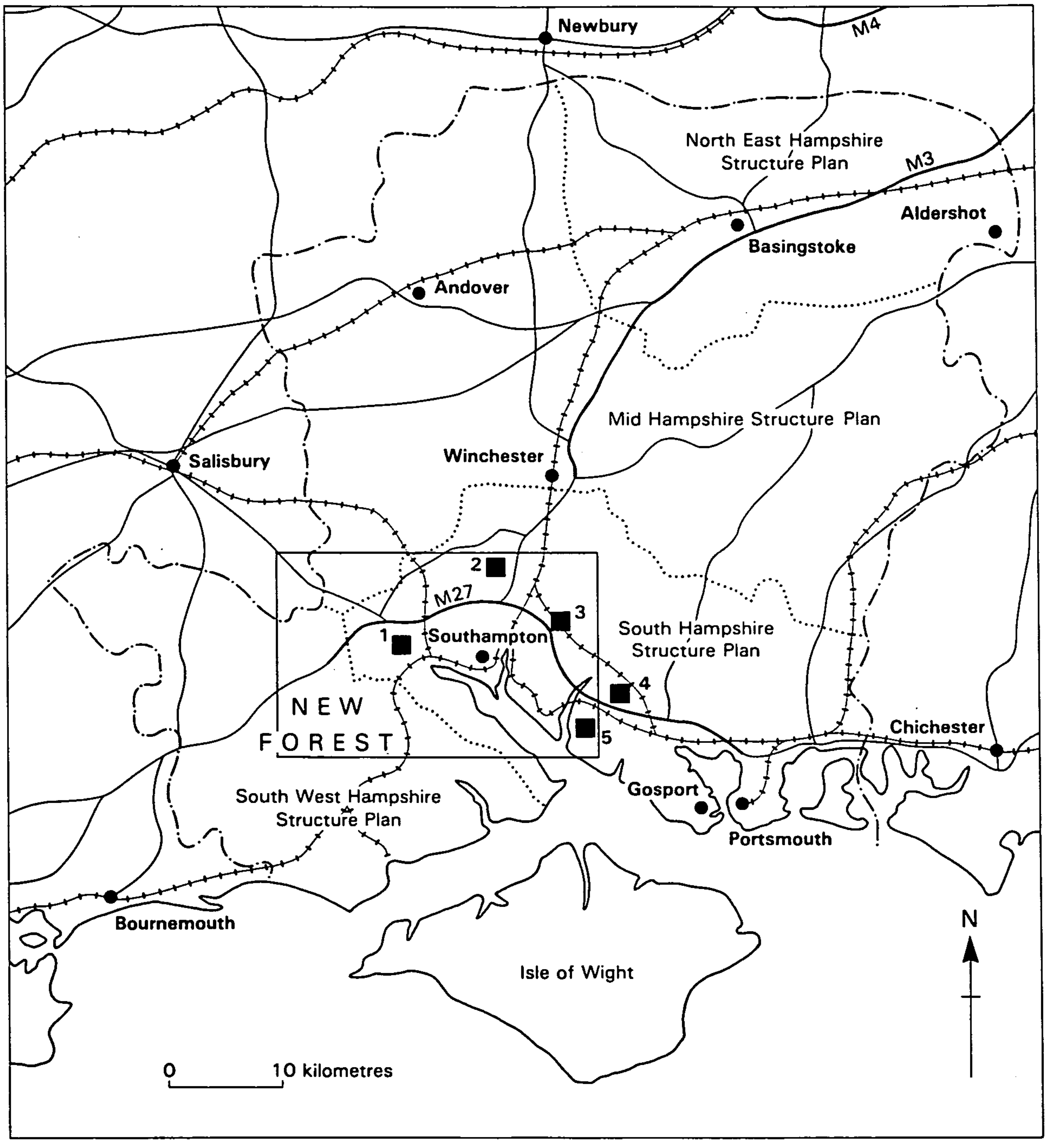
Geographical background

The study area, extending over 553km^2, is defined by the boundaries of British Geological Survey (BGS) 1:50 000 sheet 315 (Southampton), which is included mainly in the county of Hampshire except for about 25km^2 in the northwest which lies in Wiltshire. The regional setting of the study area is shown in Figure 1. Additional borehole data have also been incorporated into the database from those parts of the component 1:10 000 sheets that lie outside the boundaries of the study area. The distribution of 1:10 000 and 1:25 000 sheets in relation to the boundary of the Southampton sheet area is given in Figure 2. The topography, drainage, chief towns and communications of the study area are shown in Figure 3.

The highest ground lies in the west, where the Older River Gravels (formerly Plateau Gravels) give rise to a series of plateaux that rise in altitude northwards to a height of 129m above Ordnance Datum (AOD) near Nomansland. The eastern part of the area is characterised by undulating landscale generally below 60m AOD, although locally river terrace surfaces north of Southampton reach 90m AOD.

The study area is drained mainly by the rivers Test and Itchen which rise on the Chalk outcrop and enter the district from the north, combining to flow into the broad tidal estuary of Southampton Water. The River Hamble enters the estuary in the extreme southeast of the district. Part of the New Forest is drained by the Beaulieu River, and by the Highland Water (a tributary of the Lymington River), both of which flow south to the Solent.

In the west and southwest is a remarkable area of woodland and heathland called the New Forest, of which some 150km^2 lies within the area. It has its origins, probably in the 11th Century, as a Royal Forest set aside for hunting by William the Conqueror, but has survived the pressures of time to come down to us as probably the largest area remaining in Lowland Britain of semi-natural vegetation - a mixture of heath, wood, bog, and acid grassland. It is now administered by the Forestry Commission, who have the tasks of management of the commercial woodland, and acting as custodians of the general amenities of the Forest. The latter function is becoming more important in view of the increasing importance of the Forest as a recreational and tourist area.



—·—·— Hampshire County Boundary

············ Boundary of area covered by Structure Plan

M27 Motorway

——— Other major roads

+++++ Main railway

■ Approximate location of 'principal growth sector' as defined in the South Hampshire Structure Plan

1 **Totton**

2 **Chandlers Ford**

3 **Hedge End North**

4 **Whiteley**

5 **Fareham**

Figure 1. Sketch map showing the regional setting of the study area

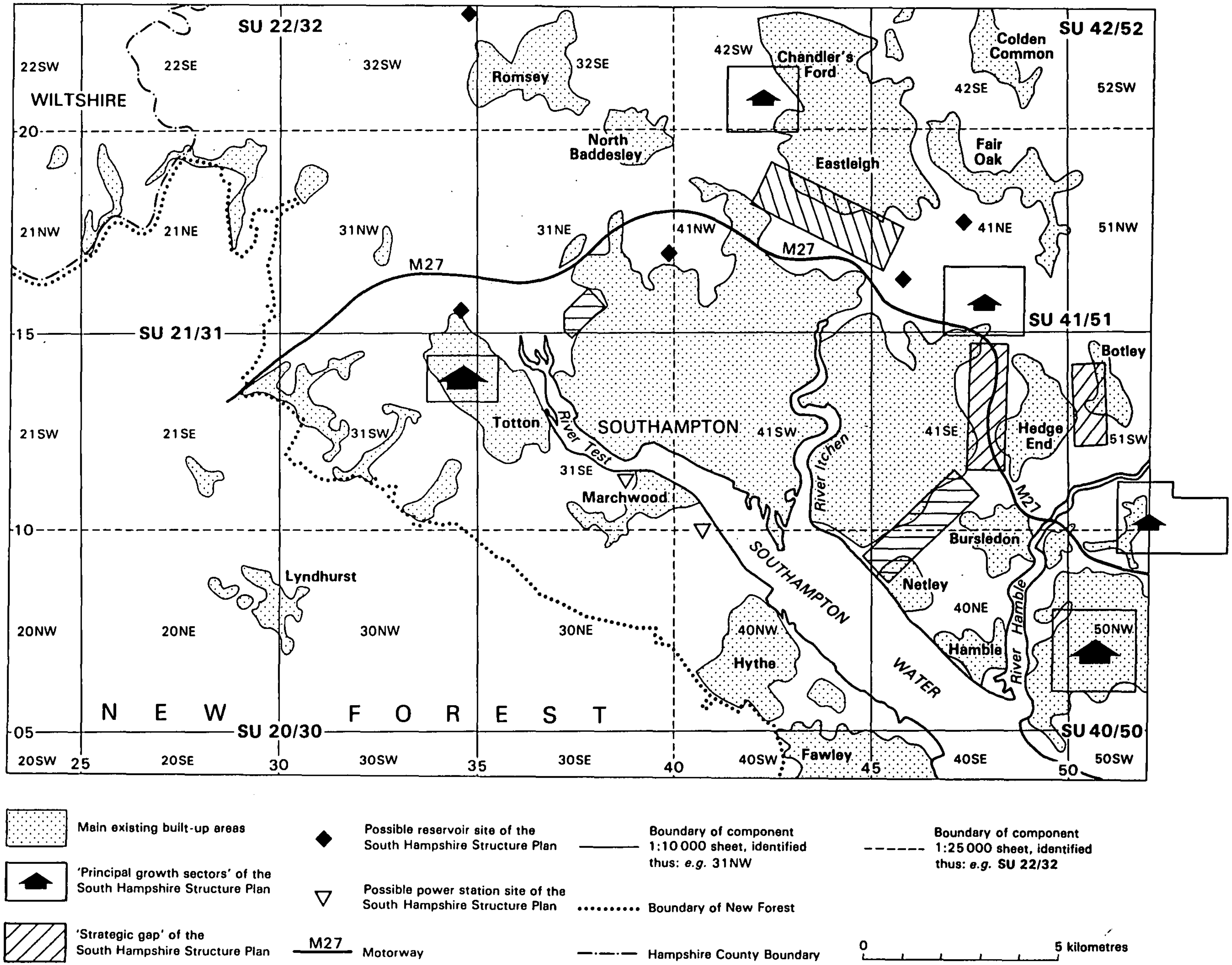


Figure 2. Sketch map showing component 1:10 000 and 1:25 000 sheets and selected planning features

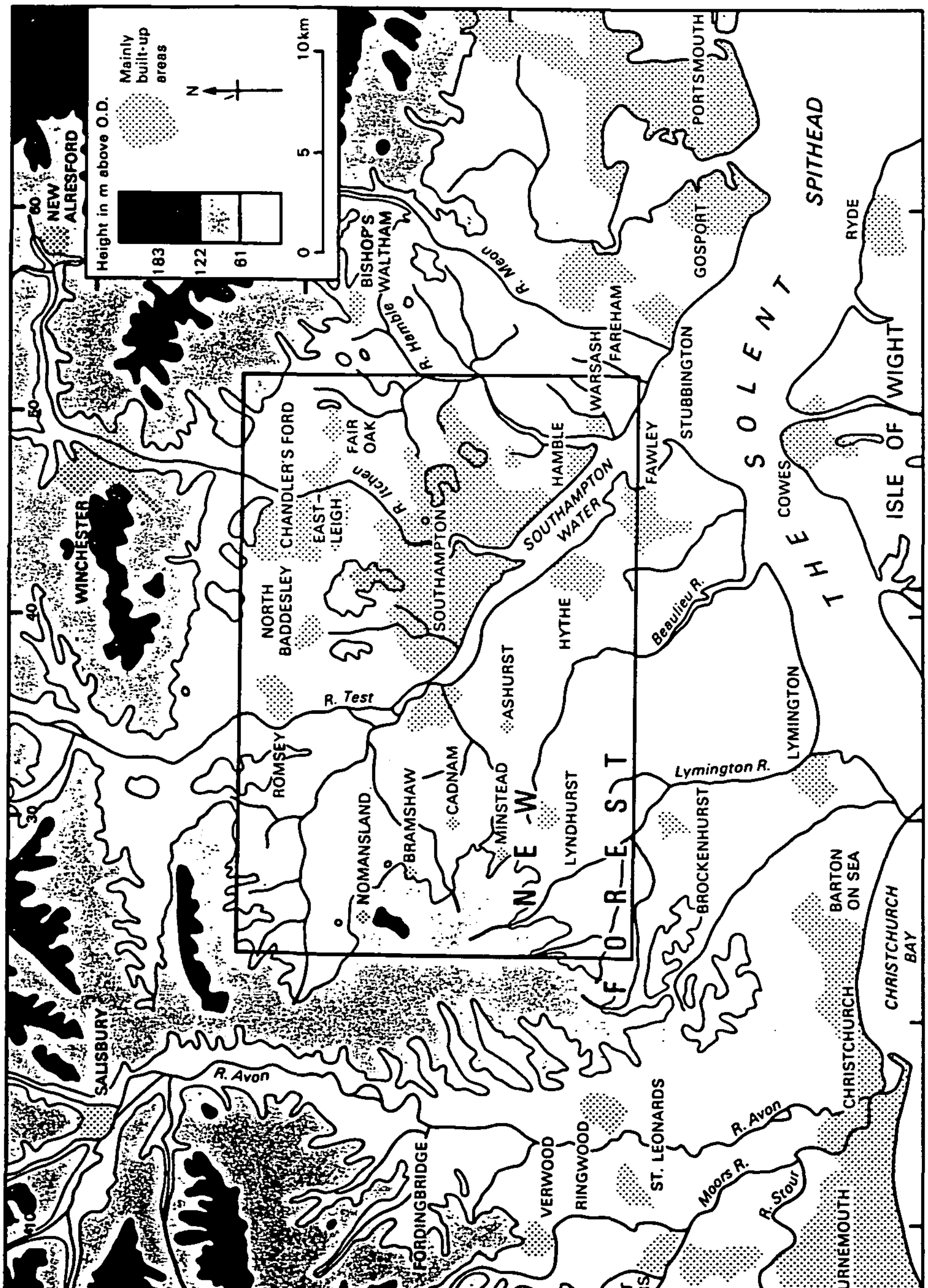


Figure 3. Topography, drainage and chief towns of the study area

Landscapes dominated by heather are widespread on infertile soils developed on the sandy formations of the project area, for example on the Marsh Farm and Earnley formations between West Wellow and Bramshaw and on Becton Sand and Chama Sand between the Lyndhurst area and Dibden Purlieu. Modern opinion (Tubbs, 1968) is that the impoverished soils of the New Forest carrying heather and acid-tolerant grassland are not primary, but originally carried woodland, the removal of which by man led directly to deterioration of the soils by increased leaching.

The heaths in the south of the district are the commonest areas of occurrences of another distinctive feature of New Forest scenery, that of valley bogs and wet heaths, some of which contain accumulations of peaty alluvium which have been worked in the historically recent past.

The clayier and siltier Tertiary formations in the New Forest - parts of the Selsey Sand, Barton Clay, and Headon Formation - are mainly covered by woodland. Pleasant streams, locally called "gutters" or "waters", flow down from the margins of the older river gravel plateaux through the woodland. Attractive streamside grasslands, called "lawns" are fertile and thus of considerable value to the grazier.

The woodlands are of two main types: the unenclosed broadleaved woodlands and the statutory silvicultural "Inclosures", the more modern of which are dominantly coniferous, which were enclosed to prevent damage to growing trees by browsing and grazing animals.

The main settlement of the Forest within the study area is Lyndhust (the so-called "capital" of the New Forest). Small settlements with associated agricultural holdings include Minstead, Brook, and Bramshaw. Nomansland, Cadnam, Bartley, and Ashurst are villages lying along and just outside the northern boundary of the Forest. The strip of land lying between the New Forest and Southampton Water includes the site (around Fawley) of one of the largest petrochemical complexes in Europe, together with two power stations, and much housing.

The largest settlement is the city of Southampton, population about 250 000, which is situated at the head of Southampton Water. The city is one of the leading ports in the country, with an important traffic in containerised cargo, for which a new terminal (the Prince Charles Container Port) has recently been constructed on 80ha of reclaimed land in the estuary of the River Test. It is also the centre, with outlying districts, for numerous light industries and services. Several other important towns are situated in that part of the district east of the River Test and Southampton Water: north of Southampton are Romsey, North Baddesley, Eastleigh, Chandler's Ford, and Fair Oak. East of the city is a variably built-up area interspersed with light industry, horticulture, and mixed farming, extending to Warsash. That part of the district north of the New Forest is mainly an area of mixed farming, with some woodland, and small villages such as Landford, Sherfield English, and West Wellow.

The main extractive industry in the area is gravel-working from river terrace deposits. Sand is also dug from a small number of pits sited on the Whitecliff Sand and Reading Formation outcrops. Brickmaking ceased as recently as 1974 with the closure of the pits at Lower Swanwick near Burlesdon.

The public water supply of the district is mainly taken from the rivers Test and Itchen, but important quantities are also pumped from the Upper Chalk at Otterbourne.

Planning background

The county of Hampshire as a whole has proved in recent years to be more prosperous than the country as a whole, owing to its good communications (particularly to London and Heathrow airport); the existence of the ports of Southampton and Portsmouth, and the presence of a skilled workforce living adjacent to attractive and varied countryside and coastline, with a good climate. Thus, between 1971 and 1985, employment in Hampshire increased by 12.1 per cent compared with a decrease of 1.9 per cent for the nation as a whole (Hampshire County Strategy 1991-2001, Draft 1986).

Within the county, planners have identified Mid Hampshire and South West Hampshire as areas of planning "restraint" by virtue of their agricultural, landscape, and historical qualities, while South Hampshire and North East Hampshire were identified as "growth areas", in which development will continue on a substantial scale.

In the South Hampshire Structure Plan, provision has been made for five new communities at Fareham Western Wards, Totton, Chandler's Ford, Whiteley, and Hedge End North (the so-called "principal growth sectors" (Figure 2). Of these, all but Whiteley lie within the present study area. Development of the first three communities is currently under way; the plans include sites for new development as well as housing. The total provision for new housing in South Hampshire in the 1990s is about 34 100 dwellings. The area between Southampton and Portsmouth is under intense pressure of development, with the consequent danger that the area will become an undifferentiated urban sprawl. Planning strategy is therefore to maintain "strategic gaps" of undeveloped land between built up areas - for example between Eastleigh and Southampton; West End and Hedge End; Hedge End and Botley; and between Southampton and the Netley-Bursledon area (Figure 2).

The development plan for South West Hampshire, as outlined in the approved Structure Plan (Hampshire County Council, 1983), is one of restraint and conservation. Most of the plan area that lies within the present study area is occupied by the New Forest. Planners have acknowledged that this is a unique area of national and international significance because of its value for nature conservation, recreation and forestry, for its historic commoners' rights, and for landscape interest. Much of the Forest is designated as a Site of Special Scientific Interest (SSSI), as shown on Map O. The importance of the New Forest is recognised in the South West Hampshire Structure Plan by its designation as a "green belt". Within the boundary of the New Forest, new construction (except for agriculture and forestry) will not normally be permitted. As far as mineral extraction is concerned, there is a strong presumption against the granting of new permission to extract sand and gravel from within the New Forest. There is also a presumption against exploration for hydrocarbons in the New Forest; and a strong presumption against development in connection with an appraisal programme, or the extraction of hydrocarbons in the New Forest.

PREVIOUS APPLIED GEOLOGY MAPS AND DATABASES RELEVANT TO THE STUDY

An early attempt to provide "environmental geology" maps of the Southampton area was made in 1978 by Austin and Cosgrove, as part of an unpublished excursion guide prepared for the Engineering Group of the Geological Society of London. The maps were based on information contained on the BGS 1:63 360 scale geological map and were essentially simplified lithology maps. The following themes were mapped:

1. Clay
2. Mixed sand and clay
3. Sand
4. Gravel and pebbles
5. Chalk

The following topics were covered in the guide: geology, topography and drainage; soils; vegetation and agricultural land; urban development; water resources; mineral resources; waste-disposal sanitary-landfill sites; and transportation.

Prior to development of the present computerised database, the main geological database for the study area consisted of the paper records in BGS archives, which are predominantly collections of commercial site investigation and water boreholes. However, an attempt was made in 1977 by CIRIA (Construction Industry Research and Information Association) to set up a National Registry of Ground Investigation Reports, for which a pilot study was carried out in the Southampton area, and subsequently extended to the Portsmouth, Bournemouth, Reading and Guildford areas. The CIRIA coverage of the Southampton urban area is between 400 and 450 boreholes, of which a large proportion come from the Fawley Oil Refinery and the M27 motorway.

LIST OF MAPS AND SOURCES OF DATA

The list of applied geology maps prepared for this report is shown in Table 1.

Table 1. List of applied geology maps

Theme	Title	Scale	Map numbers
Geology	Solid geology	1:25000	A1-A6
	Drift geology	1:25000	B1-B6
	Drift thickness	1:25000	C1-C6
	Rockhead contours	1:25000	D1-D6
Mineral resources	Sand and gravel resources	1:25000	E1-E7
	Clay resources	1:50000	F
	Distribution of worked ground	1:25000	G1-G6
Water resources	Distribution of aquifers	1:50000	H
Engineering geology	Availability of geotechnical test data	1:50000	I1-I7
	Engineering geology of solid deposits	1:50000	J
	Engineering geology of superficial deposits	1:50000	K
Slope stability	Distribution of slope angle and landslip	1:50000	L
Landfill and waste disposal	Distribution of Made Ground	1:25000	M1-M6
Data distribution	Distribution of boreholes	1:25000	N1-N6
Other	Sites of Special Scientific Interest	1:50000	O

1:50 000 geological map and memoir

The Southampton district was resurveyed on the 1:10 000 scale by BGS in 1973-80, and the results have been incorporated in the 1:50 000 scale map and accompanying memoir (both published in 1987). The latest survey updated the results of a survey carried out on the 1:10 560 scale in 1889-98. The resurvey was carried out using standard BGS mapping techniques, that is, by detailed examination on the ground of all exposures, the geological boundaries in unexposed areas being traced by sampling with a 1.2m-long soil auger, combined with examination of topographical features and soil and vegetation types. Aerial photographs have been useful in some areas for locating geological boundaries more accurately. Additional subsurface data were gathered by drilling shallow (<15m) boreholes using a piston sampling device, and by drilling four rotary cored boreholes to depths of up to 340m to provide stratigraphical control data, and samples for palaeontological and petrological study. Non-BGS borehole and other data in the BGS archives were also used to supplement the information gained from surface mapping and BGS boreholes.

Details of selected exposures located during the resurvey have been coded and added to the database.

Commercial seismic data produced during hydrocarbons exploration programmes have been available to BGS, and the base-Tertiary contours presented on the map of aquifer distribution (Map H) have been produced by processing seismic data.

The 1:10 000-scale maps produced during the resurvey of the Southampton district have been digitised and incorporated in the databases, and have formed the basis for the production of several of the applied geology maps.

The BGS Memoir (Edwards and Freshney, 1987) contains a detailed account of the geology of the district and forms the basis of the geological summaries contained in this report.

Boreholes and trial pits data

The main categories of data under this heading are:

(a) Site investigation boreholes and trial pits

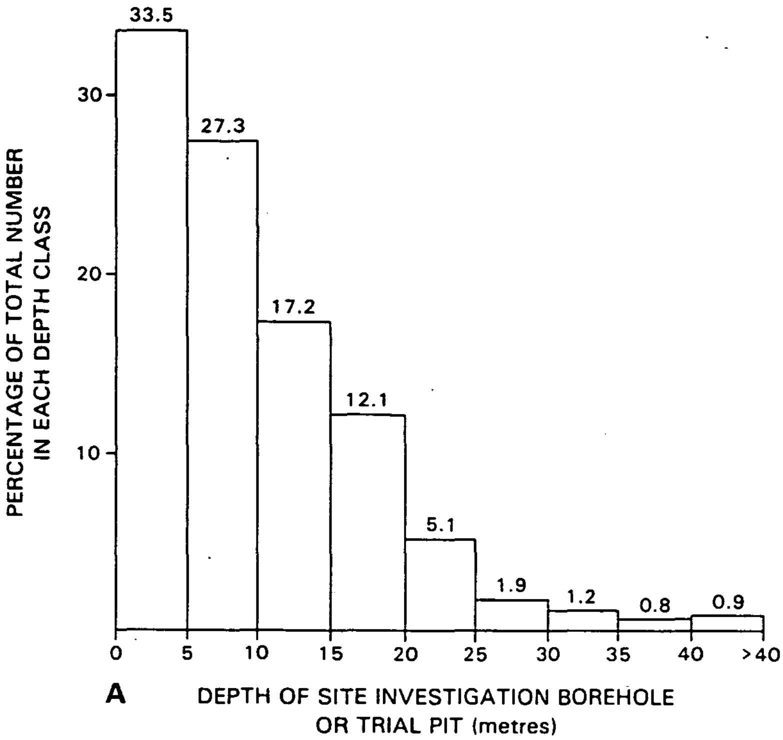
(b) Water boreholes

(c) Cored stratigraphical boreholes (including piston-sampler boreholes)

(d) Geothermal and hydrocarbons exploration boreholes

At the commencement of the project, data for some 4220 boreholes and trial pits were held in the BGS 1:10 000 record system. During Phase A of the project, additional data for some 1423 boreholes and trial pits were collected from local authority sources, giving a total archive of 5643 boreholes, trial pits and sections, the log data for which totalled 23 032 records on the computer database.

The great majority of the boreholes and trial pits were carried out as part of site investigations for civil engineering works. Most of the boreholes were drilled by shell and auger methods to depths generally <10m; the maximum depth generally achieved by shell and auger is 30m. Figure 4A is a histogram showing the frequency distribution of the different depths to which site investigation boreholes in the project area have been drilled. The quality of site investigation records is variable but most post-1970s records have been described using the appropriate British Standards. Many site investigation boreholes and trial pits are



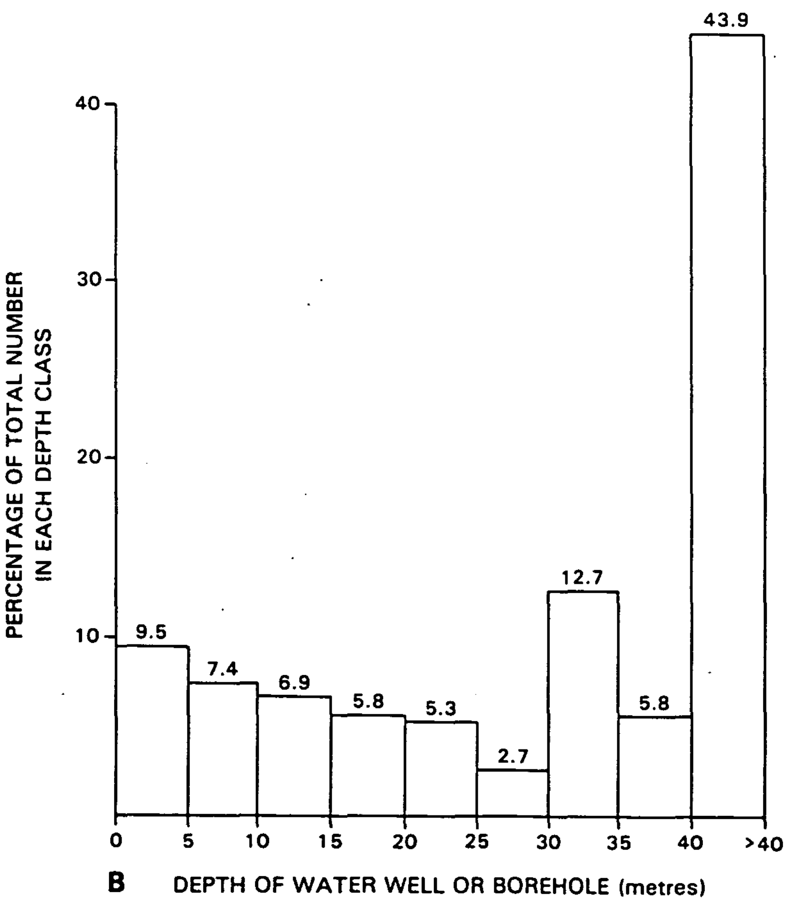


Figure 4. Histograms showing the distribution of the different depths to which A site investigation boreholes and trial pits and B water wells and boreholes have been sunk

accompanied by varying amounts of geotechnical data.

Water boreholes are generally sunk to greater depths than site investigation boreholes (see Figure 4B for histogram showing the frequency distribution of the depths to which water boreholes have been sunk), but many are 50 or more years old and are accompanied only by a drilling record of variable quality, or by no lithological record at all. No geotechnical data are available for water boreholes, but a few have details of water yield, pumping tests and water quality.

Cored BGS stratigraphical boreholes and piston sampler boreholes provide detailed subsurface stratigraphical, palaeontological and petrological data to supplement the surface geological map. The cored boreholes are up to 340m deep, and the piston sampler boreholes much shallower (<15m).

Geothermal and hydrocarbons exploration boreholes provide data about formations concealed beneath the strata outcropping within the project area. Two boreholes were drilled by BGS/Department of Energy to investigate the geothermal potential of the area. Of these, Marchwood No. 1 [3991 1118] is the deepest borehole (2615m) in the study area, penetrating the oldest proved formation (Devonian - ?Old Red Sandstone). Geothermal and hydrocarbons boreholes are mostly uncored, and lithologies are interpreted from geophysical logs and cuttings samples. Geophysical logs have also been run in all four BGS cored stratigraphical boreholes, and (using a portable gamma-ray logging tool), in selected water boreholes.

An important factor to consider is the unequal distribution of borehole and test pit locations. They are not spread evenly over the study area, but are clustered in well-defined areas, in particular along the routes of the M27 motorway and associated link roads, and locally in urban areas, as shown in maps N1 - N6.

Particle size data

Three sets of data have been utilised

(a) particle size distributions of 600 sand samples collected during the resurvey of the Southampton sheet (predominantly from Tertiary formations), and processed in BGS laboratories.

(b) particle size distributions of samples collected during a sand and gravel resource study (Mathers, 1982) of an area that overlaps into the current project area in a strip about 3km wide to the west of Southampton Water. These samples are mainly from Quaternary gravel deposits, with limited information from the underlying Tertiary Becton Sand.

The above two sets of data have been incorporated into the computer database.

(c) particle size distribution of both Quaternary and Tertiary deposits are commonly available in reports that accompany site investigations, and these have been transferred manually onto a standard base graph - they do not form part of the computerised database. Examples of particle size distribution envelopes for different units are given in figures that accompany the description of the sand and gravel resource maps.

Geotechnical data

Geotechnical test data are available from some samples; the distribution of the data, types of tests, and assessment of the data are given in the map description section. The numerical test data have been incorporated into the computer database; summary tables of data are appended to the engineering geology maps (Maps J and K).

Hydrogeological data

Water records formerly included in a registration system separate from the BGS 1:10 000 system have been incorporated in the latter system. Contours on the base of the Tertiary (representing the top of the Chalk aquifer) shown on the 1:100 000 Hydrogeological Map of Hampshire and the Isle of Wight (1979) have now been updated using the results from seismic reflection profiles; these updated contours are shown on Map H.

COMPUTER METHODS

Objectives of the study were to create a computer database of the geological and related information and to develop methods of presentation of thematic maps and models from the data by retrieving selected data and tailoring the output for specific requirements. A detailed account of the methods is given in the two accompanying reports. A related report commissioned by the Department of the Environment contains a more detailed study of the user requirements for geological data in land development (Clayton and others, 1987). It may be useful here to bring together some of the conclusions from these documents and suggest their consequences.

Information technology is a rapidly expanding field, driven by the plummeting cost of equipment and major improvements to computer programs. Work on the project began with data input, through an IBM-PC, to a DEC PDP-11/70 computer where borehole data was being managed by the Mimer database management system (DBMS) and plotted using an in-house package called GRAPE. Two years later, towards the end of the project, these products had all been replaced. Data entry from Burroughs equipment to a VAX 8500 computer using the Oracle DBMS gave output for plotting with GIMMS, and an Intergraph computer-aided drawing system had replaced a Tektronix work station attached to a Calcomp digitizer. Other systems would have to be considered for a similar project starting now. Needless to say, adjusting to such changes adds appreciably to the time and cost of the project. Yet each development is built on what goes before, and to stand aside from the new technology could make it impossible to catch up. Geologists and other users are also faced with adjustment to new methods. Without them, the systems would become irrelevant and generations of expertise might be lost.

The medium-term goals, towards which this study in particular was directed, are clear, if elusive. The objective is to enable the geologist to express his interpretation of the geology as a digital spatial model - a statement in the computer of how the rocks of an area are arranged, what they are composed of, and how they were formed (Loudon, 1986). The scientific benefit is that for the first time the creation and use of the model can be a shared activity of the geological community. At present, the model resides only in the minds of geologists, and can be illustrated, but only imperfectly represented, in maps, sections and descriptions. The benefit to the planner and developer is that the model can be linked to observational data together with explanations of the geologists' decisions in deriving the interpretations. The digital model can be the source of a wide variety of applied geology maps prepared on demand to meet specific requirements.

A shorter-term goal, on the same development path, is to retrieve and integrate data from many sources by means of Geographic Information Systems (GIS), a two-dimensional analogue of the model, and to present the result through computer graphics. Research and development in GIS has been identified as a pressing national need (Chorley, 1987). The Southampton area is of interest from this point of view. As part of this study, BGS collaborated with the Research and Development group of the Ordnance Survey in the preparation of a digital terrain model. Outside this project, experiments were performed with satellite imagery and with simulated satellite imagery of the Southampton area. Discussions have been held with the Soil Survey of England and Wales, who have been commissioned to study the Southampton area within their field of expertise. A number of types of spatial information are thus being brought together in a GIS form.

These topics alone provide a vast amount of data which the computer can process and display. The display is all-important, for the human eye and brain are unsurpassed in recognising and interpreting pattern in an image. Whatever the power of the computer, it necessarily lacks the background knowledge and understanding of the trained human interpreter. The graphic display is thus the essential link between the computer and the user.

The ability of the computer to provide a display of the required size and resolution in full colour at reasonable cost is brought tantalisingly close by modern electrostatic plotters, but the resolution is still not quite equivalent to conventional methods. For the planner and developer, Geographic Information Systems (GIS) have new possibilities to offer, for they can hold not just information on the natural environment, but also on the built environment and on plans for future developments (Chorley, 1987). The methods used in the present study are more limited but indicate a technology not far short of achieving this degree of integration. The main barrier to developing GIS nationwide is not technology but the overwhelming amount of data which must be converted to digital form. The report by Clayton and others (1987) proposes an approach to this problem for geological data related to land development, and the present study is in line with its proposals.

Following a standard format and data content widely used for shallow boreholes in BGS, data was extracted from nearly 5650 boreholes in the area, and stored using the Oracle database management system (Oracle, 1987). The system is relational, which means that the data are held in a set of tables (known in set theory as relations). Reference fields, such as borehole identifier or grid reference, provide the link between related entries in different tables. The data organisation can be readily visualised in this form, and the system is flexible, in that new tables can be added as required to expand the data content. Thus soil data could be added and geotechnical analyses were added as a new database related to the borehole descriptions.

Retrieval from the borehole database can be performed by selecting from a limited set of choices in a "menu" or by the use of the widely adopted SQL query language. A simple set of SQL commands allows the user to specify the criteria on which items are to be retrieved from the database. The user can indicate the combinations of the range of values under any of the headings in the tables that would cause the item to be retrieved, and can perform simple calculations as part of the retrieval. Thus a retrieval of boreholes with more than 5m of sand and gravel within 10m of the surface can be readily achieved. The user can specify which variables are to be retrieved and how they are to be printed. With initial reluctance, some geologists have become adept at using SQL, but considerable familiarity with the organisation of the data is needed. For those accessing the data less frequently, the menu system is simpler to use but less flexible.

Cartographic data is in some respects more difficult to handle than borehole data. The technology is newer and less stable. It is not clear how far data should be handled as a raster (a square grid of points) or a set of line segments. Both methods have been used in separate parts of the study, and the links between them have caused problems. Although graphics systems are now available which can be used by the non-expert, they lack the power needed in this application. In this project, considerable expertise and training were needed as the selection procedures used on cartographic data were difficult and time-consuming. Adequate results were obtained, however, and much has been learned. Most of the maps were prepared on a pen plotter. The topographic base maps were not held in digital form, but were merged with the computer-drawn geological lines and symbols by conventional methods. A digital topographic base map offers many advantages, and was in fact used in preparing the published 1:50 000 geological map of Southampton. The high resolution required to depict the detail such as place names requires expensive devices for plotting which did not appear at the time to be cost-effective for one-off maps.

Display techniques created problems in moving from one device to another and although a graphics standard (GKS) was adopted by NERC during the course of the project, implementation is slow and GKS is still not available on most of the devices used. Again a more limited solution was adopted which provided a practical means of preparing the maps. It is hoped that a reasonable balance has been struck between the need on the one hand to prepare documents of value to the user and the requirement on the other hand to develop systems and ways of working to match the advance of technology.

Overall, digital techniques offer methods for storing information from geological maps together with data from boreholes, geotechnical tests and other topic areas. Computer-drawn maps, profiles and other forms of graphic presentation can be generated by selecting the relevant information through a data management system and tailoring the graphic output to the specific requirements. With this young and rapidly developing technology, it is inevitable that there are frequent, inconvenient, changes to the programs and equipment, and that much work is needed to maintain the links between the parts of the system. Technically, rapid improvement can be expected. On the other hand, data collection and recording is slow, and provision of comprehensive, digital data archives is a major long-term challenge.

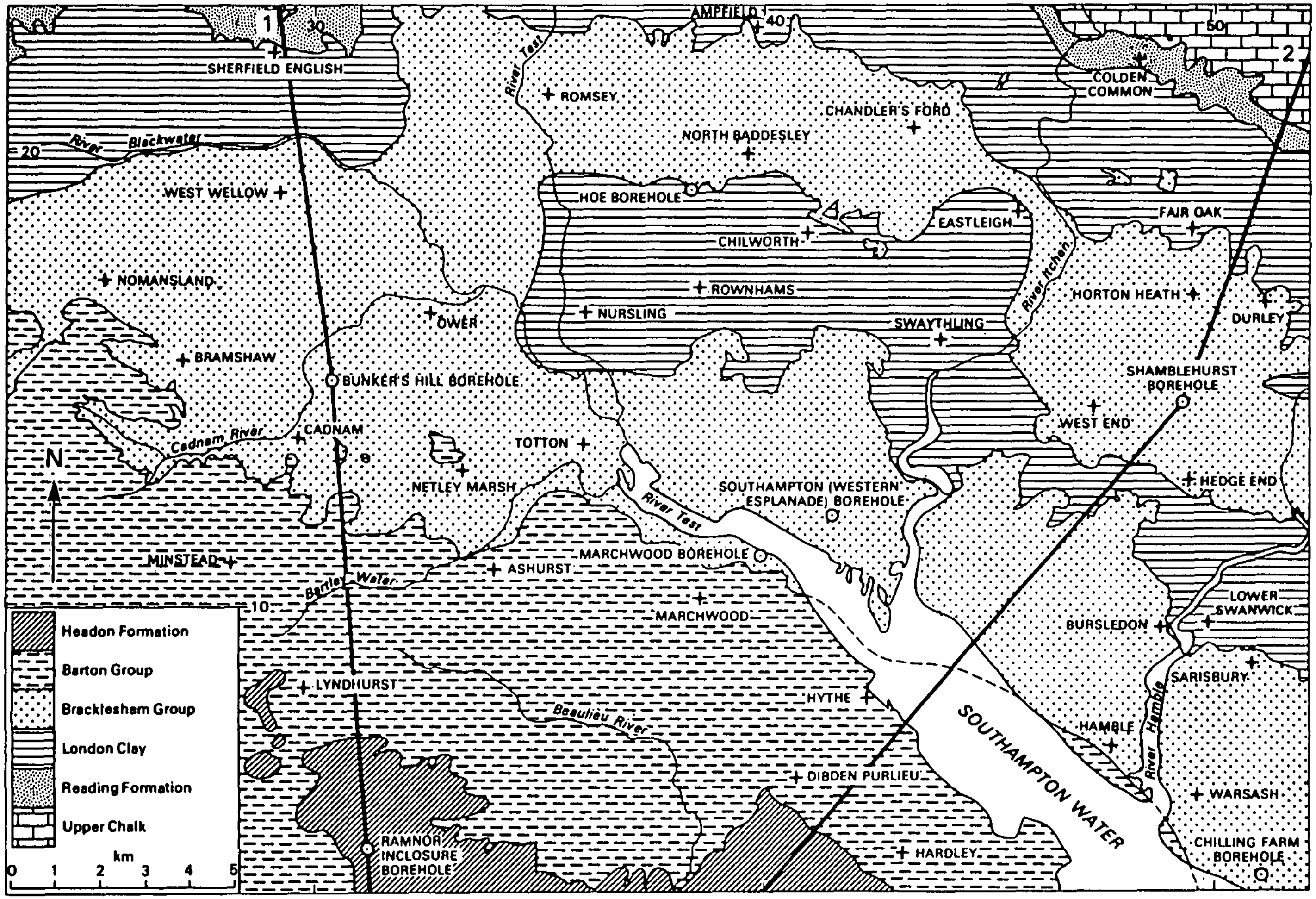


Figure 5a. Simplified geological map (Solid)

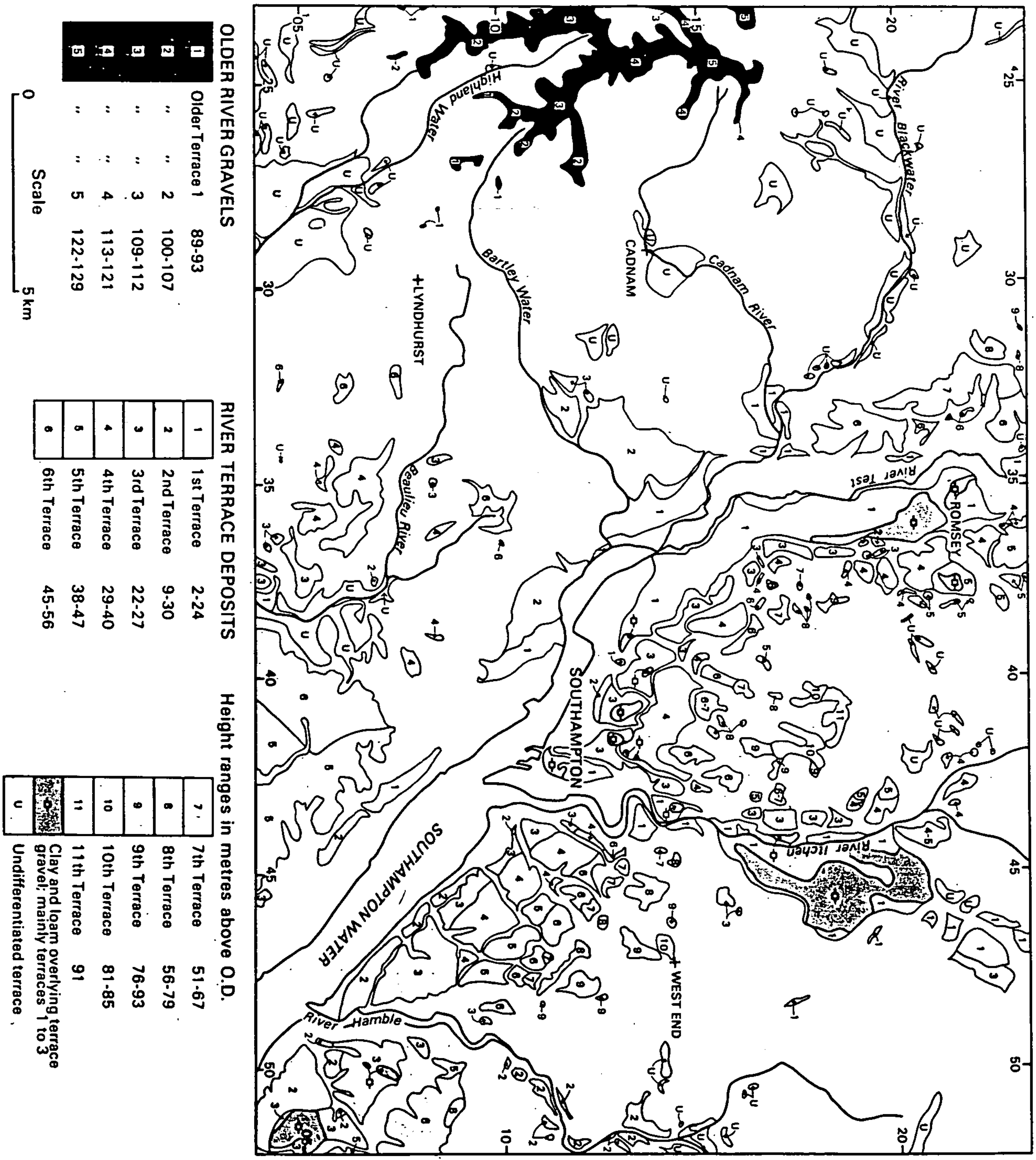


Figure 5b. Simplified geological map (Drift)

GEOLOGICAL SUMMARY

The first geological survey of the study area was on the one-inch scale (1:63 360) in 1854. The results were published on Old Series Geological Survey Sheets 11 and 15 in 1856 and 1858 respectively. The district was surveyed on the six-inch scale (1:10 560) between 1889 and 1898 and the results were incorporated in the first colour-printed edition of New Series one-inch Sheet 315, published in 1899. The accompanying memoir was issued in 1902.

A resurvey, on the 1:10 000 scale, was commenced by the BGS in 1973 and completed in 1980. The results have been included on 1:50 000 sheet 315 and in the accompanying Memoir (1987). The solid and drift geology of the study area are shown at the 1:25 000 scale on Maps A and B; simplified geological solid and drift maps are given in Figure 5. The geological sequence of the area is given later in this section.

Concealed formations of Devonian, Triassic, Jurassic and Cretaceous age have been proved beneath the study area in deep boreholes for geothermal energy and hydrocarbons exploration. The oldest rocks exposed at surface are Cretaceous Upper Chalk which outcrops in small areas in the northwest and northeast of the area.

The Chalk is unconformably overlain by up to 400m of Tertiary clays and sands which outcrop over the remainder of the study area. The Tertiary deposits form part of a larger area of Tertiary rocks called the Hampshire Basin, which has a semi-circular outcrop between Wareham in the west and Portsmouth in the east.

Structurally, the Tertiary strata of the district generally dip gently southwards at between 1° and 2°. As a result, the older Palaeogene formations crop out in the north and the younger formations in the south (see Figure A2 for an illustrative cross-section). The relatively gentle folds that affect Palaeogene and Cretaceous rocks are related to faults in the older Mesozoic rocks. The most structurally complex zone in the Tertiary rocks extends from Nomansland in the west to Swanwick in the east, and appears to be a north-westerly continuation of the Portsdown Anticline. This zone consists of a complementary anticline and syncline with sinuous axial traces. The anticline is asymmetrical with a relatively steep northern limb dipping up to 7° north. In the southern part of the district a number of very gentle anticlines and synclines are present with axial trends between E-W and ESE-WNW. Faulting affecting the Tertiary rocks has only been recorded at one locality in the study area.

The Tertiary strata are overlain by extensive areas of Quaternary (Drift) deposits, the most widespread of which are river-laid deposits, including Older River Gravels, River Terrace Deposits, Buried Channel Deposits, Calcareous Tufa and Alluvium. The River Terrace Deposits form extensive spreads at eleven levels bordering the main rivers of the study area. Older River Gravels form plateaux at five levels in the west of the area; they lie within the New Forest boundaries.

There are also broad coastal spreads of Estuarine Alluvium, and extensive though thin spreads of Head, and Clay-with-flints. Landslip has been mapped at only a few localities.

A fuller description of the individual solid and drift units is given in the Appendix.

Geological sequence

The solid formations and drift deposits known to be present within the study area are as follows:

SUPERFICIAL DEPOSITS (DRIFT)

Quaternary
- Landslip
- Calcareous Tufa
- Alluvium
- Estuarine Alluvium
- Buried Channel Deposits
- River Terrace Deposits
- Head and Head Gravel
- Older River Gravels
- Clay-with-flints

SOLID FORMATIONS (those below the Upper Chalk do not outcrop within the study area)

Tertiary (Palaeogene)	Thickness (m)
Headon Formation	up to 40
Lyndhurst Member	12
Barton Group	
Becton Sand	15 to 70
Becton Bunny Member	0 to 13
Chama Sand	7 to 15
Barton Clay	55 to 80
Bracklesham Group	
Selsey Sand	30 to 50
Marsh Farm Formation	18 to 25
Earnley Sand	0 to 24
Wittering Formation	23 to 57
London Clay	
Whitecliff Sand	0 to 21
Durley Sand	0 to 8
Portsmouth Sand	0 to 10
Nursling Sand	0 to 44
Reading Formation	15 to 32
Cretaceous	
Upper Chalk	258
Middle Chalk	54
Lower Chalk	81
Upper Greensand	30
Gault	40
Lower Greensand	7
Jurassic	
Portland Beds	49
Kimmeridge Clay	135
Corallian Beds	42
Oxford Clay	134
Kellaways Beds	18
Cornbrash	15
Forest Marble	46
Great Oolite	37
Fuller's Earth	29
Inferior Oolite	34
Bridport Sands	70
Upper Lias Clay	33
Middle Lias	53
Lower Lias	162
Triassic	
Penarth Group	20
Mercia Mudstone Group	200
Sherwood Sandstone Group	67
?Devonian	
Old Red Sandstone	over 890

DESCRIPTION OF THE APPLIED GEOLOGY MAPS

GEOLOGY

Solid geology (Maps A1-A6)

This set of maps consists of six sheets at the 1:25 000 scale showing the solid (pre-Quaternary) geology over the study area. The maps are derived directly from 1:10 000 scale geological maps produced during the most recent (1973-80) survey of the area, by digitising the solid geological lines and transferring them, with the appropriate scale-change, onto the 1:25 000 base maps.

Descriptions of the solid formations shown on the maps are given in the Appendix.

Drift geology (Maps B1-B6)

This set of maps consist of six sheets at the 1:25 000 scale showing the distribution of the drift deposits (Quaternary and Recent) and Made Ground that overlie the solid formations of the study area. Areas of worked ground are also shown.

The maps are derived directly from 1:10 000 scale geological maps produced during the most recent (1973-80) survey of the area, by digitising the drift lines and transferring them, with the appropriate scale-change, onto 1:25 000 base maps.

Description of the drift deposits shown on the map are given in the Appendix.

Drift thickness (Maps C1-C6)

This set of maps consists of six sheets at the 1:25 000 scale giving an interpretation of drift thickness over the study area. For the purposes of these maps, Made Ground is included with drift, i.e. the maps show the thickness of all materials that rest on solid formations.

The maps are based on two sources of data. Firstly, the areas where drift is present are taken directly from the drift geological map. The criterion used in mapping is that the drift should be at least 1 metre thick. The second source of data consists of boreholes which wholly or partially penetrate drift deposits. Boreholes that do not reach the base of drift deposits provide minimum values of drift thickness. Head is widespread in the study area but generally not sufficiently extensive to be mapped. It is rarely thicker than 1.2m although locally there are considerably greater thicknesses. Thus, some boreholes outside the mapped area of drift show drift (mainly Head) to be present, but it is considered that such areas are generally patchy and localised, and no attempt had therefore been made to show them on the maps.

There are generally insufficient data to contour drift thickness in detail. Rather, areas of ground have been delineated within which boreholes or outcrop data indicate that the drift thickness is generally within the range indicated. The thickness ranges selected are as follows: 1 to 5m; 5 to 10m; 10 to 15m; 15 to 20m; and over 20m. These thickness categories are indicated by different ornaments on the thematic maps. Categorisation has been carried out manually, but it is anticipated that this function will eventually be carried out by an appropriate computerised package. The accuracy of the thickness classification is naturally a function of the borehole density (shown on the data distribution map which accompanies the drift thickness maps) but, in general, areas where the greatest variation in drift thickness would be expected coincide with areas of greatest borehole density.

The maps of drift thickness are generally self-explanatory, but the following notes are provided as a guide to the main features of the maps.

With few exceptions, drift deposits thicker than 5m are confined to the river valleys and estuaries of the study area, with deposits away from the valleys and estuaries being in the thickness range of 1 to 5m. Thus, most River Terrace Deposits and the Older River Gravels are 1 to 5m thick; only in the southeast of the project area, around Hardley [431 047], Holbury and Fawley, and in the Lordshill [388 159], Shirley Warren [398 148] and Maybush [386 146] districts of Southampton, do River Terrace Deposits locally have thicknesses in the 5 to 10m range.

The most striking features of the maps is the buried channel of the River Test beneath Southampton Water, which, towards the southern edge of the study area, is filled with drift deposits exceeding 20m in thickness. The buried channel can be traced northwestwards to Southampton Docks in a belt in which thicknesses are in the range 10 to 15m. Drift-filled buried channels are also present beneath the valleys of the River Hamble and River Itchen; drift up to 20m thick is present near the mouth of the River Hamble, but this thickness is based on data from only two boreholes.

Along the alluvial tracts of the River Test and River Itchen, drift thicknesses are commonly in the range 5 to 10m, although considerable areas are also in the 1 to 5m category.

In the Test valley, the thickest (5 to 10m) drift extends in a broad belt along the west side of the valley, but at Millbrook [388 134] this belt of thicker drift swings across to the north side of the valley, and passes into an area of drift 10-15m thick that occupies a buried channel beneath the area of reclaimed land just south of Southampton city centre.

Along the Itchen valley, from Swaythling [441 157] southwards, much of the drift is between 5 and 10m thick; north of Swaythling the drift thickness range is 1 to 5m, with local areas of thicker (5 to 10m) drift.

Rockhead contours (Maps D1-D6)

This set of maps consists of six sheets at the 1:25 000 scale showing the form of the rockhead surface over the study area. Where there is no drift, and rock therefore occurs at surface, the rockhead contours are simply the topographical contours. Where there is drift cover, the rockhead contours depart from the topographical contours to an extent that is a function of the thickness of the drift. Rockhead contours in areas of drift are an interpretation based on the drift thickness maps and their accuracy decreases both with decrease in the borehole density, on which the drift thickness maps are based, and with increase in drift thickness. Where the drift is considered thin, then rockhead contours will closely parallel the topographical contours and can be drawn with some confidence even where there are few boreholes. In areas of thick drift, the rockhead contours bear little relation to topographical contours and their accuracy is entirely a function of borehole density.

The rockhead contour maps are accompanied by a distribution map showing the boreholes used in their construction.

Because the drift is thin (1-5m) over much of the study area, rockhead contours do not generally diverge greatly from topographical contours. The buried channels of the rivers are, however, clearly revealed by rockhead contours that indicate excavation of the old channel of the River Test to a depth below -20m O.D. at the southern edge of the project area and the buried channel of the River Hamble to a depth of -10m O.D. In the case of the River Test, the buried channel reaches a depth of -46m O.D. southeast of the Isle of Wight (Dyer, 1975) and is at or below O.D as far north as the confluence with the River Blackwater. The contours show that the channel lies mainly along the western side of the present river valley.

The buried channels of the rivers were excavated during a period of low sea level, probably during the last glaciation, when the rivers cut down their channels rapidly in order to adjust to the new base level. River gravels occur on submerged terraces in the buried channel of the River Test. As sea level rose after the last glaciation, the river valley was drowned, and the buried channel was filled with estuarine clay, silt, sand, gravel and peat.

MINERAL RESOURCES

Sand and gravel resources (Maps E1-E6)

The maps showing sand and gravel resources comprise six sheets at the 1:25 000 scale. Two types of resource are shown on the face of the maps, namely, areas underlain by River Terrace Deposits and Alluvium, which are important sources of flint gravel, and areas underlain by solid formations consisting mainly of sand. The gravel deposits are ornamented to distinguish resources at, or close to, surface, including the Older River Gravels, River Terrace Deposits and Alluvium of small streams, and resources which are buried beneath the silty or clayey drift deposits, mainly the Alluvium of the major rivers. The deposits considered as a sand resource include the sand units of the Reading Formation, the Whitecliff Sand, the Earnley Sand and the Becton Sand. Where the sand resources are buried by solid or drift deposits they are not shown on the face of the maps as evidence suggests that they are not likely to be economic. Areas of former and active sand and gravel working are identified on the maps.

Descriptions of the various solid and drift formations are given in the Appendix. These descriptions and Map sets A and B should be examined in conjunction with the sand and gravel resource sheets.

The Older River Gravels, River Terrace Deposits and Alluvial Gravels provide three type of product namely:

Fill material ("hoggin")
Concreting aggregate
Washed sand and gravel

The Older River Gravels ("Plateau Gravel" of earlier accounts) yield clay-bound flint gravel that is suitable for use as fill and for the surfacing of rough tracks. The lower River Terrace Deposits and tracts of Alluvium include beds of gravel which, with little treatment, yield a suitable sand and gravel mix for concrete aggregate, or may be washed to provide clean gravel and various grades of sand. The grading characteristics of River Terrace and alluvial gravels are summarized in Figures 6 and 7 respectively. The grading envelopes of Figure 6 is for 170 samples and that of Figure 7 for 45 samples. These envelopes show that the gravels range from relatively clean, moderately well-sorted medium and coarse gravels to poorly sorted gravel with 10 to 15 percent fines.

The solid formations are mainly worked for building sand, though a small production of foundry sand is maintained in the project area. In general, there is a distinction between "clean" sand with a low fines content and "soft" sands which are generally finer grained and with perhaps 10 to 15 per cent of silt and clay. The latter class is much used in rendering as the clay content aids the adhesion of the mortar to its substrate. Clean sands are used in bricklaying, as an addition to concrete mixes and in asphalt.

Of the sandy solid formations shown on the thematic maps, only the sand units in the Reading Formation and the Whitecliff Sand are worked at present. The sand units of the Reading Formation yield, in the main, grey medium- to coarse-grained sands with subordinate pebble beds. In places, the sands are fine and have a clay content. The Whitecliff Sand comprises yellow to buff-coloured, fine- to coarse-grained clean sands. It is locally pebbly, and clay pellets are present in places. A grading envelope derived from 20 samples of Whitecliff Sand is shown in Figure 8 and shows the generally well-sorted nature of the formation and its lack of fines. The Earnley Sand is worked for foundry sand at the present day, in a small pit near Hound [474 087], and for this reason is shown as a resource on the map. It comprises green to greyish green glauconitic silty sands, much disturbed by the activities of burrowing creatures at the time of deposition, and with a substantial fossil shell content in places. Although locally the Earnley Sand is relatively clean and well-sorted, the presence of silt and of shelly material, together with bands of clay render the formation relatively unattractive to the extractive industry. The fines content approaches 30 per cent in some of the

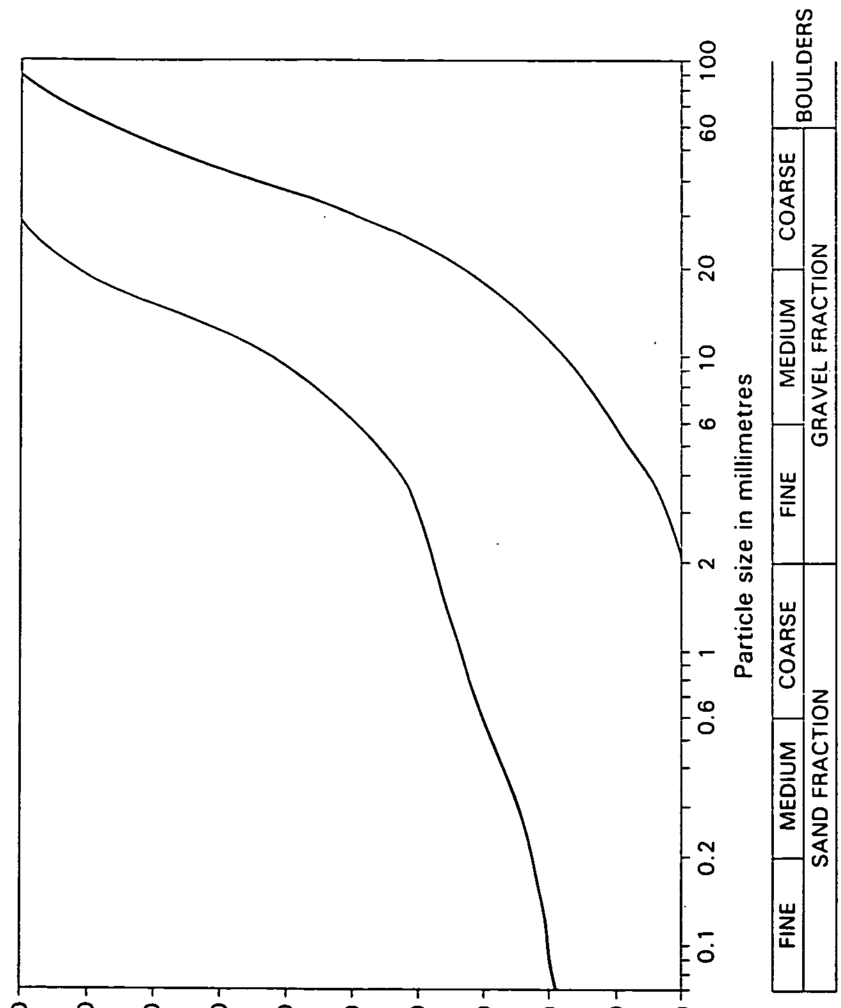


Figure 6. Grading 'envelope' for river terrace deposit gravel (170 samples)

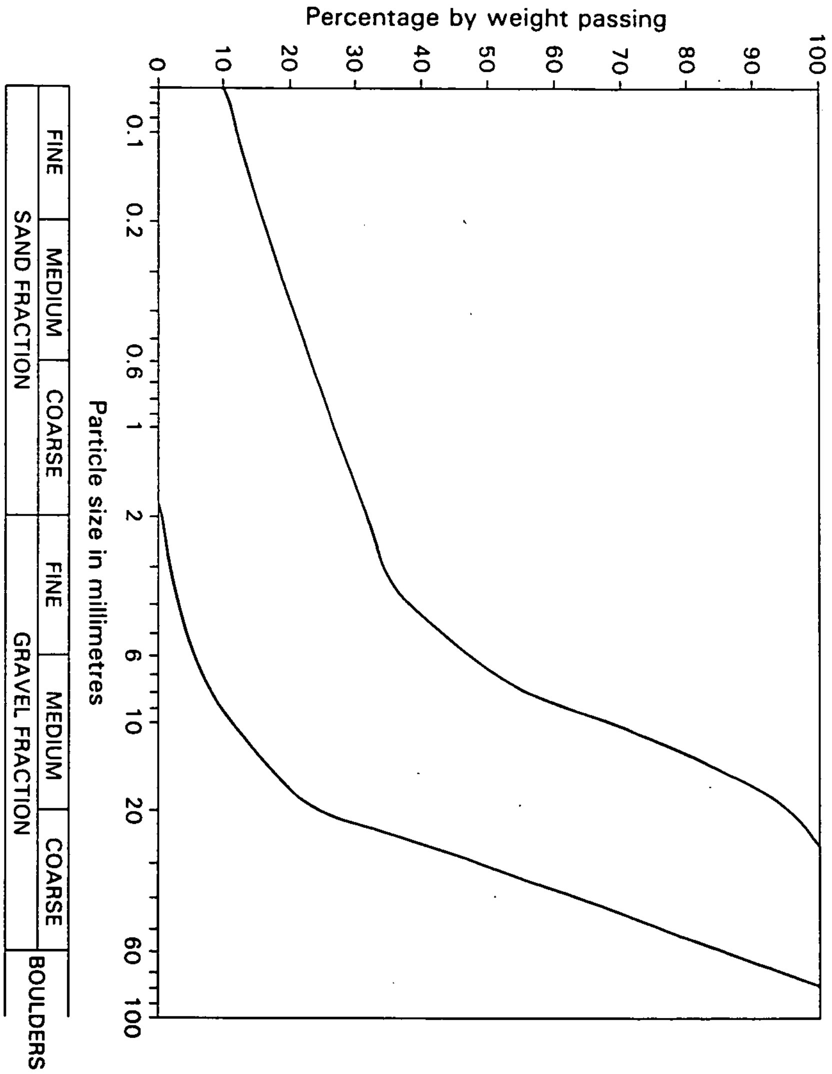


Figure 7. Grading 'envelope' for alluvium (45 samples)

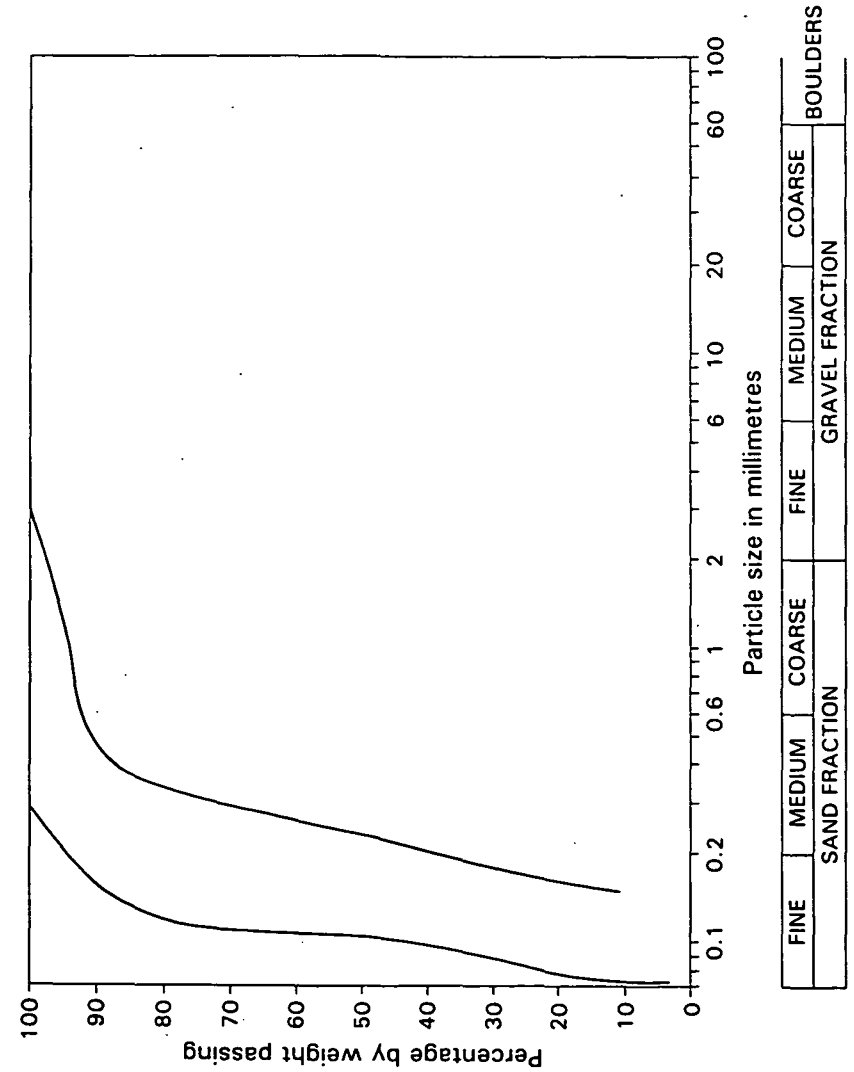


Figure 8. Grading 'envelope' for Whitecliff Sand (20 samples)

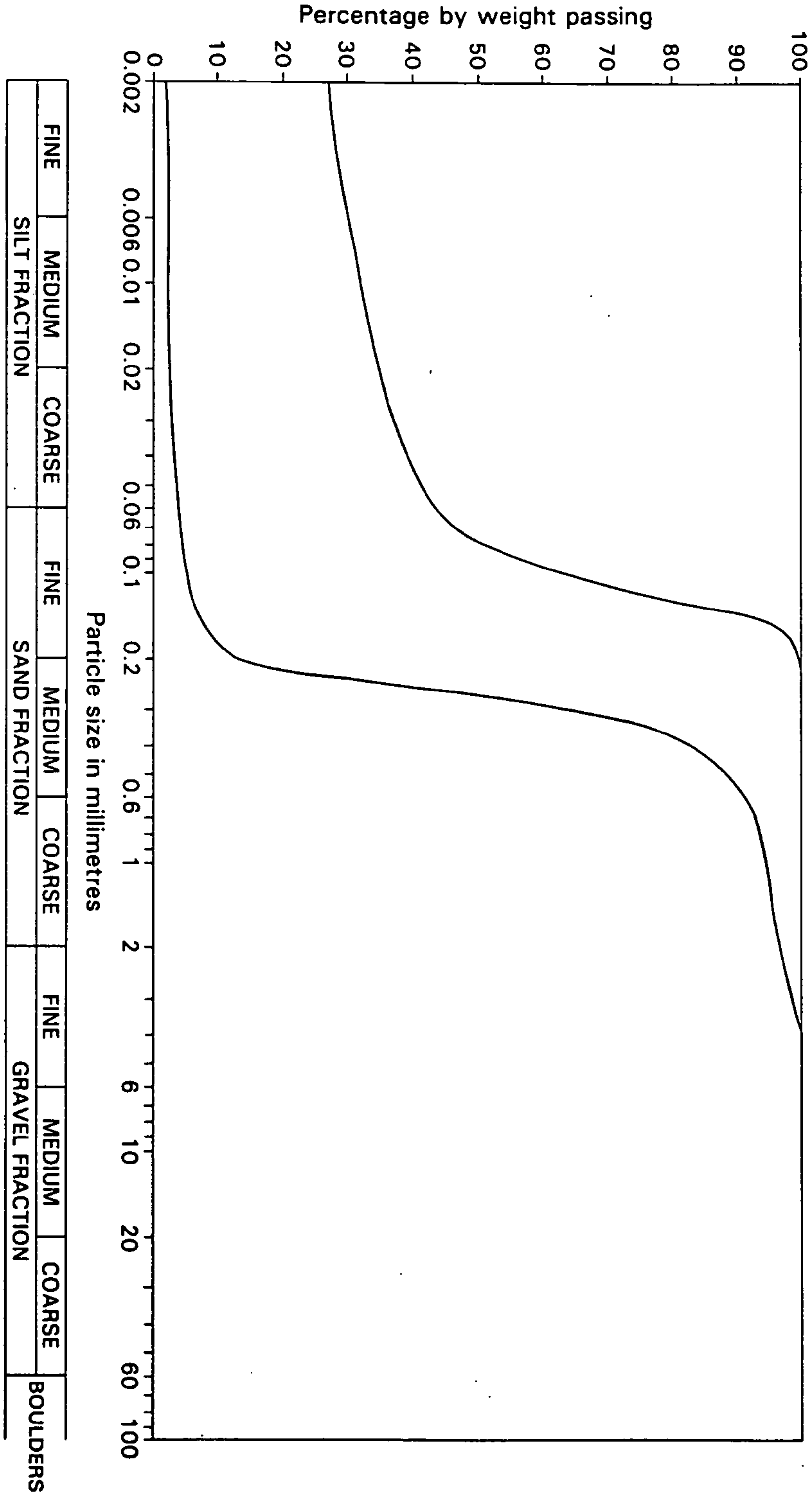


Figure 10. Grading 'envelope' for sand in the Wittering Formation (50 samples)

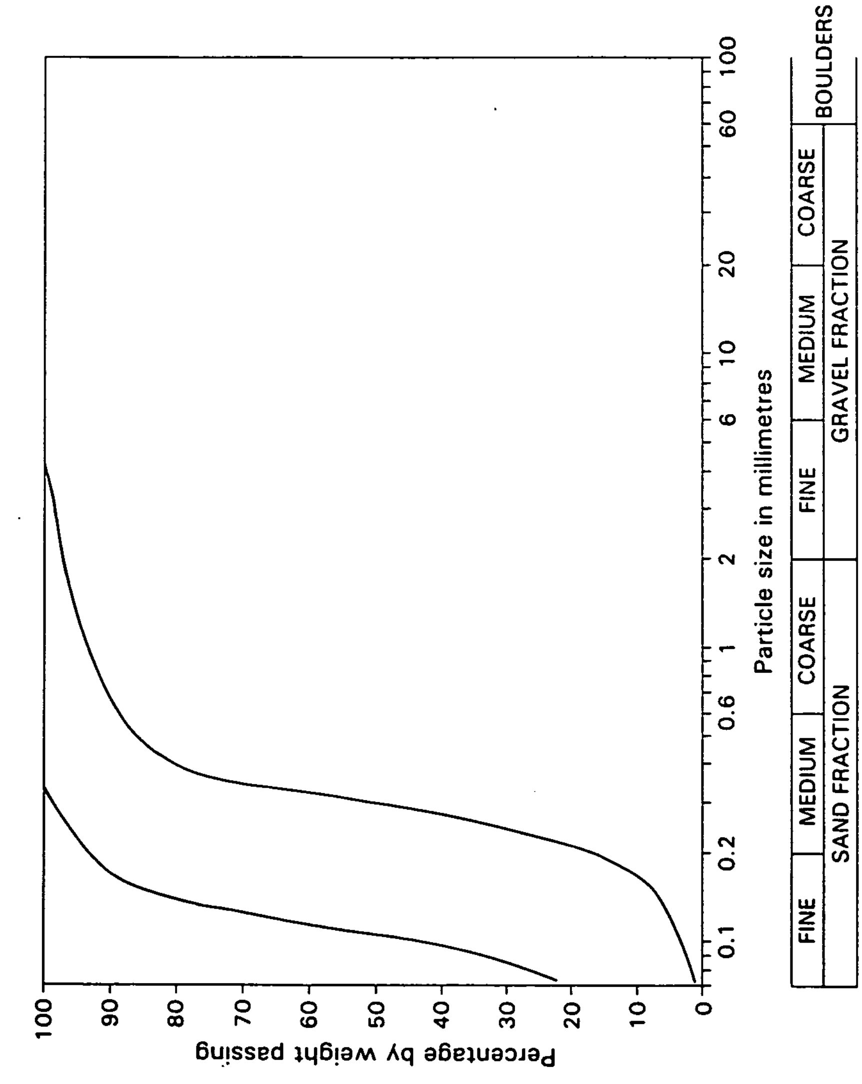


Figure 11. Grading 'envelope' for Marsh Farm Formation (55 samples)

samples analysed.

The Becton Sand is not worked in the project area at present, but was formerly worked around Lyndhurst [299 082] and in the Fawley [458 032] district. It comprises pale yellow to grey well-sorted very fine-grained sand with, in places, thin layers of sandy clay. The grain size and fines content have restricted the use of this material for general purposes.

Of the solid formations not included on the map some, notably the Wittering Formation and the Marsh Farm Formation, locally include beds of relatively clean sand. Grading envelopes for these formations, based on 50 and 55 samples respectively are shown in Figures 10 and 11.

Sand and gravel end-use analysis, Lymington and Beaulieu area (Map E7)

Prior to the present study the Industrial Minerals Assessment Unit (IMAU) of BGS carried out an assessment of the sand and gravel resources of the area around Lymington and Beaulieu (Mathers, 1982). The area covered by that survey overlaps the southern margin of the current project area and also includes the major industrial area around Fawley [458 032], only part of which lies within the Southampton project area, but which is of particular planning interest. Because of this interest and the availability of the detailed IMAU data it was decided to produce an end-use assessment map covering the same area as the eastern sheet of the Lymington and Beaulieu assessment, that is between eastings SU 32 and SU 48 and northings SZ 95 and SU 07. This extends considerably further south than the main Southampton project area.

Table 2. Grading criteria used to define sand and gravel categories

Lithology	Grading
"Gravel"	more than 40% retained on 4mm sieve less than 30% passing 0.125mm sieve
"Gravel/sand" (sand medium- to coarse-grained)	10 to 40% retained on 4mm sieve less than 40% passing 0.25mm sieve less than 30% passing 0.125mm sieve
"Gravel/sand" (sand fine- to medium-grained)	10 to 40% retained on 4mm sieve more than 40% passing 0.25mm sieve less than 30% passing 0.125mm sieve
"Sand" (medium- to coarse-grained)	less than 10% retained on 4mm sieve less than 40% passing 0.25mm sieve less than 30% passing 0.125mm sieve
"Sand" (fine- to medium-grained)	less than 10% retained on 4mm sieve more than 40% passing 0.25mm sieve less than 30% passing 0.125mm sieve
"Waste"	more than 30% passing 0.125mm sieve

The basic numerical data comprise grading analyses of bulk samples of sand and gravel. Samples were collected at regular intervals for all sand and gravel drilled and the grading results, which were obtained mostly from commercial laboratories, were entered on the computer. These data were used to generate the graphic logs displayed on the published resource maps (Mathers, 1982) and indicate both the thickness and mean grading of lithologically distinct units of sand and gravel.

For the present study the grading data have been analysed by computer in two separate complementary ways, both methods being designed to illustrate potential end-usage. The first method produces a summary graphic log of deposit lithology using the cumulative mean gradings for each distinct unit of sand and gravel. The second method uses the gradings of individual samples and generates spider diagrams which portray the potential commercial usage of the total thickness of sand and gravel proved at each sample point.

The presentation of the summary graphic logs is similar to the borehole arrays shown on the published resource maps in that the height of the grading box is proportional to the thickness of a sand and gravel unit. However, whereas the grading boxes on the published resource maps are divided vertically to show relative proportions of fines, sand and gravel, those on the summary maps are ornamented simply to portray five grading categories. Thicknesses only are given for overburden and for deposits classified as waste, either on account of the grading of the material or because the overburden to mineral ratio is greater than 3:1. Because of the more restrictive criteria used on the summary resource maps, some of the material shown on the published resource map as potentially workable, has been reclassified as waste.

The method of analysis allocates each lithologically distinct unit within a sand and gravel deposit to one of six categories. The grading criteria used to define these categories are shown in Table 2, and are based on the results of a sedimentological study by Martin (1981). The categories relate broadly to Martin's lithological facies and take account of the various British Standard specifications for aggregates sold commercially.

Any deposits containing more than 30% passing 0.125mm is considered here as waste because nearly all the British Standard specifications for aggregates rule out such material. As a result of this criterion deposits with more than 30% passing 0.125mm and containing a significant amount of gravel-grade material will have been discounted, although they may have some economic potential: some silty, fine-grained sands might also find specialised markets. Such deposits would be shown on the published resource maps where sand and gravel containing up to 40% material passing 0.063mm (fines) is regarded as potentially workable.

The spider diagrams at each sample point for which grading data are available, are intended to allow the user rapidly to judge the relative proportion of material best suited to specific end-uses. Less specifically, they also show whether deposits at a sample point are predominantly gravelly or sandy.

This approach to the analysis of the grading is strictly in terms of end-use. A search of British Standards and other codes of practice revealed that currently there are forty-three grading specifications for aggregates. As the sieve sizes specified in the standards generally differ from those used in the assessment surveys, mathematical interpolation of the grading data has been necessary. These inferred data were compared, sample by sample, with each of the forty-three end-use grading specifications using a modified version of a computer program written for the Manitoba Geological Survey (program SG02).

The sand (0.075 to 3.35mm) and gravel (coarser than 3.35mm) components of each sample are considered separately in an attempt to simulate the screening processes that are used at a quarry. Both the sand and gravel components are recalculated to 100% with the proviso that when considering the gravel component, the sample as a whole must contain no more than 80 per cent sand and when considering the sand component the sample as a whole should have no more than 60 per cent gravel; if these conditions are not met the grading of the relevant component is set arbitrarily to zero. These cut-offs were chosen by trial-and-error to reflect the approximate minimum component percentages that it is considered are required prior to processing for either the sand or gravel end uses. The results of the separate analyses of the sand and gravel components of each sample are then recombined to given an overall analysis of the sample.

A second screening is simulated by ignoring material coarser than the coarsest sieve quoted for each end-use specification; only the material passing the appropriate sieve is considered and this part of the grading is then recalculated to 100%. If more than 80 per cent, in the case of the gravel component, or 60 per cent in the case of sand, is retained on this coarsest sieve then the sample is considered to be not suitable for the particular end-use. No account is taken of the possible crushing of over-size material.

When the grading of a sample falls within the grading envelope specified for a particular end-use, the sample is considered to be suitable for that end-use. For any sieve size for which the percentage weight retained lies outside the limits stipulated in that specification, the difference between the actual figure and the nearer of the upper or lower limit of the permitted grading envelope is calculated as a residual. These residuals are summed for each sieve-size specified for a particular end-use and, if no greater than thirty, the sample is regarded as marginal. In order to simulate washing, samples with total residuals of up to forty are also considered as marginal, if the specification stipulates 0 per cent passing the 0.075mm-sieve and at least ten points of the total residual value is accounted for by the 0.075mm-sieve. All samples with total residuals greater than those stated above are regarded as not suitable for the particular end-use.

The forty-three end-uses fall naturally into eight major groupings: in order of increasing fineness they are roadstone, coarse asphalt aggregate, coarse concrete aggregate, all-in aggregate, sub-base/roadstone, fine concrete aggregate, plastering/ mortar sand and fine asphalt aggregate. For each sample a suitability integer value, 0, 1 or 2 is allocated to each of the forty-three end-uses depending on whether it is classed as not suitable, marginal or suitable, respectively. These integer values are summed for each of the eight end-use groups, after weighting to account for sample thickness and the different number of end-uses within each group, and then summed again for all samples from the same borehole. The end-use potential index for each end-use group at each sample point is the product of the sum of the integer values (described above) and the thickness. The maximum value of this index for any one end-use group for a 25m deep borehole is therefore fifty, that is 25x2.

The end-use potential is shown by computer-drawn, eight-legged spider diagrams, centred at each sample point. Each leg represents one end-use group, its length being proportional to the end-use potential index for that end-use. The roadstone is represented by the upwards vertical leg, the other legs radiating at increments of 45° in a clockwise direction in order of increasing fineness. The spider diagrams must be interpreted with caution and should be read in conjunction with the summary graphic logs, in order that the likely position within a borehole of material meeting the specifications of particular end-use groupings can be judged. For example, the spider diagram might show the material as a whole at a sample point to be an all-in aggregate, whereas the graphic log might reveal a unit of gravel overlying one of fine- to medium- grained sand. From this, the position within the sequence of material meeting particular end-use group specifications can be determined.

Clay resources (Map F)

This map is a single sheet at the 1:50 000 scale showing two classes of brick clay resource. In the first class are included formations which may be generally suitable for brick clay. It comprises the Reading Formations, the London Clay Formation and the Barton Clay Formation (excluding sandy horizons mapped in the formations). The second class of resource includes formations which may locally be suitable for brick clay but, because of lithological variation may not everywhere constitute a resource. The second class includes the Wittering Formation and the Marsh Farm Formation (excluding mapped sand units in these formations). A further subdivision of both classes on the map differentiates between areas where the various formations are within about 1.0m of ground surface and areas where more than 1.0m of drift deposits mantle the inferred resource. Areas where possible brick clay resources are buried by other solid formations are not ornamented on the face of the map as the industry usually requires its raw material to be at least partially weathered.

Lithological descriptions of the various clay formations included here as possible brick clay resources, are given in the Appendix, and it is recommended that the reader makes reference to both this and the solid geology maps (A1-6), in addition to Maps G and F.

The stiff red-mottled clays of the Reading Formation have not been much worked for brick making in the project area. Reid (1902) noted that the clays of the Reading Formation were more suitable for tile and pipe manufacture than for bricks. White (1971) states that the Reading Formation clays were formerly used for brick making in the Fareham and Gosport districts. Outcrops of the London Clay Formation were formerly much worked for brick making in the Swanwick [515 097] district within the project area. Reid (1902) stated that the London Clay furnished good brick making material to which little or no sand need be added, provided that it was excavated in a weathered condition. The quality of London Clay worked for brick clay may be adversely affected by the presence of pebble bands or of claystone nodules. The Barton Clay, like the London Clay, is predominantly composed of more-or-less sandy clay, and it has also been worked for brick making in the past. Beds of very glauconitic material may adversely affect the quality to some extent, but a more important consideration is the widespread presence in the formation of calcareous shelly material. Both of the more clay-rich formations of the Bracklesham Group, the Wittering and Marsh Farm formations, are included in the second class of brick clay resource. Both of these formations were formerly worked for brick clay, especially the Wittering Formation. The lack of lateral and vertical consistency in these formations, due to the presence of bodies of sand would render efficient working of these deposits difficult at the present day.

Distribution of worked ground (Maps G1-G6)

The 1:25 000 scale maps of mineral workings are based on the 1:10 000 geological survey of 1973-80 with supplementary information from local government and industrial sources, together with limited site inspections carried out for the present study. The location of certain sites that are no longer evident were obtained from the 1:10 560 geological maps surveyed in 1866-76. While every effort has been made to achieve a complete record, the infilling of sites, particularly in the urban areas will undoubtedly have obscured many former workings.

The classification of workings is based on the nature of their production and the following types are shown on the face of the maps.

1. Chalk - worked mainly for agricultural use within the study area.
2. Clay - mostly brick clay workings
3. Gravel - flint gravels have been extensively worked from River Terrace Deposits and alluvial tracts for use in the construction

industry.

4. Sand - worked mainly for building purposes, but there are limited workings for foundry (moulding) sand.

5. Sand and gravel - most gravel workings wash a small proportion of their production as sand but in certain cases, for example where a gravel deposit (Drift) overlies a sand deposit (Solid), both sand and gravel may achieve equal importance. Such workings are given a distinctive ornament.

WATER RESOURCES

Distribution of aquifers (Map H)

This map, presented at the 1:50 000 scale, shows the outcrops of the principal aquifers of the study area, together with the locations of boreholes which have been sunk for water supply. Those boreholes or springs with abstraction licences are indicated on the map. Also shown are contours (in metres below Ordnance Datum) drawn on the base of the Tertiary deposits. They indicate the depth (below OD) at which the major chalk aquifer is likely to be penetrated in boreholes at any site within the study area. The following account of the hydrogeology and water supply of the area is taken from the BGS Memoir (Monkhouse *in* Edwards and Freshney, 1987), with some information from the Hydrogeological Map of Hampshire and the Isle of Wight (1979), referred to in this account as the "Hydrogeological Map".

The study area lies almost entirely within Hydrometric Area 42, administered by the Southern Water Authority. A very small segment at the extreme edge is in Hydrometric Area 43, administered by the Wessex Water Authority.

The two largest rivers crossing the district are the Test and the Itchen, both deriving the greater part of their flow from groundwater discharge from the Upper Chalk in areas outside the district. The ratio of maximum to minimum daily mean flows through the year is about 4 for the Test and about 3 for the Itchen, the streams being to this extent self-regulating. Lesser streams comprise the Hamble, the Blackwater (a tributary of the Test), the Beaulieu River and Bartley Water; they derive a large proportion of their flow from catchments floored by Tertiary strata from which there is much greater run-off, and the stream flow is, therefore, more variable.

The mean annual rainfall varies from about 750mm in the south to more than 900mm in the north. The annual actual evaporation ranges from 460 to more than 500mm (Southern Water Authority, 1980).

Much of the water used for public supply is abstracted from the rivers Test and Itchen, but about 13 million cubic metres (m^3) are pumped annually from the Upper Chalk at Otterbourne [467 230]. The most important aquifer is the Chalk. Sand bands in the Reading Formation, the Whitecliff Sand, the Portsmouth Sand, and Becton Sand, are of lesser importance but shown on the map. The Bracklesham Group, Headon Formation and some units in the drift may be of local hydrogeological significance and are described below, although not shown on the map.

Chalk

The Chalk is the major aquifer of the study area and is shown on the map. It outcrops only in the northeast and northwest, being concealed beneath up to 400m of Tertiary strata over the remainder of the area. Contours (in metres below OD) on the top of the Chalk are shown on the map. The presence of east-west to east-southeast trending folds affecting the Chalk have a significant effect on the occurrences and movement of groundwater (Hydrogeological Map).

Groundwater resources of the Chalk depend upon infiltration into the outcrop outside the district. Water flows in the Chalk mainly through fissures, which are less well developed where the overburden of Tertiary strata is greatest. Fissures are also poorly developed where the Chalk is soft immediately underlying Tertiary clays. Wells and boreholes are restricted to the northern part of the district where the formation crops out or where the overburden is relatively thin. With an overburden thickness greater than 50m, the specific capacity of a borehole is likely to be less than one cubic metre per day per metre of drawdown per metre of saturated aquifer penetrated (m/d), whereas with less than 50m thickness, the value may exceed 3.5m/d. A borehole [436 109], drilled at Southampton in 1912 to a depth of 335m, reached the Chalk at a depth of 189m. Its yield was only about 590 cubic metres per day (m^3/d), and the quality was poor. With thin or no overburden, yields of $2000m^3/d$ or more can be expected from boreholes of 300mm diameter.

The yields of boreholes in the Chalk depend upon intersecting water-bearing fissures, and the random distribution of these leads to considerable variation in yield. Many boreholes have a poor initial yield due to the blocking of fissures by slurry formed during drilling, and development with hydrochloric acid ("acidisation") is common. The quality of groundwater from the Chalk is generally good. The total hardness, mostly carbonate (temporary) hardness, usually ranges between 200 and 300 milligrammes per litre (mg/l), exceptionally being as much as 400 mg/l. The chloride ion concentration is normally less than 25 mg/l, but increases with greater thickness of overburden; the borehole in Southampton previously mentioned showed a value of 700 mg/l. The use of nitrogeneous fertilisers over the Chalk outcrop has led to an increase of nitrates in the groundwater, and values exceeding 10 mg/l (as NO_3) have been recorded.

Reading Formation

Where the Reading Formation consists predominantly of sands (with subordinate pebble beds), it forms an aquifer which is shown on the maps.

Where sandy strata are present, the Reading Formation can yield up to $200m^3/d$ to boreholes, although this may in part be due to recharge of the basal sands from the underlying Chalk. Sands in hydraulic continuity with the Chalk have substained artesian overflow of 2 to 3 l/s (Hydrogeological Map). A more usual yield is less than 100 m^3/d, and boreholes may be dry where the sands are thin or absent. Further development of the Reading Formation has been inhibited by the presence of the more permeable Chalk beneath, the latter offering a more reliable source.

London Clay

Within the London Clay, the Whitecliff Sand and Portsmouth Sand are shown on the map as aquifers. The lenticularity of parts of the outcrop of these sands may have a significant effect on the occurrence and movement of groundwater.

Sandy beds in the London Clay at various levels beneath the Whitecliff Sand, such as the Portsmouth Sand, occasionally provide small yields of up to 100 m^3/d, but natural replenishment is hindered by the enclosing clayey strata, and initial yields often diminish with time. The Whitecliff Sand yields groundwater to boreholes much more readily, but the incoherence of the sands requires the use of properly designed and placed sand screens and filter packs. In the past, under-development of poorly designed boreholes has led to silting with consequential deterioration in yield. Most boreholes in the sands are of 200mm diameter or less, and yield up to 500 m^3/d. Boreholes of larger diameter have occasionally yielded more than 1000 m^3/d, but the sands are not generally able to support large industrial or public supplies. Shallow wells in the sands are liable to surface contamination and need careful siting. In the deeper boreholes, the total hardness rarely exceeds 150mg/l, and the chloride ion concentration is usually less than 30mg/l. Iron is sometimes present in amounts exceeding 0.5mg/l, giving an unpleasant taste to the water.

Bracklesham Group

The variable lithology of the Bracklesham Group make it difficult to predict borehole yield. In the area west of Southampton, sandy beds are fairly well developed, and yields may be better there. However, boreholes with little or no yield have been recorded. Boreholes up to 200mm diameter may yield up to $200m^3/d$, and those over 400mm diameter have given more than $1800m^3/d$ from the sandier strata. Sand screens and filter packs are usually necessary, and poor design and development of these has often led to silting. The groundwater quality is usually quite good, with the total hardness less than 200mg/l and the chloride ion concentration less than 35mg/l. Where shallow wells have been polluted, the chloride ion concentration frequently exceeds 50 mg/l. Iron is often present, sometimes in amounts greater than 1.0 mg/l.

Barton Group

The Barton Clay, Chama Sand and the Becton Bunny Member are likely to contain little usable groundwater, although sandier parts of the sequence may yield small supplies. Along the southern edge of the district the Becton Sand forms a useful and fairly reliable aquifer which is shown on the map. Boreholes of 300mm diameter yield up to 600 m^3/d. Northwards, yields are less good, and rarely exceed 200 m^3/d. The boundary of the sands, both with the overlying Headon Clay and the underlying clayey beds, is commonly marked by a line of seepages and springs. The latter are usually small and individually of little use for supply. The groundwater quality is generally fair, with the total hardness less than 150 mg/l and the chloride concentration less than 40 mg/l. Iron is sometimes present in sufficient quantity to given an unpleasant taste to the water.

Headon Formation

A number of shallow wells have been constructed in the Headon Formation and, where sandy strata are better developed, yields sufficient for domestic or small agricultural requirements may be obtained. In the more clayey lithologies, yields are very small. Shallow wells in this formation are vulnerable to surface pollution.

Drift

Yields from Alluvium and terrace gravels are often obtained from the adjacent rivers, and, where the latter are tidal, saline water may enter the well. Older River Gravels and River Terrace Deposits are present over fairly extensive tracts of ground around Southampton, and yields of a few cubic metres per day are taken from shallow wells. However, such sources tend to fail after extended dry periods and are particularly vulnerable to surface pollution. The extent of clay and loam capping terrace gravels is limited and their potential small. The Clay-with-flints has no importance as an aquifer, but where it provides an extensive cover for the Chalk, infiltration into the latter may be affected.

ENGINEERING GEOLOGY

The geotechnical data used to classify the geological formations into groups of similar engineering behaviour were obtained mainly from commercial site investigation reports on sites within the project area. This was supplemented by a lesser amount of information obtained from books, and papers published in scientific journals.

The data are therefore not necessarily statistically representative of the geological formations present in the area. Some formations have no geotechnical data available and some formations have information about only part of their outcrop. The values quoted are, therefore, only a guide to the geotechnical behaviour and are not to be used for foundation or building design.

The results of the following geotechnical tests were abstracted from site investigation reports and entered into a database.

1. Standard Penetration Test
2. Bulk Density
3. Dry Density
4. Moisture Content
5. Liquid Limit
6. Plastic Limit
7. Plasticity Index
8. Particle Size Distribution
9. Permeability
10. Triaxial Test (drained and undrained)
11. Shear Box Test (drained and undrained)
12. Vane Test
13. Consolidation
14. Compaction
15. California Bearing Ratio
16. Specific Gravity
17. pH
18. Sulphate Content
19. Organic Content

Details of these tests are given in the Appendix.

Most samples had been tested for only a few of the parameters, and only rarely had a full range of tests been done. In order to assist the classification of the materials in terms of their engineering behaviour, the results of the more important and more common tests were analysed, namely:-

1. Standard Penetration Test
2. Bulk Density
3. Dry Density
4. Moisture Content
5. Liquid Limit
6. Plastic Limit
8. Particle Size Distribution
10. Triaxial Test (undrained)
13. Consolidation

The results of this analysis are quoted in the tables of geotechnical properties on Map J (Engineering Geology of Solid Deposits) and Map K (Engineering Geology of Drift Deposits).

Where geotechnical information about a formation was not available from within the project area, data from outside the area have been used (where possible) and the source quoted.

Although the geotechnical data obtained by the project is not a statistically valid sample of the formations present, it does form the basis for a guide to the engineering behaviour of the materials of the area. The classification should be used as a guide when planning a site investigation rather than as a substitute for a site investigation.

Availability of geotechnical test data (Maps I1-I7)

These maps, at 1:50 000 scale, each show the distribution of a particular type of geotechnical test data. The topics covered on individual maps are standard penetration tests, particle size analysis, consolidation tests, shear strength tests and tests and chemical analyses of soil, ground water and sulphates.

The maps are based on an analysis of the test results contained in site investigation reports held by BGS. Where a report contains data on a particular type of test then all boreholes referred to in the report have been plotted. The assumption has therefore been made that the same tests have been carried out on samples from all boreholes referred to in a report, and while this is often the case, it is by no means always so. The maps therefore tend to overestimate the number of individual sites from which test data has been obtained, but can be taken as a guide to distribution and relative abundance of data referring to different types of test.

Engineering geology of solid deposits (Map J)

The solid formations of the study area, with the exception of the Upper Chalk, show marked cyclical sedimentation. This has resulted in geological formations with variable geotechnical properties due to changes in particle size of the sediments at different levels within the cycle. It is, therefore, not easy to classify formations in terms of engineering behaviour when they undergo a gradual change from sandy clay to clayey sand. However a simple classification has been made into four groups based on the overall behaviour of the geologically mapped lithostratigraphic units which will act as a guide to their engineering performance. But minor amounts of clay may occur in the non-cohesive group and likewise sand in the cohesive group. The engineering geological classification of the lithostratigraphic units is as follows:-

Rock	Upper Chalk
Cohesive	Headon Formation Barton Clay London Clay Reading Formation
Non-cohesive	Lyndhurst Member Becton Sand Becton Bunny Member Chama Sand Barton Clay (sand) Selsey Sand Earnley Sand London Clay (sand) Whitecliff Sand Durley Sand Portsmouth Sand Nursling Sand Reading Formation (sand and pebble beds)
Laminated	Marsh Farm Formation Wittering Formation

Mean values and ranges of values for the more commonly used geotechnical parameters are given in a table accompanying Map J. Details of the engineering properties and behaviour of the solid deposits are as follows:-

Rock

Upper Chalk

The Upper Chalk crops out in the northeast and northwest of the study area and is present, at depth, beneath the entire area. It is a fine-grained, pure (98% $CaCO_3$), limestone of organic origin and is unusual in its lack of recrystallisation. Its strength is due to the mechanical interlocking of its component grains aided by a small amount of pressure solution (Higginbottom, 1966). The Upper Chalk contains occasional beds of nodular and tabular flint.

Chalk is also unusual in having a high porosity (40%-50%) with a low permeability (10^{-6} to 10^{-8} m/s). The pore spaces are therefore poorly interconnected. However, in the field, transmissibility measurements indicate that permeability en masse may be from 10^2 to 10^4 times greater owing to the well developed jointing and fracturing of the Chalk.

The freeze and thaw activity associated with the last ice age has left the Chalk deeply weathered in many areas. Chalk close to the surface may be intensely fractured; the intensity decreases with depth but may still be detectable at depths of about 7m. At the surface, chalk may have been reduced to a slurry which has been transported down slope by solifluxion to produce deposits of remoulded chalk sometimes called Coombe Rock, or Chalk Head.

The Upper Chalk in a fresh state has a high bearing capacity with a low coefficient of volume compressibility and a high coefficient of consolidation. However, most foundations are in chalk which has been softened to some degree by weathering, in which case initial settlements may be large, and are a critical factor in foundation design (Wakeling, 1966).

The high porosity and moisture content of chalk have a major effect on its behaviour as an engineering material. Chalk at its natural moisture content is often close to its optimum moisture content for compaction. It is therefore well suited for use as a fill material. But because of its low permeability, over-compaction may result in high pore water pressures being built up resulting in a "spongy" fabric which will require time for the pore pressures to dissipate before a satisfactory bearing capacity is reached. The natural moisture content may also be close to the liquid limit of the completely remoulded material; this means that in cases of extreme over-compaction the chalk may be turned to a highly plastic state or a liquid slurry (putty chalk).

Another problem caused by a moisture content near to the liquid limit is the difficulty in obtaining undisturbed samples of chalk for the laboratory determination of its physical properties. Any method which causes disruption of the fabric of the chalk, such as the driving of U100 sample tubes with a drop hammer, will give samples that are, at least, partially remoulded and will result in an underestimation of the in situ strength.

In situ methods of testing such as the standard penetration and plate loading tests are considered easier, cheaper and more reliable than laboratory tests done on poor quality samples. Higher quality samples can be obtained by careful rotary coring techniques but are expensive. The loss of strength by chalk on remoulding is also an important factor during pile driving. Chalk behaves in an almost thixotropic manner. Only when the pile is allowed to stand for a while (and the excess pore water pressure allowed to dissipate), does the pile achieve a "set" and its full load bearing capacity is developed.

Beds of tabular and nodular flints which are present in the Upper Chalk may present problems for drilling and excavation because of their very hard abrasive nature. High wear rates on cutting edges may be caused and the jamming of drill bits due to flint nodules moving during cutting may take place. Tunnelling machines may also be affected by beds of flint causing excessive wear and deflection from line.

The deep weathering which may affect chalk causes physical properties to vary over a wide range in a weathered profile. It is important, therefore, that the weathering grade of chalk (Ward and others, 1968) is established and that the properties of chalk, even below a superficial cover, are not assumed to be those of unweathered bedrock.

In soliflucted deposits of Coombe Rock, relict shear surfaces left by ancient movements may be present. These are important because of the possibility of reactivation during excavations or surcharge loading.

Chalk, like other limestone, is soluble and swallow holes, dolines or pipes may form. These may be in the form of voids or be filled by superficial material such as Clay-with-flints. These features could present a hazard to structures by giving an uneven (or zero) bearing capacity beneath a foundation which would result in uneven settlement of a building founded on a doline.

A similar problem may be caused by ancient workings for flint or chalk which may or may not have been back filled. In both cases the use of aerial photographs may assist in their detection.

Cohesive

Reading Formation

There is little available engineering or geotechnical information regarding the Reading Formation of the area, which comprises mainly red mottled plastic clays of intermediate to high plasticity with local developments of sands and gravel. Cripps and Taylor (1981) give geotechnical information on consistency, strength and consolidation for the clays of the "Woolwich and Reading Beds" from the London Basin (see geotechnical property table on Map J) but it is not known how applicable these values are to the Hampshire Basin.

London Clay

The London Clay of the Hampshire Basin is mainly olive-grey, silty, sandy, over-consolidated, firm to very stiff, generally highly fissured clay of low to very high plasticity (Figure 13). The London Clay weathers to a yellowish-brown to grey-brown colour which may extend to a depth of about 12 metres. However, weathering is not thought to affect the engineering index values by more than about 10% (Burnett and Fookes, 1974).

In the Hampshire Basin, the London Clay was deposited in five upward-coarsening cycles of sedimentation. Discrete sandy partings of fine sand or clayey sand are present, although bedding is not usually evident. The relatively coarse nature of the London Clay in the Hampshire basin is demonstrated by the plasticity chart shown in Figure 13a.

There is an extensive literature relating to the geotechnical properties and behaviour of the London Clay, most of which refers to the London Clay within the London Basin. The London Clay of the Hampshire Basin is not well represented and the geotechnical properties and behaviour quoted in the bulk of the literature must therefore be viewed in the light of regional variations in composition and mineralogy. In general, the London Clay of the Hampshire Basin is

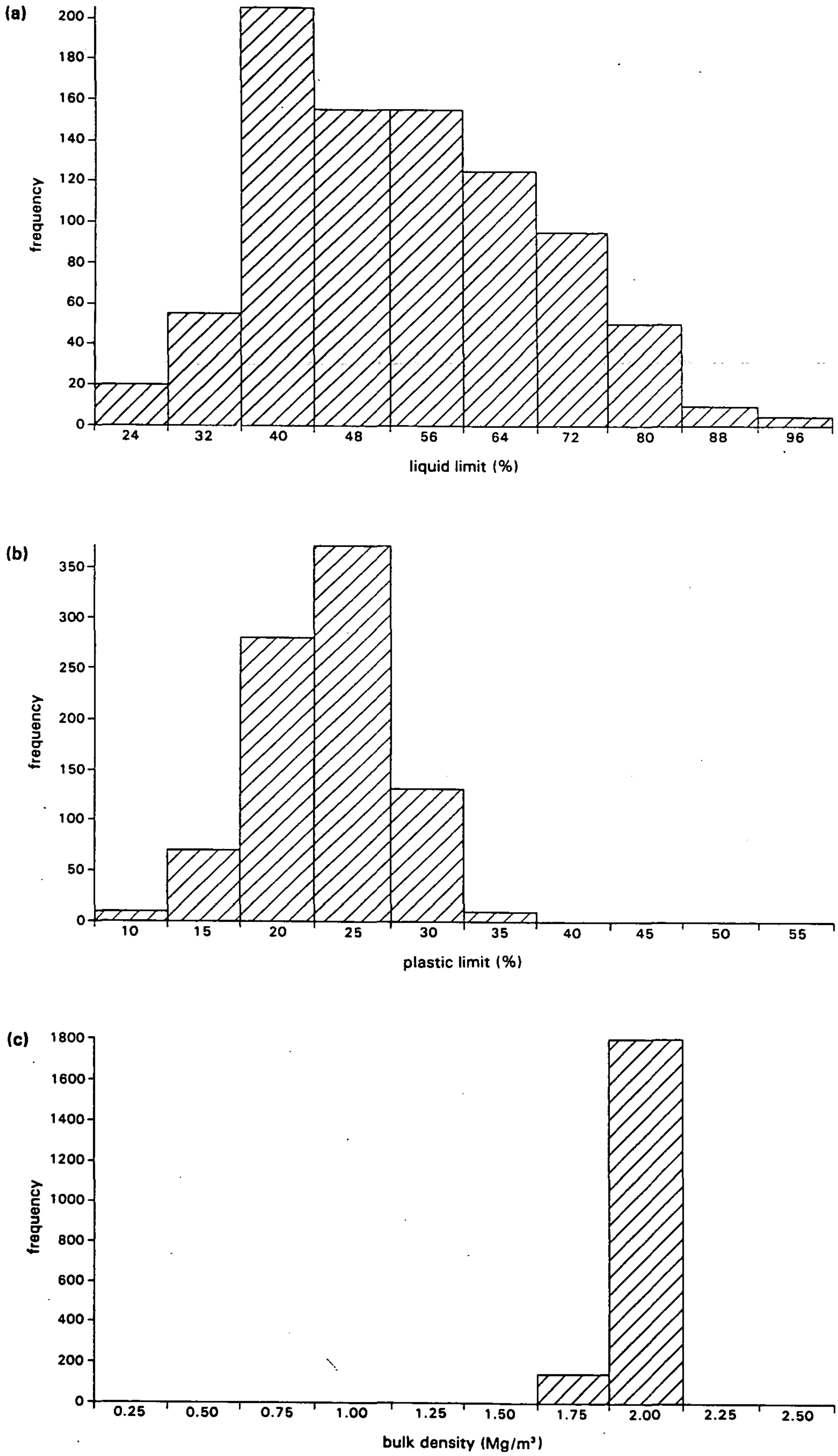
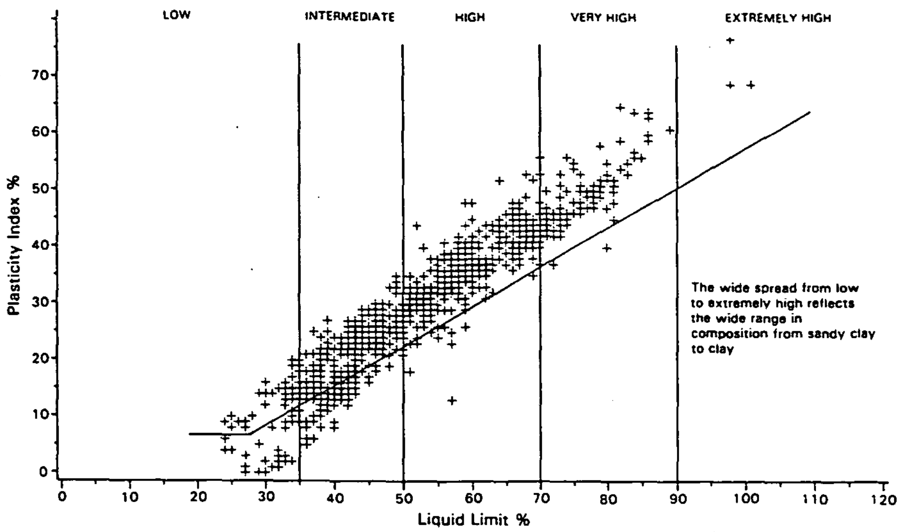
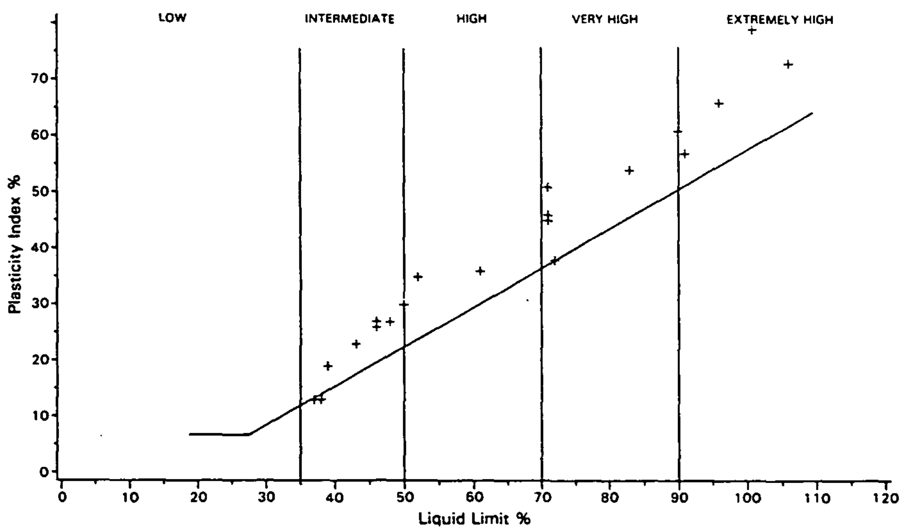


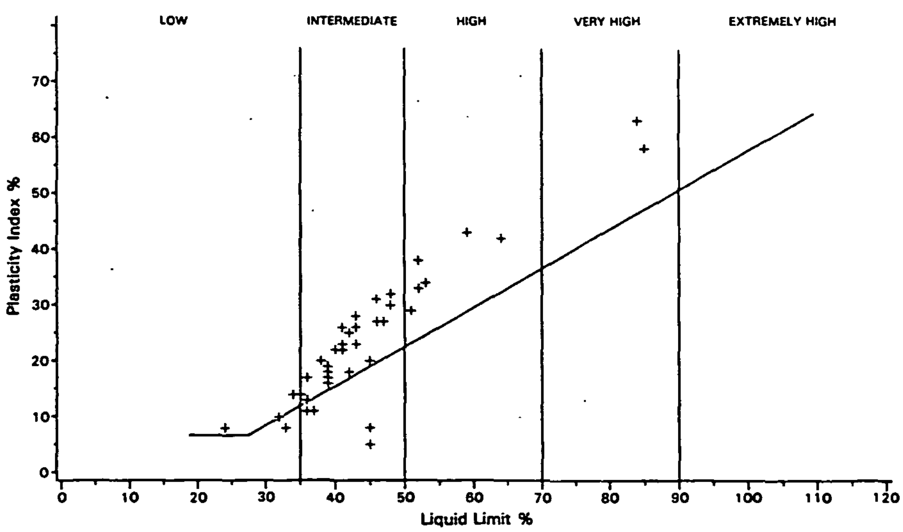
Figure 12. Frequency bar charts for liquid limit, plastic limit and bulk density values for the London Clay in the Hampshire Basin



(a) London Clay

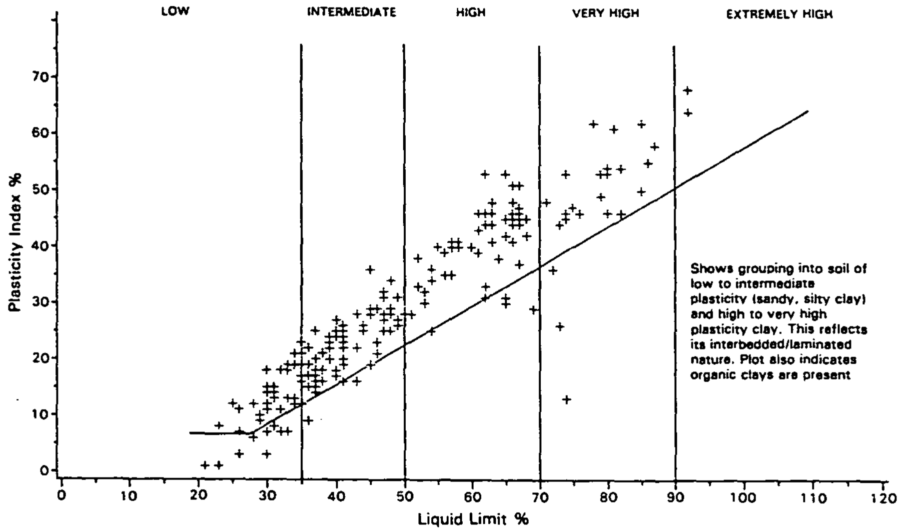


(b) Barton Clay

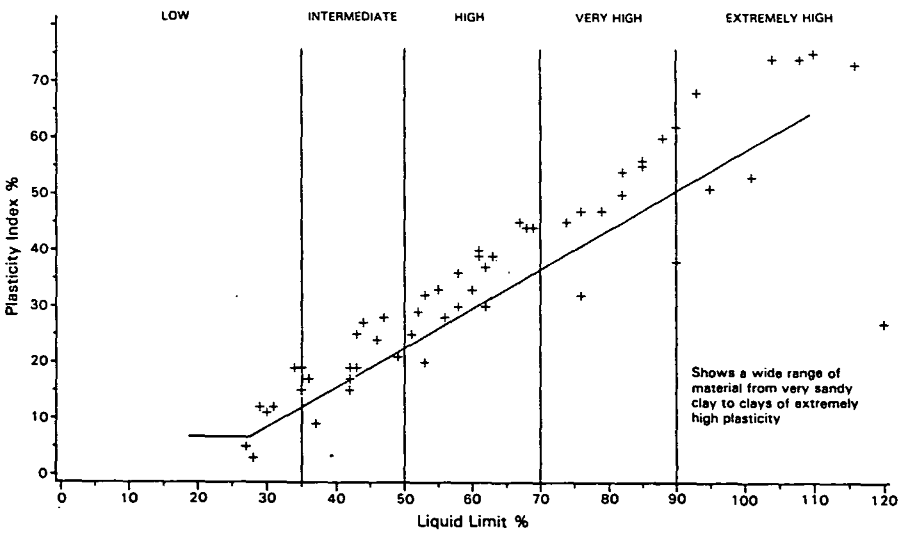


(c) Nursling Sand

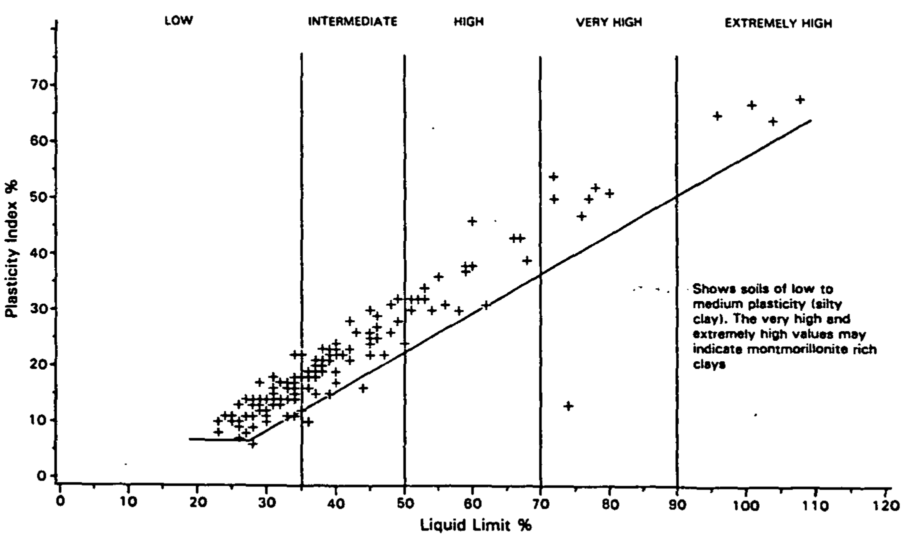
Figure 13. Plasticity charts for the London Clay, Barton Clay, Nursling Sand, Wittering Formation, Alluvium and River Terrace Deposits



(d) Wittering Formation



(e) Alluvium



(f) River Terrace deposits (including Brickearth)

Figure 13. Plasticity charts for the London Clay, Barton Clay, Nursling Sand, Wittering Formation, Alluvium and River Terrace Deposits

coarser-grained than elsewhere, with an increased quartz content. In addition, the proportion of kaolinite to montmorillonite increases towards the west. These mineralogical changes indicate that the area which now forms the Hampshire Basin was bounded on the west by a shoreline during the deposition of the London Clay.

The regional variation in the geotechnical properties of the London Clay is described in detail by Burnett and Fookes (1974). They concluded that the lateral variation in composition and geotechnical properties across the basin of deposition is of the same order as that occurring vertically in the material. Therefore variation in geotechnical properties on an engineering site is not significant within a stratigraphic horizon but may be important vertically through the sequence. The liquid limit and plastic limit both decrease south-westwards across the original basin of deposition giving values of less than 70% and less than 45% respectively in the Hampshire Basin. Dry density tends to increase towards the south west with densities in the Hampshire Basin generally higher than 1.60 Mg/m^3. These findings are generally confirmed by the values from the data base, shown in Figure 12.

Engineering problems associated with the London Clay are largely those of slope instability and the effects of water.

The natural angle of ultimate stability for London Clay within the London Basin is quoted as 8° for the free degradation of a cliff (Hutchison, 1967). The steepest natural slopes which occur inland are about 10°. It is important to remember that although the superficial features of slipping may have been removed by ploughing, at depth relict shear surfaces may be reactivated by construction or excavation activities on the slope or by alteration of the drainage regime which may affect the position of the groundwater table.

Artificial slopes which have had suitable drainage installed have been cut to slopes of between 1:3 (18°) to 1:2 (27°) depending on lithology. For slopes higher than 7m, a berm at least 9m wide has been recommended. The sandy layers within the clay may carry water, possibly under artesian pressure. This will require pumping prior to, and during, excavation to control groundwater inflow which would cause softening of the clay, and ground heave where a thin layer of clay above an aquifer is lifted under artesian pressure. Clay which is to form a foundation surface should also be protected from the softening effect of rain.

London Clay will undergo changes in volume (swell and shrinkage) with changes in moisture content, or, if confined, swelling pressures may develop. Johnson (1982) quotes a swelling pressure of 200 kN/m^2 when London Clay absorbed moisture after a tree was removed. The tree had dried out the clay in the immediate vicinity by root suction to a depth of four metres. Johnson recommends that a soil moisture profile down to five metres depth be included in site investigations in a clay area. If swelling or shrinkage is likely to be a problem then a pile and beam foundation may be required.

The sulphate content of the London Clay and its groundwater is such as to require precautions against sulphate attack on concrete below the groundwater level. London Clay usually falls in class 2 or 3 of the B.R.S. Digest 90 (Building Research Station, 1968).

The net allowable bearing capacity for London Clay varies with lithology but falls in the range 75-540 kN/m^2 with 200-300 kN/m^2 most often quoted.

Barton Clay

The Barton Clay crops out in a band running south-southwest from the middle of the western margin of the area to the south-east corner where it lies below Southampton Water.

The Barton Clay is an olive grey to greenish grey, slightly sandy to sandy, fissured, overconsolidated, stiff to very stiff clay of intermediate to extremely highly plasticity (Figure 13), containing occasional beds and pockets of clayey fine sand or silt.

The Barton Clay has been studied extensively as a result of its role in cliff instability at Barton on Sea (Barton, 1973; Barton and Coles, 1984) but there is little information in published sources regarding its engineering behaviour within the project area. Some geotechnical information is available from site investigation reports.

A study of the strength of Barton Clay at Fawley (Marsland and Butler, 1967) showed that the strength of the rock mass was controlled by the intensity of fissuring and fracturing of the rock and that the degree of fracturing and fissuring varied considerably both vertically and horizontally. The fissuring and fracturing had been caused by periglacial action and the behaviour of the Barton Clay at Fawley may not be representative of Barton Clay elsewhere, which was not exposed during glaciation and therefore not subject to periglacial action.

The sandy layers present in the Barton Clay will increase horizontal permeability and therefore increase the rate of consolidation. However, water may also be transmitted into excavations and may cause softening of clay when overburden is removed. Adequate drainage measures must therefore be taken for excavations and cut slopes. The presence of thin aquifers must also be considered as potential pathways for leachate pollution in waste disposal facilities within the Barton Clay.

Headon Formation

The Headon Formation crops out over a relatively small area in the south-west of the area. It is a greenish grey shelly clay with some sands and carbonaceous layers and lignite near its base. Little geotechnical data relating to this Formation has been found.

Non-cohesive

Reading Formation

At the base of and within the Reading Formation there are glauconitic sands and Pebble Beds. No geotechnical information was found regarding the properties or behaviour of these.

Nursling Sand

The Nursling Sand is a dense to very dense silty, fine grained sand which crops out within the London Clay in the north-west and north-central part of the area. Plasticity data indicates that it also includes silty clays of intermediate plasticity (Figure 13c). The Nursling Sand may give rise to running sand conditions in excavations and boreholes and may be susceptible to frost heave in freezing conditions above the water table.

Portsmouth Sand

The Portsmouth Sand is a medium dense to very dense fine to coarse grained sand. It may carry water under pressure and give rise to running sand conditions in excavations and boreholes.

Durley Sand

The Durley Sand is a clayey fine grained sand. Although no geotechnical details were found for this sand it is geologically similar to the Nursling Sand and probably has similar geotechnical properties and associated engineering behaviour.

Whitecliff Sand (and pebble beds)

The Whitecliff Sand is a very dense fine to coarse grained sand. It may carry water under pressure causing running sand conditions in excavations and boreholes.

London Clay (sand)

Small lenticular bodies of sand occur locally within the London Clay, similar to the Nursling, Portsmouth, Durley and Whitecliff sands. No geotechnical information is available.

Earnley Sand

The Earnley Sand is a green to grey dense to very dense silty fine grained sand and sandy silt. The Earnley sand may give running sand conditions in excavations and boreholes and may be susceptible to frost heave in freezing conditions above the water table. Water at artesian or sub-artesian pressure is commonly encountered.

Selsey Sand

The Selsey Sand is a dense to very dense silty, clayey fine to very fine-grained sand and is very similar in properties and behaviour to the Earnley Sand.

Barton Clay (sand)

The sand units within the Barton Clay are isolated lenticular bodies of fine grained clayey sand. No geotechnical information was found.

Chama Sand

The Chama Sand is a greenish grey medium dense clayey silty very fine-grained sand which crops out extensively in the south and west of the area. It may give rise to running sand conditions in boreholes and excavations and may be susceptible to frost heave in freezing conditions above the water table.

Becton Bunny Member

The Becton Bunny Member is a localised development of shelly clay and carbonaceous clayey sand of very limited outcrop in the south-west of the area. No geotechnical information is available and its status as cohesive or non-cohesive is uncertain.

Becton Sand

The Becton Sand crops out in the south-west of the area and is a yellow to buff, medium dense to very dense, fine to very fine-grained, well sorted sand. It may be susceptible to frost heave above the water table and give rise to running sand conditions in boreholes and excavations.

Lyndhurst Member

The Lyndhurst Member of the Headon Formation is an extremely sandy clay and clayey sand. No geotechnical information is available and its status as cohesive or non-cohesive is uncertain.

Laminated

The Marsh Farm and Wittering Formations are both the result of intertidal sedimentation and are therefore similar lithologically. The Wittering Formation contains lignite in its upper part and, overall, contains more organic material. Both formations are predominantly laminated and are, therefore, anisotropic in their properties, particularly with regard to permeability which is much greater horizontally than vertically. Their rate of consolidation is much more rapid than laboratory tests indicate.

Both formations show marked lateral and vertical variation in lithology. The geotechnical properties of these formations are strongly influenced by the structural arrangement of their components and therefore parameters such as liquid and plastic limits determined on a remoulded sample, or on the individual components of the material (Figure 13d), may not indicate behaviour as a whole. The thin sand beds and laminations within the essentially clay formations act as pathways for the passage of water and control the engineering behaviour of the material to a high degree. Under conditions of consolidation the thin sands will conduct excess pore pressure rapidly away so that consolidation is achieved rapidly. Conversely in an unloading situation water may be absorbed by the clays which, although they are not particularly swelling clays, may be softened and their shear strength reduced. Water in the sand layers may be under an artesian head which will increase the softening effect and may cause heave in the bottom of an excavation if the sand aquifer is exposed or lies below a thin layer of clay.

In practice, therefore, before excavations are carried out, dewatering may be required to ensure that in the short term, the excavation is not flooded and the sides are stable. In the long term permanent drainage may be required to maintain the water level behind a cut face and bleed wells may be necessary to relieve artesian pressure below the excavation floor. Cuts at an angle of of the order of 20°, accompanied by suitable drainage schemes have been made.

A net bearing capacity of between 50 to 200 kPa is quoted for foundations on the Bracklesham Group. In cases where greater bearing capacity is required, piling to stiffer formations at depth may be necessary. If bored piles are used then running sand under artesian conditions may cause problems; problems may also be caused with driven piles and in either case pile tests should be carried out before a major programme of piling is started, to ascertain the suitability of the technique at the site.

Sulphate concentrations in the Bracklesham Group sediments and groundwater indicate that these formations fall into Class 1 or 2 (Building Research Station, 1968) and therefore sulphate attack resisting concrete mixes may be required for concrete structures below the water table.

Engineering geology of drift deposits (Map K)

The superficial deposits of the project area are largely river and estuarine deposits with lesser amounts of Head. The deposits have been grouped into four classes on the basis of their geotechnical properties. The classification is as follows:

Cohesive	River Alluvium Estuarine Alluvium River Terrace Deposits (loam and clay) Peat Calcareous Tufa
Non-cohesive	River Terrace Deposits 1 - 11 Older River Gravels 1 - 5 Buried Channel Deposits Head Gravel
Mixed	River Terrace Deposits Clay-with-flints Made Ground
Head	

Mean values and ranges of values for the more commonly used geotechnical parameters derived from the geotechnical data base, are given in a table accompanying Map K. Details of the properties and behaviour of the superficial deposits are as follows:-

Cohesive deposits

Alluvium (River Alluvium)

The main deposits of River Alluvium of engineering significance are found in the valleys of the Itchen and the Test where up to 10m of Alluvium may be present. The Alluvium consists of peat, clayey peat and organic silty clay resting on flint gravel.

There is little published geotechnical information about the River Alluvium but data from site investigation sources indicate a behaviour similar to the Estuarine Alluvium; that is, low strength, low to extremely high plasticity (Figure 13e), medium to high compressibility and slow consolidation. It is important to remember that the relative rise in sea level in the area has resulted in considerably thicker deposits of Alluvium in river valleys than might be expected from the current topography and it is therefore important to define the extent of the buried river valleys by boreholes or geophysical means at the site investigation stage of a development before construction.

Estuarine Alluvium

The Estuarine Alluvium is a grey, very soft to soft, highly compressible, silty, locally sandy, organic clay. The alluvium is of low strength with a bearing capacity of the order of 30 kN/m^2; compressibility is high and consolidation is slow. The surface layers of alluvium may be dessicated which will make them stronger and less compressible than the alluvium at depth.

Engineering problems are largely those associated with low bearing capacity and a large settlement for a given load. Engineering solutions include the removal of alluvium and its replacement by material of a higher bearing capacity, ground improvement by placing stone columns using vibroflotation or bog blasting, piled foundations, preconsolidation, and the use of lightweight concrete to reduce the weight of a structure and keep the foundation loading low.

These methods require specialist contractors and may require pilot tests to be carried out before use on a large scale.

Slope instability of cut faces in Estuarine Alluvium is a major problem during excavation. Where possible, excavations should be supported or carried out in a flooded condition, keeping the water level in the excavation balanced with that of the groundwater. In this way faces of about 65° with a factor of safety of about 1.2 (Leggatt and Bratchell, 1973) may be maintained.

The sampling of alluvium for geotechnical testing presents problems in terms of the closure of boreholes during drilling and sample disturbance.

Thin wall piston samplers or Delft continuous sampling offer the greatest possibility of high quality undisturbed core samples. U100 samples are, inevitably, disturbed in this type of material. In situ test methods, such as the cone penetrometer which gives a continuous vertical assessment of the geotechnical properties of soft sediments, have much to recommend them in the estuarine environment.

The sulphate content of groundwater within the alluvium may be high enough (class 2) to require sulphate resisting concrete mixes to be used below the water table.

The dessicated surface of the alluvium may be sufficiently strong for the passage of vehicles but at depth the alluvium will still be soft. If traffic is sufficient to require improvement of the surface, then the use of a geotextile is necessary before hardcore is laid, to avoid the sinking of the hardcore into the soft material below.

River Terrace Deposits (loam and clay)

The River Terrace Deposits (loam and clay formerly called "brickearth") are structureless, soft to firm, silty, quartz bearing clays of medium plasticity (Figure 13f). Although loessic in nature, they do not appear to have the collapsing capability of a true loess which has been deposited sub-aerially.

Available geotechnical information concerning the "brickearth" deposits in Hampshire and their relatively thin and limited outcrop, indicate that they are unlikely to present any major problem to engineering activities. However, the plasticity chart indicates some highly plastic material present which, if it is montmorillonite clay, may have potential shrinking or swelling problems.

Peat

Peat up to 2.7m thick (Barton and Roche, 1984) is found within the Estuarine Alluvium. It also occurs within the River Alluvium. Peat is highly compressible with a low bearing capacity and rapid primary consolidation. It will maintain, however, a relatively stable face in an excavation owing to its low density. The geotechnical behaviour of peat is in some respects similar to a normally consolidated clay in the relationships between index properties and engineering properties, other than strength. But in others it is very different such as the relationship between water content and strength which is affected by the reinforcement action of its fibrous texture (Hobbs, 1986).

Calcareous Tufa

Calcareous Tufa occurs locally within river alluvium. It is of very limited extent and no geotechnical information is available.

Non-cohesive Deposits

River Terrace Deposits 1-11, Older River Gravels, Buried Channel Deposits

The river gravels of the area occur at sixteen levels above Ordnance Datum and at three levels below Ordnance Datum. The deposits at the five highest levels are termed Older River Gravels.

The gravels are all flint gravels with varying amounts of clay, silt and sand. They are generally loose to medium dense at the surface, becoming dense to very dense with depth. Their composition in terms of particle size distribution may vary both laterally and vertically and the thickness of a gravel terrace deposit may also vary considerably over a distance of a few tens of metres (Barton and Roche, 1984). The terrace gravels do, however, offer good foundation bearing capacity with low compressibility.

Engineering problems which may be encountered include sub-artesian groundwater in excavations below the water table and overloading of the material beneath the gravel. The bearing capacity of the gravel is generally greater than that afforded by the Bracklesham and Barton Group lithologies which usually lie below it. If foundations on the gravel terrace material have an insufficient thickness of gravel between them and the underlying Tertiary formation then failure may occur. The provision of an adequate gravel thickness below the foundation level is particularly important in the case of piled foundations.

Sulphate-resisting concrete may be required for structures founded below the water table or below Ordnance Datum within the estuary. The natural angle of repose of the gravel is likely to be of the order 30° - 40° and excavations deeper than 1m will require support.

Head Gravel

Head Gravel is a distinct deposit of head derived from the Older River Gravels and River Terrace deposits. No geotechnical information is available. The deposit is presumed to be a loose to medium dense clayey gravel.

Mixed deposits

River Terrace Deposits - Undifferentiated

No geotechnical information is available for this mapped unit, which is assumed to be mainly gravel with sand, silt and clay and properties in the ranges shown for other terrace deposits.

Clay-with-flints

Clay-with-flints is a deposit representing partly the insoluble residue of Chalk and partly material from former Tertiary deposits, especially the Reading Formation. It occurs only on the Upper Chalk in the north-east corner of the area. Clay-with- flints is a cobbly gravelly clay and is generally thin (0.5 - 1m) but may fill solution pipes and hollows to a depth of 11m. No geotechnical information was found relating to this material.

Made Ground

The geotechnical properties of Made Ground are highly variable and difficult to predict.

The behaviour of fill is dependent upon the nature of the material used and its compaction during placement. When fill is placed as a part of an engineering project then the material used will usually be of known geotechnical properties, placed in a controlled manner and compacted to a specified density. When fill is placed as part of a waste disposal operation the nature of the waste may vary from inert, inorganic waste such as brick rubble to highly organic domestic refuse. The geotechnical properties will vary depending upon the nature of the tipped material and, in the case of organic material, they will also vary with time. As the organic material decays the properties of the fill will change and it will suffer a loss of volume of up to 50%.

The bearing capacites determined for domestic landfill sites in the past may not be applicable to current or future sites because the nature of domestic refuse changes with social and technological changes. For example, the proportion of ash has decreased and the amount of paper increased over the last fifty years. It is essential that any construction on a filled site be carried out only after detailed site investigation.

Extensive areas of the Solent Estuary have been reclaimed by imported fill, often material dredged from the estuary. When reclaimed land is developed, the presence of soft Estuarine Alluvium beneath the fill must be taken into account, as well as the properties of the fill which may be the stronger of the two materials.

Head

Head is a superficial material resulting from the weathering and erosion of solid and superficial material. It is of variable composition depending on the nature of its parent material. Head is commonly thin (<1m), but greater thicknesses may accumulate at the foot of slopes or in hollows. It may be the result of solifluction with relict shear surfaces present within it and it may be significant in some engineering works. The geotechnical properties are variable but it is generally a loose, soft to firm low strength material whose strength reflects the remoulded values of the parent material. Problems may include settlement and instability of Head-covered slopes.

SLOPE STABILITY

Distribution of slope angle and landslip (Map L)

The map, at 1:50 000 scale, shows the distribution of slope angle as derived from the contours of the Ordnance Survey 1:50 000 scale topographical map, as well as areas identified as landslip during the 1:10 000 scale geological mapping. Slope angle, shown by isopleths at 5° intervals, is generally low, being in the main less than 5°, and only very locally reaching a maximum in excess of 10°. Areas of 5° to 10° slope angle occur mainly on the Upper Chalk, the London Clay to the north and east of Southampton, and on the Barton Group and Headon Formation of the New Forest in the west of the project area. Slopes in this category also occur on the Wittering Formation mainly on the west side of the River Test and the east side of the River Itchen. There are insufficient slopes in excess of 10° to show any pattern of occurrence.

There are only five small areas of landslip on the map, the majority of which coincide with, or are close to, areas of higher than 5° slope. In addition, four of the five areas of landslip occur where Wittering Formation laminated clays are overlain by, or are in close proximity to, River Terrace Deposits. Austin and Cosgrove (1978) also refer to a slip at Bitterne [440 121] involving the Wittering Formation forming a river cliff.

Landslipping of natural slopes does not therefore appear to be a problem in the study area. However, the work of Hutchinson (1967) on the London Clay of the London Basin indicates an angle of ultimate stability for London Clay of 8°. It would, therefore, be prudent to assess the potential for slope instability for any development involving slopes greater than 5° which coincide with cohesive materials particularly London Clay, Barton Clay, Headon Formation and Reading Formation. Landslip risk should be carefully evaluated in areas where slope angles above 5° coincide with outcrops of the Wittering or Marsh Farm Formations, particularly if these formations are overlain by or are near to River Terrace Deposits. The map should therefore be read in conjunction with the maps of solid and drift geology (Maps A1-A6 and B1-B6).

LANDFILL AND WASTE DISPOSAL

Distribution of Made Ground (Maps M1-M6)

The identification of Made Ground, particularly infilled land, is an extremely important aspect of land use planning. Apart from presenting problems in foundation conditions for prospective building developments, there are implications in the fields of agriculture and forestry.

Major problems associated with deposits of domestic and industrial waste stem from their low strength and inhomogeneous nature. Large structures built on such deposits may require special foundation designs to overcome possible settlement and differential compaction. Such problems may be particularly important at the boundary of infilled land where structures straddle an area with contrasting ground conditions.

Land that is returned to agriculture after infilling may not be in the same condition as the surrounding natural ground. Differences in drainage characteristics and the nature of the restored upper soil layer may variously affect the type and yield of crops. Attempts to afforest areas of landfill may be affected by the penetration of deep root systems into layers of buried domestic or industrial waste.

The disposal of toxic substances in landfill sites can present special problems affecting the environment. Such waste can be considered in two categories: firstly material which is inherently toxic and secondly, materials which may react to generate toxic or hazardous substances. Examples of the former are a wide range of industrial chemical waste such as mineral acids, cyanide residues and phenols. Some materials rich in cellulose, such as domestic refuse, can break down by the action of bacteria to form methane or undergo combustion to form gases rich in carbon monoxide and these examples would fall in the second category. The potential pollution of aquifers by leachate from waste disposal sites should be considered as a factor in the licensing of sites. The disposition of aquifers is dealt with in the section describing Map H.

It is essential that site investigation programmes are designed to take account of the problems outlined above and probe the thickness, lateral extent and composition of Made Ground deposits.

This is particularly important where waste disposal has been effected prior to the licensing regulations of 1976.

The maps of Made Ground at the 1:25 000 scale are based on the 1:10 000 Geological Survey of 1973-80 with updated information from local government and other sources. For the purposes of this study three categories of Made Ground have been shown on the face of the map, namely:-

1. Areas of landfill, in this district most commonly on the sites of former mineral workings. In many instances the type of fill is not known, but in the case of licensed sites (post-1976) or at sites where specific investigation is available an indication of the main fill components is given. The types of fill recognised are hardcore, domestic waste and industrial waste.

2. Areas of Made Ground raised above the natural surface level and constructed to provide engineering foundations. Examples include embankments for roads and railways, reclamation works for docks and wharves, and the foundations of large buildings or industrial complexes. In this category there is a general requirement for the fill to possess uniformity and strength and domestic and industrial wastes are generally excluded. For roads, railways and building foundations the fill is usually hardcore derived from cut-and-fill operations or specially imported materials such as chalk rubble. In areas adjoining the rivers, ground has been built up behind retaining structures using dredged mud and silt. These sites are identified where information exists.

3. Some former mineral workings have been partially backfilled with quarry waste and covered with topsoil, and are then left with a lowered surface level. In many cases, a proportion of domestic or industrial waste has been included with the backfill, though the nature and extent of this is seldom known. These partially backfilled sites are placed in a separate category.

The thickness of Made Ground is generally less than 5m, although locally much thicker deposits are present. Owing to the great variability in thickness and the data distribution, it has not been possible to give an indication of thickness on the maps. In particular over much of the urban area of Southampton patches of Made Ground of very variable thickness are present, especially in districts damaged by enemy bombing operations in the Second World War.

While the maps show all the data collected in the course of the recent geological survey together with later amendments, they must not be considered an exhaustive or accurate representation of Made Ground in the study area. Old landfill sites, particularly in areas now covered by urban development, are difficult to identify and may be completely obscured. In areas of intensive former mineral working, such as the brick-clay pits of the Swanwick area, the extent of landfill within the worked area is difficult to establish. Careful attention to site investigation must be given when areas of Made Ground are included within the boundaries of any proposed developments.

DATA DISTRIBUTION

Distribution of boreholes (Maps N1-N6)

The six maps, at 1:25 000 scale, show the distribution of all boreholes held in the BGS archive and sited within the area of those OS 1:10 000 sheets in whole or in part covered by the project area. The maps therefore include some boreholes outside the project area which were not used in the present study. Borehole in this context includes trial pits dug using a mechanical excavator.

No indication of borehole depth is given on the maps but the majority are shallow and put down for site investigation surveys. Of the 4549 boreholes plotted on the maps 1456 are less than 5m deep and 2645 less than 10m deep.

The distribution of those boreholes used in producing particular applied geology maps is given in the margin of the relevant map.

OTHER

Sites of Special Scientific Interest (Map O)

This map, at 1:50 000 scale, shows the locations and approximate boundaries of Sites of Special Scientific Interest (SSSIs) that occur within the project area. The boundaries of the SSSIs have been taken from 1:10 000 and 1:25 000-scale maps supplied by the Nature Conservancy Council (NCC), and users requiring to know precise boundaries of particular SSSIs are recommended to consult the definitive maps held by the NCC.

Sites of Special Scientific Interest are notified to the Department of the Environment, local authorities, and to landowners of the sites.

Notifications were made under section 23 of the National Parks and Access to Countryside Act, 1949, or section 28 of the Wildlife and Countryside Act 1981. Some of the sites shown on the map have still to be notified under the 1981 Act, and there may well be additional sites to be notified.

SSSIs are defined as areas of land which have special scientific interest because of their flora, fauna, geological or physiographical features. The map of SSSIs is included in this report because the presence of an SSSI has relevance to planning and development decisions. A local authority is required to consult the NCC if a planning application is made for development within an SSSI. If development is proposed that does not require planning permission, the landowner is required to consult the NCC directly in order to gain consent for the development, or to negotiate a management agreement.

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GLOSSARY

A capitalised word within an entry is a cross-reference to another entry in the glossary

ANHYDRITE: A mineral consisting of anhydrous calcium sulphate

ANHYDRITIC: Containing the mineral ANHYDRITE

ANTICLINE: A FOLD, the core of which contains older rocks; it is convex upward

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

ARGILLACEOUS: A deposit containing an appreciable amount of clay

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

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

AXIS (fold): In a FOLD, a line that connects the central points of each constituent stratum, from which its LIMBS bend

BASE LEVEL: A curved or planar surface extending inland from sea level, inclined gently upward from the sea, and representing the theoretical limit of stream erosion

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

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

BOG BLASTING: A system, using controlled explosions, whereby fill may be placed in a bog by displacing the peat

BRICKEARTH: Clayey and sandy silt, and silty clay overlying river terrace gravel; it may include a proportion of windblown material (LOESS)

BULK DENSITY (see also Appendix): The mass of an object or material divided by its total volume

BURIED CHANNEL: An old channel concealed by DRIFT deposits

CALCAREOUS: A deposit that contains calcium carbonate

CALCITE: A common rock-forming mineral, $CaCO_3$

CALIFORNIA BEARING RATIO (see also Appendix): A standard test for comparing the strength of roads and air strips with a standard material

CARBONACEOUS: A deposit that contains organic matter

CLAYSTONE: A CALCAREOUS concretion commonly found in clay units

COEFFICIENT OF CONSOLIDATION (see also Appendix): The rate at which volume change takes place for a given increase in stress

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

COHESIVE: A sticky SOIL like clay or clayey silt. Some authorities define it as a soil with an undrained shear strength equal to half its unconfined compressive strength

COMPACTION TEST (see also Appendix): A test to determine the moisture content at which SOIL may be compacted to its maximum density. This is called the optimum moisture content

COMPRESSIBILITY: The reciprocal of bulk modulus

CONGLOMERATE: A coarse-grained SEDIMENTARY ROCK composed of rounded to subangular fragments larger than 2mm in diameter in a finer-grained matrix

CONSOLIDATION (see also Appendix): Reduction of bulk volume of soil that results from the closer packing of particles caused by an increase in effective stress

CONTINENTAL (DEPOSIT): A deposit laid down on land or in water not directly connected with an ocean

CUTTINGS, SAMPLES: Rock chips or fragments produced by borehole drilling and brought to the surface

CYCLICAL SEDIMENTATION: A rhythmic repetition of SEDIMENTATION conditions

DATABASE: In a broad sense, an organised collection of data, generally stored by computer for non-specific applications

DATABASE MANAGEMENT SYSTEM: A major

item of software for editing, updating and selectively retrieving from a DATABASE

DIGITISING: Converting points or lines on a map into sequences of (x,y) coordinates on a computer

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

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

EROSION: The general processes by which the materials of the Earth's crust are worn away

ESTUARINE: Formed in a river estuary

EVAPORITE: A rock composed primarily of minerals produced from a saline solution by evaporation

FAULT: A surface or zone of rock fracture along which there has been some displacement

FINING-UPWARD (CYCLE): A SEDIMENTARY CYCLE in which the particle size decreases upwards, e.g. from gravel at the base through sand and silt, to clay at the top

FISSURES: Surfaces of fracture or cracks in rock or soil along which there is a distinct separation

FLASER BEDDING: A ripple BEDDING type in which clay streaks are preserved in the troughs and crests of a sand unit

FLASH-FLOOD: A local and sudden flood of relatively great volume and short duration, commonly in an arid or semi-arid area

FOLD: A curve or bend of an originally planar structure such as BEDDING

GAMMA-RAY LOGGING: A radioactivity log obtained by recording the natural radioactivity of rocks penetrated in a borehole

GEOPHYSICAL LOGS: Logs obtained by lowering instruments into a borehole and recording some physical property of the rock material penetrated

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

GEOTHERMAL ENERGY: Useful energy that can be extracted from naturally occurring steam and hot water found in the Earth's crust

GLACIATION: The formation, movement and retreat of glaciers or ice sheets over large land areas of the Earth

GLAUCONITIC: A deposit that contains the green iron silicate mineral glauconite; generally considered to be characteristic of the marine environment

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

HARDNESS: A property of water causing formation of an insoluble residue

HYDROCARBONS: Any organic compound, gas, liquid or solid, consisting solely of carbon and hydrogen

HYDROGEOLOGY: The science that deals with subsurface waters and related geological aspects of surface waters

INTERBEDDED: Said of a bed, typically thin, of one kind of a rock material occurring between or alternating with beds of another kind

INTERGLACIAL: Pertaining to or formed during the time interval between two successive glacial stages

INTERTIDAL: Said of a deposit laid down in the depth zone between high water and low water

ISOPLETH: A general term for a line on a map or chart along which all points have a numerically specified constant or equal value, e.g. a contour line

KAOLINITE: A clay mineral of the kaolin group

LACUSTRINE: Pertaining to, produced by, or formed in a lake or lakes

LAGOONAL: Pertaining to a lagoon (a shallow stretch of seawater near the sea and partly or completely separated from it by a low, narrow, elongate strip of land)

LAMINATED: A very fine type of BEDDING, generally less than 1cm thick

LEACHATE POLLUTION: A polluting solution formed by water percolating through deposits containing soluble substances

LENTICULAR BEDDING: A type of BEDDING consisting of discontinuous lenses of sand in a predominantly clayey sediment

LIGNITE: A brownish black organic deposit intermediate in character between peat and sub-bituminous coal

LIMBS (fold): The sides of a FOLD; each limb is common to its adjacent folds

LIMESTONE: A SEDIMENTARY ROCK consisting chiefly of calcium carbonate

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

LITHOLOGICAL: Pertaining to rocks

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

LOESS: A drift deposit, predominantly of silt, generally considered to be windblown dust

MARL: A deposit containing 35-65% clay and 35-65% carbonate

MOISTURE CONTENT (see also Appendix): The amount of moisture in a given soil mass, expressed as the mass of water in a soil divided by the mass of solids in a soil

MONTMORILLONITE: A group of expanding-lattice clay minerals notable for the way they take up and lose water

MUDSTONE: An indurated mud, generally rather structureless

OOLITIC: Pertaining to a rock composed mainly of small spherical particles, usually of carbonate

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

PALAEONTOLOGICAL: Pertaining to the study of fossil plants and animals

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

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

PERMEABILITY (see also Appendix): The property or capacity of a rock, sediment or soil for transmitting a fluid

PETROLOGICAL: Pertaining to the study of the origin, occurrence, structure and history of rocks

pH (see also Appendix): The measure of the acidity or alkilinity of a solution

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

PISTON SAMPLER: A device for sampling soft sediments, containing a piston inside a cylinder

PLASTIC LIMIT (see also Appendix): The water content at the lower limit of the plastic state of a clay. It is the minimum water content at which a soil can be rolled into a thread 3mm in diameter without crumbling

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

PLATE LOADING TEST: A test in which a steel plate is placed on the stratum to be tested and loaded while settlement is measured. Ultimate bearing capacity of the stratum may be calculated. Particularly useful for granular soils

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

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

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

PRESSURE SOLUTION: Solution (in a SEDIMENTARY ROCK) occurring preferentially at the contact surface of grains

PYRITIC: Containing the mineral pyrite (FeS_2)

RASTER: A predetermined pattern of scanning lines that provides a substantially uniform coverage of an area. In computer graphics, each scan line comprises a sequence of small uniform areas known as picture elements, each coded in digital form.

RED-BED: Sedimentary strata deposited in a continental environment, and predominantly red in colour owing to the presence of hematite

REGOLITH: A general term for the mantle of untransported weathered material developed on the underlying bedrock

REGRESSIVE CYCLE: Said of a SEDIMENTARY CYCLE in which deposition takes place during the retreat of water from a land area

RESERVOIR ROCKS: Any rock (especially in petroleum geology) with adequate POROSITY or joint and fracture systems to contain liquid or gaseous HYDROCARBONS

ROCK (ENGINEERING): A naturally found material with a uniaxial compressive strength over a certain minimum value (usually taken as $1MNm^{-2}$), and composed of mineral grains

ROCKHEAD CONTOURS: Contours drawn on the sub-drift surface; where there is no drift, rock occurs at surface, and the rockhead contours are therefore simply the topographical contours

SANDSTONE: A consolidated SEDIMENTARY ROCK consisting of grains, usually predominantly of quartz, between 0.063 and 2mm in size

SEAT-EARTH: A unit, generally of clay, that underlies a coal or LIGNITE bed, and represents the fossil soil on which the vegetation grew

SEDIMENTARY CYCLE: A sequence of related processes and conditions, repeated in the same order, that is recorded in a sedimentary deposit

SEDIMENTARY ROCK: A rock resulting from the consolidation of loose SEDIMENT that has accumulated in layers

SEDIMENTATION: The process of deposition of sediment

SEDIMENTOLOGICAL: Pertaining to the scientific study of SEDIMENTARY ROCKS and SEDIMENTS

SEDIMENTS: Solid fragmental materials that originate from the weathering of rocks and are transported by air, water or ice to form in layers on the earth's surface in an unconsolidated form

SEISMIC: Pertaining to an earthquake or Earth vibration, including those artificially induced in geophysical exploration

SEISMIC REFLECTION PROFILES: A profile through the earth's crust derived from analysis of reflected elastic waves

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

SHEAR SURFACES: Surfaces along which differential movement has taken place parallel to the surfaces

SILTSTONE: A consolidated SEDIMENTARY ROCK composed of grains, predominantly of quartz, between 0.063 and 0.004mm on size

SHELLY: Said of a SEDIMENT or SEDIMENTARY ROCK containing the shells of animals

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

SOLID: Bedrock geology (excluding DRIFT deposits)

SOLIFLUCTED: Material that has been affected by solifluction, that is, the slow downslope movement of superficial material as a result of the alternate freezing and thawing of the contained water

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

STANDARD PENETRATION TEST (see also Appendix): An in situ test for SOIL where the number of blows with a standard weight falling through a standard distance to drive a standard core or sample tube is counted. It is a measure of the BEARING CAPACITY of a soil

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

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

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

SWELLING PRESSURE: The pressure exerted by a clay or shale when it absorbs water in a confined space

SYNCLINE: A fold, the core of which contains the younger rocks; it is concave upward

THIXOTROPIC: A substance, usually a clay, that displays thixotropy (the property of weakening or changing from a gel to a sol when shaken, but to increase in strength upon standing)

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

TRIAXIAL TEST (DRAINED AND UNDRAINED): A test of the shear strength of a SOIL sample contained in a rubber membrane surrounded by liquid under pressure. A load is applied by a piston to one end, and the deformations, loads, and pressures are recorded

UNCONFORMITY: A break in the history of SEDIMENTATION represented by missing strata, and commonly by a structural contrast between superimposed sets of strata

VIBROFLOTATION: A system of soil improvement by vibrocompaction using water jets

VANE TEST: A test in which a four-bladed vane is inserted into a SOIL; it is then rotated with a measured force until the soil shears. This test gives shear strength and residual shear strength either in situ or in the laboratory

WELL-SORTED: Said of a SEDIMENT or SEDIMENTARY ROCK that consist of particles all approximately the same size

APPENDIX

GEOLOGICAL HISTORY

The oldest known rocks in the study area are sandstones of probable early Devonian age. These sediments, seen at depth in the Marchwood and Southampton geothermal boreholes, may have been deposited in a river or rivers flowing from the continental landmass of the London Platform to the north. No evidence exists of higher Devonian or Carboniferous beds in the area and the depositional history continues, after earth movements, with a Triassic continental red-bed sequence. At the base of the Triassic are river-laid sediments which include sandstones and conglomerates belonging to the Sherwood Sandstone Group, deposited as gravel fans by flash-floods in a hot, arid climate. With a decline in the availability of coarser-grained sediments owing to the reduction in relief a period of deposition of reddish brown silty mudstone and siltstone of the Mercia Mudstone Group took place in temporary lakes. At times the lakes dried out and evaporite minerals, mainly anhydrite, were deposited. At the end of this period of red-bed deposition the sea spread over the area in the late Triassic, which ushered in a period of mainly marine sedimentation that lasted until the end of the Cretaceous.

Jurassic sediments were laid down in shallow seas on a broad continental shelf in a warm climate. World-wide changes in sea level combined with more local events led to deposition on a series of advances and retreats of the sea. Most of the Jurassic sediments of the Southampton area are marine clays with subordinate beds of shelly and oolitic limestones which were deposited on near-shore rises where they were winnowed by currents. At the top of the regressive cycles near-shore sands, such as the Bridport Sand, were deposited. Other near-shore sands occur in the Corallian Beds.

At the end of the Jurassic the sea retreated leaving coastal lagoons in which the marls, limestones, evaporites, and fossil soils of the Purbeck Beds were formed. Lagoonal and lacustrine conditions continued into the early Cretaceous, but the sea retreated from the area and river-laid sands and clays were deposited in the Wealden. At this time the forerunner of the main Alpine earth movements caused tilting and erosion, and most of the Portland Beds, Purbeck Beds and Wealden sequences were eroded from the study area. Again the sea invaded the area and introduced the sands of the Lower Greensand and, subsequently, the clays of the Gault. After deposition of the sands of the Upper Greensand, the area became the site of a shelf sea with little influx of silt and sand, in which the Chalk was deposited.

In the late Cretaceous, the British Isles were uplifted, the Chalk was gently warped, and much of the area became land. There followed a considerable period of erosion before deposition of the first Tertiary (Palaeogene) sediments. The late-Cretaceous earth movements were relatively subdued compared to the later Miocene movements, and there is generally very little discernible angular discordance between the Tertiary and Cretaceous rocks; it is only the fact that the basal Tertiary now lies on different zones of the Chalk that reveals the amount of tilting and erosion that has taken place.

Tertiary sedimentation in the Hampshire Basin records the history of several advances of the sea out of the North Sea Basin, and its subsequent retreat followed by deposition of shoreline sediments in the previously marine areas. This sequence of events gives rise to a marked cyclicity of sedimentation. In the Southampton district twelve main sedimentary cycles can be recognised between the base of the Reading Formation and the base of the Lyndhurst Member (Headon Formation).

The first advance of the sea into the area spread a thin blanket of pebbly glauconitic sand and clay over the Chalk, to form the Reading Formation Basement Bed. The fully marine conditions were short-lived however, and the remainder of the Reading Formation consists of red-mottled clays, and sands with occasional pebble beds, there being marked lateral variation in the proportion of these two main lithologies. The mottled clays are likely to have formed in semi-arid coastal lagoons and salt marshes, with periods of sub-aerial exposure during which soils formed. The sands and pebble beds are considered to have formed in the channels of rivers.

The next flooding of the area by the sea marks the base of the London Clay, which comprises five cycles of sedimentation, each characterised by an upward increase in grain size from clay to silt and sand. Lenticular bodies of sand (the Whitecliff Sand and Portsmouth Sand) occur channeled in at the tops of the uppermost two cycles and represent sand filling tidal channels. During the fifth cycle, the sea shallowed and much of the area was the site of dominantly intertidal to subtidal sedimentation, in which the

Wittering Formation was deposited; in the east however, the sea spread into the area and introduced sands and silts. These are overlain by laminated clays; near the top of the Wittering Formation is a widespread fossil soil horizon (the Whitecliff Bay Bed) represented by a lignite or brown clay with rootlets beneath, deposited in a salt marsh.

The Wittering Formation strata were drowned by the next influx of the sea which deposited glauconitic sands of the Earnley Sand. The overlying Marsh Farm Formation marks the rather abrupt retreat of the sea from the district, which again became the site of predominantly intertidal sedimentation.

The Selsey Sand marks another advance of the sea into most of the area and glauconitic silty sands were deposited. Further deepening of the water led to a decrease in grain size and deposition of the Barton Clay. The sea then gradually shallowed, giving rise in succession to the clayey silty sands of the Chama Sand, and the overlying well-sorted Becton Sand which was probably deposited in shallower water, or even on a beach, with some possible wind-blown sand.

At the top of the Becton Sand a fossil soil with a rootlet bed indicates subaerial conditions, and the succeeding shelly clays of the lower Headon Formation were deposited in freshwater lagoons behind a sand barrier, with little evidence of any connection to the sea. The Lyndurst Member was deposited in the sea or in brackish water, followed by deposition of clays of the upper Headon Formation in freshwater lagoons. No higher Tertiary sediments now remain in the study area, and later deposits in the Isle of Wight consist mainly of freshwater clays and limestones, and sands, with two short-lived episodes in which the sea spread over the area. It is likely that similar conditions or non-deposition occurred in the study area.

During the Quaternary, the district lay south of the ice sheets, which were at times probably not far distant. The Quaternary history of the district is difficult to unravel owing to the difficulty of dating the deposits. The younger terraces contain hand axes that may date from the last interglacial phase; the Older River Gravels were probably deposited during one of the earlier glaciations. The buried channel of the Southampton Water was excavated to its greatest depth during low sea levels of the last glaciation, and was infilled during the subsequent rise in sea level.

DESCRIPTION OF THE SOLID DEPOSITS

In the following account, the solid formations are described in ascending order of succession. The sequence is shown as a generalised vertical section in Figure A1.

Concealed formations

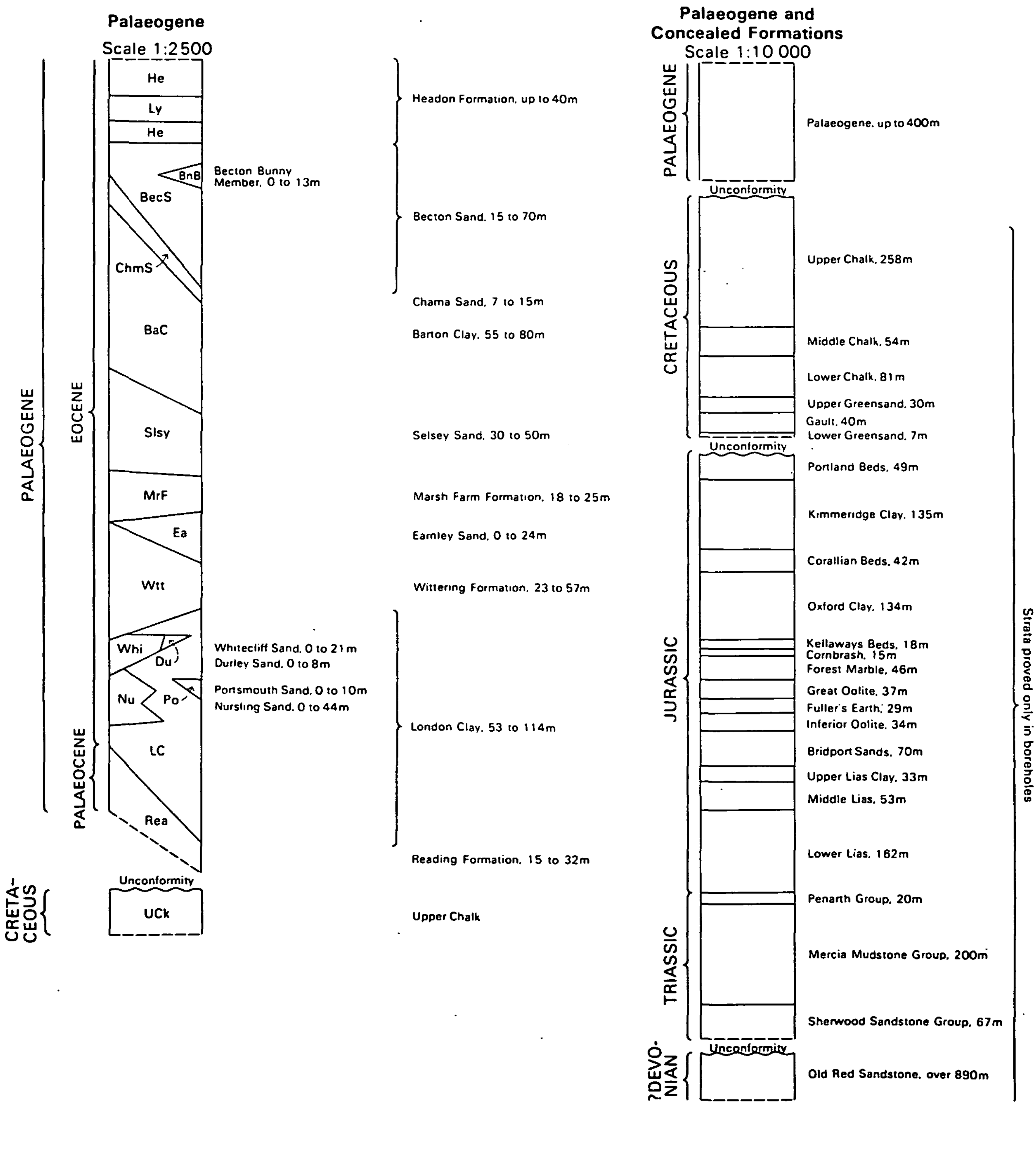
The units do not outcrop at surface and therefore do not appear on the thematic maps; they have no direct impact on present land use patterns. However, exploitation of geothermal and hydrocarbons resources potentially contained within the concealed formations could have effects on surface development.

?Devonian

The oldest rocks proved within the study area consist of hard greyish green and reddish brown sandstone alternating with siltstone and mudstone, of presumed Devonian age: 890m of these beds were penetrated in the Marchwood Borehole [3991 1118].

Triassic

The Triassic rocks rest with angular unconformity on the presumed Devonian rocks and form a sequence in which pebble beds are succeeded by sandstones and then by mudstones. The two lower divisions, the Budleigh Salterton Pebble Beds and the Otter Sandstone, comprise the *Sherwood Sandstone Group.* The *Budleigh Salterton Pebble Beds* consist of green to reddish brown conglomerates; the *Otter Sandstone* is predominantly a reddish brown fine to medium-grained sandstone with many siltstone and conglomerate interbeds, the latter commonly forming the erosive bases of small-scale fining-upward cycles. Most of the overlying *Mercia Mudstone Group* is made up of reddish brown mudstones and silty mudstones with some anhydritic layers. At the base are siltstones with thin sandstone interbeds, while near the top are greyish green silty mudstones and siltstones (Blue Anchor Formation). The topmost Triassic strata, included in the *Penarth Group* (formerly Rhaetic Beds), are divided into the Westbury Formation below, consisting of dark grey to black fissile pyritic mudstones with thin silty limestones, and the Lilstock Formation above. The latter consists of the Cotham Member, grey and greyish green calcareous pyritic mudstones, overlain by the pale grey to white limestones of the Langport Member.



A1. Generalised vertical section

Jurassic

Most of the Jurassic strata are marine clays with subordinate beds of sandstone and limestone. The *Lower Lias* and *Middle Lias* are composed mainly of grey silty mudstones and siltstones, the lower part of the Lower Lias consisting of alternating mudstones and argillaceous limestones (Blue Lias). The *Upper Lias* is divided into a lower (*Clay*) unit of mudstone and siltstone, overlain by the *Bridport Sands*, greyish green very fine-grained sandstone with calcareous-cemented layers (doggers).

The *Inferior Oolite* and *Great Oolite* consist predominantly of shelly oolitic and sandy limestones. They are separated by the *Fuller's Earth*, grey mudstones with limestone interbeds, and overlain by the *Forest Marble*, mudstones with thin limestones. The *Cornbrash* consists of grey limestones. It passes up into the *Kellaways Beds*, consisting of greyish brown silty mudstone (the Kellaways Clay), overlain by white sandstone and siltstone (the Kellaways Rock).

The Jurassic sea probably deepened during *Oxford Clay* times, when grey mudstone and siltstone were deposited. The succeeding episode of cyclical regression and transgression produced the variable facies of the *Corallian Beds*, which include oolitic limestone, sandstone, and mudstone. The Jurassic basin reached its greatest extent during deposition of the grey mudstones and siltstones of the *Kimmeridge Clay*. In the Western Esplanade Borehole [4156 1202] the Kimmeridge Clay is overlain by *Portland Beds*, consisting of sandstone and grey silty and sandy limestone. The youngest Jurassic formation, the Lulworth Formation, may be present beneath the district, but has not been penetrated in boreholes.

Cretaceous

The older Cretaceous formations, the Durlston Formation and the Wealden Beds, may be present beneath the district, but they too have yet to be proved in boreholes. The district was affected by early Cretaceous earth movements and an angular unconformity occurs at the base of the youngest widespread Cretaceous deposit, the glauconitic sands of the *Lower Greensand*. This unconformity cuts down progressively westwards in the district. The overlying *Gault* consists of marine grey silty mudstone; it passes up into glauconitic sandstone and siltstone of the *Upper Greensand*. The remainder of the Cretaceous is occupied by the white to grey fine-grained limestones of the *Chalk*.

Exposed formations

Upper Chalk

The Upper Chalk typically consists of white or greyish white fine-grained limestone with layers of nodular flints at many levels; in places the flints occur scattered throughout the chalk. The formation has only small outcrop areas in the northwest and northeast of the study area. In boreholes the Upper Chalk is proved to be up to 258m thick, but only about the upper 50m outcrop within the boundary of the area. The formation was dug for agricultural or building lime, but many pits are now overgrown or backfilled. No Chalk is worked from within the area at present.

Reading Formation

This formation, the basal unit of the Tertiary (Palaeogene) sequence, shows considerable variability. The commonest lithology is red-mottled clay, but locally fine-, medium- and coarse-grained sands and pebble beds predominate. At the base of the formation is a thin (0.1 to 2.1m) bed (the "Basement Bed") of glauconitic sand and clay with flint pebbles, that rests unconformably on the Upper Chalk. The Basement Bed, although thin, is persistent over the study area, but the beds above show rapid lateral and vertical changes between sand- and clay-dominated sequences. The formation is mainly sand with pebble beds at outcrop in the northwest of the district, whereas red-mottled clay is predominant at outcrop in the northeast. Thickness of the formation ranges between 15 and 32m (average 27m).

London Clay

About 90 percent of the formation consists of olive-grey silty and sandy clay, clayey and sandy silt, and silty sand; sporadic claystones occur, and thin but persistent beds of rounded flint pebbles occur at the bases of sedimentary cycles. The London Clay is divided into five coarsening-upward sedimentary cycles, or divisions, lettered A to E, and the occurrence of a particular lithology depends on its position within a cycle: clay occurs at the base of a typical cycle, and is succeeded upwards by silt and then sand at the tops of the cycle. The *Portsmouth Sand* occurs channeled in at the top of Division C, and the Whitecliff Sand at the top of Division D1. Nursling Sand occurs mainly in divisions C and D.

The *Durley Sand*, clayey fine-grained sand that outcrops in the east of the district is probably laterally equivalent to the Whitecliff Sand. The *Nursling Sand* is silty sand and sandy silt that locally contains thin beds of shelly calcareous sandstone, the *Glycymeris Sandstone*.

The main outcrop of the London Clay is 4 to 6km wide, extending in an arc along the northern edge of the study area between Hamptworth and Durley. London Clay is also brought to surface along the axis of the Portsdown Anticline between Nursling and Sandwick. The formation varies between 53 and 114m thick.

Bracklesham Group

The Bracklesham Group of the study area is divided into four formations, which are, in ascending order: Wittering Formation, Earnley Sand, Marsh Farm Formation, and Selsey Sand.

Wittering Formation

The formation succeeds the London Clay, and rests on Whitecliff Sand or on clays of Division D or E. The commonest lithology is laminated clay with partings, thin beds and lenses of sand and silt; the two other main lithologies are sand interbedded with clay in subequal proportions; and fine- to medium-grained sand with thin clay laminae and bands. A distinctive 4m-thick marker bed of brown to black carbonacous clay and lignite, with associated seat-earth clay penetrated by rootlets (the "*Whitecliff Bay Bed*") is persistent throughout the study area.

The three main lithologies interfinger both laterally and vertically, so that the formation is variable.

The formation crops out in a curved belt that crosses the study area from Hamptworth in the west to Locks Heath in the east. An anticline and syncline cause the outcrop to broaden considerably between West Wellow and Ower. East of the River Test, the outcrop bifurcates round the Portsdown Anticline, the northern branch occupying a syncline between Romsey and Botley. The thickness of the formation in the study area ranges between 23 and 57m (average 38m).

The Wittering Formation of the study area has locally been used as a source of brickclays, but there are at present no working pits in the formation.

Earnley Sand

The formation consists of green and greyish green glauconitic silty sand and sandy silt, in places very fossiliferous; the sharp base on Wittering Formation is locally marked by a scatter of flint pebbles. The main outcrop extends from Nomansland in the northeast of the study area through Southampton Docks to Hamble; outliers between West Wellow and Chandler's Ford and between West End and Botley occupy synclines north of the Portsdown Anticline. Over much of the study area, the formation gives rise to moderately pronounced hills and ridges that rise above the more subdued ground underlain by Wittering Formation.

The Earnley Sand is mostly 4 to 8m thick in the western part of the study area between Nomansland and Copythorne; it dies out just west of Nomansland. Elsewhere in the area the formation is 15 to 18m thick at outcrop.

Marsh Farm Formation

The formation is lithologically similar to the Wittering Formation, that is laminated clays and sands with clay laminae, and shows similar marked lateral variation in the proportions of sand and clay present. Sand is dominant in the area west of Calmore, clay generally in the remainder of the area, although variations in lithology are so marked that this statement is very much a generalisation.

The formation crops out in the area extending from Nomansland in the northwest, through Totton and Southampton Docks, to Warsash in the southeast. It is generally between 18 and 25m thick.

Selsey Sand

The Selsey Sand of the study area consists dominantly of green to greenish grey silty sand, silty clay, and sandy clayey silt, commonly glauconitic and shelly at some levels. A scatter of flint pebbles occurs locally at the junction with the underlying Marsh Farm Formation. Its outcrop extends from Nomansland in the west via Netley Marsh, Marchwood and along Southampton Water to Chilling in the southeast. It is generally between 30 and 50m thick.

Barton Group

The Barton Group of the study area is divided into three formations, namely, in ascending order Barton Clay, Chama Sand, and Becton Sand.

Barton Clay

The Barton Clay is distinguished from the underlying Selsey Sand by an upward increase in clay content. The formation consists of olive-grey to greenish grey clay with a variable content of glauconite. The clays are locally shelly. The formation crops out in a belt extending from Fritham to Fawley via Minstead, Ashurst and Hythe. Thicknesses vary between 55 and 80m.

Chama Sand

Next in sequence is the Chama Sand, which has a gradational base on the Barton Clay. It consists of greenish grey to grey slightly glauconitic silty very fine-grained sand and glauconitic extremely sandy clay. It is between 8 and 15m thick in the study area.

Becton Sand

A continuation of the upward-coarsening sequence of the Barton Group culminates in a transition from Chama Sand to the overlying Becton Sand, which consists of yellow to pale grey-weathering well-sorted fine-grained to very fine-grained sand. Included in the Becton Sand is the *Becton Bunny Member*, consisting at outcrop of carbonaceous, clayey very fine-grained sand and silt that passes eastwards into clay-free sand. The formation is 15 to 70m thick.

Headon Formation

The youngest Tertiary formation in the study area is the Headon Formation, up to 40m thick, consisting of greenish grey shelly clays, silts and sands; the *Lyndhurst Member*, olive-grey extremely sandy clay and clayey sand, separates the lower and upper parts of the formation.

DESCRIPTION OF THE DRIFT DEPOSITS

Clay-with-flints consists of reddish brown clay with unworn flints; it rests on the Chalk in the northeast of the study area. It is generally only 0.5 to 1.0m thick, but up to 11m are locally present in solution pipes penetrating into Chalk.

Head is widespread in the area, and consists mainly of weathering products derived from the solid and older drift deposits by a combination of downwash and solifluction; it probably also includes at most localities a proportion of in situ weathering material (regolith). Head is generally thin (up to 1m) and is in some cases difficult to distinguish from solid formations. Lobes of *Head Gravel*, consisting of clayey gravel, occur adjacent to outcrops of Older River Gravels and River Terrace deposits.

The Older River Gravels (formerly called Plateau Gravels) form plateaux in the west of the study area at heights between 89 and 129m AOD; five levels are present. The deposits are clayey sandy flint gravels, generally 4m thick.

River Terrace Deposits are widespread along the valleys of the River Test and Itchen. Eleven terraces occur, with surfaces ranging from 91m AOD in the north of the study area, to OD at Southampton Water; another three terraces lie beneath the estuary. The deposits are mainly flint gravels with considerable sand content, generally between 1 and 7m thick; the five highest terrace deposits contain more clay than the lower terraces. The 1st, 3rd, 5th and 6th terraces are overlain by clays and sandy silt and silty clay (formerly called "brickearth").

The estuaries of the rivers Test, Itchen and Hamble contain buried channels, flanked by terraces which are now flooded by the sea. The oldest channel-fill deposits are fluviatile clays, silty sands, freshwater marls, and subordinate sands, succeeded upwards by salt-marsh and estuarine sediments.

Estuarine Alluvium, mainly mud, silt and sand, with minor amounts of gravel, forms extensive areas of intertidal mud flats and salt marshes along Southampton Water and its associated tributaries.

The main areas of *Alluvium* in the study area occur along the valleys of the rivers Test and Itchen. The alluvial flats of the main rivers are underlain by 2 to 6m of flint gravel overlain by 1 to 2m of peat, clayey peat and organic silty clay. The Alluvium locally contains beds of soft *Peat* and *Calcareous Tufa*.

Landslip is limited in extent, being confined to slopes around Romsey and near Bitterne, where Wittering Formation laminated clays are overlain by, or are in close proximity to, River Terrace Deposits.

STRUCTURE

The Tertiary strata of the study area generally are inclined southwards at between 1° and 2°, so that the older formations outcrop in the north and are successively overlain by younger formations to the south. This general trend is interrupted in the area east of the River Test by the presence of a gentle anticlinal fold, the Portsdown Anticline, which has the effect of repeating the outcrop of the London Clay. A cross-section that includes the Portsdown Anticline is shown in Figure A2. In the east of the study area, the anticline has a relatively steep northern limb dipping northwards at up to 7°. West of the River Test, the effects of the Portsdown Anticline are to broaden the outcrop of the Wittering Formation, but no London Clay is brought to surface; the structure is illustrated in the cross-section through the western part of the study area (Figure A2). Paralleling the Portsdown Anticline to the north is the complementary syncline, which contains extensive outliers of Wittering Formation, Earnley Sand and Marsh Farm Formation, present as far west as the Blackhill area [3018].

In the south of the study area, the Tertiary rocks are affected by a number of very gentle anticlines and synclines that trend between E-W and ESE-WNW, and which control in detail the distribution of the Headon Formation and Barton Group. The Headon Formation outcrop is mainly contained within a gentle NW-SE trending syncline which may be the continuation of the Bembridge Syncline of the Isle of Wight.

Most of the fold structures in the Tertiary rocks are related to faults in the underlying Mesozoic rocks; the Tertiary strata are "draped" over the earlier faults to produce the present fold pattern.

A fault affecting the Tertiary rocks has been detected at only one locality [348 040], in the south of the study area.

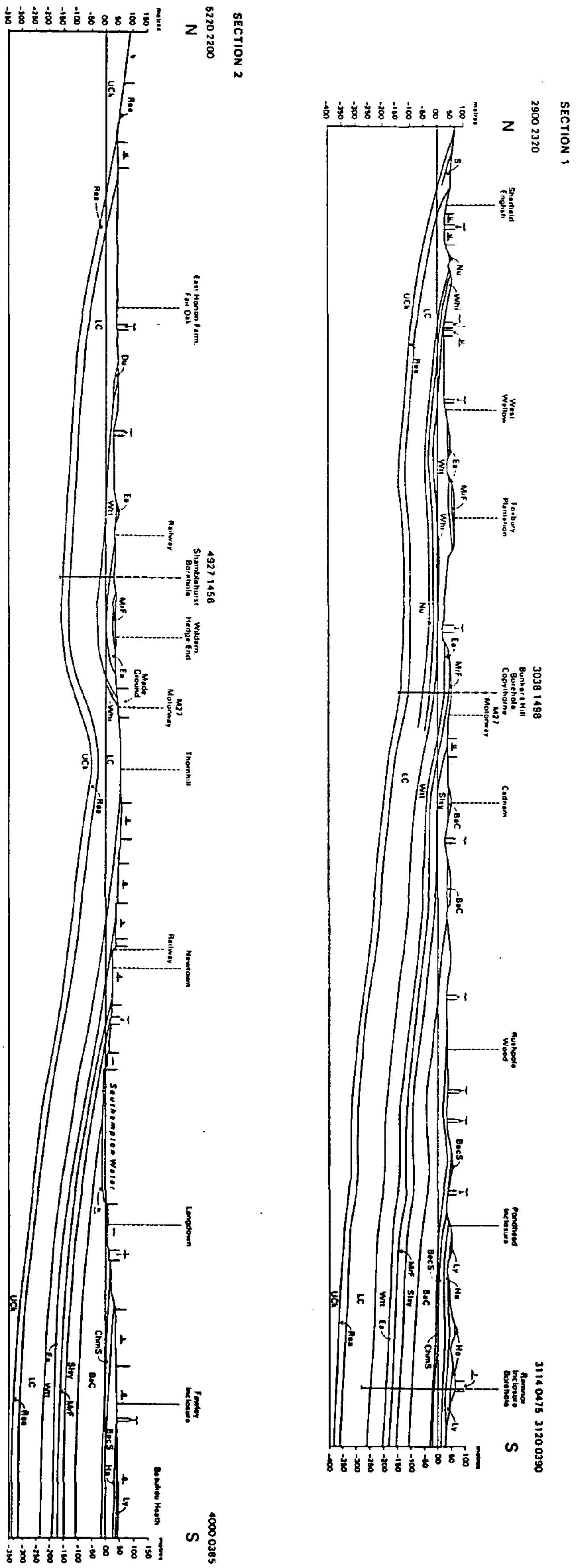
HISTORY OF MINERAL WORKING

At the present day, mineral working in the project area is restricted to quarrying for sand and gravel. In former times a variety of bulk minerals were worked and a summary of the information available on these is given below.

From an early period, chalk has been worked from pits for the purposes of providing an agricultural dressing (clay soils were "marled" to improve their texture) and providing the raw material for burnt lime. For agricultural use the chalk was dug from shallow pits to obtain weathered, rubbly material. Chalk pits are numerous on the Upper Chalk outcrops in the extreme northeast of the project area, especially close to the Reading Formation outcrop, where the material obtained was spread locally on intractable clay soils. Many of the chalk pits have been partially or completely filled: none are active at the present time. Flints obtained as by-production from these chalk pits were used as road metal, though Reid (1902) notes that flints dug from chalk lacked the strength of those produced from Drift deposits.

Brick and tile works were formerly supplied with raw materials from the project area. In early times much of the production of bricks was from clays and loams ("brickearths") found in places overlying River Terrace deposits. In the 19th century, improved production techniques and increased outputs demanded greater volumes of raw materials of a more consistent quality. The drift deposits were abandoned in favour of workings opened in the solid Tertiary formations. Both the London Clay and Wittering Formation furnished large quantities of brick clays, as, to a lesser extent, did the Reading Formation and Barton Clay. The plastic clays of the Reading Formation were stated by Reid (1902) to have been suitable for pipe and tile manufacture. The brickmaking industry of the Southampton area declined in the second half of the 20th century in competition with the large workings in the Oxford Clay of eastern England. A late surviving working, the Lower Swanwick Brickworks, closed in 1974 and clays are no longer dug for brickmaking in the district.

The history of sand and gravel working in the project area is not easy to trace; many workings have been filled or obscured by building developments. Until the introduction of controls on the quality of materials used for building and engineering purposes, sand and gravel were dug on an *ad hoc* basis as close as possible to the site of use. River Terrace gravels and the various deposits of Alluvium furnished flint gravel and the sandy solid formations, such as the Whitecliff Sand were dug for building sand. The extent to which these raw materials were washed and graded is unknown. Gravel for paths and drives was probably washed to reduce the fines content, but gravel with an appreciable content of silt and clay was generally applied to roads, tracks and courtyards, in towns and villages. This last material, which can be dug in many places from Head deposits and the Older River Gravels, is known in southern England as "hoggin". Sand was worked for general building purposes, and these included the production of mortar and rendering. More specialised types of sand were produced on a limited scale for glassmaking, which requires a high silica content, and for foundry moulding, which requires the presence of sufficient fines to bond, without the addition of extra clay.



A2. Cross-sections through the Tertiary rocks

In the present century, River Terrace Deposits have been heavily exploited for sand and gravel production and solid formations, including the Whitecliff Sand and Reading Formation have been quarried for sand. At present, five main uses of aggregates have been established by Hampshire County Council (1983) in the project area:

i) Building sand - a major constituent of mortar and rendering. Sands worked from the solid formations are used for this purpose.

ii) Concreting aggregate - the River Terrace Deposits furnish material which commonly has the correct ratio of sand and gravel for use in concrete, with comparatively little washing. Other sources of such aggregate are sea-dredged sediment and crushed rock, of which a considerable quantity (mainly limestone) is imported into the area.

iii) Fill material - the Older River Gravels and some Head deposits yield clay-bound gravels which are suitable for use as fill ("hoggin"). Imported crushed rock and chalk rubble are also used for this purpose.

iv) Surfacing materials - imported crushed rock is generally used in tar or bitumen mixes, but some locally produced sand is used in asphalt. Hoggin is used for tracks and paths.

v) Drainage works - River Terrace Gravels furnish clean washed stone for use in drainage works.

Production of sand and gravel in Hampshire, as a whole, reached a peak in 1974 at just under 5 million tonnes of building sand (0.95 million tonnes), concreting aggregate (2.3 million tonnes) and hoggin (1.65 million tonnes). Since that time, when production was boosted by borrow pit excavations during the building of the M27 motorway, the overall figures have declined. At present, total production in the above categories is estimated to be below 2 million tonnes for the county of Hampshire as a whole. Production in the study area is constrained by urban development, by conservation measures designed to protect the environment and by the exhaustion of resources in the remaining areas. Heavy reliance is placed on crushed rock, particularly Carboniferous Limestone from the Somerset outcrops, and the bulk of the concrete prepared in the project area at the present day uses that material. The project area produces hoggin for fill, and clean washed gravel and building sand. There is a small production of foundry sand.

It is unlikely that the established pattern of aggregate use in the district will alter in the foreseeable future. Imported materials will continue to exceed local production and this deficit will be met by imported crushed rock and sea-dredged aggregate.

GEOTECHNICAL TESTS AND THEIR APPLICATIONS

The geotechnical tests referred to in the descriptions of the engineering geology maps are explained here, together with their application.

Density tests

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

Dry density is calculated by dividing the mass of soil after drying at 105°C to constant weight (i.e. solids only), by its total volume before drying.

Saturated density is calculated by dividing the mass of soil with its pore space filled with water, by its volume. Full details of the determination of soil density are given in BS 1377 "Methods of testing soils for civil engineering purposes." The density of soil in its various states of saturation are basic soil properties which are used in a variety of calculations including assessing overburden pressure, slope stability, surcharge pressure, and earth pressure on retaining walls.

Moisture content

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

Atterberg or consistency limits

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

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

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

Particle size analysis

The particle size distribution of a soil is determined by sieving and sedimentation. A sample of soil is dried, weighed and sieved to remove the fraction greater than 20mm in size. It is then immersed in water with a dispersing agent such as sodium hexametaphosphate to break up soil aggregates. The sample is then wet sieved to remove particles less than 0.063mm. The fraction retained on the 0.063mm sieve is dried and passed through a nest of sieves of mesh size ranging from 20mm to 0.063mm. The fraction retained on each sieve is weighed and the cumulative percentage passing each sieve is calculated. A grading curve of percentage passing, against sieve size is plotted. The fines which passed through the 0.063mm sieve are graded by sedimentation. A representative subsample is made up into a suspension with distilled water placed in a tall jar and made up to a volume of 500 ml. It is then agitated vigorously and allowed to settle. Samples are removed by pipette from a given depth at specific times. The samples are dried and the contained solids weighed. The size distribution can then be calculated using Stokes' law which relates settling time to particle size. The entire grading curve for coarse and fine material can then be plotted. Full details are given in BS 1377. An alternative method, for the fine fraction, using a hydrometer is also described in BS 1377.

Particle size distribution is used for classifying soil in engineering terms (BS 5930). Particle size distribution curves will indicate soil behaviour with regard to permeability, susceptibility to frost heave or liquefaction, and will give some indication of strength properties. Particle size analysis does not however indicate structure and will not distinguish between a sandy clay and a laminated sand and clay which may behave very differently.

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

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

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

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

California Bearing Ratio (C.B.R.)

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

A series of samples are compacted in a 152mm diameter mould at moisture contents around the optimum moisture content for maximum compaction. A surcharge weight is placed on the soil which is then immersed in water for four days. The mould is placed in a load frame and a plunger 48.5mm in diameter is forced into the sample to a penetration of 2.5 mm and 5mm. The C.B.R value is determined as the higher of the ratios of the resistance at 2.5mm and 5mm penetration to the standard resistance of crushed stone at the same penetrations. (Details are given in BS 1377). In the field the plunger is jacked into the ground against the reaction of a heavy lorry. (Field values are usually lower than laboratory values). The results of the C.B.R test are used to assess the suitability of soil for use as base, sub-base and subgrade in road construction.

Compaction

The compaction test determines the moisture content at which a soil may be compacted to its maximum density. A quantity of soil (5kg) is compacted in a standard mould using a standard rammer (2.5kg or 4.5kg) which is dropped from a standard height (300mm or 450mm) a standard number of times (27). The density of the compacted soil is then measured and its moisture content determined. The procedure is then repeated using the same soil at different moisture contents.

The density of the compacted soil is plotted against its moisture content and the moisture content at which maximum compacted density may be achieved is read from the curve. (Details are given in BS 1377).

The results of the compaction test show the moisture content at which it is best to place a given soil as fill or to use it to build an embankment.

Permeability

The permeability of a soil is its capacity to allow water to flow through it. It may be measured in the laboratory using samples or in the field using boreholes.

In the laboratory two tests are commonly employed, the constant head test for coarse grained soils and the falling head test for fine grained soils. In the constant head test a sample of granular soil is confined in a perspex tube, a constant head of water is applied to one end and water is allowed to flow through the sample. Manometers are connected through the cylinder walls to monitor the pressure along the flow path. Permeability may then be calculated, using Darcy's Law, the path length, pressure difference, cross-sectional area of the sample and the quantity of water passed in a given time.

In a falling head test a sample of fine grained soil containing clay or silt is placed in a cylinder standing in a tray of water. A glass standpipe is connected to the top of the sample and filled with water. The time taken for the water level in the standpipe to drop a given distance is then measured. Permeability may then be calculated from the time, the drop in height, the cross-sectional area of the standpipe, the cross-sectional area of the sample and the length of the sample. (Details are given in BS 1377).

Laboratory tests do not take account of the structural differences in the soil, such as fissuring, and may not give a true permeability of the ground in situ. Pumping tests using boreholes give a more representative value but are more expensive.

In a field permeability test water is pumped out of a borehole and the effect on the water level in adjacent boreholes is monitored, or if a single borehole is being used it may be pumped out and the water level recovery time recorded. An alternative approach is to pump water into a borehole under pressure and measure the volumes of water flowing into the borehole at a number of different pressures (details are given in BS 5930). The information obtained from either method enables a coefficient of permeability for the ground as a whole to be calculated.

Permeability is used to predict the inflow of water during excavations or tunnelling and to design groundwater control schemes to deal with it. Permeability is important when assessing waste disposal sites, the siting and construction of water retaining structures such as dams, lagoons and canals. The assessment of potential well yields requires field permeability determination for the formations concerned.

Consolidation test

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

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

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

Triaxial Compression Test

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

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

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

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

Shear Box Test

A rectangular prism of soil is cut from an undisturbed sample and placed in an open-ended, square, metal box which consists of an upper and lower half bolted together. The sample is fitted top and bottom with perforated metal plates and porous stones and the assembly placed in a trolley. A vertical load is applied to the sample via a hanger assembly. The bolts holding the upper and lower halves of the box are then removed and the specimen is sheared by applying a horizontal force to one half of the box assembly. The magnitude of the shearing force and the displacement are measured and the maximum shearing stress determined. The procedure is repeated several times with samples of the same soil at different vertical loads. From the combined results the apparent cohesion and angle of shearing resistance can be calculated.

The shear box test measures the same parameters, cohesion and angle of shearing resistance, as the triaxial compression test but does so in a manner which does not allow the drainage conditions to be controlled. Also the plane of failure is governed by the test apparatus not by the soil properties. The triaxial test is therefore preferred in most applications.

However, the shear box test is able to test granular soils more easily than the triaxial method and it is also able to test greater displacements. It is therefore suited to determining the peak and residual strength parameters needed to assess slope stability of hillsides and the landslips which may have taken place on them.

Chemical Tests

Sulphate

The sulphate content of soil is determined by leaching a weighed sample of soil with hydrochloric acid and precipitating the dissolved sulphate by the addition of an excess of barium chloride. The precipitate is then filtered, ignited in a furnace and weighed.

The sulphate content of groundwater or an aqueous soil extract is determined by passing the water through a column of ion exchange resin which converts the sulphate content to hydrochloric acid. The acid content, and hence sulphate, is then determined by titration with sodium hydroxide. Details are given in BS 1377.

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

pH

About 30gms of soil are weighed and placed in 75ml of distilled water in a beaker. The mixture is stirred and allowed to infuse overnight. A glass electrode connected to a pH meter is then placed in the stirred mixture and the pH reading taken. The electrode and meter may also be used to determine the pH of groundwater samples; pH may also be determined colorimetrically. Details are given in BS 1377.

The pH of soil or groundwater is important when designing concrete structures below ground surface. Ordinary Portland cement is not recommended in situations with a pH below 6, high alumina cement can be used down to pH 4 and supersulphated cement has been used to pH 3.5. Acidic groundwaters can also cause corrosion in buried iron pipes.

Organic Content

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

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