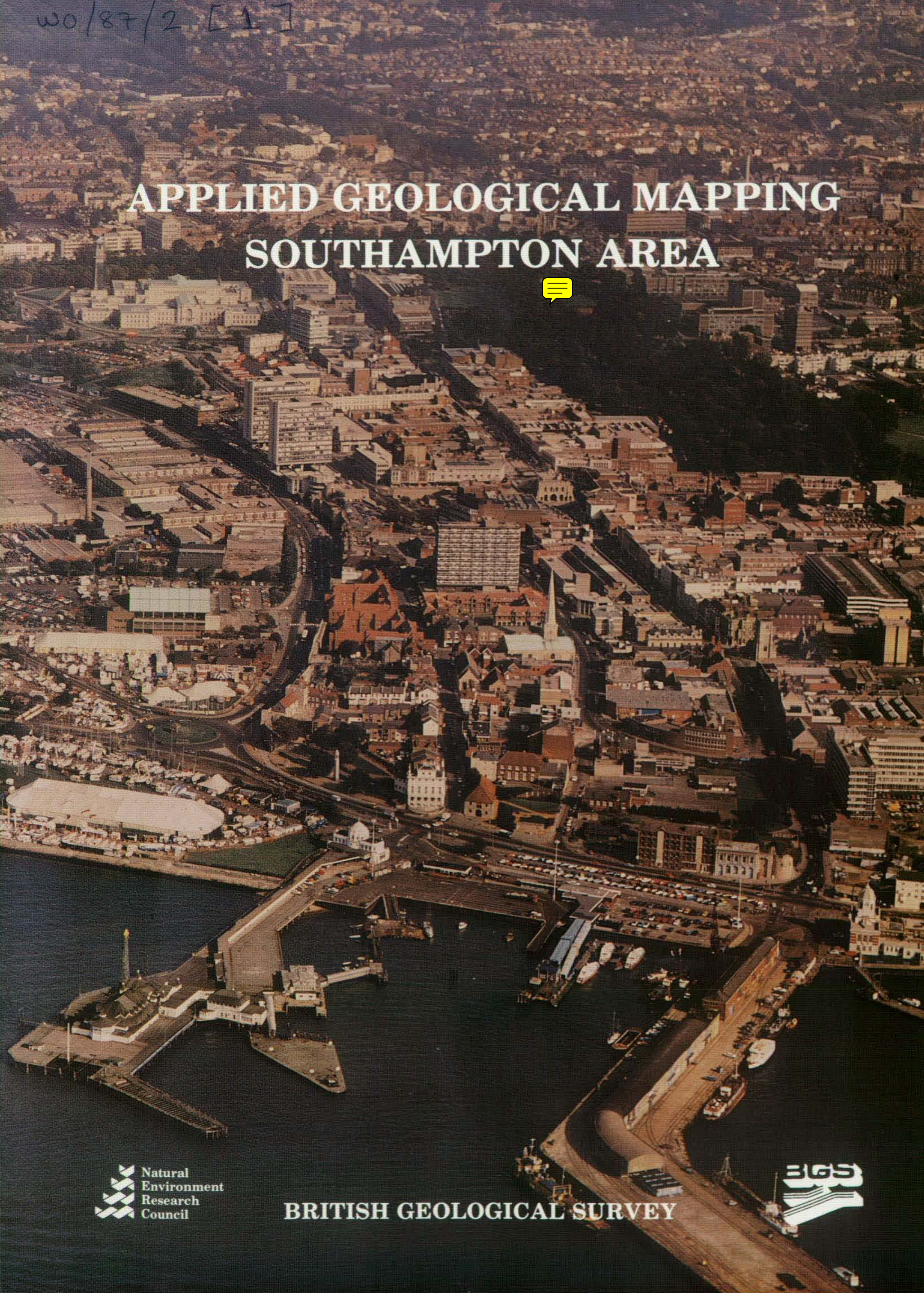
APPLIED GEOLOGICAL MAPPING
SOUTHAMPTON AREA



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.

MAPS OF ENGINEERING GEOLOGY (J, K) SLOPE (L) AQUIFER DISTRIBUTION (H)

VOLUME 9

BGS Research Report ICSO/87/2

Natural Environment Research Council
BRITISH GEOLOGICAL SURVEY

APPLIED GEOLOGICAL MAPPING SOUTHAMPTON AREA

Area covered by
1:50 000 Geological sheet No. 315 (Southampton)
Parts of OS 1:10 000 sheets SU20, SU21, SU22, SU30, SU31, SU32, SU40, SU41, SU42, SU50, SU51 and SU52

VOLUME 9: MAPS OF ENGINEERING GEOLOGY, SLOPE AND AQUIFER DISTRIBUTION

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.
Applied geological mapping: Southampton area.
Research Report of the British Geological Survey, No ICSO/87/2, vol 9.

Authors
R. A. Edwards BSc PhD
R. C. Scrivener BSc PhD
British Geological Survey
St Just
30 Pennsylvania Road
Exeter EX4 6BX

A. Forster BSc

British Geological Survey
Keyworth
Nottingham NG12 5GG

EXETER BRITISH GEOLOGICAL SURVEY 1987

This page is blank

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.

DESCRIPTION OF APPLIED GEOLOGY MAPS

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 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 the Engineering Geology of Solid Deposits Map (J). Details of the engineering properties and behaviour of the solid deposits are as follow:-

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.

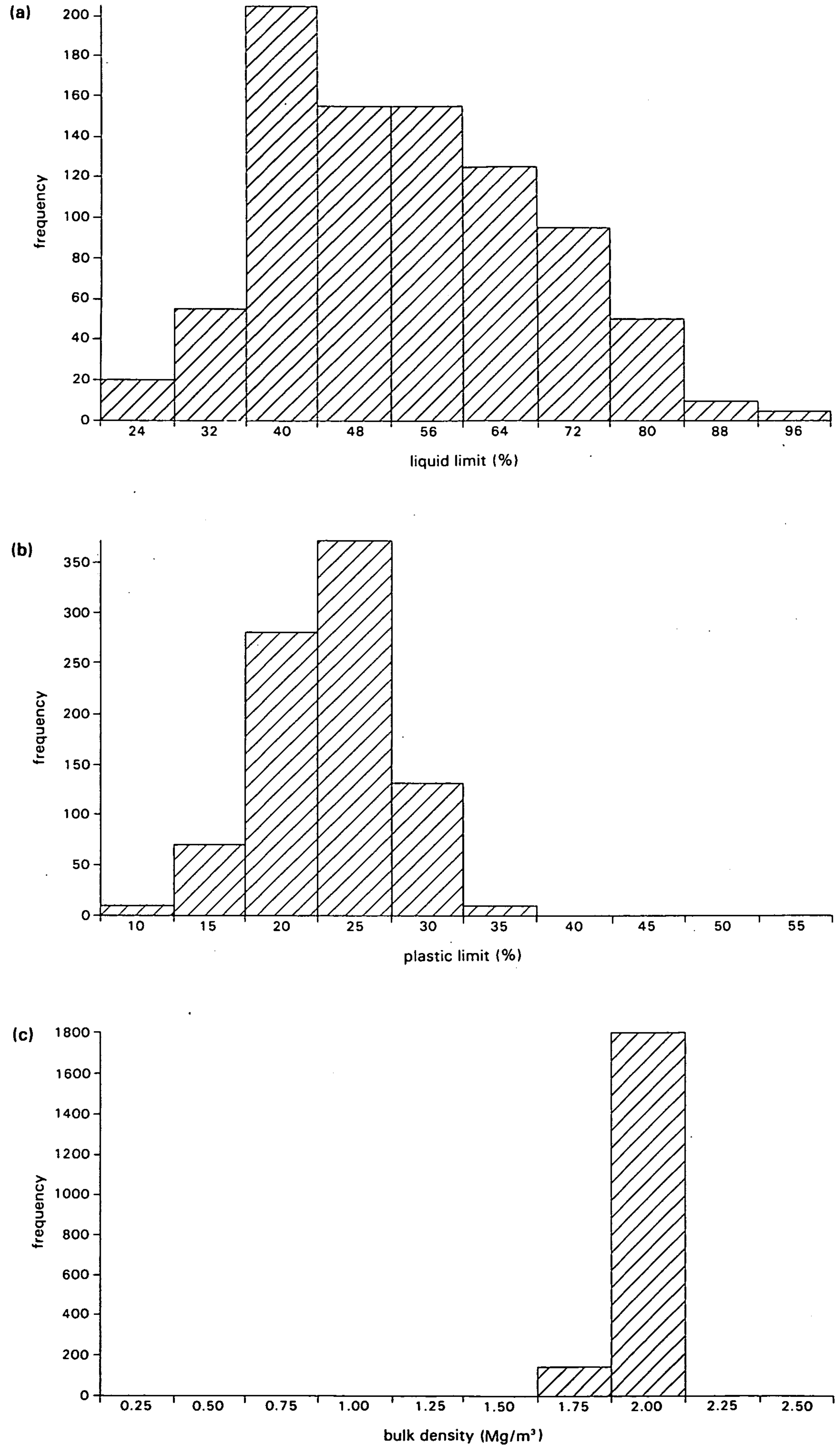
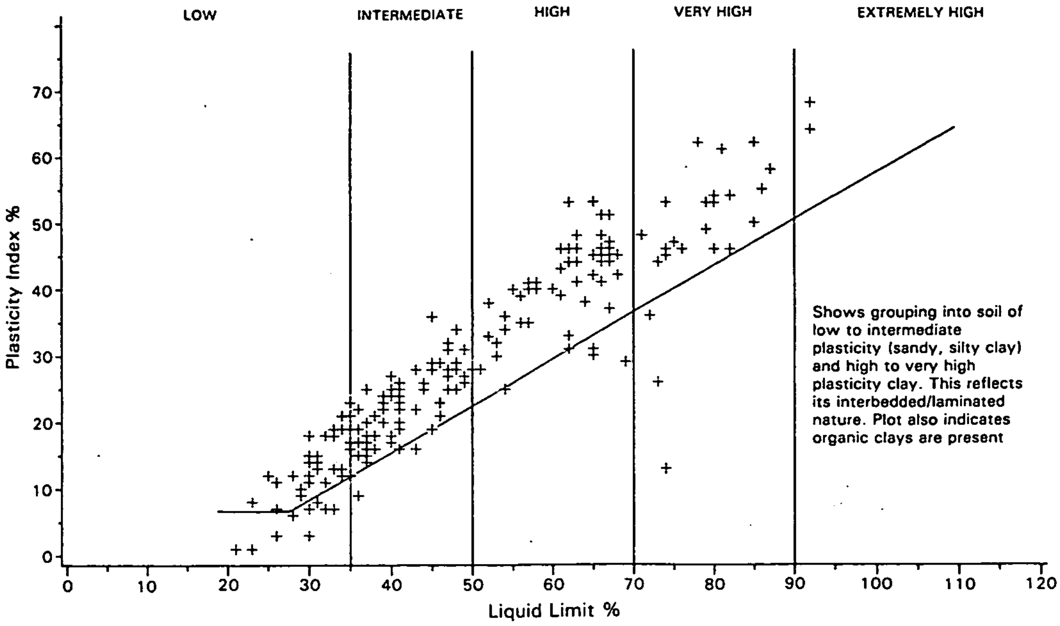
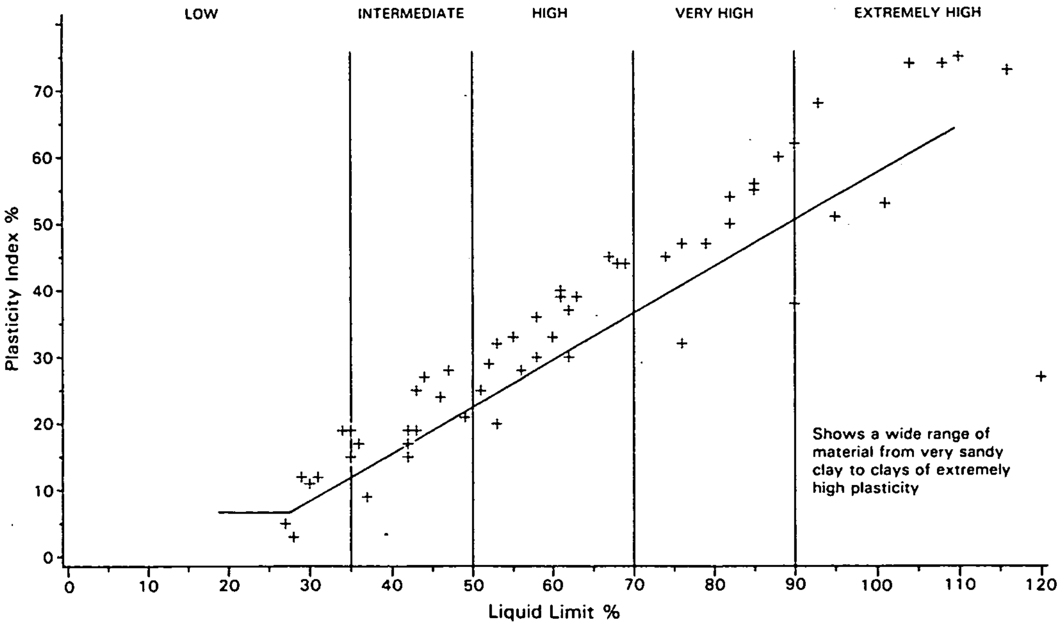


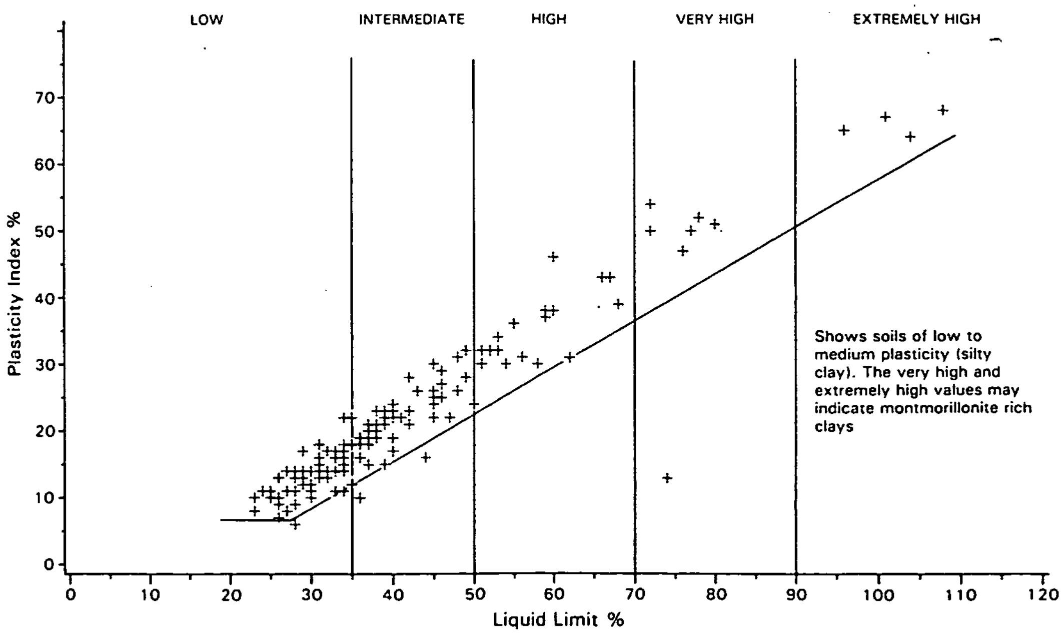
Figure 12. Frequency bar charts for liquid limit, plastic limit and bulk density values for the London Clay in the Hampshire Basin



(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

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 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 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 cl 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. 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 the material dredged from the estuary having been used. 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° and 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° slope angle 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).