NATURAL ENVIRONMENT RESEARCH COUNCIL

BRITISH GEOLOGICAL SURVEY

Geological Survey of England and Wales

WA/VG/86/2

Aspects of the drift geology of the Crosby, Bootle, Aintree area

Part of 1:50 000 Sheets 83 (Formby) and 84 (Wigan)

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Bibliographical reference

NUTT, M J C and LOWE, D J 1986
Aspects of the drift geology of
the Crosby, Bootle, Aintree area
(Keyworth: British Geological Survey)

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Production of this report was funded by the Department of the Environment

The views expressed in this report are not necessarily those of the Department of the Environment.

KEYWORTH: BRITISH GEOLOGICAL SURVEY 1986

USER'S RESPONSIBILITY

The responsibility for assuring the accuracy of the data for any given site, as indicated by the maps and the report, must remain solely that of the user. Care has been taken in selecting, plotting and interpreting data. Emphasis has been placed on data obtained by geotechnical engineers and geologists, and on observations made in the field.

Nevertheless, it is possible that anomalous ground conditions may exist undetected at any particular site. Each site should, therefore, be investigated by detailed surveys with the drilling of exploratory boreholes to prove the ground conditions present, after taking into account the extent, nature and setting of the proposed development.

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SUMMARY

This report presents the results of a study commissioned by the Department of the Environment in 1985 to provide a geological information base that would facilitate informed consideration of planning and decisions on development proposals in the Crosby, Bootle, Aintree area. Planning and development are mainly concerned with the surface and immediate subsurface materials which in this area are largely superficial deposits. For this reason no revision of the underlying solid geology has been undertaken. The extent, characteristics and variations of the recognised superficial deposits are described, together with their known interrelationships. An introductory section deals with the methods whereby the various output thematic maps were derived and how they are intended to be used. The relevance of various features to planning and land use is indicated. Additional sections deal with the actual geological history of the area (explaining the formation and distribution of the deposits described) and the history of previous geological research.

In the light of the study carried out and as a complement to the results presented, recommendations for future work in the area are included.

INTRODUCTION

The project to produce thematic geological maps of the Crosby, Bootle, Aintree area (referred to as the Sefton Project) derived from a feasibility study carried out in 1983 into the production of thematic geology maps for the whole of the Liverpool area. Undertaking the complete Liverpool study was considered to be impracticable within the available funds. It was decided, therefore, to attempt a somewhat more limited study of the two 1:10 000 scale maps (SJ39NW and SJ39NE) covering Crosby, Bootle and Aintree (Figure 1), which have a wide range of features of the superficial geology of direct interest to land-use planning.

a. Sources of data

Existing geological map coverage of the area dated from surveys carried out between 1930 and 1937 and certain aspects were in need of revision or reinterpretation in the light both of increased sub-surface data and general advances in geological and geotechnical knowledge. Proposals for the project involved the expansion of the existing British Geological Survey sub-surface data archive for the two sheets and adjacent areas, by collection of records held by various authorities in the area. This having been accomplished, the complete database was rationalised and interpreted to allow the existing geological drift maps to be revised and the most suitable thematic map output to be identified and derived.

The first stage of the study involved the assessment of information available within the BGS geological archive. Potentially useful data were present in the following forms:

a. 6-inch scale County Series geological maps covering the study area and surrounding district, surveyed by Wray and Tonks between 1920 and 1937.

b. 6-inch scale County Series field maps produced during the above survey. These included useful manuscript data of various types which had not been published. The maps also gave an indication of the topography of the area at the time of survey.

c. 6-inch scale County Series field maps with geological data surveyed by De Rance prior to 1900. These were on a different topographic base from that used in the Wray/Tonks survey and also included geological data and interpretations not directly used in the later maps.

d. 6-inch scale County Series field maps (southern part of the area only) surveyed by Hull in about 1850. These maps showed a still earlier topography, predating extensive urban development, and included later revision of Solid geology and added Drift information by De Rance.

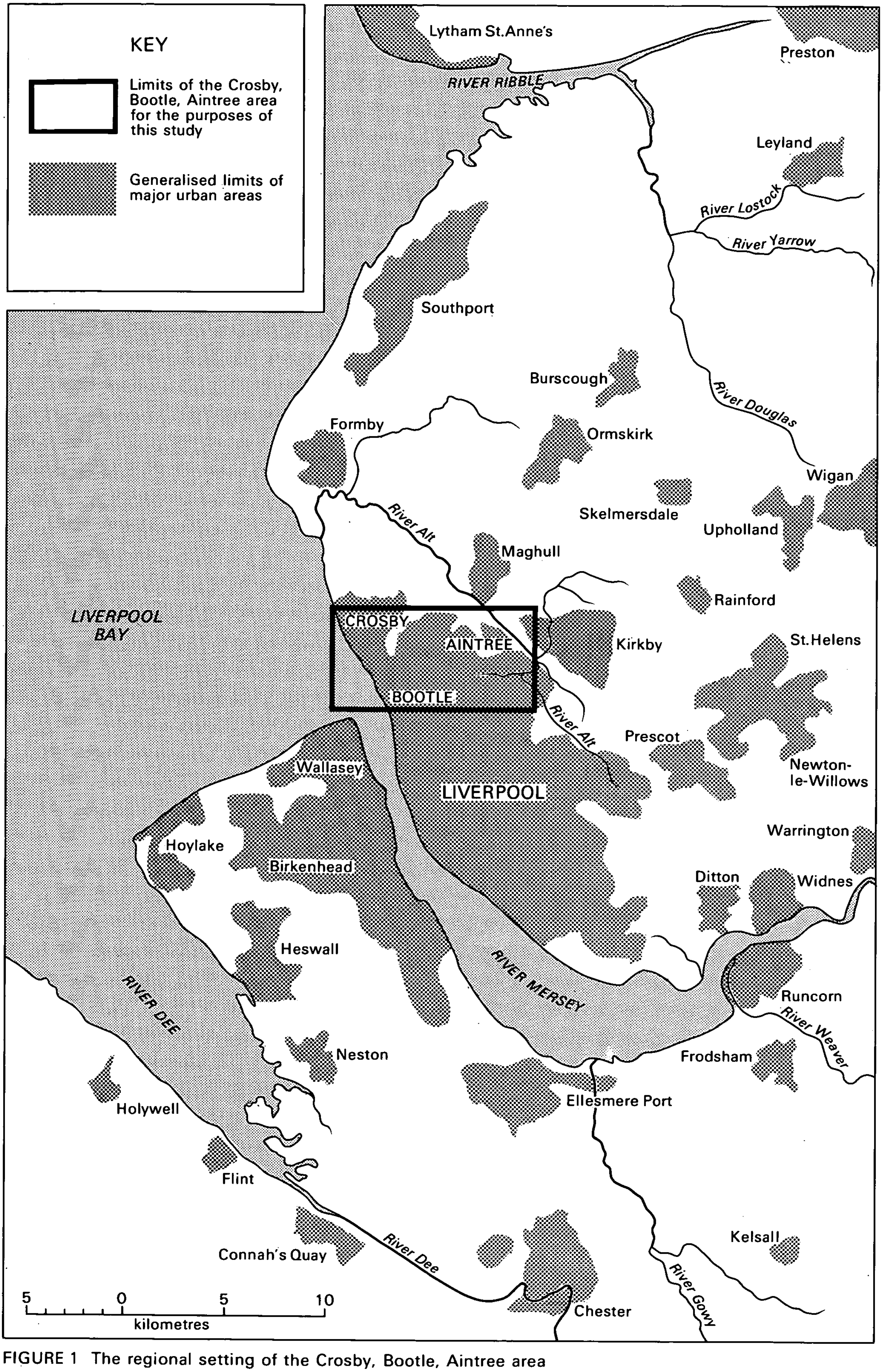

FIGURE 1 The regional setting of the Crosby, Bootle, Aintree area

e. Memoirs descriptive of the findings of the latest geological survey of the area included an explanation of the geological interpretations shown on the maps in a. above and detailed observations recorded during the survey. Older Memoirs by De Rance described the observations and conclusions of the earlier surveys.

f. Field note books. Only those of Wray have been preserved and these added little to the data on the field maps and in the Memoirs.

g. Borehole records and 6-inch site plans for sheets SJ39NW and SJ39NE and for a 1-km strip to the north, south and east of the study area.

h. Published papers dealing with various aspects of the geology provided background information.

During this initial assessment, a number of obvious inconsistencies were resolved. For instance, manuscript data on Wray's field maps allowed the accurate siting of an number of boreholes previously uncertainly located on the 1:10 560 sheet site plans (BGS borehole data records), and Wray's field map notations provided details of several boreholes previously not included in the borehole records. Conversely, the same field maps showed the location of boreholes for which no details could be located.

By processing the existing BGS borehole records, a comprehensive yet straightforward data-gathering method was devised for application in Liverpool, by locally recruited, geologically-trained, assistants. In brief, this involved the location of all borehole or trial pit sites on 1:10 000 scale site maps, and the collection of the actual record, linking site to record by means of unique registration numbers. Details of number and site were registered together with 8-figure National Grid reference, with a surveyed or approximated level of the borehole collar relative to Ordnance Datum and the actual depth of the borehole or pit. Ancillary steps included the metrication of all Imperial units and the adjustment to the present Ordnance Datum, of levels previously related to older, obsolete, datums such as the Old Dock Sill and Liverpool Bay Datum.

Having assessed the extent of the BGS archive the next stage was to make contact with the various local authorities and other organisations in the north Liverpool area which might be expected to hold sub-surface records. Copies of borehole and trial pit data were obtained directly from those sources with few records, and arrangements were made for on-site data collection from the other authorities.

In all some 1270 borehole records were collected for this study. This includes boreholes occurring within a 1 km periphery to the Crosby, Bootle, Aintree area shown on the maps. Unfortunately two major collections of borehole information were unavailable to us during the data-gathering stage. First, the British Rail collection was in the process of being transferred from Liverpool to Manchester. Second, the borehole records originating from the Property Services Department of the former Lancashire County Council at Preston were not curated after they had been transferred to the new Metropolitan Borough of Sefton on its inauguration, but remain in store. No separate schedule of these records is known to exist.

The temporary assistants were also able to produce drawn-up journals of the borehole and pit records, using a simple colour code to identify broad lithological groups. These journals provided a rapid means of assessing the drift geological sequence in an area and provided a starting point for a more detailed interpretation. Using the same colour code as employed in the journals, the borehole location symbols on the site maps were shaded to indicate the lithology of the uppermost drift deposit at each data point.

Another aspect of the data collection exercise was the plotting of sewer trench lines on the appropriate site maps and the copying of scale drawings of geology exposed during the sewer construction. Generally the sewer lines crossed areas with limited borehole coverage and since they included accurately levelled bench marks at intervals along their length and often showed lateral relationships of deposits, they were a valuable data source.

b Preparation of maps

With data collection in Liverpool complete, the next stage of the study was to commence map production. The accumulated borehole data from all sources were assessed. Individual boreholes were entered in the BGS register, and sited on a 1:10 000 topographic plastic master map, Map 1.

Provisional 1:10 000 drift maps were prepared from existing 6-inch maps. Borehole information was superimposed and lines amended as necessary, by reference to the original field evidence. Having been surveyed before the area was heavily built up, landscaped and 'paved', these early maps provided a valuable guide to geological and topographical features which were obscured at the time of the most recent survey. Generally, by making use of the topography and geological observations shown on the various field slips, it was possible to amend the drift boundaries on the maps to agree with the sub-surface data. Rarely, in the absence of useful evidence on the field maps, minor amendments were made on a conjectural basis in such a way as to satisfy the borehole indications and fulfil the requirements of local topography and geological feasibility. Map 2, showing the distribution of superficial (drift) deposits, was thus completed.

The thinner deposits of Made Ground or Fill were omitted from the compilation of Map 2 since, in such a heavily urbanised area, they were expected to occur over much of the ground. An arbitrary limit of 0.5 m of these materials was considered a suitable cut-off for map presentation. Map 3, which gives a broad indication of the extent and composition of Made Ground greater than 0.5 m in thickness, was compiled from the numerous sub-surface records, from records of waste disposal sites, from notes on the various field maps and a knowledge of the sites of pits and quarries, now filled in, as shown on the older maps. Of necessity, lacking adequate records in some areas, the lines and compositions shown on Map 3 are locally uncertain (see also pp.32-33).

Map 4, showing the distribution of peat deposits at surface and beneath younger formations, was compiled in a broadly similar manner. Surface occurrences were taken directly from Map 2 and the limits of the subcrop of all identifiable peat beds more than 0.3 m thick were derived by consideration of the borehole records, the pre-existing field maps and the anticipated three-dimensional variation of the deposits. In some areas of low borehole density, unmapped peat may occur beneath younger deposits or peat may be locally thin or absent within the subcrops shown.

To produce the indurate rock-head contour map (Map 5), the first stage was to plot all known data points for the upper surface of the solid strata onto a base map. A certain amount of interpretation was required to identify the optimum level in sub-surface records. Once these relatively precise points were located and their density of distribution was apparent, obvious gaps in the coverage were filled by less-satisfactory data points indicating the level of deepest penetration into the drift deposits. Having established this framework the contours shown on Map 5 were interpolated at 5 m vertical intervals. In those areas where data coverage was not definitive, the contours were spaced equidistantly between the nearest reliable figures.

The superficial deposit thickness (isopachyte) map (Map 6) was compiled in a broadly similar way. Along the coast it was necessary to employ fixed levels for the Made Ground land surface of the docks (see NOTE Map 6 SJ39NW), because many of the boreholes were drilled before the docks were constructed. Across the entire area it was possible to establish a network of secondary thickness data points by taking the difference in value of surface and rock-head contours at their points of intersection and by comparing surface spot-heights with the level of the underlying rock-head surface. Isopachytes were drawn at 5 m vertical intervals and where data were sparse the lines are spaced proportionally between the nearest definitive points.

In using any map which shows geological information, such as geological boundaries, contours or isopachytes, or in looking at geological cross-sections, it must be remembered that the data shown are interpretive. Many geological boundaries are not directly observable and their surveyed position is based upon the utilisation of various visible or predictable factors by a geologist. Similarly, sub-surface contours such as those of Map 5 and Map 6 cannot be directly surveyed after the manner of surface contour lines. Thus, although certain of the geological boundaries which are directly observable are accurate within the limitations imposed by scale and drafting techniques, the majority of the lines shown on the various maps are interpretive and, to some degree, conjectural. They must, therefore, be treated as such and not assumed to be precise at any one location.

c Content and limitations of maps

Map 1: Borehole and Trial Pit Locations provides an up-to-date guide to the locations and registration numbers of the sub-surface records on sheets SJ39NW and SJ39NE which were considered during the present study. The nature of the symbol denoting each site indicates the accuracy of the position shown and whether rockhead was proved at the site. The map gives no indication of the origin of the record, the detail or reliability of the information it contains, or the nature and thickness of the deposits penetrated. These records and additional records from a 1 km strip around the margins of the area which were taken into consideration in map compilation, may be inspected, by arrangement, at the British Geological Survey National Geosciences Data Centre, Keyworth, Nottingham NG12 5GG (Tel. 06077 6111). On the broad scale, the density of records within a given area on Map 1 will provide an approximate guide to the data that were available for the compilation of the remaining maps in the series.

Map 2: Distribution of Superficial (Drift) Deposits is essentially a traditional drift geology map, except that deposits of Made Ground or Fill are omitted. It shows the lateral, but not vertical, extent of the various unconsolidated deposits which cover most of the area and the limits of drift-free solid rock outcrops, together with their lithologies. So far as is possible in the Index and Explanation on the maps, the deposits are listed in increasing age, with the youngest drift deposit at the top and the oldest bedrock at the bottom.

Indication of a particular deposit on the map does not necessarily imply that the deposit will be visible throughout its mapped extent, since often it will be covered by soil, vegetation or fill materials, but with the exception of the latter (which are shown separately on Map 3) these thin surface layers can generally be ignored. By referring to the map and bearing in mind the possible sequences of superficial deposits (as illustrated by Figures 5, 6 and 7 and proved by the many boreholes in the area) it is possible to predict, though not guarantee, the deposits present beneath a site. Reference to the map index will provide a brief and generalised lithological description of the material forming each deposit as well as a figure for the maximum thickness of each deposit encountered during this study. From this, it follows that across much of the area the deposits present will be thinner than this maximum figure, but also that locally there might be greater, as yet unproven, thicknesses.

In using the map it is important to appreciate that the junctions between some deposits may be gradational or transitional and that the boundary lines shown on the map are drawn at a suitable level within this passage zone.For example, the boundary between "Till" and "Sand", undifferentiated, may locally be drawn within a sequence of sandy till and in this situation material more typical of Till may appear on the sand side of the boundary at some locations, and vice versa.

If used in the light of the above considerations, Map 2 provides a useful guide to the planning of a first-stage site investigation programme for any proposed development. In the case of planning transport routes such as roads or railways, available corridors could be compared in the first instance on the presence or absence of potential geological problems. If tunnelling was anticipated the map would provide a guide to suitable portal sites and, used in conjunction with Maps 5 and 6, a first indication could be gained of the materials likely to be encountered in a tunnel or a deep surface cutting.

Map 3: Distribution of Made Ground and Fill shows the known or predicted extent of all the deposits resulting from human activity which overlie the original land surface or fill former excavations. In the urban areas this artificial veneer is ubiquitous, but the mapped extent of fill is based upon thicknesses greater than or equal to 0.5 m. The limits shown are a best approximation, derived by the means outlined above, and similar deposits may remain unrecorded.

In the west of the area a belt of sand-dunes has been landscaped and the material redistributed both within and outside the mapped Blown Sand outcrop. Since the landscaped material overlies similar undisturbed sand deposits it has not been possible to differentiate the two. However, it is believed that earlier hard core and industrial waste deposits have been covered over by the redistributed sand and this must be borne in mind when investigating a site within the general area of Blown Sand (Map 2 SJ39NW).

Within the limits imposed by the database used in its compilation and the problems of recognising landscaped material, as outlined above, the map gives a first indication of whether significant Made Ground or Fill is present at a given locality. Reference to the index symbols provides broad details of the type of material to be anticipated at the site. Not all fill deposits will present problems, but potential problems which could be deduced from the map include those associated with chemical activity and differential compaction. Much of the material in these artificial deposits is inert but a proportion, including household refuse and industrial waste, may be chemically active, if not specifically toxic. In particular, dangerous gases, including methane, can be generated within this type of material.

Where the deposits, of whatever type, fill old excavations they will be less well compacted than surrounding, natural, materials. A combination of potentially active waste in an infilled excavation can lead to still more serious problems due to cavitation following chemical or bacterial breakdown of the fill. On Map 3 the known backfilled areas are identified by symbols and, where known, the nature of the fill is indicated. Similarly symbols are used to indicate the approximate composition and extent of the various materials within Made Ground spreads. Where the data sources include more than one type of material a combination of symbols is employed. Generally no attempt has been made to draw boundaries between different materials within a mapped spread, the exceptions being where backfilled areas occur within or adjacent to Made Ground.

Thus Map 3 provides a first step in assessing the likelihood of artificial deposits being present at a site and gives a broad guide to their nature and, hence, to potential problems. On this basis the requirements for detailed investigations, possibly including a chemical survey, can be assessed at an early stage.

<u>Map 4: Distribution of Peat</u> shows not only the surface extent of Peat deposits (as also shown on Map 2) but the conjectured limits of peat beds beneath younger deposits. Used in conjunction with the generalised drift sequences illustrated in Figures 5, 6 and 7 and thickness ranges detailed in the report (see pp.42-44) the map provides a first step towards assessing the scale of

any foundation or excavation problems likely to be caused by peat deposits. The map provides an indication of the areas where peat is recorded and where particularly careful and detailed site investigation is recommended. Due to the uneven spread of data points the map is not definitive and peat beds of significant thickness but relatively limited lateral extent may occur, unrecorded, particularly within the post-Till sequence. This map indicates peat deposits for which evidence has been located. However, all ground shown as being covered by post-Till deposits on Map 2 may contain peat locally. In addition it is theoretically possible that peat may occur within a till sequence, but those areas shown as Till on Map 2 are unlikely to pose any problems due to interbedded peats.

Map 5: Indurate Rock-head Contours provides a 'best estimate' of the relief of the upper surface of unweathered solid formations. As pointed out above, the contours are locally generalised in areas of poor data coverage, but the map gives a reasonable indication of the trends of the indurate surface. It differs from many other rockhead contour maps insofar as weathered bedrock is included with the drift deposits lying above the contoured surface. This means that there is not a total equivalence of the contoured surface with the supposed pre-drift landscape. Generally, however, the disparity is of only limited importance and is equal to the thickness of weathered rock present.

Within drift-free areas the indurate rock-head cannot be assumed to lie at the present-day surface level. Drift-free areas may contain a zone of weathered rock and/or made ground; however, these areas have not been contoured because of the lack of accurate information. They would, therefore, need to be investigated in detail if an indurate rock-head foundation was required.

Bearing in mind the generalisation implicit in its compilation and accepting possible inbuilt errors due to estimated surface levels and uncertainty within the borehole logs the map will provide a guide to the approximate level of indurate rock at any given point and to precise levels at many data points. A contour interval of 5 m was chosen as being the most accurate that could be used. The contours are shown as continuous lines in those areas where data control allows reasonable precision but in areas of generalisation the contour lines are broken. Since in some forms of development it may be necessary to place foundations on the indurate surface or in certain forms of tunnelling it is advantageous to avoid the indurate material, the map provides a useful starting point in planning and costing these types of project. The examination of the varied strengths of cementation within the indurate solid rock sequence did not form part of this study.

Map 6: Thickness (Isopachytes) of Superficial Deposits presents a 'best estimate' of the thickness variation of all the non-indurate materials, including Made Ground, lying between the surface contoured on Map 5 and the present land surface. It suffers the same limitations of generalisation that have been described for Map 5, as well as built-in errors deriving from ambiguous terminology and lack of detail in the original data. In areas of Solid rock outcrop, which are otherwise free of superficial deposits, Made Ground or quarry fill have not been contoured because of the lack of accurate information. These areas, as picked out on Map 3, would need to be investigated in order to assess the thicknesses present. Elsewhere the map provides a basis for estimation of the potential thickness of superficial deposits in an area, these data being useful in assessing the feasibility of excavated or piled foundations or the gross nature of materials likely to be encountered in tunnelling or trenching operations. The map does not, however, give any indication of lithological variation within the superficial sequence, nor any intermediate levels within the sequence where foundation or excavation conditions may change.

DESCRIPTION OF THE DISTRICT

The district comprises the 50 km^2 of country on the northern fringe of the Liverpool conurbation (Figure 1) covered by Ordnance Survey 1:10 000 sheets SJ39NW and SJ39NE. Approximately 6 km^2 of this total area in the west and southwest is part of the estuary of the River Mersey and another 3 km^2 fringing the estuary represents land reclaimed from the river.

a Topography

A system of subdued ridges and minor hills extends north-west to south-east across the centre of the district, reaching a maximum elevation of about 45 m OD on the southern margin (Figure 2). To the west and northwest of this higher ground the land falls gently towards the Mersey estuary, with a broad belt of flat or slightly undulating land of 7.5 m to 15 m elevation fringing the coast. This flattish area is partly of natural origin, partly the result of landscaping of existing sand dunes and partly the product of land reclamation from the Mersey. A narrow tongue of ground less than 8 m in elevation penetrates inland along the course of the Rimrose Brook. The original valley profile is obscured locally by man-made deposits.

North-eastwards from the central ridges (Figure 2) the ground again falls gently into the valley of the River Alt, which has a flood plain up to 2 km wide falling from about 15 m to 8 m north-westwards across the area. To the north-east of the Alt the land rises steadily, reaching about 25 m O.D. in the Waddicar area.

West of the high ground in the centre of the district (Figure 2) there was original natural surface drainage to the Mersey. Most of the smaller streams are now obscured by recent development and whilst some drainage probably follows older, culverted, routes, much water now reaches the Mersey by way of modern integrated drainage systems. Only the Rimrose Brook in the north of this westward-draining area remains an essentially surface stream and most of its headwaters are now culverted. West of Litherland numerous artificial drains feed water to Rimrose Brook and the lower reaches of the stream were once prone to flooding, a situation alleviated in the 20th century by the construction of an extensive system of underground channels which carry storm drainage to the Mersey.

Eastwards of the district's central watershed (Figure 2) more surface streams remain, but many smaller drainage routes are now culverted beneath built-up areas. Relatively high ground in the south drains northwards and eastwards by way of Tue Brook (which follows a looping and largely culverted

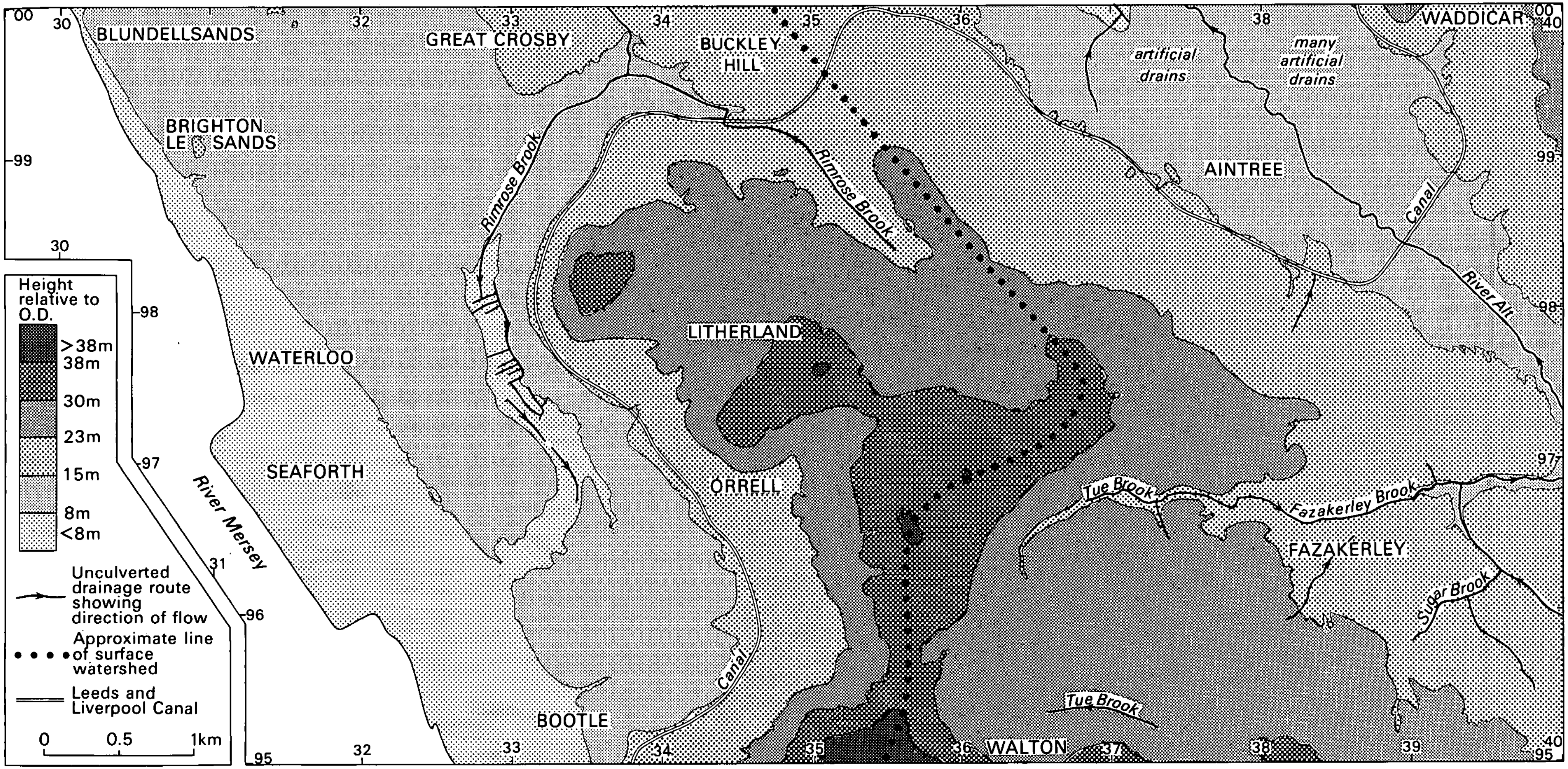

FIGURE 2 Sketch map of the relief and drainage of the Crosby, Bootle, Aintree area

route), Fazakerley Brook and Sugar Brook, all of which flow into the River Alt. The Alt collects almost all of the surface drainage in this eastern district, only a very minor part (including Bechers Brook at Aintree Racecourse) being captured by the Leeds and Liverpool Canal. During the 20th Century the meandering course of the Alt, across a moderately wide flood plain, has been artificially straightened and the drainage of the floodplain itself has been improved by man-made cuts.

Throughout the area, on both sides of the surface watershed, where rocks of the Sherwood Sandstone Group either reach the surface or are overlain by sandy drift, abundant transfer of precipitation must take place directly into the ground and ultimately into the saturated zone within the Permo-Triassic aquifer.

b Land use and communications

The district lies on the northern edge of the Liverpool conurbation (Figure 1) and is well-served by a number of major roads and railways (Figure 3). Once a very important commercial link, the Leeds and Liverpool Canal winds across the area, closely following the '30-foot' contour (Figure 2).

Most of the area is covered by urban residential development of various ages (Figure 3), including not only housing, but shops, schools, hospitals and other public buildings. Some minor industry is found within these generally residential areas, particularly in the older developments adjacent to the docks, but the major factories tend to be grouped together, some on modern industrial estates (Figure 3). Open areas which include recreational facilities, such as parks, playing fields, golf courses, and a race course, as well as derelict areas and agricultural land, are fairly evenly scattered across the district. Only in the northeast, between Aintree and Waddicar, does a significant area of farmland remain, with a very much smaller remnant north of the Rimrose Brook between Buckley Hill and Great Crosby.

Adjacent to the River Mersey a strip of largely reclaimed land is occupied by docks and associated facilities such as warehouses and hard-standings, comprising the older Bootle docks in the south and the modern Seaforth complex to the north. Still farther north on this coastal strip, also on reclaimed land, is an essentially recreational area which includes a marina, boating lake and miniature golf course.

Open space for future development, either residential or industrial, is limited. With the exception of the surviving agricultural land and major

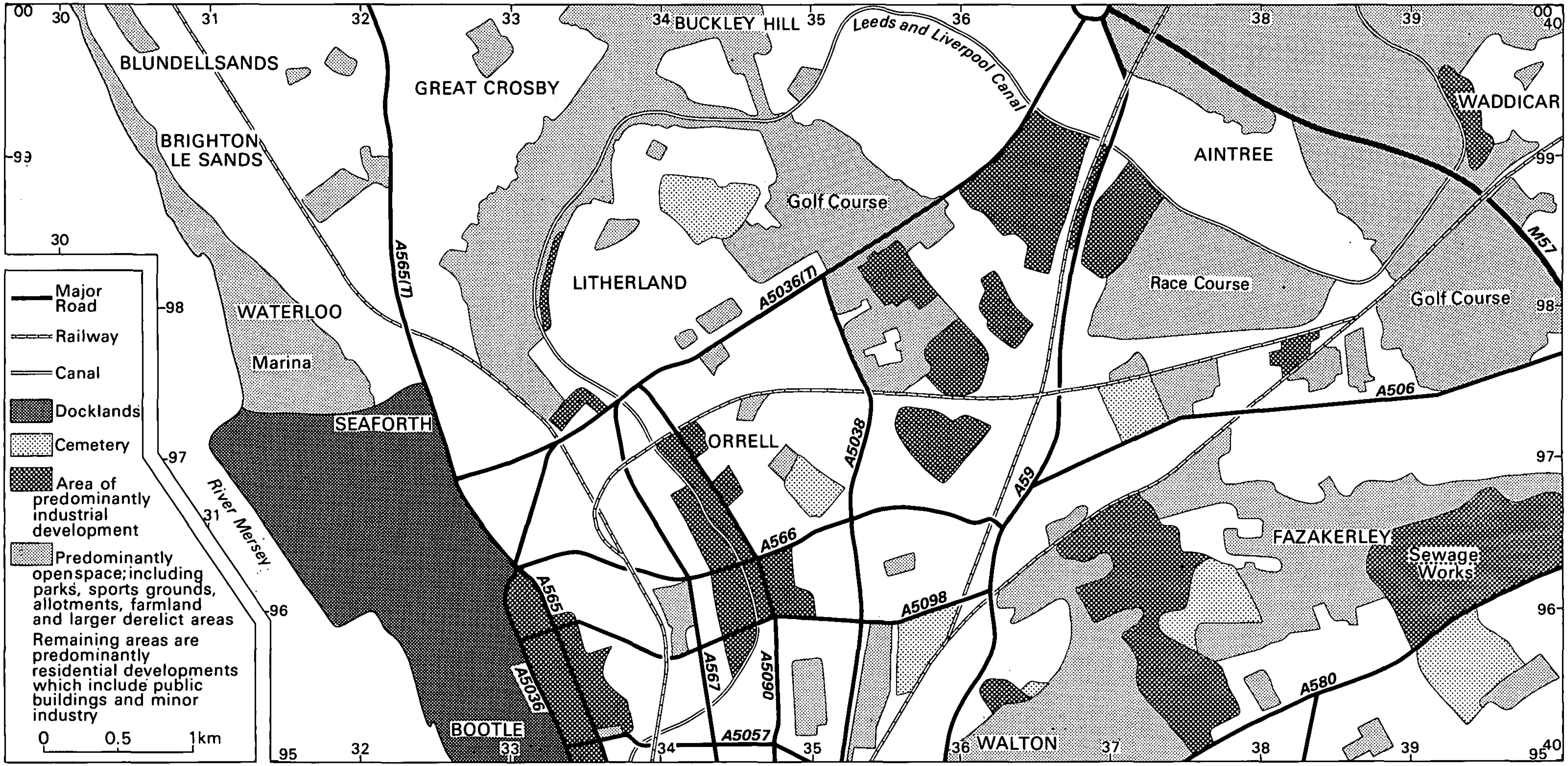

FIGURE 3 Sketch map showing main communication routes and generalised land use in the Crosby, Bootle, Aintree area

recreational areas mentioned above, most open land is derelict or despoiled, representing the sites of old quarries and pits or areas previously considered unsuitable for building for various reasons. Many of these areas have been used for tipping. Modern techniques of foundation engineering might make some of these areas into potential development sites, but it seems more likely that the easier alternative of redeveloping existing built-up or demolition areas will be pursued, keeping development within the existing built-up areas and preserving the few extant open spaces.

HISTORY OF PREVIOUS WORK

Local amateur geologists were active in the Liverpool area and more particularly in coal-bearing areas to the east during early Victorian times, before 1850, but little of relevance to the Crosby, Bootle, Aintree area was published. Edward Hull, of the Geological Survey, worked along the southern margin of the study area and produced six-inch geological maps of the Liverpool district which were included in Old Series One-inch Sheet 79NE, published in 1850. On this map the major divisions of the Solid rocks were delineated, together with the major faults which affected them. No Drift deposits were shown on Geological Survey maps at this time, though Hull's mapping included some observations on the broad extent and lithology of the Drift. The six-inch maps which overlapped northwards from One-inch Sheet 79NE onto One-inch Sheet 90SE were published in 1863. Six-inch survey of the major part of the Crosby, Bootle, Aintree area was carried out by Charles De Rance in 1868, completing Old Series One-inch Sheet 90SE, which was published in 1869. De Rance's mapping delineated the same divisions of the Solid as mapped by Hull to the south, the various formations fitting into a scheme of Triassic subdivisions proposed by Hull (1859) which remained largely unchanged for many years. Descriptions of the various rock units in the area appeared in a short memoir on the geology of Old Series One-inch Sheet 90SE (De Rance, 1870).

In the same memoir De Rance commented upon the nature of the Drift sequence, stating particularly that in the Liverpool-Southport area there was little evidence for a 'triplex' arrangement of glacial deposits such as had been described by Hull in areas to the east. In De Rance's opinion there was little local evidence for a 'Middle Sand and Gravel' division separating an 'Upper' and 'Lower Boulder Clay'. He considered that over most of the study area only the 'Lower Boulder Clay' was present and that such sand beds as were present were intercalations within the latter formation. Short sections in the memoir gave details of a lower peat deposit, the Shirdley Hill Sand, the Lower 'Cyclas' Clay, an upper peat, the Upper Scrobicularia and Cyclas clays and Blown Sand. These units are still locally identifiable, the two clay formations being included in Marine and Estuarine Alluvium during the present study.

Geological work in the area was continued by De Rance and local amateurs, building upon the early Geological Survey results. In 1877 De Rance produced a comprehensive memoir entitled 'The Superficial Geology of the Country adjoining the Coasts of South-West Lancashire' which provided greater detail than his previous description of Sheet 90SE. Between the publication of the two memoirs a tripartite sequence of glacial deposits had been observed and described at Linacre Road, Bootle (Roberts, 1871), but De Rance maintained his view that in the study area a true 'Middle Sand and Gravel' division did not exist. He did, however, accept that the threefold division applied elsewhere in south-west Lancashire.

Other important contributions to the understanding of the superficial deposits were made by Reade (1872, 1876) on glacial striations and fossil remains, Morton (1877, 1897) on striations and erratics and again by De Rance, who carried out a revision of Hull's mapping and the first Drift survey to the south, his six-inch maps being published in 1896. Towards the end of the nineteenth century deep excavations for docks were commenced and as these continued much information regarding the thickness and nature of the Drift deposits (Travis, 1913) was revealed. Mammalian remains were found in the post-glacial deposits (Morton, 1897; Travis, 1913, 1926).

The early years of the twentieth century produced little work of note in the immediate area, but the concept of an 'Irish Sea Glaciation' was developed by Lamplugh (1903) working in the Isle of Man. Commencing in 1910, New Series One-inch Sheet 96 (Liverpool) was resurveyed at the six-inch scale, covering ground previously included on Old Series sheets 79NE and 79SE. The six-inch maps produced extended northwards into the study area, which lies mainly on New Series One-inch Sheet 83 (Formby). This mapping was completed in 1920, with a sheet Memoir, which includes a detailed bibliography, published in 1923 (Wedd and others) and the one-inch map published in 1923. D A Wray was the geologist responsible for the resurvey of Liverpool itself, and he produced a number of papers detailing sections revealed in excavations and boreholes (Wray, 1916, 1922).

Six-inch maps covering the study area and forming parts of New Series One-inch Sheets 83 (Formby) and 84 (Wigan) were resurveyed by Wray and L H Tonks between 1930 and 1937. The Wigan Sheet was published in 1937 and the Formby Sheet in 1942, their memoirs being published in 1938 (Jones and others) and 1948 (Wray and Cope) respectively. Little revision of the Solid geology resulted from the resurvey, though revised estimates of thicknesses were possible, based on borehole data, and the lines of several faults were amended. There was no attempt on the revised maps to separate upper and lower boulder clays, although Wray (in Wray and Cope, 1948) seems to have accepted the occurrence of a tripartite glacial sequence across most of the area, conspicuously avoiding direct reference to the number of glaciations involved in the supposed depositional history. Wray also described in detail the local occurrences of Shirdley Hill Sand, Downholland Silt (the Lower Cyclas Clay and associated beds of De Rance) and thick peat deposits in the Rimrose Brook valley. Referring to a deep well boring in the Aintree area, Wray pointed out the apparently greater relief of the subglacial surface than the present land surface, though his data were insufficient for recognition of any definite channel features, except in the area around the Bootle docks, where there were broad indications of a depression in the rockhead trending up the Rimrose Brook valley.

Between the completion of the above resurvey (1937) and the publication of the Formby Memoir in 1948 an exploratory borehole programme was carried out by the D'Arcy Exploration Company. No boreholes were sunk within the study area, but those in closely adjacent areas provided more precise data for the thicknesses of the various Triassic formations and underlying Permian rocks (Kent, 1948; Wray and Cope, 1948).

Since the publication of the Formby Memoir there has been no work carried out in the Crosby, Bootle, Aintree area by the Geological Survey (now British Geological Survey) until the present study, though other workers have been active. The variation of sea-level since the end of the ice age and the deposits and coastal changes associated with it have been studied, particularly by Gresswell (1957, 1964) and, more recently, Tooley (1974). These studies, and others dealing with superficial deposits, have been greatly aided by the development of radiometric dating techniques, such as carbon-14, which have enabled deposits and hence events to be correlated within and outside the district. A review of the current understanding of post-glacial deposits and events relating to sea-level has been provided by Tooley (1985) and includes reference to relevant earlier contributions.

During the same period there has been a great advance in the interpretation of glacial and immediate post-glacial processes and deposits. The idea of a rigid tripartite sequence which was the product of two glacial advances has been replaced, partly because of the recognition of supraglacial (ice decay) till formation (see, for instance, Boulton, 1972). Whereas the presence of a lodgement till, which in some cases is the Lower Boulder Clay of the old classification, is recognised across most of the area, the higher glacial deposits are now seen as part of a complex of supraglacial sediments and landforms which varies laterally and vertically. The entire sequence, including the lodgement till, has been referred to as the Stockport Formation (Worsley, 1967, 1985).

To the west of the study area sea-bed sampling in the Irish Sea by the Institute of Geological Sciences (now British Geological Survey) has given insight into the late-glacial history of the area (Pantin, 1978). Interpretation of borehole records, seismic data and fossil evidence has produced a detailed picture of the Quaternary processes, deposits and morphology of the Irish Sea basin (Thomas, 1985). On land there has been an increase in the number of boreholes sunk in recent years, mainly due to the recognition of the need to carry out site investigation prior to building development. Much of the borehole and trial pit information is of use in geological interpretation, particularly if considered as part of a widespread study, but its importance may not be apparent if only viewed in isolation. A review of the Quaternary geology of the Lancashire Plain by Longworth (1985) illustrates the potential use of borehole data in geological interpretation along motorway lines.

Since the completion of the resurvey of the one-inch Formby sheet by the Geological Survey in 1937, the Solid rocks beneath the study area have received little attention. Elsewhere in the region the Triassic rocks have been the subject of study by geologists such as Thompson (1969, 1970) in Cheshire and the stratigraphical nomenclature of Hull (1859) has been superseded by modern lithostratigraphical and chronostratigraphical terminology (Warrington and others, 1980). By making a comparison with the older nomenclature the new formational names for Triassic rock units in adjacent areas can be applied to rocks in the study area (see pp.58-60).

Geophysical techniques such as electromagnetic conductivity/resistivity and borehole gamma-ray logging have been applied to Solid and Drift deposits during a study of the Liverpool to Ormskirk area commissioned by the North West Water Authority (University of Birmingham, 1984). The report of the study explains the application of the techniques to the assessment of Drift thicknesses and to general geological interpretation, and also includes a general but up-to-date synthesis of the state of geological knowledge in the area. Detailed studies of the hydrogeology of the district, including the study area, have been carried out by the North West Water Authority. The results of the study are currently unpublished, but in anticipation of them, hydrogeological considerations are largely omitted from the present report. A collection of papers dealing with various aspects of the local Quaternary geology, some previously referred to above, is included in a compilation of geomorphological essays edited by Johnson (1985).

GEOLOGICAL SUCCESSION AND HISTORY

The Crosby, Bootle, Aintree area is underlain by geological formations referred to as 'Solid', which are almost everywhere covered by much younger superficial deposits known collectively as 'Drift' (Figure 4). In this context 'Solid' includes all deposits which have undergone a process of lithification (or diagenesis), a complex series of chemical and physical changes, including compaction and cementation, transforming particulate material into 'rock', in the non-scientific sense of the word. To the geologist, the 'Drift' deposits are also rocks, but their diagenesis is incomplete; they are generally, but not exclusively, soft or plastic rather than hard or brittle.

The following Drift and Solid deposits are present in the area, either at the surface or beneath younger formations:

DRIFT	(Made Ground or Fill)	
	Blown Sand)	
	Marine and Estuarine Alluvium)	
	Alluvium)	QUATERNARY
	Peat)	(Recent and
	Sand, undifferentiated)	Pleistocene)
	Till)	
	Basal Sand and Gravel)	
SOLID	Mercia Mudstone Group)	TRIASSIC (see also
	Sherwood Sandstone Group)	Table 1, p.59)

The geological history of the area reflects the various environments and processes which have prevailed during and since the deposition of these formations, and the interrelationships between the deposits, earth movements and climate. Much of the evidence for the simplified history presented below is derived from subsurface data which include a large number of borehole and trial pit logs within and outside the study area. Consideration of these records, together with surface exposure, enables a comparison and correlation between the deposits preserved from place to place to be made (as for instance illustrated in Figures 5, 6 and 7) and allows an understanding to be reached of the nature and cause of the complex three-dimensional variation of the deposits.

Approximately 250 million years ago, at the beginning of the Triassic Period, the district formed part of an arid landmass which was crossed by a

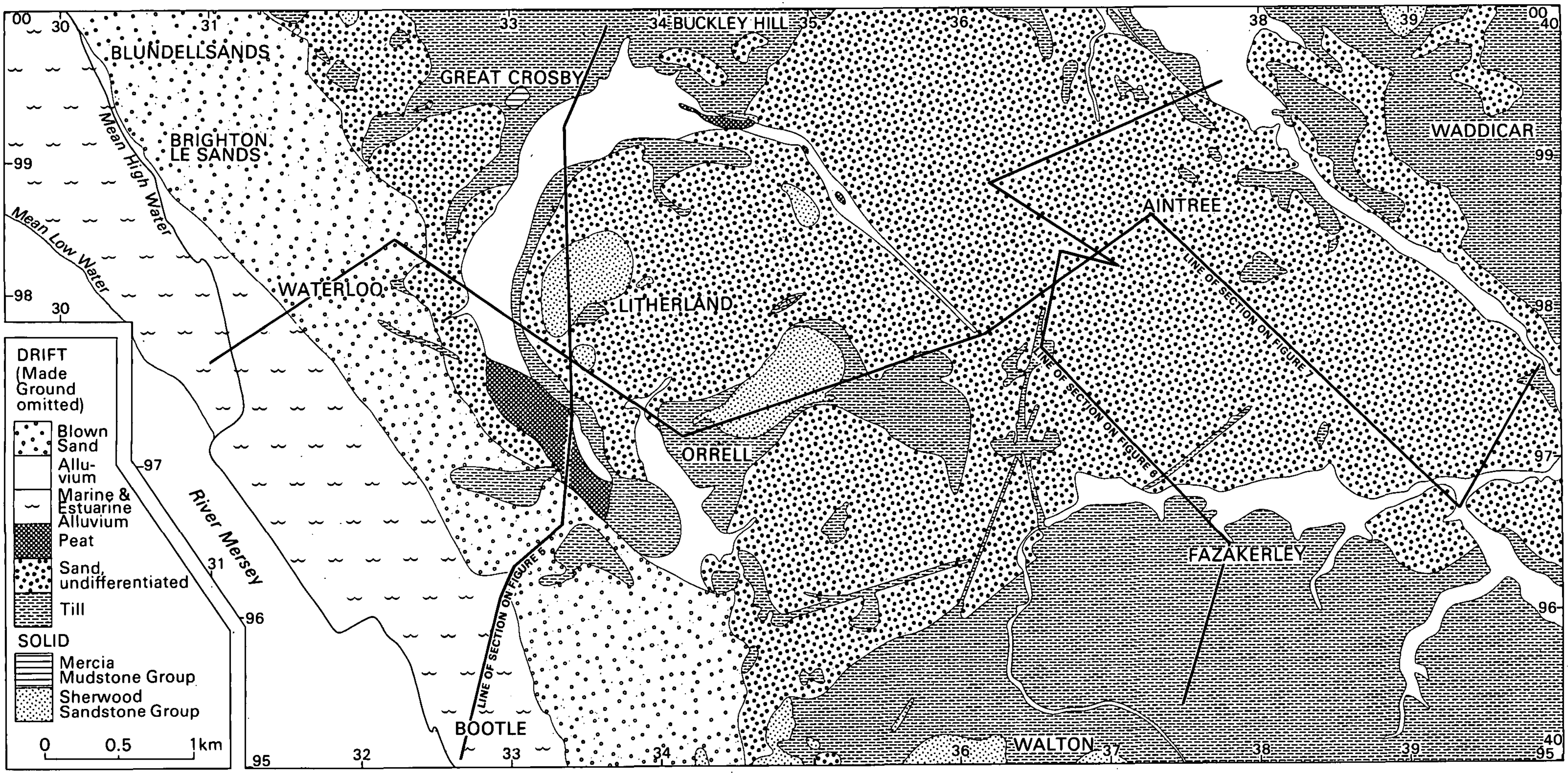

FIGURE 4 Sketch map showing distribution of superficial (drift) deposits in the Crosby, Bootle, Aintree area

number of rivers (Warrington and others, 1980). The landscape probably had little relief and the rivers meandered widely across it, laying down deposits of sand, silt and clay. Simultaneously, winds blowing across the area transported and deposited similar material, producing dunes of sand on the land between the rivers. Occasional flash floods led to the deposition of coarser sediments, including gravels and pebbly sands, and finer fluviatile sediment was spread over wide areas of normally dry land. This regime of wind and river transport and deposition, with flash floods, was eventually modified as both the climate and sea level changed. Much of the area became flooded, some parts intermittently drying out to form extensive mud flats, others forming fringing plains just above high-tide level. Periodically the sea level fluctuated and all or parts of the area became totally submerged. During this episode great thicknesses of fine-grained sediment were deposited, much of the material probably being carried into the area as wind-blown dust. Eventually the mixed sediments described above underwent complete lithification. The earlier deposits became an essentially sandstone sequence, now known as the Sherwood Sandstone Group, and the overlying, finer, deposits produced a predominantly mudstone unit known as the Mercia Mudstone Group. These formations are described in more detail elsewhere (see pp.58-60).

Somewhat later a number of episodes of earth movement occurred which had the effect of folding and faulting the Triassic rocks. The effects of the faulting and minor folding in the Crosby, Bootle, Aintree area have produced locally varied angles and directions of dip. There is, however, a general gentle dip towards the north in most parts of the area, such that progressively younger Solid formations should be present beneath the Drift from south to north, except where faulting has modified this pattern.

Broad features of the present-day drainage and rockhead topography may have commenced to form in the Tertiary period, during a prolonged episode of erosive activity (Edwards and Trotter, 1954). The overall effect was probably to subdue the major upstanding features, such as escarpments along fault lines, and to remove a considerable thickness of the uppermost strata, leaving the Sherwood Sandstone Group rocks at surface. Interaction of the dip of the beds, the faults which dislocated the beds and the variation of resistance to erosion within the rock sequence produced a series of gentle escarpment-like ridges and valleys which were further modified by surface drainage. Major drainage routes exploited the natural valleys provided by the 'slacks' of less resistant rock and valleys or gaps along fault lines, and once established on these lines they incised deeply into the relatively weak rock beneath. Close

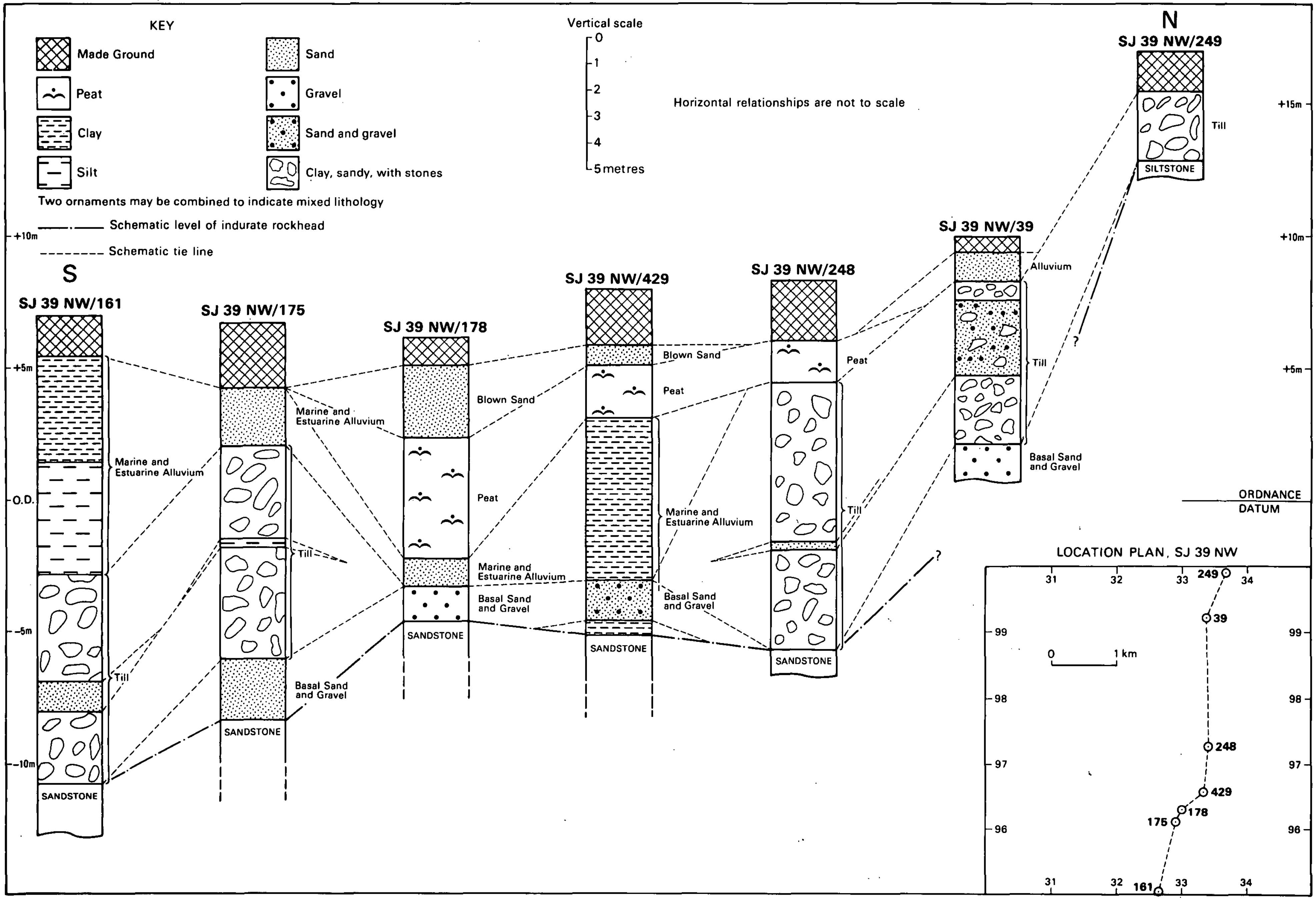

FIGURE 5 Comparative sections through the drift deposits of SJ 39 NW

to the land surface the cementing matrix of the sandstones was partially removed by solution and the land surface was locally covered by a veneer of sand and rock fragments produced by weathering of the parent rock. Thus, by the end of Tertiary times (about 1.6 million years ago) the local landscape probably resembled in general terms the topography indicated by the indurate rock-head contour map (Map 5), though the higher areas were relatively higher and the rockhead valleys generally less deep than now.

Similar conditions probably prevailed into the Quaternary Period, but about 850 000 years ago (Bowen, 1978, p.5) the area underwent a remarkable climatic change with the onset of the 'ice age'. At this time, enormous ice-sheets, which had begun to grow in other regions towards the end of the Tertiary Period, expanded and spread southwards over the British Isles. During the next 840 000 years there were alternating periods of glacial advance and relative glacial retreat, until the major ice-sheets finally withdrew towards their current position. There seems little doubt that each successive advance and retreat during this complex episode caused both a modification of the rockhead surface and deposition of various types of sediment, but to all intents and purposes in the current area the deposits and landforms of the early phases have been obscured by the effects of the latest advance and retreat. A possibility exists that certain of the deposits occupying the floors of deep channels in the bedrock surface may be remnants of earlier glacial deposits (see for example Figure 5, record SJ39NW/429 and Figure 7, record SJ39NE/8) but these could equally well be the first deposits associated with the final advance.

With the beginning of the last advance (Late Devensian, about 25 000 years ago) an ice-sheet expanded into the area from the north. Streams flowing from beneath it carried sedimentary material, including reworked debris from earlier glaciers, away to the south. Some of the debris was deposited in valley floors within the area, and inevitably some of it was itself overrun and reworked as the glacier advanced. Probably, however, a small proportion of these deposits, predominantly relatively coarse-grained material, survived as a part of the Basal Sand and Gravel (see pp.54-56).

As the ice-sheet moved southwards into the study area it incorporated much debris in the form of broken-down rock of all grain sizes, from very fine 'rock flour' to large boulders. Many of the larger fragments, or clasts, are recognised as deriving from rock outcrops in Scotland and the Lake District, and the broken shells of marine animals indicate that the ice-sheet also crossed the Irish Sea area. The clasts brought into the area from distant

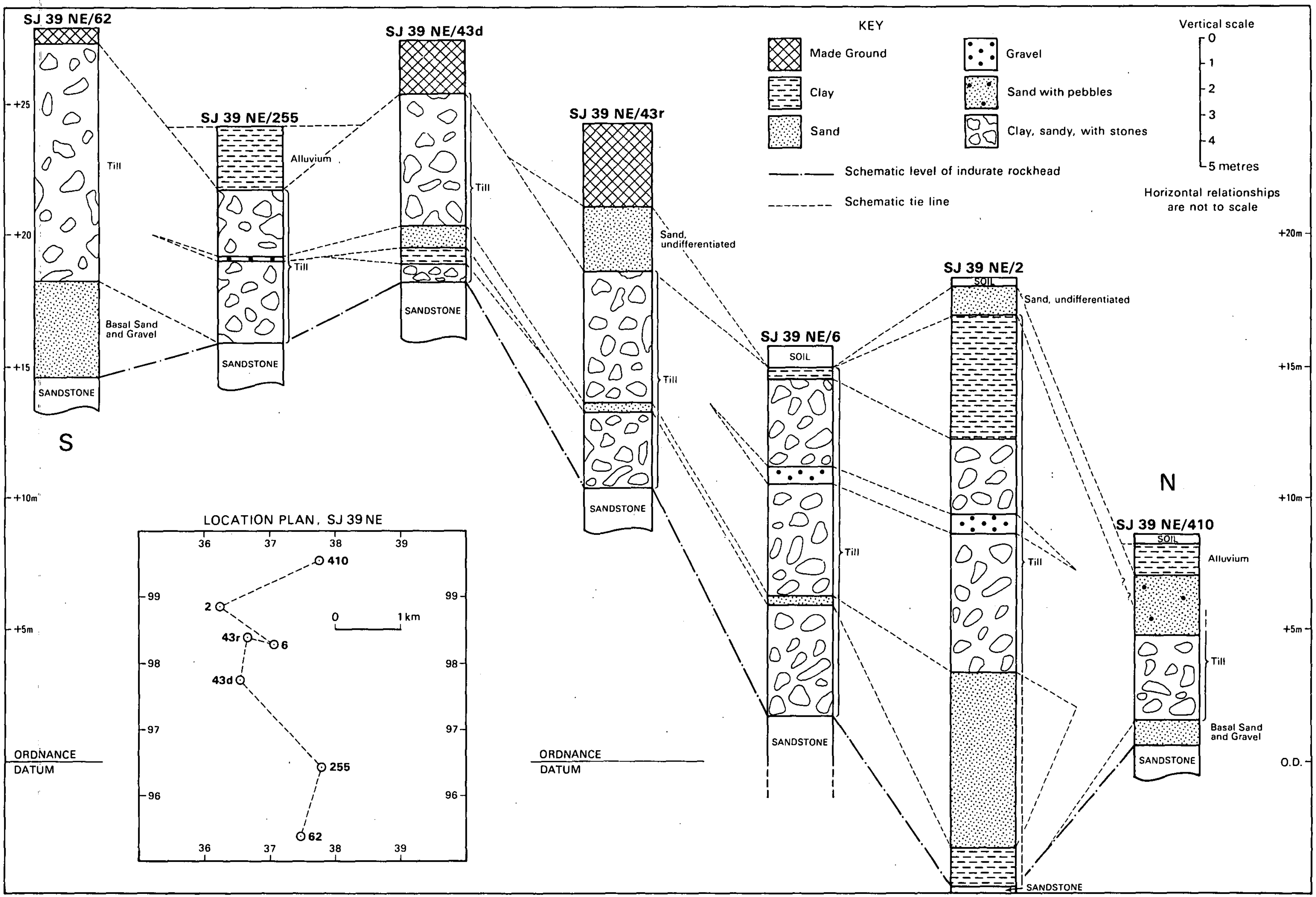

FIGURE 6 Comparative sections through the drift deposits of SJ 39 NE

sources are known as erratics, and many of these, together with clasts of locally-derived rock, sand and clay, were deposited beneath the ice-sheet, forming a skin of till (p.00) above the rockhead surface. Movement of the ice and its basal debris load also eroded and scoured the underlying rock surface, removing material from high points and overdeepening existing valleys, whilst streams of pressurised meltwater beneath the ice also cut deep drainage channels and carried debris away beyond the ice-front.

The Late Devensian ice-sheet reached its maximum about 18 000 years ago, then began to melt as climatic conditions ameliorated and fresh ice formation could not keep pace with wastage. As the ice melted in situ, powerful streams flowed away carrying heavy loads of sediment, some of which was deposited as terrace-like features in valleys to the south, the remainder being carried farther south or south-west to be laid down in temporary lakes or lagoons which were impounded by remnant ice and higher ground. All around the decaying ice-sheet abundant water was in evidence, in the form of streams and rivers flowing beneath or above the ice and as lakes impounded by the residual ice, solid rock ridges and mounds of glacial debris. Into this environment the clastic material carried by the ice-sheet was dropped or carried and a complex set of tills, clays, silts, sands and gravels (see pp.49-53) was deposited (Figures 5, 6 and 7).

With the melting of the ice-sheets on a regional scale, there was a dramatic rise in sea level, and arms of the sea extended into areas which are now dry land, such as the line of Rimrose Brook (Figure 2). Following a delay of unknown duration, the land rose relative to the sea as it adjusted to the removal of the previous ice load. Eventually the present position of the coasts was established. During this period several distinct types of deposit were formed overlying the Till deposits (Figures 5, 6 and 7).

As the ice withdrew, abundant fine sediment was deposited by streams flowing into the estuaries and arms of the sea around the coast, forming thick beds of silt and clay referred to as Marine and Estuarine Alluvium (see p.38). Winds blowing from the north or north-west carried sand and finer material into the district, laying down sand-dunes. These older blown sand deposits, locally termed the Shirdley Hill Sand, are included in the Sand, undifferentiated section (see p.45). Streams flowing across the area deposited coarse and fine sediment in the form of River Terrace deposits and Alluvium (see p.36), a process which has continued to the present day. As the sea level oscillated in approaching its present situation, areas of Alluvium, including Marine and Estuarine Alluvium, were colonised by vegetation, giving rise to

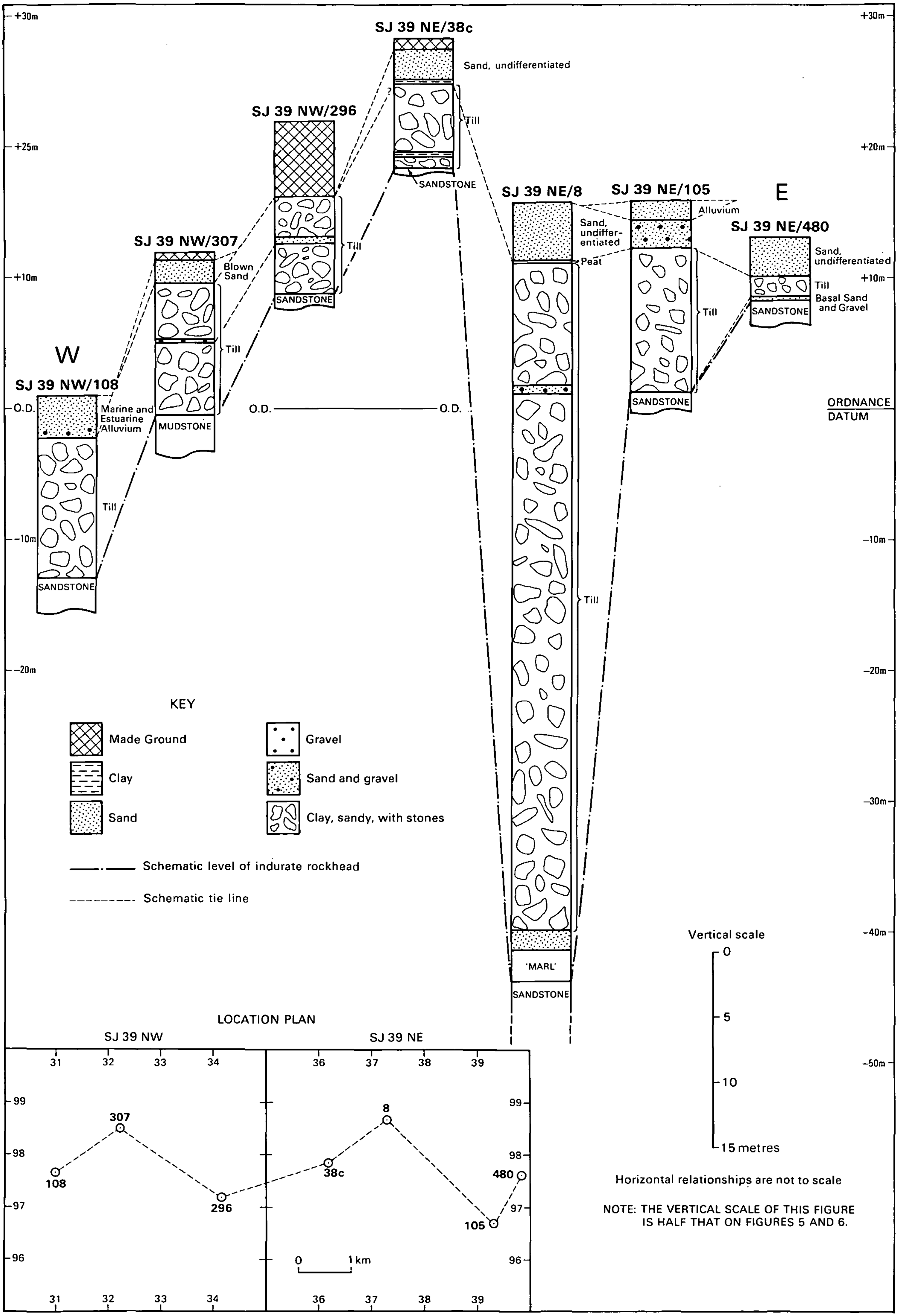

FIGURE 7 Comparative sections through the drift deposits of SJ 39 NW and NE

swampy areas and eventually to Peat deposits (see p.42). Peat also formed on a smaller scale in hollows within the Shirdley Hill Sand dunes. Much of the peat was subsequently buried by later alluvial deposits or by a later generation of Blown Sand (see p.34) which formed extensive dunes along the coastal strip. With these deposits the depositional history of the area is complete.

Weathering and erosion have continued, however, and the older sand dunes have been smoothed and in places their sand has been cemented by minerals such as carbonates deposited from solution. Some areas of till have had their clay fraction leached downwards, leaving a clayey sand, and areas of solid sandstone have had their cementing matrix removed by solution. These cemented sands, leached tills and weathered sandstone are included within the Sand, undifferentiated section (see p.45).

Other processes have continued at greater depths. Various hydrocarbon compounds, believed to have originated in Carboniferous rocks now deeply buried, have slowly migrated upwards to accumulate in locally suitable reservoirs within the Sherwood Sandstone Group to the north-east of the present area, in Morecambe Bay and at Formby. Upward leakage has occurred, probably along the fractured rock associated with fault zones, and in the Formby district, just north of the present area, hydrocarbons have been trapped beneath the Drift cover. This hydrocarbon migration is a continuing process, and as similar geological conditions occur locally in the Crosby, Bootle, Aintree area, the possibility of residual hydrocarbons being present in sandstones beneath the Drift or at depth cannot be discounted (see p.60).

In much more recent times human activity has left a strong mark on the area. Quarrying and digging have taken place for building stone, brickclay, sand and peat and many of the excavations have since been filled in by a variety of materials which together comprise Fill or Made Ground (see p.31). In the west of the area the pre-existing dunes of Blown Sand have been levelled and redistributed, some sand being spread across adjacent areas of till. Elaborate systems of drains have been built to carry away normal streams and flood water so that much alluvial deposition has been curtailed. Sedimentation off the coast has also been altered by the construction of barrages to divert incoming river flow, and channels have been dredged to facilitate navigation to and from a series of deepwater docks cut out of the coastal strip or built into a broad swath of reclaimed land in the Bootle to Seaforth area. The greater part of the land area (Figure 3) is now covered by man-made structures - buildings, roads, railways, docks and a canal - and the underlying geological sequence is largely obscured and stabilised by having been smoothed and covered. Beneath this thin surface layer, however, the complex mixture of sedimentary material remains and its properties and behaviour must be taken into account in the consideration of any new development or in assessing the safety of existing developments.

DETAILS OF THE GEOLOGICAL FORMATIONS

The following section is an account of the geological formations, both 'Solid' and 'Drift', occurring within the Crosby, Bootle, Aintree area (see p.21). Commencing with the youngest deposits, Made Ground, the formations are described in order of increasing age. An introductory section defines each formation and discusses its mode of origin, lithology and engineering properties. This is followed by a detailed description of the formation within the study area.

a MADE GROUND

i Introduction

An area artificially filled or formed by the deposition of various materials is referred to as made ground. This includes refuse tips, mine and quarry dumps, banked up and reclaimed land. The materials which form the made ground are referred to as fill while the term backfill is used for material filling a former excavation such as a quarry or clay pit.

Made ground is common throughout urban areas and is significant in terms of foundation conditions and in certain cases potential pollution problems. For example, ground composed predominantly of town refuse usually provides an unsatisfactory foundation of low strength for large surface structures. Gases, particularly methane, commonly occur in this ground resulting in additional problems.

The materials used in the formation of made or infilled ground are often heterogeneous. This gives rise to a wide range of ground conditions with differing geotechnical properties. Under such conditions, different parts of the fill will compact differentially under loading and may lead to foundation failure.

Similarly the contrast between infilled land and the adjacent undisturbed ground can be considerable. This is particularly so with backfilled quarries or pits. Structures built on the boundary of such occurrences are liable to suffer considerable damage as a result of differential compaction, if the situation has not been recognised.

When hard core (building rubble, sandstone waste etc.) has been used as the fill material, large irregularly shaped blocks may prove difficult to deal with in foundations and trenches. Large voids resulting from the haphazard dumping of these blocks may also occur.

Made ground containing industrial waste may pollute the ground water giving rise to corrosion problems for foundations set on such ground. It may be necessary to investigate such a site chemically to see if, for example, sulphate-resisting foundations are required. In addition, toxic elements can prove dangerous to personnel when the site is opened up for construction. Industrial waste may also contain large quantities of scrap metal which may give difficulties during site investigations and construction.

ii Details

Thematic Map 3 shows the location of areas of made ground/fill exceeding 0.5 m in thickness. Extensive thin (less than 0.5 m thick) deposits of made ground are common throughout urban areas; these have been omitted from the map. Likewise, minor areas of made ground, for example road, railway or canal embankments have been omitted except when they form part of a larger tract of made ground. Nevertheless, road, railway or canal embankments should, in any case, be readily identifiable from topographic maps.

Much of the evidence for the location and nature of made ground/fill areas has been determined from documentary sources. The earlier geological surveys of the area failed to map those areas of made ground that existed at the time of survey. However, all of the surveyors included brief notes on their field slips of tips and back filled excavations. Other sources of information included those supplied by local authorities and the numerous borehole records examined. Since much of the fill is not recorded on detailed plans many deposits may have been missed or not accurately delimited.

An exception to the above is the land reclaimed from the River Mersey to form the docks on the western side of the district. Detailed plans of this made ground and its fill are held by The Mersey Docks and Harbour Company at Pier Head, Liverpool.

The location and extent of backfilled quarries and pits has been taken from the maximum recorded extent of the original working. Thus the extent of the backfilled deposit must be regarded as approximate.

Prior to the area being developed small ponds existed in almost every field. These have now been filled in, but as they were in the main small and shallow, they have been omitted from the map.

Within the belt of Recent Blown Sand along the western margin of the district (see Map 2 SJ39NW) there are areas of redistributed sand. This made ground was formed by the levelling of former sand dunes and the infilling of hollows into which it is believed other materials have been tipped. It is not possible to indicate the boundaries of these areas as the evidence has been destroyed.

The areas of made ground have been subdivided into six categories (see Map 3) on the basis of their fill, so far as this is known. In any one area there may be a mixture of more than one category and this is indicated on the map, for example HC/SC. Likewise, within any one area, more than one category of fill may be present, but separated from its neighbour. In this case the symbol for the fill is situated over the area it is known to occur even though its boundaries cannot be shown.

The tabulated information for the six categories shown on Map 3 should be regarded as a general description only. Any proposed developments on tracts of made ground/fill should be preceded by a site investigation. This is particularly true for sites of industrial waste and back filled excavations.

The thickness of made ground is usually very variable. Except for the area of the docks and backfilled excavations made ground may range up to around 5 m in thickness. The made ground forming the dock area increases in thickness westwards to about 14.5 m and backfilled excavations are known to range up to 12 m in thickness.

b BLOWN SAND

i Introduction

The term blown sand, sometimes known as aeolian sand, is self explanatory. It is sand transported and deposited by the wind, usually in an area without a continuous cover of vegetation. Along a sea-coast, sand is often carried landwards in great quantities by the wind to form extensive sand-hills or dunes as they are known.

Characteristically this sand has no plasticity, swelling or cohesion and its permeability is very high. The water-table may be at any depth according to the local circumstances. It is however, well defined when present and may cause problems in deep excavation trenches and in the construction of buildings with basements. Usually this deposit provides unsatisfactory foundations for surface structures, unless treated, and needs to be removed if possible. Likewise, it will produce problems when trenched because of its loose nature ('running sand') and water content. If not stabilised by vegetation it is liable to renewed wind erosion. This may be a problem if the ground is opened up for construction, with blowing sand affecting man and machinery.

ii Details

The Blown Sand deposits formed relatively recently, having been deposited since the 17th century (De Rance, 1870, p.7). This deposition took place as a result of the prevailing south westerly winds sweeping across the extensive sand banks and beaches of the Mersey Estuary at low tide. Any further accumulations of blown sand have been arrested by the construction of the docks and amenity areas to the north-west, resulting in the obliteration of the foreshore.

Blown sand forms a belt up to 1.3 km wide along the western margin of the district. It extends north-west south-east from Blundellsands in the north to Bootle in the south.

Thickness ranges up to 6 m but there is an overall thinning across the belt to the east and to the south-east. In the south-east around Bootle the sand may be locally absent within the area mapped as Blown Sand.

Prior to urban development extensive dunes up to at least 6.5 m in height were present. The general alignment of the dunes was west-north-west — east-south-east with waterlogged depressions or 'slacks' as they were known locally, occurring between some of the dunes. With urban development, the former dunes have been levelled or carted away and the hollows filled in (see Made Ground p.32).

The western boundary of the Blown Sand is at the old high water mark (spring tides) which existed prior to the construction of the docks. The eastern boundary has been taken as the edge of the recent sand dunes surveyed by De Rance in 1868 prior to urban development.

The sand is generally pale/buff-yellow to pale grey in colour, clean, and loose. It is composed almost entirely of coarse to fine grains of quartz and rock fragments, with minor amounts of other detrital materials, of which calcareous shell debris is the most common. Within the sand the calcium carbonate content may range between 6% and 0.2% (Salisbury 1938, p.818).

In places a significant amount of organic matter may be present as a result of former vegetation cover being overwhelmed by an advancing sand dune. This could be represented by a thin bed of peat if the vegetation grew in a former waterlogged depression. Silt and clay are virtually absent from blown sand, but may occur in association with organic matter at the base of the sand in a former waterlogged depression. In Seaforth thin seams of red marl (sic) have been noted (De Rance 1877, p.113).

Within the sand there is often a perched water table and water may be expected at a depth of 0.3 m to just over 2 m, if present. This water is said to be fresh to brackish (Wray and Cope, 1948, p.43). and may be slightly salty or acid.

c **ALLUVIUM**

i Introduction

The term sediment in its ordinary interpretation signifies solid material that has settled down from a state of suspension in a liquid. Alluvium consists of sediments laid down by a stream or river in its bed or on its flood plain. It is, therefore, a general term for clay, silt, sand and gravel or similar unconsolidated detrital material deposited during comparatively recent geological time. The more familiar types of alluvium are found in mature valleys with meandering streams where organic matter or peat may form part of the deposit. Alluvium normally forms a flat expanse on a valley floor with an almost imperceptible slope down stream. It is usually less than 3 m in thickness, but may be considerably thicker in buried channels.

A river terrace is composed of unconsolidated alluvium and is one of a series of level surfaces (terraces) in a stream valley flanking and more or less parallel to the stream channel. They are produced by the renewed downcutting of the flood plain, or valley floor, by a rejuvenated stream.

For alluvium, the plasticity, cohesion and permeability cannot be generalised as these factors depend mainly on the local particle size and mineral composition. However the permeability is high, usually higher than any other geological material. The consolidation characteristics are very variable due to the intercalations of sand/peat or clay/silt etc.

Within a flood plain the water table is usually high and intercalated peats or peaty hollows are common (see p.42). Water bearing layers or lenses of granular material are also common in alluvium. This material tends to flow in the form of 'running sands' if for example an excavation intersects the water table. Alluvium, therefore, may prove difficult for foundations and excavations in it.

River terrace deposits were laid down under the same general conditions as the modern river alluvium and have, therefore, similar characteristics. However, they normally occur above the water table, which simplifies working, but they may have been exposed to weathering for a considerable time and the constituents could be partly decomposed. Cementation within such deposits is common.

ii Details

Alluvium is developed mainly in the valleys of the River Alt and its tributaries, the Tue/Fazakerley and Sugar Brooks, in the east and the Rimrose Brook in the west.

In the River Alt system the alluvium is generally up to 4 m in thickness, but reaches 7.5 m in borehole SJ39NE/399. It consists mainly of sand, locally clayey; with intercalations of gravel, silt and clay. The silt and clay are locally peaty with a high organic content. Peat is also present (see p.43) and is probably more extensive than is known at present. A layer of sand and gravel is usually present at the base of the alluvium for much of the River Alt and the lower reaches of its tributaries. River Terrace Deposits of sand and gravel may be present in the upper reaches of the River Alt and the Fazakerley Brook. These deposits are now degraded and obscure and have not, therefore, been differentiated from the Alluvium on Map 2, SJ39NE.

Alluvium within the valley of the Rimrose Brook has been penetrated by only a few boreholes and 6 m is the maximum thickness recorded to date. The alluvium consists mainly of sand, locally clayey; with intercalations of gravel, silt and clay. This alluvium is associated with thick deposits of peat, especially in the lower reaches of the Rimrose Brook (see pp.42-43). A basal deposit of sand and gravel is present in places, especially in the middle reaches of the brook. In the lower reaches of the brook beneath the alluvium and peat there is an estuarine alluvium deposit (see p.38-40).

Prior to the development of the area the Rimrose Brook flowed into the River Mersey at a point where the north east corner of the Gladstone Dock [329 962] stands today. North-east from this location to the Southport railway line at Seaforth [335 968] the alluvium of the Rimrose Brook has been covered by recent blown sand (see Map 2 SJ39NW).

South of Litherland and west of Orrell [340 970] there occurs an isolated patch of alluvium, the lower reaches of which have also been covered by recent blown sand (see Map 2 SJ39NW). Prior to being buried this alluvium extended into that of the Rimrose Brook by way of a route followed by the Southport railway line to the south-east of Seaforth Station [338 964]. Boreholes have shown that this isolated patch of alluvium is at least 3.5 m thick in places and consists in the main of sand and silt with some peaty silt and clay locally.

d MARINE AND ESTUARINE ALLUVIUM

i Introduction

For the purpose of this report the term Marine and Estuarine Alluvium is used to describe all the sediments laid down by or in the sea or the Mersey estuary, including the coastal beach strip and the various banks which are revealed at low tide. Material of clay, silt, sand and gravel grade is represented and the deposits are complexly variable both vertically and laterally. Since sedimentation probably commenced during the melting of the last ice-sheet and has continued to the present day there is a considerable age range within these deposits and sea-level fluctuation has led to deposition of Marine and Estuarine Alluvium in areas which are now above Ordnance Datum (Figure 5), and also allowed local peat development within the sequence.

Most of the Marine and Estuarine Alluvium in the area is water-covered all or part of the time and only of interest for specialised development including reclamation. Apart from varying widely in both age and composition, these deposits will be essentially or potentially waterlogged materials, their upper layers comprising water-supported muds or slurries. Away from direct contact with the estuarine waters the degree of dehydration is greater, but the deposits are probably thixotropic in nature and thus liable to liquefaction if subjected to vibrations or earth tremors. Any excavation or tunnelling in these deposits may be difficult and piling or large-scale dredging may be required to ensure a reasonable foundation. In those inland areas where older Marine and Estuarine Alluvium is present beneath younger deposits it may also be relatively weak and have high water contents where filling hollows or channels in the underlying till deposits. Much of this older material is predominantly silt of fairly low plasticity and cohesion (known in adjacent areas as the Downholland Silt) which is very weak, particulary when wet. Local peat deposits which mainly postdate the older and predate the recent alluvial deposits will potentially present the same problems as the other peat beds in the area (see p.42) and would require similar treatment.

ii Details

In immediate post-glacial times the sea or Mersey estuary extended farther east into areas which have since become dry land due to a combination of a relative fall in sea-level, the upward isostatic recovery of the pre-existing land after removal of its ice load and subsequent addition of younger superficial deposits. An arm of the sea or estuary extended eastward from the vicinity of the present Gladstone Dock (c. 328 963) along the line of the Rimrose Brook, following the line of the brook to the northwest and possibly also extending south-eastwards towards Bootle. A further arm may have run eastward from the current Seaforth Dock area (c.323 970) to join the Rimrose Brook line near Seaforth Station, and a third arm could have been present along a line running northeast from the Alexandra Dock (c. 333 951). Between these various inlets were islands of till. In the case of the first mentioned, Rimrose Brook, inlet there is conclusive borehole evidence for the deposition of marine or estuarine silt and clay and hence for the eastward extension of the flooded area (Figure 5, record SJ39NW/429). The other inlets are postulated on the evidence of the rockhead topography, the same criterion suggesting a broad embayment of the sea into the present Waterloo area. Within these areas, freshwater streams loaded with silt and clay encountered the saline waters of the estuary and, as a result both of a reduction in velocity and particle flocculation, some of the suspended material was deposited. Where the inlets or channels were deepest, thick sequences of homogeneous clay and silt were laid down until eventually the deposits built up to the then current sea level, first at the inland end of the inlets but progressively reaching out into the sea. Boreholes in the lower reaches of the Rimrose Brook valley have proved more than 6 m of these deposits, forming a relatively narrow strip which passes out into the present day estuary between the Gladstone and Seaforth docks. The deposits thin rapidly away from the main inlets, but thin clay and silt bands beneath Blown Sand in the Seaforth - Waterloo area are probably of contemporary origin. These fine-grained homogeneous deposits are believed to be equivalent to the Downholland Silt (Wray and Cope, 1948) which is better known in the coastal area to the north. In this northern area the Downholland Silt has been proved to occur considerable distances eastward of the present coastline, extending towards the current valley of the River Alt, but there is no definite evidence for an arm of the sea having entered the area from the north.

The older Marine and Estuarine Alluvium, or Downholland Silt, is essentially homogeneous and structureless, usually described as blue or blue-grey in colour, and is generally weak and normally-consolidated. With the exception of those inlet areas mentioned above, where deposits of at least 6 m thickness may be present, the formation is generally thin in present dry land areas. Off the coast it passes upwards into younger deposits of similar lithology. The upper surface of the main deposit proved in Rimrose Brook is at between +2.5 m and +3 m relative to modern Ordnance Datum, indicating a relative lowering of sea-level of at least this amount since its deposition. If this upper limit is consistent across the area similar deposits may be present beneath Blown Sand in much of the area between the Rimrose Brook valley and the modern coastline (Figure 4) and in the area between Rimrose Brook and Bootle, depending on the elevation reached by the pre-existing rockhead surface and the till resting on it.

Almost everywhere the Downholland Silt is overlain by peat deposits which reach their maximum thickness in Rimrose Brook (see p.42-43) and mark a return to terrestrial conditions in these areas. Following this phase, deposition of Blown Sand commenced and the landward areas of Marine and Estuarine Alluvium were effectively cut off from the gradually lowering sea by a coastal strip of dunes (see p.34).

In the current estuary, deposition of Marine and Estuarine Alluvium has probably been more or less continuous since the melting of the last ice-sheet. A number of boreholes prove small thicknesses of peat within the sequence, indicating sporadic reversion to terrestrial conditions, but the depositional environment has been essentially marine. Abundant fine material is brought into the area by wave action and currents from various banks to the north, as well as that which has been carried into the area along the Mersey and its tributaries, including the River Alt and Rimrose Brook. In this relatively high energy environment, deposited sediment is constantly being reworked and redeposited. In some areas strong currents have scoured channels down to the level of underlying till deposits and these tend to stay clear of all but a thin veneer of potentially mobile mud. Elsewhere banks of silt, sand or gravel (shingle) may be deposited, only to be destroyed or moved by storm or wave action. As mentioned briefly in the introduction above, these more recent deposits of Marine and Estuarine Alluvium are not only variable in their extent and thickness, but also highly variable in composition and hence in engineering properties. They are all normally-consolidated and have high water content, many being at best thixotropic and at worst more akin to liquids than solids. Since they will mainly be encountered in development work involving land reclamation they could be effectively stabilised by dewatering after isolation from the estuary, by mixture with suitable hardcore fill or, in areas where this treatment fails, by dredging to a suitable substrate and refilling with hardcore. An alternative which might be suitable for some kinds of development would be to pile through the wet materials and raft foundations on the piles.

No thickness figures are reliable for these deposits since the potential thickness is not only variable from point to point due to undulation of the underlying rockhead/till surface, but the thickness at any point still affected by the sea can be increased or decreased literally overnight, a factor which would have to be considered in projects involving the laying of pipelines or cables beneath the estuary.

e PEAT

i Introduction

In a lowland environment peat accumulates in stagnant or slow moving bodies of fresh water which are gradually filled up by vegetable debris. This results from a luxuriant flora, with a considerable variety of species, spreading into the water from the margins and becoming associated with peat mosses. The peat formed may be many metres thick, cover large areas and contain up to 93% water. Within this peat a variable amount of muddy sediment is usually present.

Peat formed as described above is known as basin or topographic peat. It often occurs as patches, or lenses, in alluvium where it may pose unexpected engineering problems.

Many peat deposits are fairly tough and fibrous and may stand well in excavations. They are, however, usually associated with high water-tables and pumping from excavations in peat may cause rapid and large settlement. This is because the peat suffers from a high shrinkage on drying. It also possesses a low bearing capacity with the result it is easily compressed. Peat is therefore unsuitable for foundations and it may be necessary to remove it or pile through it. Instances of spontaneous underground combustion of peat are known from outside the study area, and this should be borne in mind if peat seams are likely to be dried out as a result of proposed activities.

In compiling Thematic Map 4 an arbitrary lower limit of peat thickness of 0.3 m has been used, as below this limit such beds are less likely to cause engineering or foundation problems. However, any peat deposit may cause problems and all occurrences, when located, should be investigated.

ii Details

The peat within the Crosby, Bootle, Aintree area may be divided into three associations:

1) with the Rimrose Brook;
2) with the River Alt and its tributaries;
3) with the River Mersey.

In the lower reaches of the Rimrose Brook (Map 4 SJ39NW) peat attains the greatest thickness recorded in the district, at Seaforth Station (BH SJ39NW/24 [3337 9707]). Here 9.14 m of peat is separated by 0.3 m of sand from a lower, 2.74 m bed of peat resting on a marine estuarine alluvium of blue, silty clay ('Downholland Silt'). South-south-east of Seaforth Station (BH SJ39NW/16 [3352 9677]) 6.7 m of peat rests on till. South-west of this location, towards the

Gladstone Dock, the peat continues to thin beneath a cover of blown sand. These deposits lie along the infilled Rimrose Brook valley which today is followed by the Borough Constituency Boundary line (see Map 4 SJ39NW). Along the line of this former valley the peat rests on the Downholland Silt. Under the Gladstone Dock the peat thins to 0.3 m beneath a thin cover (2 m) of sand and silt (marine estuarine alluvium).

North-west of Seaforth Station (BH SJ39NW/25 [3328 9721]) the Rimrose Brook peat thins to 6.4 m and rests on till. It continues to thin going up the middle reaches of the brook, where it is hidden by later alluvium (see Map 4 SJ39NW). In the upper reaches of the brook, around [344 993], up to 1 m of peat is encountered at the surface. A further thin deposit of peat, partially hidden by alluvium, occurs under the Bootle Golf Course [352 988].

Around the former headwaters of the Rimrose Brook at Orrell [360 976] peat is to be found beneath 0.3-0.5 m of Sand. The peat occurs at two levels separated by a bed of sand up to 0.6 m thick. The upper peat is up to 0.3 m thick and the lower just over 0.3 m thick.

Peat occurring within the alluvium of the River Alt and its tributaries has only been proved in two areas. Just to the north-east of the M57 motorway at Aintree [378 996] up to 2.2 m of peat occurs beneath about 2.0 m of alluvium. In the headwaters of the Fazakerley Brook [379 967] 1.2 m of peat occurs beneath 1.5 m of alluvium. Around the headwaters of a former tributary to the River Alt, north-west of the Aintree Race Course [368 989], two beds of peat, separated by up to 0.46 m of sand, are to be found occurring beneath about 0.6 m of sand. The upper bed of peat is up to 0.3 m thick and the lower is just over 0.3 m thick. This is a very similar situation to that occurring around the headwaters of the Rimrose Brook and other occurrences of peat are to be expected, therefore, beneath the Sand, undifferentiated, in the general area of these hidden peat deposits. Further deposits of peat are to be expected also within the alluvium of the River Alt and its tributaries, but lack of borehole evidence prevents us from identifying such areas at present. However, this peat might be expected in the former meanders of the River Alt or its tributaries. In the lower reaches of the River Alt, just beyond the northern margin of the area, peat is well developed beneath the river alluvium to the east and north of Sefton (Wray and Cope, 1948, p.32).

Along the margin of the River Mersey, peat hidden beneath blown sand and marine estuarine alluvium occupies an extensive tract at Blundellsands [305 995] with smaller areas occurring beneath blown sand at Seaforth [327 968] and Bootle (see Map 4 SJ39NW). Excavations for the Alexandra and Langton Docks are said to have revealed 0.9-2.7 m of peat beneath blown sand and resting on blue clay or silt in places (Wray and Cope, 1948, p.32). In excavations for the Gladstone Dock the blue silt is said to have a thick bed of peat at its base (Wray and Cope, 1948, p.29). Boreholes from within the area of these three docks have not recorded peat, other than that associated with the Rimrose Brook (see p.43). The peats, therefore, must be very local and we are unable to indicate their extent on Map 4 SJ39NW.

Within the Blundellsands area the peat ranges from 0.3 m to 1.6 m in thickness beneath a cover of 1 m to 4.5 m of blown sand. On the eastern side of the area the peat forms a single bed, but westwards it splits into two beds separated by sand. The lower bed is up to 1 m thick and the upper bed ranges up to 0.6 m. Overall the peat appears to thicken from south to north across the Blundellsands area to beyond the northern margin of Map 4 SJ39NW into the area between Hall Road Station [304 006] and Little Crosby [317 016], where it is known to attain 3.6 m (Wray and Cope, 1948, p.32).

The Seaforth area of peat ranges from 0.3 m to 1.4 m in thickness beneath 1.2 m to 3.5 m of blown sand.

In the Bootle area the Marsh Lane [337 958] peat reaches 0.9 m beneath 4.5 m of blown sand (Wray and Cope, 1948, p.32) while in the Bootle New Strand Station area [340 956] peat reaches 0.76 m beneath 2.9 m of blown sand. A further small area of peat, 0.3 m thick, occurs beneath 3.0 m of Sand, undifferentiated, to the north-east of the New Strand [348 957].

Generally the peat is black and spongy near the surface, but becomes brown, fibrous and compact with depth; mammalian bones are not uncommon. Within the Merseyside Dock occurrences (see above), Blundellsands and the lower reaches of the Rimrose Brook, large embedded tree trunks, usually horizontal, are present in profusion within the peat, usually near or at its base. This has given rise to the descriptive term "submerged forest bed" for some of the peat deposits.

f SAND, UNDIFFERENTIATED

i Introduction

This category of deposits includes sandy material of several different types which cannot be separately mapped in this predominantly urban area. Much of the sand represents an Older Blown Sand, of broadly similar origin to the Blown Sand (see p.34), known as the Shirdley Hill Sand (Wray and Cope, 1948). Smaller areas of undifferentiated Sand probably represent the weathered upper layers of sandy till deposits from which the clay content has been leached by downward water movement, while an even smaller proportion of the sand is the weathered remnant of underlying sandstone (cf. Basal Sand and Gravel, p.54).

In some respects the Shirdley Hill Sand has properties similar to Blown Sand, having formed in essentially the same way, but being considerably older it has undergone a number of changes. Being almost totally clay-free, the sand lacks cohesion or plasticity and will not swell. Its porosity and permeability are generally high and, where deposited on top of till, perched water tables may be encountered so that the saturated sand is liable to flow in excavations. It differs from the Blown Sand in being generally more compact and in some situations weakly cemented, so generally it is less likely to be subject to renewed erosion by the wind if exposed by excavation, and is by nature a more stable deposit both on the land surface and where encountered in trenches.

The other types of undifferentiated Sand have broadly similar properties, particularly that derived by the weathering of sandstone. In the leached sandy till a proportion of clay may remain with a consequent decrease in porosity and slight increase in cohesion and plasticity, but the material remains essentially a sand. Potentially, local perched water tables would be expected on this type of sand, but not on that derived from weathered sandstone.

ii Details

Shirdley Hill Sand is the major component of the Sand, undifferentiated, shown to the east and south-east of Rimrose Brook on Map 2 (see also Figure 6). The Shirdley Hill Sand is a blown (aeolian) sand which began to be deposited in immediate post-glacial times, possibly while the ice-sheet in the area was still decaying and the major ice front was in a state of relative retreat. Strong, cold winds blowing from the relatively high pressure area to the north carried fragmentary material both from the surface of the ice and from detritus left by the melting ice, in a generally south-easterly direction. The wind-borne fragments included not only sand and finer material, but also shells of marine animals which had been picked up by the ice sheet from the bed of the Irish Sea. When first deposited the Shirdley Hill Sand probably had a dune morphology such as characterises modern coastal blown sands. Its undulating upper surface included hollows or 'slacks' and some of these were colonised by vegetation, particularly in areas where the water table was close to the surface. Progressive movement of the dunes under the influence of prevailing winds resulted in the filling in of 'slacks' such that small lenses of vegetable matter were engulfed by sand, eventually giving rise to thin deposits of peat within the sand sequence. The maximum thickness of this older sand in the present area is about 5 m, though generally it is thinner and it may be locally absent at some points on its supposed outcrop; peaty inclusions, where present, are generally only a few centimetres thick.

The presence of distinct beds, rich in the shells of marine animals, within the Shirdley Hill Sand suggests that the strength of the contemporary winds was variable, only occasionally being able to transport and redeposit these larger fragments. Also across part of the area (and the outcrop of the Shirdley Hill Sand elsewhere) a layer of gravel with dreikanter (wind-faceted pebbles) is recorded at the base of the sand. This layer probably represents a residual surface of eroded till from which the smaller clay and sand particles had been removed by the wind and which was subsequently itself covered by sand.

With the exception of the layers of shells and the gravelly base where present, the majority of the Shirdley Hill Sand is a very pure deposit, which has been used in the past as raw material for glassmaking. Its colour is variable between reddish brown and off-white, the iron minerals responsible for any colouration being only a minor constituent of the predominantly quartz sand. Some borehole records indicate that a degree of cementing may occur within the sand, but this seems to be patchy and discontinuous. Such cementing is probably caused by solution of minor impurities - mainly the calcite of marine shells and iron oxide - beneath a local water-table and the subsequent recrystallisation of these minerals due to change of physical or chemical conditions within the sand. Perched water-tables may be present above the underlying till.

Deposits attributed to the Shirdley Hill Sand are generally thin, rarely exceeding 5 m, and are not normally identified below younger deposits. If site investigation revealed thin peat beds within the sequence or showed that the sand had unsuitable bearing characteristics for a proposed development, it might be necessary to sink piles through the unsuitable material or in more extreme circumstances the troublesome beds might have to be removed by excavation.

To the northwest of Rimrose Brook, in the Great Crosby area, the undifferentiated Sand shown on Map 2 is believed to be largely the weathered surface layer of a sandy till deposit. Surface geological detail has been obscured by landscaping during development and a certain amount of recent Blown Sand from the coastal strip has probably been distributed over the area. Early geological mapping, prior to this modern development, indicated a well-marked division between the sand dunes to the west and 'boulder sand', the latter being the deposit now referred to undifferentiated Sand. During this same early mapping a number of brick pits were recorded,where workings penetrated the thin 'boulder sand' to exploit underlying till. The combined evidence of these workings and the nomenclature used to describe the surface deposit suports the idea that the sand in this area was formed from a sand-rich till by downward migration or leaching of the clayey matrix of the original material. This downward movement of fines is confirmed in a number of boreholes where a 'pan' of concentrated clay is recorded at depths varying down to about 2 m. Elsewhere the term 'boulder sand' has been applied to areas now considered to be of Shirdley Hill Sand, and a degree of inter-relation between very sandy till and the 'Older Blown Sand' is probable.

As with the sand deposits described above, this till-derived sand is of no great thickness, only rarely attaining 2 m, though sandy till may continue to greater depth. The sand is generally less pure and less homogeneous in grain size than the Shirdley Hill Sand and usually includes a proportion of finer material which increases with depth. Similar engineering problems might be anticipated to those already mentioned for sandy deposits, except that no contemporaneous peaty inclusions are present. Locally, however, pre-existing depressions in the surface, which may have supported vegetation in recent times, have been infilled and levelled in such a way that apparently continuous sand sequences with inclusions of old soil and vegetation probably occur. Additionally, as with the Shirdley Hill Sand, perched water-tables may be present locally, the water within the porous sand being constrained by clay-rich hardpans or till deposits below. The sandy layer being normally 2 m or less in thickness, with till or sandy till beneath, the deposits could be excavated or piled through if investigations proved them to be unsuited as foundations for a particular building development.

With the exception of minor, un-mappable, spreads of recent Blown Sand overlying older deposits and not separately identified in boreholes, the final component of the undifferentiated Sand is weathered or non-indurate rock. This deposit occurs also at depth beneath the drift succession (see Basal Sand and Gravel, p.54), but where other drift deposits are lacking, on and adjacent to the Solid outcrops shown on Map 2, a variable thickness of sand is often present. Deposits previously described, of sandy till and Shirdley Hill Sand, are partly derived from this decomposed solid rock and locally the deposits pass transitionally from one to another. The sand, or 'rock-sand', is essentially in the position it occupied as sandstone, but its cement or matrix has been removed by solution, the dissolved material being carried away into the saturated zone below the water-table. This is an ongoing process and in some areas where groundwater movement is appreciable, the original sandstone may lack cement to considerable depth. The actual depth and extent of leaching depends upon the original nature of the sandstone, and particularly its cement, as well as water movement and it is evident that the areas of solid sandstone on the map, forming somewhat higher ground than is general in the area, represent a relatively more resistant rock type. However, a thin skin of sandy debris is present across the solid outcrops and a marginal area of rock-sand surrounds most such areas, merging into other sand deposits and passing beneath the drift as a weathered upper layer of the sandstone at depth. (Basal Sand and Gravel in part).

As with the varieties of undifferentiated Sand described above, the effective thickness of this 'rock-sand' deposit is generally small, particularly close to the solid outcrops. Some borehole records however include greater thicknesses of what seems to be non-indurate sandstone, and it is not known whether these deposits are in reality sand or soft sandstone which was disaggregated during drilling. Being essentially in situ and not affected by more recent transport and redeposition, this component of the undifferentiated Sand is denser and more homogeneous than the deposits previously described. By definition it must always be underlain by rock, into which it might pass transitionally, whilst it can also pass laterally into other types of redeposited sand. Those comments above regarding excavation or piling are equally valid here. Where 'rock-sand' occurs at the surface, overlying sandstone, in the current area it is well-drained, though in certain situations at depth (see Basal Sand and Gravel, p.55) the same deposit can be waterlogged due to its continuity with the underlying sandstone aquifer and the constraint of impermeable till layers above.

g TILL (BOULDER CLAY)

i Introduction

In broad terms till is any unsorted or poorly sorted glacier-derived deposit and it can be composed of varying proportions of clay, silt, sand, pebbles and boulders. There are numerous types of till and several sets of criteria exist by which the deposit may be subdivided. A genetic classification tends to be favoured however, within which a number of major till types are broadly identified according to their mode of formation. These major types can then be subdivided according to their actual lithological composition, internal structures and various other factors. Within the current area several types of till are present. Deformation till represents pre-existing bedrock which has been disrupted by the passage of an ice-sheet, moved, however slightly, from its original position and redeposited beneath the ice, with or without the admixture of non-local material carried by the glacier. A proportion of the Basal Sand and Gravel (see pp.54-55) could be described as a deformation till derived from the Sherwood Sandstone Group. Generally overlying rockhead (or deformation till if present) is lodgement till, a till formed beneath the ice-sheet, which can incorporate both locally-derived and far-travelled debris. In this area the lowest till deposits at most localities are of lodgement type, sometimes passing down into deformation till. Other types of till to be expected in the area are melt-out till, derived from the relatively slow melting of debris-rich ice and commonly deposited through static water, and flow till, composed of debris deposited on or by melting ice and subsequently modified or transported by plastic mass flow, sometimes in standing water. From general considerations of the above modes of formation it is apparent that although the various tills may contain the same types of material in the same or different proportions, they will potentially exhibit differing properties depending on whether they were deposited and over-run by an advancing ice-sheet (deformation and lodgement till) or deposited either sub-aerially or subaqueously from a decaying ice-sheet.

The mode of formation also affects the structure of the deposit in that the sub-glacial tills are generally totally chaotic and structureless, whereas the supraglacial tills can exhibit crude lamination and grading of particles due to settling through water and can pass laterally into finely laminated silts and clays where clouds of suspended debris escaped from a mass flow to settle out slowly in adjacent standing water. Thus, although the lodgement tills of the area are in themselves chaotic and heterogeneous in composition, they are consistently so and hence recognisable. The flow and melt-out tills on the other hand probably include beds of relatively homogeneous material, but within a sequence at one locality, and certainly from place to place, there is potential for great variation of lithology and properties within them. Additionally, since the supraglacial tills were deposited in an environment where other sedimentary processes were active, their sequence is often broken by beds of sand or gravel laid down by outwash from the decaying ice-sheet (Figures 5, 6 and 7). Across parts of the area the first deposit above the lodgement till comprises outwash sand or sand and gravel; elsewhere the lodgement till is succeeded by supraglacial tills or their associated silts and clays. The occurrence of lodgement till overlain by sand and gravel in turn followed by supraglacial till led early workers to suggest a tripartite division of the glacial sequence into 'Lower Boulder Clay', 'Middle (Glacial) Sands' and 'Upper Boulder Clay', with the two boulder clay (till) horizons representing the lodgement deposits of two glacial advances. More recent evidence shows that the mixed sequence above the lodgement till represents different products of the decay of the same ice sheet and that several higher tills and sand or gravel horizons may be present (Figure 6, record SJ39NE/6). In this account and on the geological maps (Map 2) the entire sequence of lodgement till and overlying supraglacial tills, gravel, sand, silt and clay is covered by the single, till, division.

Few engineering problems would be anticipated in areas where the till sequence comprises only lodgement or deformation material. Elsewhere the presence of beds of clay, silt, sand or gravel, which are laterally and vertically variable, within the supraglacial sequence, can cause problems. Lenses of granular material within the predominantly clay sequence may be waterlogged. The finer lithologies, particularly pure clays, may develop shear surfaces during compaction or remain capable of plastic flow. Whereas lodgement and deformation tills are almost always overconsolidated due to ice loading, the supraglacial tills and associated deposits are usually normally-consolidated. Compression of a mixed sequence can cause preferential compaction of clay-rich beds by dewatering into adjacent granular material, and if re-exposed the clay is liable to swell as it re-absorbs water. A more local factor, which is potentially misleading at site investigation stage, is the presence within all the tills of boulders up to several metres in size. Particularly if of local sandstone, rather than far-travelled (erratic) rock types, these boulders can be mistaken for rockhead in boreholes, especially if percussive drilling is employed. It is advisable to make every attempt to confirm any supposed proving of bedrock, possibly by rotary drilling. The latter course of action may however be difficult or impossible in circumstances where boulders move and jam the drill string.

ii Details

Most of the area shown as drift covered on Map 2 has till deposits either at surface or beneath younger formations. Locally, the very lowest material, composed predominantly of degraded rock with only minor clay, could be considered deformation till. These deposits, of variable thickness, have not been studied in detail and are recognised only in borehole records. Commonly they pass downwards into still purer sand deposits which are essentially in situ, but uncemented, bedrock (see also Basal Sand and Gravel, p.55 and Sand, undifferentiated p.48), and in general there is an upward transition into lodgement till. In lithological terms these deformation till deposits are clayey sands or clayey sand and gravel, the sand reflecting the grain-size and colour of the underlying bedrock and the larger clasts being fragments of intact sandstone. Clay is present in minor amounts and represents both fine material present in the underlying rock and that which was carried in a thin meltwater layer beneath the advancing glacier. The arbitrary nature of the upper and lower limits of these deposits makes it meaningless to discuss potential thickness beyond the generalisation that deformation till might be effectively absent or form a transitional layer up to several metres thick between the weathered bedrock and true lodgement till.

The lodgement till of the area has long been recognised as the product of a glacial advance and is a 'Boulder Clay' of older terminology. Although all boulder clay deposits fall within the definition of till, not all tills are boulder clay, so this term is used here only informally. Most earlier workers in the area referred to the 'Lower Boulder Clay' (Wray and Cope, 1948), a strong brown, reddish-brown or grey clay with a high proportion of sand and a variable content of pebbles and boulders of locally-derived and exotic rock types. Many of the stones show glacial striations, suggestive both of long transport and appreciable grinding action within or beneath the advancing glacier. The underlying rock surface is also striated in places and the direction of the grooves indicates that ice came into the area from the northwest-north sector. Fragmentary marine shells confirm that some ice crossed the Irish Sea and erratic rock types have been identified with origins in Scotland and the Lake District. Thicknesses up to 10 m of lodgement till are recorded and greater thicknesses may be present in deep channels, such as that beneath Aintree (Map 5).

In those areas where it has been undisturbed since deposition the lodgement till presents a very strong and dense formation with low values of porosity, permeability, moisture content and plasticity. Where exposed by natural means or by excavation it can alter its properties markedly either by taking in water to increase its plasticity of by losing its normal water content to become completely desiccated. In the latter case the deposit will crack and be easily broken down by the weather, and its permeability will dramatically increase.

Across much of the area a simple tripartite division of the till sequence is present (Figure 5, record SJ39NW/248), the lodgement till being followed by a bed of sand (or, more rarely, sand and gravel) up to 2 m thick. This sand, or in its absence the lodgement till, is overlain by a thick and complex sequence of supraglacial tills with interbedded sands, silts and clays of various types. The entire, variable, sequence is equivalent to the 'Middle Sands' and 'Upper Boulder Clay' of earlier workers (see pp.17 and 50). Thicknesses of up to 23 m are known in the northeast of the area. Where it is not possible to recognise the division between the lodgement till and higher deposits in borehole logs, total thicknesses greater than 50 m are recorded (e.g. record SJ39NE/8, Figure 7).

Such a varied series of deposits as overlies the lodgement till will inevitably present a complex set of engineering properties. In general terms the various sand and gravel beds, which are probably all discontinuous, exhibit properties to be expected of granular soils, with void ratio/porosity depending upon the degree of sorting or grading of the individual grains. Where the material is poorly sorted and clay or silt grade sediment is included, as seems to be a relatively common situation, the porosity will be decreased whereas cohesion and plasticity will be somewhat higher. Occurring as they do between clay-rich deposits the sands and gravels will be likely to contain perched water-tables which may present hazards in surface excavations or in tunnelling operations. Small isolated sand bodies may exist which are not located by exploratory drilling, and these too would potentially contain water.

Little is known about the non-till clays in this upper sequence. They are variously described as laminated or smooth and range between firm and very stiff in consistency. Though their moisture content tends to be low, due to dewatering into adjacent more sandy strata, they will potentially absorb water, swell and become plastic or lubricative. In their undisturbed state however they are probably non-porous and may be over-consolidated and contorted. If associated with sand beds or sandy till they may support perched water-tables above or confine them below. Recorded beds of laminated clay are commonly less than 1 m thick, rarely reaching 2 m, and beds of massive clay or silt are also recorded to 2 m in thickness. Thicker deposits may exist unrecognised in mixed till sequences.

Like the lodgement till below, the higher tills can be broadly described as sandy, pebbly clay, with scattered cobbles and boulders, but variation of the proportions of the components is great. Locally the tills contain no cobble nor boulder sized material. Elsewhere they comprise graded bands of clay, silt or sand, as a result of gravity settling through water or mass flow above or below water. The more common sandy, pebbly clay is very similar in appearance to the lodgement till, locally exhibiting crude bedding or flow structures, but otherwise only differing in being normally-consolidated rather than overconsolidated. Even so the more clay-rich horizons may be apparently overconsolidated due to post-depositional water loss to adjacent sandier beds. The engineering properties of the upper tills are as variable as their composition and their behaviour is dependant upon moisture content. A 'strong' till encountered in a borehole may desiccate when exposed by excavation, becoming less plastic, but will also shrink and crack, potentially allowing ingress of excess water and reversion to a plastic state. Any foundation work, trenching or tunnelling would have to be carried out not only in the expectation of meeting isolated waterlogged sand beds, but with a clear understanding of how the tills will react if their natural moisture content is disturbed.

h BASAL SAND AND GRAVEL

i Introduction

These variable deposits, grouped together for convenience, comprise sand, with or without pebbles and boulders, occurring beneath the lowest till and above the indurate rockhead surface. They have not been mapped as a separate unit as where they do appear at the surface they comprise deposits included within the Sand, undifferentiated, division on Map 2.

Much of the Basal Sand and Gravel recorded in boreholes (Figures 5, 6 and 7) is weathered or broken down sandstone of the underlying Sherwood Sandstone Group and might be approximately in situ or might have been moved beneath glacial ice. Some of the sands and gravels recorded at this horizon by boreholes would probably be better described as sandy till, but since they generally pass into the deposits described above they are included as Basal Sand and Gravel. A proportion of the Basal Sand and Gravel, a true glacial sand and gravel, was probably transported and deposited by streams of meltwater flowing beneath and out from the advancing ice-sheet at the start of glacial times.

The various deposits described above exhibit the general properties of granular soils. Effectively they have no plasticity or cohesion and do not swell and their porosity and permeability are high. In the case of sand and gravel akin to sandy till cohesion and plasticity will increase as the clay content increases and porosity/permeability will be less than in the purer sand deposits. Being in continuity with sandstone bedrock below, no perched water-tables are present, but in certain topographical locations the ground water-table extends upwards into the unconsolidated material and water may be held under artesian conditions by overlying till. Flooding could result if the Basal Sand and Gravel is penetrated during tunnelling or the excavation of deep foundations. Also in these conditions the sand deposits can become 'quick' or 'running' and heavy loading of a relatively thin skin of overconsolidated till could lead to sudden failure. More gradual foundation failure might take place if loading initiated dewatering of the sand and gravel, leading to differential compaction, a process which could also take place due to local water-table depression.

ii Details

The Basal Sand and Gravel is recorded in numerous borehole logs (Figures 5, 6 and 7), but where the horizon reaches surface from beneath the till it has been treated as Sand, undifferentiated (see pp.47-48), being essentially transitional to either sandy till above or indurate sandstone below. Occurring at it does, commonly beneath considerable thicknesses of overburden, its geological and geotechnical properties have not been studied in detail, and its variability of origin and topographic level relative to other deposits make it difficult to describe in more general terms. The Basal Sand and Gravel across much of the area represents the in situ weathering product of the Sherwood Sandstone Group, the sand being left undisturbed after solutional removal of a calcareous cement. In this situation a dense and homogeneous deposit of quartz sand, usually red or reddish brown in colour, remains. It may contain 'pebbles' or 'boulders' of the original sandstone and be described as sand and gravel in borehole logs. The thickness of these deposits is variable and depends on the depth to which leaching or weathering has taken place, but may be as much as 8 m adjacent to the coast or at low rockhead levels, where groundwater movement is probably greatest. Elsewhere, and often in adjacent boreholes, till is recorded directly overlying solid sandstone with no intervening sand and gravel, so the possibility must be borne in mind that some records of Basal Sand and Gravel might reflect disturbance of weak solid strata by drilling - or the converse that some records might not differentiate sand if it was recognised as broken down bedrock. The term 'rock-sand' appears in some records and indicates that the potential transition is recognised.

Elsewhere descriptions of the Basal Sand and Gravel indicate that it is less homogeneous, often with a greater proportion of gravel or boulders and sometimes with a notable content of clay or silt. Available records do not indicate whether the pebbles and/or boulders are of locally-derived sandstone or whether far-travelled (erratic) material is also present, but likelihood is that both occur in some situations. On the one hand some deposits are the transported equivalents of the in situ sand mentioned above. Large amounts of sand and sandstone were caught up and carried beneath glacial ice crossing the area and deposited, with or without the admixture of clay, sand and pebbles from farther afield, on the decay of the ice sheet. The degree of transport might be little more than local disruptive movement of the pre-existing land surface, or it could be many kilometres. Such deposits are essentially sandy till and considering their origin they are probably transitional downwards into in situ weathered sandstone and upwards into till. In a number of boreholes scattered across the district and also apparently in some of the dock excavations (Mr P. Lucas, Mersey Docks and Harbour Company; oral communication, 1986), Basal Sand and Gravel deposits which are of sub-aqueous origin occur. These appear to be true glacial sands and gravels which were deposited by melt-water streams flowing either beneath or in advance of an active ice-sheet. Being overlain by the lodgement till they cannot be considered as the decay products of the last glacial retreat. Certainly in the dock areas and in some cases elsewhere, these deposits are located in valleys or channels in the indurate rockhead surface, but not all such deposits lie in channels and, conversely, not all channels contain such deposits. Possible examples of these postulated glacial meltwater deposits are variable in both thickness and composition and it is not considered feasible to define even their potential extent.

From the above generalised comments it will be apparent that deposits referable to Basal Sand and Gravel might be present in all areas overlain by lodgement till, whilst exactly similar deposits may remain in areas with no extant till cover, these being described elsewhere (see Sand, undifferentiated, pp.47-48).

i SOLID FORMATIONS

i Introduction

A sandstone is a medium-grained sedimentary rock composed of clastic grains, usually quartz, ranging from 2 mm grain diameter down to 1/16 mm. The grains are usually cemented together by quartz, calcite or iron oxide. This cementation may be complete in a well cemented sandstone, giving a hard, consolidated rock, whereas in a poorly cemented sandstone, cementation is virtually non-existent and the rock behaves almost like free sand.

Sandstones have very variable engineering properties usually depending on the degree and type of cementation. This may vary from a hard sandstone or quartzite to a scarcely consolidated sand. The composition of a sandstone needs to be examined closely along with its engineering properties prior to any construction. A well cemented sandstone will probably be self supporting in excavations or tunnels. A poorly cemented sandstone may require support or grouting. Conversely a well cemented sandstone may prove difficult to excavate whereas a poorly cemented sandstone may be easily dug out.

The stability of a sandstone is controlled by the natural discontinuities which define the structure of the rock mass. These include bedding, jointing and faults. The degree, orientation, frequency, extent, infillings etc. of such structures need to be known along with the lithology of a sandstone when planning foundations, tunnels, or excavations.

Water may prove to be a problem in any construction involving sandstone as sandstone usually has a high porosity and permeability. This ability to store and transmit water results in many sandstones forming aquifers, usually with a high water table.

Similarly because of their high porosity and permeability sandstones may store and transmit hydrocarbons, liquid or gas. The presence of hydrocarbons will raise special problems in construction while the former presence of hydrocarbons in a sandstone often results in a leaching of the sandstone and its subsequent weakening. Both oil and gas are known from sandstones in the Liverpool area (see below).

A mudstone/siltstone is a sedimentary rock composed of fine grained constituents less than 1/16 mm in diameter. Such strata usually consist of clay minerals with lesser amounts of quartz and mica. As with sandstone the engineering characteristics are very variable, depending on the degree of consolidation, cementation and the amount of pore water retained. Similarly the stability of a mudstone/siltstone is controlled by the natural discontinuities which define the rock mass (see above).

The weathering behaviour of a mudstone/siltstone will depend in part on the mineralogy of the clay(s) making up the rock. This could be important if, for example, the mineralogy of the clay(s) allowed a fresh recently exposed mudstone to weather very much faster than an adjacent mudstone. Such a situation would lead to a rapid loss in strength of the rock and a consequent failure in say a foundation or road cutting.

Groundwater is usually not a problem in these rocks as their permeability is very low and they form aquicludes. However, if the mudstone/siltstone is highly fractured with many joints and/or faults, groundwater may be a further problem, particularly when tunnelling. Similarly, a highly fractured mudstone/siltstone, even if well cemented, may require support when excavated; whereas a poorly cemented mudstone/siltstone, even if it is not fractured, will certainly require support during excavations.

Marl is an intimate mixture of clay and calcium carbonate; marlstone is an indurate rock of the same composition. However, in the records of the Liverpool area marl has also been used to describe a clay or earthy material including weathered mudstone.

ii Details

The solid geology of the Crosby, Bootle, Aintree area was last surveyed in detail during the 1930's. This information was published on the one-inch to one mile Geological Survey Sheets 83 (Formby) and 84 (Wigan) in 1942 and 1937 respectively. Since that time evidence has been obtained to indicate that a revision of the solid geology is required. However, this was not commissioned in the present study and the following is a generalised account based on the published maps (see above and below) to which the reader is referred.

Sandstones of the Triassic Sherwood Sandstone Group underlie the entire study area except for three small areas in the west, Bootle [337 967], Blundellsands [305 999] and Great Crosby [330 994] where mudstones/marls of the Mercia Mudstone Group occur. A very small area of Carboniferous red mudstone may also occur on the eastern edge of the area at West Derby [399 959].

The sandstones and mudstones/marls occurring at crop beneath the drift of the Crosby, Bootle, Aintree area, are summarised in Table 1 (p.59). Modern stratigraphical nomenclature together with the older nomenclature are used in the table. This will enable the reader to consult the updated 1:50 000 Sheet

		LITHOSTRATIGRAPHICAL UNITS	LITHOLOGY	PREVIOUS NOMENCLATURE	
TRIASSIC	**MERCIA MUDSTONE GROUP**	Unnamed Mudstone Formation	Red, brown and grey mudstone/marl	Keuper Marl	
		Tarporley Siltstone Formation up to 60m	Red, brown, yellow, greenish-grey and 'blue'interbedded sandstone, siltstone and mudstone/marl	Waterstones	
	SHERWOOD SANDSTONE GROUP	Ormskirk Sandstone Formation up to 180m	Grey and yellow to red sandstone, with mudstone/marl bands and scattered quartz pebbles/marl pellets	Keuper Sandstone	
		Wilmslow Sandstone Formation up to 200m	Red to yellow, locally mottled, sandstone, normally current bedded, but may be flaggy; usually poorly cemented	Upper Mottled Sandstone	Bunter Sandstone
		Chester Pebble Bed Formation up to 320m	Dull red to yellow pebbly sandstone, normally current bedded and well cemented; rare thin interbedded bands of mudstone/marl	Bunter Pebble Beds	

Table 1. Triassic rock succession in the Crosby, Bootle, Aintree area

84 (Wigan), published 1977, and the reprinted 1:50 000 Sheet 83 (Formby), published 1976, for an indication of the underlying rock at any particular site.

So far as is known, at present, faulting within the study area is substantially that shown on the published maps. It is highly probable, however, that the steep-sided buried channel trending north-north-west south-south-east across Aintree and West Derby (see Map 5 SJ39NE), lies along a major fault zone, hitherto unknown.

The reservoir sandstones for the hydrocarbons of the off-shore Morecambe Bay Gas Field are located within the Waterstones and the Keuper Sandstone (Ebbern, 1981). Likewise hydrocarbons in the former Formby Oil Field, just to the north of the area, were located in the same formations (i.e. Waterstones and Keuper Sandstone, Wray and Cope, 1948, p.40). Oil has also been recorded, as a seepage, at the junction of these two formations at Little Crosby (Wray and Cope, 1948, fig. 2, p.6), just beyond the northern boundary of the study area. A further show of oil was encountered in red sandstones of the Permo-Trias from the Croxteth No 2 borehole just beyond the south-eastern corner of the study area (Pinfold, 1958, p.117). Thus it is likely that residual hydrocarbons may be encountered within the sandstones of the study area and this must be kept in mind during planning and site investigations. Whilst this study was taking place gas and oil were encountered in sandstones during site investigations in Liverpool for the main interceptor sewer.

RECOMMENDATIONS FOR FUTURE WORK

The study covered by this report, including the output of maps and figures, was as specified by the Department of the Environment, who financed the work within severe financial constraints. Nevertheless it is evident that a more detailed investigation within the Crosby, Bootle, Aintree area would have been beneficial. The following recommendations apply solely to the area covered by 1:10 000 maps SJ39NW and NE:

1. **A complete revision of the solid geology.**

   The succession of solid rocks in the Liverpool area is well established (Table 1, p.59). However, on the geological 1:50 000 Sheet 83 (Formby) the map fails to distinguish the Waterstones, Upper Mottled Sandstone and the Bunter Pebble Beds "because of the paucity of exposure and widespread mantle of Superficial Deposits" (Wray and Cope, 1948, p.8). Further difficulties have arisen because the early surveyors did not appreciate the effects of hydrocarbon leaching, with the result that some exposures are incorrectly correlated. Assessment of borehole evidence and recent geophysical work (University of Birmingham, 1984), together with a re-examination of the field exposures, will produce a better account of the solid geology of the area. In particular, it will identify those areas in which the poorly cemented Upper Mottled Sandstone crops out.

2. **The production of maps showing:**

   a) contours on the upper surface of the Till

   b) thickness (isopachytes) of Till

   c) the extent of the Middle Sands within the Till.

   Within the drift sequence consolidated till forms the only major deposit suitable for foundations. The overlying sediments are in the main unconsolidated; therefore a contour map of the upper surface of the Till would indicate the first major foundation level within the superficial deposits. It is also necessary to know the likely thickness of Till present at any locality. For this, a Till thickness (isopachyte) map is required. Within the Till the Middle Sands could prove to be a problem if they contain a perched water table; a map showing their extent is therefore necessary.

3. **The production of detailed horizontal sections showing the lateral variations in the drift deposits.**

Sections across the area as depicted by Figures 5, 6 and 7 were requested by the Department of the Environment. However, accurately constructed horizontal sections showing the lateral transitions and relationships of the drift deposits would be more meaningful and useful.

4. **The collection of the geotechnical data available, and its presentation in a suitable form.**

An assessment of the geotechnical data available from superficial and solid deposits of the area would enable planners, site investigators and engineers to plan site investigations.

5. **Future users of this report should consult the British Geological Survey for any update of the information included in the report.**

ACKNOWLEDGEMENTS

We wish to acknowledge the assistance of the local authorities in the Merseyside area in supplying us with borehole and site information: in particular, Mr F Armstrong of the Sefton Borough Engineer's Department, Mr J Ashurst of the Liverpool City Engineer's Department and Dr J G Raybould of the Merseyside County Engineer's Department.

The help extended to us by Mr P Lucas, Chief Engineer of the Mersey Docks and Harbour Company, was greatly appreciated, as was the use of his extensive geological records.

Finally, we wish to record our appreciation for the work done by our two temporary scientific assistants, Miss Andrea Lambert and Mr Donald McLean, formerly in the Geology Departments of the Liverpool Polytechnic and University respectively.

REFERENCES

BOULTON, G.S. 1972. Modern Arctic glaciers as depositional models for former ice sheets. Journal of the Geological Society of London, Vol. 128, 361-393.

BOWEN, D.Q. 1978. Quaternary Geology. (Oxford: Pergamon.)

DE RANCE, C.E. 1870. The geology of the country between Liverpool and Southport. Memoir of the Geological Survey of Great Britain, Old Series Sheet 90SE.

——— 1877. The superficial geology of the country adjoining the coasts of south-west Lancashire. Memoir of the Geological Survey of Great Britain, parts of Old Series Sheets 91SW, 91SE, 90NW, 90NE, 90SW, 90SE, 89NW, 89SW and 79NE.

EBBERN, J. 1981. The geology of the Morecambe gas field. In Petroleum Geology of the Continental Shelf of North-West Europe, 485-493. (London: Institute of Petroleum.)

EDWARDS, W. and TROTTER, F. M. 1954. British Regional Geology: the Pennines and adjacent areas (3rd Edition). (London: HMSO for Institute of Geological Sciences.)

GRESSWELL, R.K. 1957. Hillhouse coastal deposits of south Lancashire. Liverpool and Manchester Geological Journal, Vol. 2, 60-78.

——— 1964. The origin of the Mersey and Dee estuaries. Geological Journal, Vol. 4, 77-86.

HULL, E. 1859. On the new subdivisions of the Triassic rocks of the Midland counties. Transactions of the Manchester Geological Society, Vol. 2, 22-34.

JOHNSON, R.H. (Editor and contributor) 1985. The geomorphology of North-west England. (Manchester: Manchester University Press.)

JONES, R.C.B., TONKS, L.H. and WRIGHT, W.B. 1938. Geology of Wigan. Memoir of the Geological Survey of Great Britain, Sheet 84.

KENT, P.E. 1948. A deep borehole at Formby, Lancashire. Geological Magazine, Vol. 85, 253-264.

LAMPLUGH, G.W. 1903. Geology of the Isle of Man. Memoir of the Geological Survey of the United Kingdom.

LONGWORTH, D. 1985. The Quaternary history of the Lancashire Plain. In The geomorphology of North-west England, 178-200. JOHNSON, R.H. (Editor). (Manchester: Manchester University Press.)

MORTON, G.H. 1877. The glacial striæ of the country around Liverpool. Proceedings of the Liverpool Geological Society, Vol. 3, 284-296.

——— 1897. The geology of the country around Liverpool, including the north of Flintshire (3rd Edition). (London.)

PANTIN, H.M. 1978. The Quaternary sediments from the north-east Irish Sea: Isle of Man to Cumbria. Bulletin of the Geological Survey of Great Britain, No. 64, 1-50.

PINFOLD, E.S. 1958. The search for oil in Lancashire. Liverpool and Manchester Geological Journal, Vol. 2, 106-123.

READE, T.M. 1872. The post-glacial geology and physiography of west Lancashire and the Mersey estuary. Geological Magazine, Vol. 9, 111-119.

——— 1876. The Formby and Leasowe Marine Beds, as shown in a section near Freshfield. Proceedings of the Liverpool Geological Society, Vol. 3, 120-122.

ROBERTS, I. 1871. Sections of the boulder clay at the gas works, Linacre, near Liverpool. Proceedings of the Liverpool Geological Society, Vol. 2, 68-70.

SALISBURY, E.J. 1938. Plants of the sand dune and why they grow there. Nature, Vol. 141, 279 and 814.

THOMAS, G.S.P. 1985. The Quaternary of the northern Irish Sea basin. In The geomorphology of North-west England, 143-158. JOHNSON, R.H. (Editor). (Manchester: Manchester University Press.)

THOMPSON, D.B. 1969. Dome-shaped aeolian dunes in the Frodsham Member of the so-called "Keuper" Sandstone Formation (Scythian -- ?Anisian: Triassic) at Frodsham, Cheshire (England). Sedimentary Geology, Vol. 3, 263-289.

———— 1970. The stratigraphy of the so-called Keuper Sandstone Formation (Scythian -- ?Anisian) in the Permo-Triassic Cheshire Basin. Quarterly Journal of the Geological Society of London, Vol. 126, 151-181.

TOOLEY, M.J. 1974. Sea level changes during the last 9000 years in northwest England. Geographical Journal, 18-42.

TRAVIS, C.B. 1913. Geological notes on recent dock excavations at Liverpool and Birkenhead. Proceedings of the Liverpool Geological Society, Vol. 11, 267-275.

———— 1926. The Peat and Forest Bed of the south-west Lancashire coast. Proceedings of the Liverpool Geological Society, Vol. 14, 263-277.

UNIVERSITY OF BIRMINGHAM, 1984. Saline Groundwater Investigation, Phase 2 - North Merseyside. Final Report to the North West Water Authority. (Unpublished.)

WARRINGTON, G., AUDLEY-CHARLES, M.G., ELLIOTT, R.E., EVANS, W.B., IVIMEY-COOK, H.C., KENT, P.E., ROBINSON, P.L., SHOTTON, F.W. and TAYLOR, F.M. 1980. A correlation of Triassic rocks in the British Isles. Geological Society of London, Special Report, No. 13.

WEDD, C.B., SMITH, B., SIMMONS, W.C. and WRAY, D.A. 1923. Geology of Liverpool Memoir of the Geological Survey of England and Wales, Sheet 96.

WORSLEY, P. 1967. Problems in naming the Pleistocene deposits of the north-east Cheshire Plain. Mercian Geologist, Vol. 2, 51-55.

——— 1985. Pleistocene history of the Cheshire-Shropshire Plain. In The geomorphology of North-west England, 201-221. JOHNSON, R.H. (Editor). (Manchester: Manchester University Press.)

WRAY, D.A. 1916. A description of the strata exposed during the construction of the new main outfall sewer in Liverpool, 1915. Proceedings of the Liverpool Geological Society, Vol. 12, 238-251.

——— 1922. On a boring at Bootle near Liverpool. Summary of Progress of the Geological Survey of England and Wales for 1921, p.159.

——— and COPE, F.W. 1948. Geology of Southport and Formby. Memoir of the Geological Survey of Great Britain. Sheets 74 and 83.

GLOSSARY

(Terms are defined in the context of this report)

Aquiclude — a rock body which is virtually impermeable to water.

Clastic — consisting of fragments (clasts) of rock or organic debris which have been moved from their place of origin.

Cohesion — shear strength of a rock not related to inter-particle friction.

Crop — outcrop; the part of a geological formation that appears at the surface of the Earth or, in the case of a solid formation, covered only by superficial deposits.

Deltaic — pertaining to or characteristic of a delta (the low, nearly flat, alluvial tract of land near the mouth of a river).

Detrital — pertaining to or formed from detritus (a collective term for loose material such as sand, silt or clay derived from older rocks).

Diagenesis — the complex process of physical and chemical change which takes place in converting deposited sediment into consolidated rock.

Escarpment — a more or less continuous cliff or steep slope (the 'scarp') facing in one general direction, backed by a gentler slope (the 'dip slope') facing in the opposite direction.

Fluvial — of or pertaining to a river or rivers; produced by the action of a stream or river.

Indurate — made hard, hardened.

Isostatic recovery — the process of readjustment whereby a block of the earth's crust returns to a state of gravitational equilibrium (isostasy) by relative upward movement after the removal of a surface load, such as a thick ice sheet.

Lithology — the description or physical character of a rock, usually as visible to the naked eye or under a hand lens.

Orogeny — literally the process of formation of mountains but more realistically an episode of geological activity leading to the deformation and relative uplift of rock sequences prior to the formation of a mountain landscape.

GLOSSARY (continued)

Perched water table — the water table of a body of perched groundwater (unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone).

Permeability — the property or capacity of a porous rock or sediment for transmitting a fluid; it is a measure of the relative ease of fluid flow.

Plasticity — the ability of a material to change shape continuously under stress and to retain the new shape when the stress is removed.

Porosity — the ratio of the volume of voids in a rock or soil sample to the total volume of the sample.

Supraglacial — carried upon, deposited from or pertaining to the upper surface of a glacier or ice sheet.

Swelling — expansion or increase in volume caused by the absorption of water.

Thixotropic — having the property of certain colloidal materials (e.g. clay) to weaken or change from an apparently solid state to a mobile or fluid one when shaken, but to increase in strength on standing.

Till — dominantly unsorted and unstratified drift, generally unconsolidated, deposited by a glacier and consisting of a heterogeneous mixture of clay, silt, sand, gravel and boulders.

Void ratio — the ratio of the volume of voids in a rock or soil sample to the volume of solids in the sample.

HEIGHTS IN METRES

SHEET SJ 39 NW

BRITISH GEOLOGICAL SURVEY

Department of the Environment

DRIFT GEOLOGY OF THE CROSBY, BOOTLE, AINTREE AREA

SCALE 1:10 000

MAP 1: BOREHOLE AND TRIAL PIT LOCATIONS

INDEX AND EXPLANATION

- ○ Borehole or trial pit
- ⊕ Borehole or trial pit penetrating rock-head
- △ Borehole or trial pit, exact site uncertain
- ▲ Borehole or trial pit penetrating rock-head, exact site uncertain
- Site investigation area with several boreholes or trial pits

The number adjacent to a symbol denotes the registration number in the B G S archives Thus ○319 refers to record SJ 39 NW/319

The results of this study are presented as two groups of six maps, covering Sheets SJ 39 NW and NE respectively They are accompanied by a descriptive report.

Nutt, M J C and Lowe, D J, 1986 Aspects of the drift geology of the Crosby, Bootle, Aintree area (Keyworth British Geological Survey)

THIS MAP GIVES AN INTERPRETATION OF DATA AVAILABLE AT THE LAST DATE OF SURVEY, ADDITIONAL INFORMATION IS AVAILABLE IN B G S FILES IT IS TO BE USED ONLY FOR PRELIMINARY STUDIES AND IS NOT INTENDED AS A SUBSTITUTE FOR ON-SITE INVESTIGATION

USER'S RESPONSIBILITY

The responsibility for assuring the accuracy of the data for any given site, as indicated by the maps and the report, must remain solely that of the user Care has been taken in selecting, plotting and interpreting data Emphasis has been placed on data obtained by geotechnical engineers and geologists, and on observations made in the field

Nevertheless, it is possible that anomalous ground conditions may exist undetected at any particular site Each site should, therefore, be investigated by detailed surveys with the drilling of exploratory boreholes to prove the ground conditions present, after taking into account the extent, nature and setting of the proposed development

Production of this map was funded by the Department of the Environment

Any enquiries concerning this map should be directed to British Geological Survey Keyworth, Nottingham NG12 5GG Tel 06077-6111

WA/VG/86/2

HEIGHTS IN METRES

SHEET SJ 39 NE

BRITISH GEOLOGICAL SURVEY

Department of the Environment

DRIFT GEOLOGY OF THE CROSBY, BOOTLE, AINTREE AREA

SCALE 1:10 000

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BRITISH GEOLOGICAL SURVEY

Department of the Environment

DRIFT GEOLOGY OF THE CROSBY, BOOTLE, AINTREE AREA

SCALE 1:10 000

MAP 2 : DISTRIBUTION OF SUPERFICIAL (DRIFT) DEPOSITS

INDEX AND EXPLANATION

DRIFT (RECENT TO PLEISTOCENE)

- Blown Sand 0 to 6m
- Alluvium 0 to 6m. Mainly sand, locally clayey; intercalations of gravel, silt, clay and organic material
- Marine and Estuarine Alluvium (including beach deposits) 0 to 14m. Mainly sand overlying silt and clay
- Peat 0 to 12m
- Sand, undifferentiated 0 to 5m. Mainly older blown sand ('Shirdley Hill Sand') but including weathered sandy till (sandy boulder clay) and completely weathered sandstone
- Till (Boulder Clay) 0 to 16m. Clay with stones, locally sandy to very sandy, with lenses of sand and gravel

SOLID (TRIASSIC)

- MMG — Mercia Mudstone Group. Brown and grey mudstone/marl
- SSG — Sherwood Sandstone Group. Red, brown, yellow and grey sandstone, generally medium-grained, bedded or current bedded, poorly to well cemented

_____ Geological boundary, Drift

NOTE: MADE GROUND OR FILL IS SHOWN SEPARATELY ON MAP 3

The results of this study are presented as two groups of six maps covering Sheets SJ 39 NW and NE respectively. They are accompanied by a descriptive report:

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USER'S RESPONSIBILITY

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Nevertheless, it is possible that anomalous ground conditions may exist undetected at any particular site Each site should, therefore, be investigated by detailed surveys with the drilling of exploratory boreholes to prove the ground conditions present, after taking into account the extent, nature and setting of the proposed development

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WA/VG/86/2

HEIGHTS IN METRES

SHEET SJ 39 NW

BRITISH GEOLOGICAL SURVEY

Department of the Environment

DRIFT GEOLOGY OF THE CROSBY, BOOTLE, AINTREE AREA

SCALE 1:10 000

MAP 3: DISTRIBUTION OF MADE GROUND AND FILL (>0.5m THICK)

INDEX AND EXPLANATION

HC	Hard Core - building rubble, rock fragments, slag and ashes
SC	Soft Core - soil, clay (including till) and sand
TR	Town Refuse - ashes, paper, organic matter and household waste including metals
IW	Industrial Waste - ashes, slag, metal, chemical waste and building rubble
BF	Back Fill - may consist of any of the above as a thick deposit
UN	Undifferentiated - usually unknown
- - - - -	Boundary of Made Ground

NOTE: Extensive thin (<0.5m thick) deposits of made ground are common throughout urban areas; these have been omitted from the map. Likewise, minor areas of made ground, for example road, railway or canal embankments have been omitted, except where they form part of a larger tract of made ground.

Much of the evidence for made ground, especially backfilled quarries or pits, has been derived from documentary sources. Since much of the fill, however, is not recorded on detailed plans, many deposits may have been missed or not accurately delimited.

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WA/VG/86/2

HEIGHTS IN METRES

SHEET SJ 39 NE

BRITISH GEOLOGICAL SURVEY

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DRIFT GEOLOGY OF THE CROSBY, BOOTLE, AINTREE AREA

SCALE 1:10 000

MAP 3: DISTRIBUTION OF MADE GROUND AND FILL (>0.5m THICK)

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BRITISH GEOLOGICAL SURVEY

Department of the Environment

DRIFT GEOLOGY OF THE CROSBY, BOOTLE, AINTREE AREA

SCALE 1:10 000

MAP 4: DISTRIBUTION OF PEAT (>0.3m THICK)

INDEX AND EXPLANATION

- Peat at surface
- Peat within or beneath Blown Sand
- Peat within or beneath Marine and Estuarine Alluvium
- Peat within or beneath Alluvium
- Peat within or beneath Sand, undifferentiated

NOTE: THE PRESENCE OF MADE GROUND OR FILL IS OMITTED FROM THE ABOVE CLASSIFICATION

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HEIGHTS IN METRES

SHEET SJ 39 NE

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Department of the Environment

DRIFT GEOLOGY OF THE CROSBY, BOOTLE, AINTREE AREA

SCALE 1:10 000

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Department of the Environment

DRIFT GEOLOGY OF THE CROSBY, BOOTLE, AINTREE AREA

SCALE 1:10 000

MAP 5: INDURATE ROCK-HEAD CONTOURS

INDEX AND EXPLANATION

Contour deduced on the evidence of reliable sub-surface data point

Contour interpolated in areas of poor sub-surface data coverage

Contours are at 5m vertical intervals relative to Ordnance Datum (O.D.).

Drift-free area of Sherwood Sandstone Group

Drift-free area of Mercia Mudstone Group

Areas shown as drift-free may be overlain by Made Ground, see Map 3

NOTE: The interface between weathered rock (above) and indurate or non-weathered rock (below) is not always recognised in sub-surface records and if noted may be defined by differing criteria. Whilst every effort has been made to standardise the data used in compiling the map the possibility remains that weathered rock extends to a greater depth than is shown in some areas. In areas of limited or unreliable data, the contours are generalised.

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SHEET SJ 39 NE

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DRIFT GEOLOGY OF THE CROSBY, BOOTLE, AINTREE AREA

SCALE 1:10 000

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