A COMPUTERISED STORAGE AND RETRIEVAL SYSTEM FOR THE COMMUNICATION OF GEOTECHNICAL DATA

A THESIS SUBMITTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

BY

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SUMMARY

A computer based storage and retrieval system has been developed to collate the large amount of geological and geotechnical information derived from civil engineering activities. This will greatly enhance the information available to the civil engineer at the pre-site investigation stage. Existing storage and retrieval systems are reviewed and none of the available systems was suitable for this application.

A set of data preparation sheets based on the standard 80 column computer card have been developed to facilitate the transference of borehole information into eleven data storage files. Each contains different categories of information and is designed to allow for immediate correlation between files. The collation and transference of data onto these sheets was hindered by various deficiencies in the records. The classifications for lithological description currently in use have been employed but a new terminology has been set up to describe coarse grained sediments.

Data were obtained for a redevelopment area of some 15 sq. km. to the northeast of the Birmingham City Centre. The area yielded a high density of data with some 520 boreholes penetrating a variety of glacial, interglacial and postglacial deposits overlying Triassic mudstones and sandstones, providing a broad range of geotechnical properties.

To meet the wide variety of user requirements basic routines were developed in Fortran 1V to retrieve and present data: factual data in the form of tabulations and plans and interpreted data as two dimensional maps and sections, and three dimensional projections. Two computer programs have been used to produce maps indicating the drift lithology distributions and bedrock topography. The reliability of these contour maps and their dependence upon the distribution of data points is discussed. Although the data distribution is poor, the validity of the techniques employed is shown to be equally as viable as a manually produced map of the same type.

The viability and commercial value of the system are discussed and suggestions made for its extension.

Key words: Automatic Data Processing. Engineering Geology.
Site Investigation. West Midlands.

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1. INTRODUCTION.

1.1. Objectives.

The vast amount of geological and geotechnical information derived from site investigations, construction records, temporary excavations and similar operations, is at the present time, widely dispersed. The usefulness of this information is therefore limited due mainly to its lack of immediate availability. However, there are several sources of information readily available which include published maps and memoirs, information from official bodies (e.g. many abandoned mine workings are recorded in the Divisional Plans Record Offices of the National Coal Board), and aerial photographs, and these have been reviewed by Dumbleton (1973) and Dumbleton and West (1971). Such sources allow the collation of available information on topography, hydrology and geology at the initial investigation stage of a scheme. This relevant information together with aerial photograph interpretations and data from existing site investigation records in the near vicinity, or from areas where similar materials have been encountered, is then used to assess the extent of additional data still required for the project design (Gordon, 1976). The fact that information on ground conditions will continue to accumulate rapidly has been recognised by Rhind and Sissons (1971). Although this is potentially beneficial, the problems envisaged in the collection, indexing, storage and retrieval of this information has led to the development of this study.

The primary object of the study is to collate as much of the available information as possible on ground conditions in the West Midlands and to store that information in a computerised format in such a way that would make it readily available to engineers and architects of both local and regional authorities and private industry. The type of information required by the engineer must be recognised even before the effective recording of the information can proceed. This demands a full appraisal of the nature of the information and the requirements of those who could make use of such information. Such an appraisal inevitably involves a critical evaluation of the many existing classifications, their terminology and methods of recording.

As variations still exist in the recording of borehole information, the first part of this study sets out to establish a form of recording which, whilst not conflicting with existing methods, would be totally compatible with available and proposed computer systems. Many computer systems could be utilized but the only system encountered with similar objectives was that proposed by the Institute of Geological Sciences (Cratchley, personal communication). The development of new, or the utilization of established classifications and terminology is constrained by the need to transfer information from existing records (e.g. borehole logs) without any loss of detail, onto standard 80 column computer cards. The subsequent management of this information must involve programs designed to sort, select, manipulate and present data in an immediately communicable form, and this constitutes the second part of the study.

Although this study must provide for a large variety of users, not all of which will require the same information or the same manner of presentation, the data retrieval will fall into two broad categories:

(i) direct information retrieval and collated data employing either graph plotter or line printer;

(ii) interpretive retrieval, for instance utilizing computer contouring programs for two dimensional maps and sections, and three dimensional projections.

The output format is, above all, a means of communication and it is therefore imperative that the output should not only contain the relevant information, but also be presented in a manner with which the user is familiar. The system is designed primarily to be of value to the practicing engineer and the relevant information can be classified under the following headings:

(i) general geology;

(ii) detailed drift geology;

(iii) geotechnical properties;

(iv) groundwater conditions;

(v) problem areas for
   a) excavations;
   b) foundations;
   c) slope stability;
   d) chemical conditions.

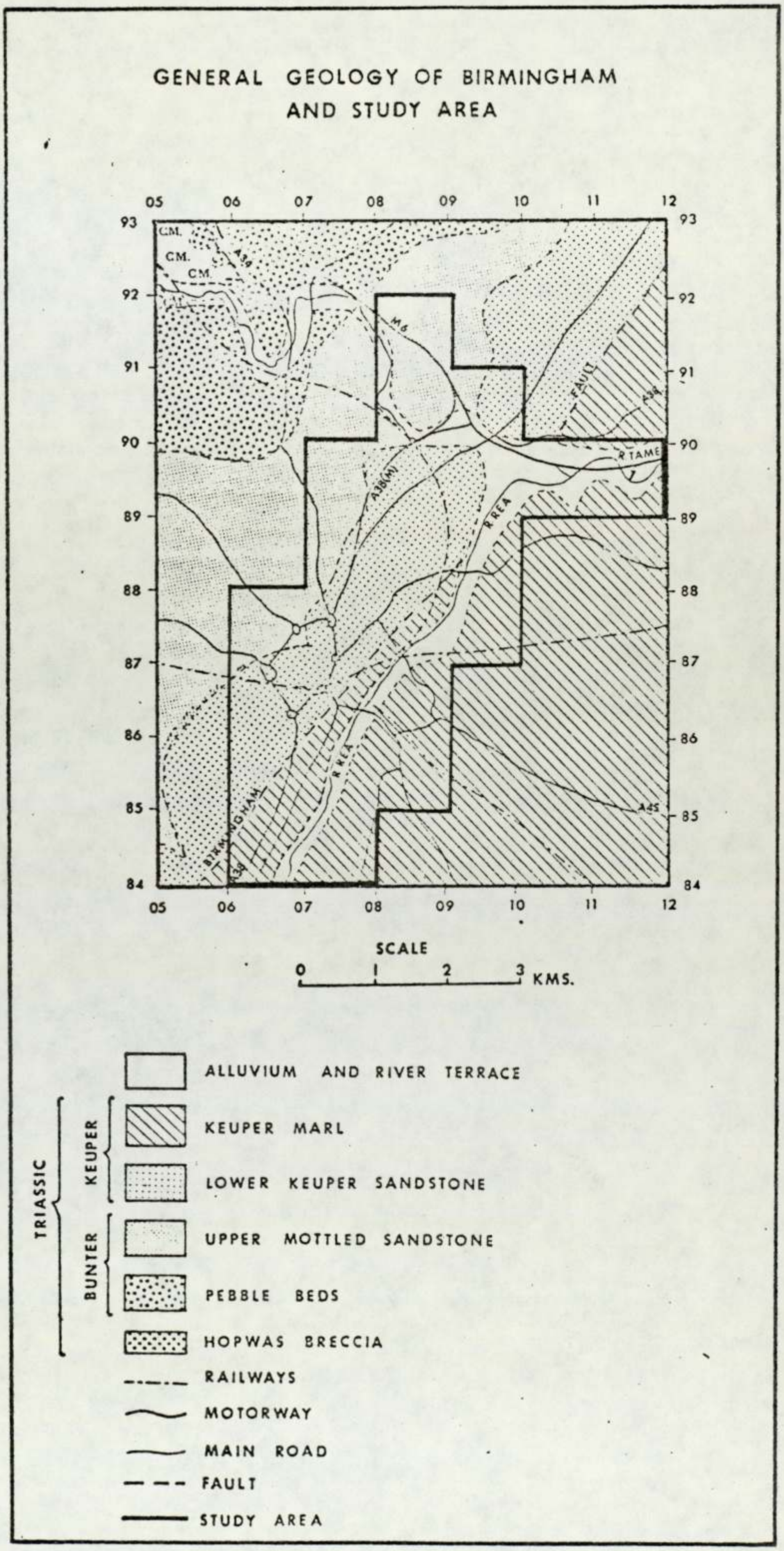
The system, seen as an ongoing project, must be capable of dealing with the very large volumes of information available at the present time. It must also be sufficiently flexible to accommodate the addition of new information in the future which may be of a different character to that available today. At the same time, in order for the system to provide a viable service, it must be economic and therefore in the design of the various programs and presentations simplicity is paramount.

1.2. Study Area.

In deciding upon a specific area within which to develop and investigate the viability of the system two constraints are immediately apparent. Firstly, the area must provide a high density of data and secondly, these data should be of a wide variety.

The first of these constraints effectively limited the choice of the pilot study area to a major developing (or redeveloping conurbation which could provide the comprehensive coverage of detailed geological and geotechnical information. To satisfy the second constraint of variety, the Midland conurbations with their complex glacial history were thought to be ideal. Bedrock variety posed some problems but it was decided to avoid any involvement with the Coal Measures and concomitant mining even though this restricts the bedrock to the Trias.

Of the two choices immediately available, namely Telford and Birmingham, the latter was preferred on the basis of proximity and the willingness of the Birmingham City Corporation to participate in a project of this nature, (fig. 1.1.).


GENERAL GEOLOGY OF BIRMINGHAM
AND STUDY AREA
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89
88
87
86
85
84
C.M.
A34
M6
FAULT
A38(M)
R TAME
R REA
BIRMINGHAM
A45
SCALE
0 1 2 3 KMS.
ALLUVIUM AND RIVER TERRACE
KEUPER MARL
LOWER KEUPER SANDSTONE
UPPER MOTTLED SANDSTONE
PEBBLE BEDS
HOPWAS BRECCIA
TRIASSIC
KEUPER
BUNTER
RAILWAYS
MOTORWAY
MAIN ROAD
FAULT
STUDY AREA

FIG. 1.1

1.3. Previous Work.

A literature search was carried out to provide background information on the numerous computer-based storage and retrieval systems which have been devised to manipulate and display data from the earth sciences.

Many of the earlier systems were designed in an attempt to index and reference the vast amounts of books, papers, reports, conference proceedings etc., e.g. Graves et al (1969), Orosz (1973) and laboratory collections e.g. Creighton (1969). However, there have been some significant developments in fields allied to this study, e.g. geology and hydrogeology, and computer based systems which have been successfully tried in Canada, United Kingdom, United States and Australia are considered relevant to this study.

Following a feasibility study by the Geological Survey of Canada in 1965 (which revealed that many organisations were preparing, or had established computerised data processing systems, e.g. Buller (1964), and were now seeking further advice), the National Advisory Committee on Research in the Geological Sciences established an ad hoc committee to develop a national system for the storage and retrieval of geological data in Canada (Brisbin and Ediger, 1967). The original proposal was that a single file and support system be designed, capable of storing data of all disciplines contributing to geology. It was apparent that such a file would become so complex and ponderous that it would defeat its own purpose. A concept for a separate owner-controlled file system was developed using common standards for geographic location, geological terminology and coding, reference numbering etc., and using a national index to serve as a comprehensive link identifying all files in the system. These systems not only provided basic information on the methodology of data storage but also on the display of the data.

Roddick and Hutchinson (1968*, 1972) undertook to research and develop a workable scheme for machine retrieval and processing of data, in conjunction with the Geological Survey of Canada, from the reconnaissance mapping of the Coast Mountains of British Columbia. The recording of field data in this scheme includes: the entry of data in coded form onto preprinted 'station' sheets, recording of the description by tape recorder for later use, filling out of preprinted rock specimen sheets for computer intake, and finally the digitising of station locations from base maps. This system has since undergone a series of changes, (Hutchinson and Roddick, 1974), the most important of which is the use of free text to complement data.

Drummond (1969), in response to an increased influx of geological data and the need for efficient utilization of the data collected, developed a storage and retrieval system. This was outlined for the Geological Survey of Canada and later modified to stress the geology of an individual property or deposit. Data are stored in a coded form on files which can be easily updated and which can be retrieved on a geographical basis in the form of line printer lists and intensity contouring.

Other field data systems have since been described, e.g. Wynne-Edwards <u>et al</u> (1970), Reinhardt and Jackson (1973), in which details regarding data items recorded, codes, input forms and computer programs to store, retrieve, manipulate and plot collective data can be found. Similar projects were also

* 1968 Hutchinson & Roddick

undertaken in: mineralogy (Whitmore, 1974), exploration geochemistry (Garrett, 1974), aeromagnetic surveys (Holroyd, 1974), geochronology (Frith, 1974), laboratory collections (Lambert and Reesor, 1974), statistical analysis of geological data (Agterberg, 1974) and hydrogeology (Gilliland and Treichal, 1968).

One of the most relevant studies is that by the Terrain Sciences Division of the Geological Survey of Canada in 1970 where a study was initiated to investigate the requirements of geological and related earth science data for efficient land use planning in urban areas (Belanger, 1974). In 1971 the first phase of the project was completed and the first map of superficial geology of the Ottawa - Hull region was produced from an adapted version of SYMAP (Fisher, 1968), a standard line printer produced map plotting package. A similar study was made by Grice (1971) to facilitate the handling of engineering geological data in urban areas.

The Geological Survey of Canada are, at the present time, investigating the possibilities of establishing a new body to be solely responsible for co-ordinating development, input and distribution of the products of the national system.

Studies have also taken place in this country to investigate the practicability of the Institute of Geological Sciences establishing automatic data processing facilities for its own internal research and to provide data banks for collaborative use with other organisations (Gray, 1968). Initially three pilot studies were started in November 1967 using the Atlas Computer Laboratory at Chilton. The first study is concerned with mainly numerical gravity station data; the second, well records and descriptive hydrogeological data, and the third is concerned with the records of boreholes in the Carboniferous succession of Central Scotland. Studies also include the use of codes to cover stratigraphical classifications, petrographical-lithological terminology and geographical location (which includes Ordnance Datum level), and also the utilization of free-format recording as opposed to fixed format. It is fair to say that these studies were influenced by those instigated in Canada but there were earlier experiments involving small geological computer data files e.g. Loudon (1969).

The pilot study on the storage and retrieval by computer of geological information from cored boreholes in Central Scotland was developed to enable a geologist to present his record for computer data preparation in a form similar to his present field log (Gover et al, 1971). This scheme utilizes a small vocabulary of some 200 words to describe data in the field and enable this information to be fed directly into the computer without prior coding. The data are then automatically coded into a condensed form for storage on magnetic tape. The retrieval of information has been developed using a 'near-English' language and questions can be put forward by a geologist in a reasonably understandable manner. The output is in the form of listings but further development is indicated for the plotting of contour maps and for the statistical analysis of the data utilizing the Rocdoc package (Loudon, 1967).

Subsequently Rhind and Sissons (1971) investigated the feasibility of data banking of drift borehole information and provided a scheme which incorporated data from 14,000 boreholes in a data bank with storage on magnetic tape. Programs were devised for storing and retrieving the data in the form of tabulations, graphical displays of borehole distributions, trend surface and contour maps and also in the form of histograms. The computer manipulation of such data is extended with the use of automated cartographic techniques to produce maps or other displays quickly and in a form usable by the geologist (Rhind, 1973).

These studies have led to the creation of data banking facilities for the earth sciences being provided at the Institute of Geological Sciences by the installation of the G-Exec system. This system, still under development, provides for the storage of data from the many fields of the earth sciences in fixed length records with the hierarchy requiring crossfile listing. It contains many analytical and display programs.

Research in other countries is following similar lines. For example in America core-log data on Upper Pennsylvanian and Lower Permian coal-bearing strata in southwestern Pennsylvania are being stored and retrieved by computer methods by the United States Geological Survey (Kent, 1969). Earlier work in the United States was primarily concerned with data processing for petroleum exploration, e.g. Buller (1964), and from these studies many contributions to automatic data processing have emanated. The most relevant of these are those of the Kansas Geological Survey, where many programs have been designed for the analysis of geological data. These have included multivariate and factor analysis, polynomial and Fourier trend surface analyses, contouring routines, clustering etc. These programs and research papers were made available through the publication of 'Computer Contributions' by the Kansas Geological Survey, but are now published under the title of 'Geocom Programs'. The state of such work is well summarised in texts and the foremost of these standard works are by Harbaugh and Merriam (1968) and Davis (1973). Numerous other texts have also been produced and although mainly concerned with the statistical analysis of earth science data are relevant to this study, e.g. Koch and Link (1970, 1971), Krumbein and Graybill (1965), Miller and Kahn (1962), Harbaugh and Bonham-Carter (1970), Cutbill (1969). Similar work has also been undertaken at Harvard University, Massachusetts, particularly in the contouring of two dimensional data and three dimensional projections e.g. Fisher (1968), Shepard (1968).

In Australia the Geological Survey of Queensland have developed a computerised storage and retrieval system for hydrogeological data (Laycock and Siggers, 1973). This system is designed to store data from boreholes or wells on magnetic tape. Information is collected on data preparation sheets in the field and further information such as chemical analyses and pump test results added later. The information is then punched onto six different card types: master (basic location information), bore and aquifer details, chemical analyses, additional chemical analyses, lithological log and pump test. All card types are interlinked by the bore reference number and separate sequencing features occur on all card types. Information is recorded in a fixed format on 80 column cards, i.e. particular columns are used for the presentation of data for a particular item of information, and retrieval, by line printer listing, is on the basis that values occur in certain fields as specified by the parameter request.

Grant and Lodwick (1969) have set up a framework for the storage and transfer of terrain information relevant to engineering projects, such as road construction. Data collected in the laboratory, from aerial photographs and geological maps, and in the field by observation and measurement of topographic, soil and vegetative details, are fed into the computer by means of punched cards for storage on magnetic tape. Retrieval is in the form of line printer listings and when fully developed will facilitate the extrapolation of engineering information from one locality to other areas of similar terrain.

The necessity to standardise all these systems, is illustrated by the establishment of Cogeodata, the International Union of Geological Sciences Committee on Storage, Automatic Processing and Retrieval of Geological Data in 1967. The aim of Cogeodata is: to appraise existing systems, to establish factors common to all records of geological data, to work out formats for machine processible files in a limited number of specific fields and to establish an index of geological data (Hubaux , 1972). It was intended that Cogeodata would be a platform where problems of geological data storage and retrieval would be studied and experiences exchanged, by the establishment of liaisons with the members of the International Union of Geological Sciences.

The discussions above on automatic data processing in the earth sciences clearly indicate the considerable volume and breadth of research carried out to date. However, whilst much of the work discussed is relevant to this study none is immediately applicable.

2. REQUIREMENTS FOR A DATA RECORDING SCHEME.

2.1. Requirements Of The Civil Engineer And Information Sources.

2.1.1. Requirements of the Civil Engineer.

The Civil Engineer is involved in the design and construction of a variety of structures, almost all of which involve the local geology to some extent. These may include light surface structures, such as single storey factories, where the geology is of little concern, and tunnels or deep cuttings, where the geology is of the utmost importance. The geology is also involved when construction materials are sought and extracted for use elsewhere.

The majority of civil engineering structures impose an additional load on the soils and rocks beneath the site. These materials will deform under such loads and it is important that the engineer is made aware of the relevant physical and mechanical properties of the strata involved and of the manner in which the strata are distributed beneath the site.

Two important mechanical properties of soils and rocks are strength and compressibility, which can often be correlated with moisture content and density. In most situations it is necessary to perform laboratory tests to determine such properties as moisture content and density quantitatively, but for light traditional structures an accurate qualitative assessment of the lithology, based on considerable experience, may be sufficient to formulate an economically acceptable design.

The geology of a given site also plays an important role in construction: the ease of excavation, the choice of excavation plant, the side slopes or supports required in excavations and groundwater control are all aspects which are highly dependent on the geology.

In conditions where high residual, locked-in stresses exist in the rocks, the problems of heave, creep and even rock bursts demand a highly critical examination of the geology before any design can be attempted.

Groundwater conditions are of considerable importance. The position of the water table has a profound effect on the cost of construction in cohesionless soils, and in the construction of filter tanks and swimming pools the problem of hydrostatic uplift must not be overlooked. For surface water impoundment schemes the water conditions before and after filling of the reservoir must be carefully investigated and assessed if serious leakage is to be avoided and the side slope stability maintained (Kiersch, 1964).

In reuse situations the engineer must be fully aware of the manner in which his selected materials will behave in their new environment. Certain materials used in embankments have been found to swell with time and the anticipated settlement of the embankment was negative (Birch,1965). Materials for earth dams must be carefully selected, core clays must not shrink and crack with time and shoulder materials should not degrade on successive slaking and drying.

The engineer thus requires a considerable amount of information, which is dominantly geological before he can proceed through the various stages of the scheme. Broad geological parameters will be required at the planning stage and more detailed specific information, which includes quantified geotechnical data, will be needed as the scheme proceeds through design into construction.

2.1.2. Information Sources.

2.1.2.1. Introduction.

There are several preliminary sources of site information available in the United Kingdom. These sources include: published maps and memoirs, records of official bodies, aerial photographs, and previous site investigations. These sources can provide valuable initial information to enable the data obtained at a later date by direct subsurface exploration to answer the specific requirements of the engineer.

However, these sources are not always readily available, or may not prove useful for a particular project, but they are available at a low cost compared with that of information obtained directly from subsurface exploration. Many sources of information are covered generally in this following section, more detailed information is available from the report by Dumbleton and West (1970, 1971).

2.1.2.2. Geological maps and memoirs.

Geological maps constitute a most valuable source of preliminary site information. The Institute of Geological Sciences produces several types of geological maps, e.g. 'Solid' or 'Drift' editions, at a 1:63360 scale (currently being reissued at 1:50000), from which material types and geological structures can be obtained, or at a 1:10560 scale (reissue at 1:10000) incorporating borehole and similar exposure descriptions.

A further series of maps, produced by Her Majesty's Stationery Office, shows the distribution of coal, ironstone, limestone and, sand and gravel deposits. Numerous geological maps can also be found published in journals, monographs and books illustrating particular problems in specific areas.

Regional geological descriptions can be found in the Handbooks of British Regional Geology for England, Wales and Scotland. Further detail is obtainable from the 'One-Inch' Sheet Memoirs which supplement the geological maps and contain detailed information on geological strata, exposures, borehole and well logs, groundwater and water supply, slope stability and local engineering materials.

Information is also available on coalfields and mining areas, such as boreholes, shaft records and mineral deposits from Coalfield Papers and Economic Memoirs. Records of abandoned coal mines are also available from the National Coal Board.

2.1.2.3. Hydrogeological maps and publications.

Groundwater conditions can be ascertained from numerous hydrogeological maps published by the Institute of Geological Sciences and the Water Resources Board. In addition, the Institute of Geological Sciences Water Supply Papers, Water Supply Memoirs (County based) and the Well Catalogue Series (related to the 'One-Inch' Series), may also contain relevant information. Information may also be obtained from research reports on problems in particular areas.

Data on river and tidal levels, stream flow and flood levels can be obtained from the Surface Water Year Book of Great Britain, compiled annually by the Water Resources Board.

2.1.2.4. Soil Survey, Land Utilization Surveys and Agricultural Land Classification.

Maps and memoirs of the Soil Survey can be used for engineering purposes. Soil maps may provide a better indication of the near surface drift materials in areas where the geological mapping is old. A better lithological description is given together with variations, and areas of poor drainage and peat are shown.

Land Utilization Surveys, using Ordnance Survey 1:25000 scale as a base-map, show sixty-four land-use categories divided into thirteen main groups:

Settlement	Arable
Industry	Market Gardens
Transport	Orchards
Derelict Land (abandoned tips)	Woodlands
Open Spaces	Heathlands
Grass	Moorlands and Rough Land

Water and Marsh and Unvegetated Land.

The Agricultural Land Classification indicates the relative value of land for agricultural use which is of considerable value in the planning of highway routes.

2.1.2.5. Aerial photographs.

Aerial photographs representing the state of affairs at the time the photograph was taken may provide more recent information than the published map. Stereophotography is capable of conveying much more information to experienced eyes than a topographic map. It is of particular value in ascertaining land use, slope stability and geological boundaries. The interpretation of aerial photographs is well documented by Dumbleton and West (1970).

2.1.2.6. Previous site investigations.

There are many organisations which keep records of site investigations which they have carried out themselves or records of investigations made whilst under contract. Because of the legalities involved a large proportion of the private civil engineering firms are often reluctant to disclose information. However, official bodies such as the Road Research Laboratory, who are developing their own computerised data bank, local authorities and the Institute of Geological Sciences can provide valuable supplementary data. The last also receive records of all wells sunk to depths of more than 50 feet by provision of the Water Act 1945 and the Second Schedule of the Science and Technology Act 1965, and this information may enable the Institute to provide data on the groundwater conditions of the area. All information obtained from the sinking of boreholes and shafts for minerals, including petroleum, is also made available to the Institute of Geological Sciences when the drilling is for more than 100 feet, through the relevant sections of the Mining Industry Act, 1926 and the Petroleum Protection Act, 1934.

2.1.2.7. The engineering interpretation of existing information.

'Geological maps, overlaid on a topographical base map and providing information on the lithologies, stratigraphy and structures present, have several shortcomings from the viewpoint of an engineer' (Anon., 1972):

(i) rocks and soils of markedly different engineering properties may well be bracketed together as a single group because of equal age or similar origin;

(ii) the lack of quantitative information on the physical properties of the rocks and soils;

(iii) the lack of quantitative information on the extent of weathering;

(iv) the lack of quantitative information on groundwater;

(v) the lack of quantitative information on geotechnical properties.

However, some specific information for engineers is still obtainable from geological maps. On the 1:10560 Geological Survey maps, locations and descriptions of selected boreholes, with depths and thicknesses of encountered strata can be found. Sections are provided on many of the 1:63360 series of maps indicating the structure and where these are not present sections can be constructed easily to show the subsurface structure in any required position. Other geological information presented on both these series includes dips of strata, faults, igneous bodies, glacial deposits, buried channels, river terraces, springs and seepages. These last major surface features being shown by conventional symbols on topographic maps. Landslips, foundered strata (disturbed and displaced) and escarpments where landslips commonly occur are clearly indicated on the Institute of Geological Sciences Hydrogeological maps.

Although this information is useful to the engineer, one must not forget the scale on which it is presented. As the engineer is often dealing with small sites, local variations which may be too small to be shown on such maps may have considerable influence on the development of such a site.

Similar arguments can be applied to other sources of information such as the Soil Survey and Land Utilization Survey where the information contained is not specifically useful to the engineer, but often provides necessary background information for a site investigation. The interpretation of aerial photographs depends on the experience of the user. An experienced operator can make a detailed analysis of an area from aerial photographs; geologists are able to map and interpret features such as those produced by a stronger rock. The engineering geologist can assess slope stability in clays or even water conditions. Each interpretation is dependent on the request and the background of the operator.

Where the records of existing site investigations are available, they may well provide useful information but a careful assessment must be made of the quality of the data whilst re-interpreting these records. Often, the older the records the more dubious the quality of the data.

2.1.2.8. Availability of information.

Much of England, Wales and to a lesser extent Scotland is covered by 'Solid' and 'Drift' geological maps as well as by the Ordnance Survey Series, which can be effectively used as base maps. However, not all the 1:63360 scale geological maps have been published, or at best may be out of date, e.g. Birmingham Sheet 168, Eastwood et al (1925). If the latter is true, the general geology of the area can always be obtained to provide useful information in the preliminary stages of an investigation. Many of the 1:63360 Series have a related memoir giving more detailed local information and where these are unavailable 'Old Series' memoirs may exist.

Only a small proportion of the country has been covered by the Soil Survey, but in England and Wales surveys have commenced on selected areas in each county, whilst the remainder of the country will be covered by a reconnaissance survey.

A second Land Utilization Survey of Britain was initiated in 1960 and maps have been produced at a scale of 1:25000 for most of England and Wales. The Agricultural Land Classification of England and Wales using the 1:63360 as base map has also been produced for parts of England and Wales.

Most parts of Britain have been covered recently by aerial photographs which can be obtained from: Ordnance Survey, Department of the Environment or Local Authorities. Where recent photographs are not available specialist firms can be located to provide the cover required.

The availability of existing Site Investigation reports has already been mentioned.

2.1.2.9. Site inspection.

After examination of all available information from maps and memoirs, aerial photographs etc., a site inspection is carried out. This is usually performed by an experienced geologist who can interpret the geomorphology in terms of soils and rocks present. It may be necessary to produce a detailed geological map of the area where no suitable map is already available. The detail of the inspection and of the subsequent map or report will be dependent on the scheme envisaged, but in most cases a much greater level of detail is required than that commonly available from published sources. Such aspects as lateral variations in lithology, degree and depth of weathering, minor geological structures including their associated discontinuities, may be of considerable importance to certain schemes. Particular attention may have to be paid to the available sources of construction materials of suitable quality.

Collating all this information with that gleaned from the above mentioned sources, a more effective site investigation can be planned to answer specific questions which may have arisen during the search of existing information, and to provide data for both design and construction. Boreholes, trial pits, adits and pilot tunnels with associated sampling, in situ tests and subsequent laboratory analyses may be utilized to provide the most effective and economic site investigation.

2.2. Fulfilment of Requirements By Various Schemes.

2.2.1. Introduction.

Apart from the information obtainable from the sources discussed in the earlier section, relevant data may be found in the private files of engineers,planners or architects. If this existing information was made available to the engineer prior to a site investigation and with a minimum of time and cost, a more efficient planning of an investigation could be attained, and engineering problems more successfully anticipated. To achieve this a system must be developed, or existing systems expanded to store information in such a way that it can be rapidly retrieved.

2.2.2. Existing Systems.

Present information - storage - retrieval systems have been categorized by Guinne and Mobly (1969) as follows:

(i) None: a system in which the individual discards bits of information which he cannot or will not retain mentally. This is of no use to another individual and can be discounted.

(ii) Haphazard: information which is not catalogued or separated in any manner, completely disorganised and useless for quick and easy access.

(iii) Card Index: Perimeter punch: most filing systems are based on this system, it allows for cross indexing and it is relatively easy to access records. However, for vast numbers of records manual retrieval is time consuming and therefore expensive. This is also the case for microfiche storage where additional expense is involved.

(iv) Computer based: as the system to be used falls into this category, the use of computer based systems is discussed in more detail in the following section.

2.2.3. Use of Systems.

2.2.3.1. Non-computerised systems.

Rhind and Sissons (1971) stated that the volume of information, especially that of borehole data from site investigations, has expanded rapidly over the past few years and no doubt this trend will continue. This rapid expansion, though beneficial, produces problems of collection, indexing, storing and then retrieval. It is therefore essential to use a system which can incorporate all this vast amount of information and, which considers several important factors: time, space, the importance of the information and cost. It has also been reported (Rhind and Sissons, 1971) that rapid access to an up-to-date body of borehole information for superficial deposits is becoming increasingly necessary to engineers, architects and planners for both local and regional planning, and also for specific sites.

At the present time the vast amount of geological and geotechnical information derived from site investigations, construction records, temporary excavations, etc. is widely dispersed and most remain in their original report form. A great deal of time and money would be needed to duplicate all the available information, even in microfiche, and collect it for use in a centralised system.

It was pointed out that if costly masses of data continue to grow in an unrelated and unco-ordinated manner through the increase in reports and research papers containing information, the loss of time, money and achievement would be immense (Burke, 1969).

By using a manual systematic approach, such as a card index storage and retrieval system, the present situation could be contained, but there should be a more efficient means of dealing with the problems of data storage and rapid systematic retrieval (Guinne and Mobley, 1969).

2.2.3.2. Computer systems.

To harness the vast data resources of the present and the future on a national or even regional scale, and to focus it on particular problems, such as research or constructional aids, a highly efficient system is required. Burke (1969) stated that with modern technology it is now possible to handle efficiently these vast volumes of data, and the retrieval and processing of required information is relatively simple and direct.

In the report "Research in the Geological Sciences" 1975, by the National Environmental Research Council the problems of cost and cost effectiveness in new methods of data processing in geology and geophysics were considered.

(i) New methods seldom reduce costs, but normally slightly increased costs are coupled with greatly increased output.

(ii) The unit cost of computing is falling steadily. The costs have halved in real terms, about every five years and this trend seems likely to continue.

(iii) Costs of research into new methods are largely dependent on the manpower involved and will continue to rise.

It was also stated that the making of observations and the assembly of data are often the most expensive and time consuming parts of a project, particularly where field work is involved.

With a computer based system it is possible to retrieve information and present it to the engineer in the form he requires:

(i) plans of borehole positions, groundwater levels, physical and chemical properties of soils and rocks;

(ii) graphical displays of physical and mechanical characteristics;

(iii) borehole logs and test results in tabulated form;

(iv) contour, proximal and isopleth maps;

(v) cross sections;

(vi) three dimensional drawings.

Statistical methods of data analysis can be used to reduce large amounts of geological data to a manageable form and reveal complex patterns and relationships which otherwise may not have been observed. This ability to analyse large files of data in detail and to extract as much information as possible from the data is perhaps one of the major benefits of using computer techniques.

The handling of large data files in any system is not simple and it may also be necessary to maintain files for long periods for repeated examination, correction, deletion and for the addition of new information. It is also possible to provide different output formats from all, or selected parts of the data, to suit the requirements of the user.

3. SYSTEM REQUIREMENTS.

3.1. Geological And Geotechnical Information.

3.1.1. Introduction.

For the development of a computer system, the various types of data necessary for all types of geotechnical investigation have to be recognised and categorized.

The information required by an engineer can be assigned to two basic groups: location and basic borehole information, and the data required for construction and design.

3.1.2. Location and Basic Borehole Information.

The location of a data element can be indicated accurately using the National Grid Reference to ±5 m in plan and Ordnance Datum Level to ±50 mm in elevation. A number of items are considered important in terms of basic information and these comprise:

(i) a completion date, invaluable, as older records appear to be less accurate and non standardised;

(ii) drilling methods;

(iii) groundwater conditions, during drilling.

3.1.3. Construction and Design Information.

3.1.3.1. Geological information.

Geological information is required for each stratum or lithological unit at a particular location and this information can be subdivided into the following:

(i) Soil or rock nomenclature.

As recognised by the Geological Society of London

Working Party (Anon., 1972), the description of bedrock and superficial deposits should be as detailed as possible in lithological terminology in accordance with the Code of Practice, CP2001 (1957). It should include a stratigraphical classification of the deposit and avoid the use of vernacular or local terms.

The basic lithological description includes: colour, mineralogy, stratigraphy, genesis, texture, fabric, weathering, strength and discontinuities, but of fundamental importance is the particle size distribution which enables the rock or soil to be precisely defined. A classification was needed to run concurrent with the Working Party Report (Anon., 1972) which suggested that the soil name be based on particle size distribution and plasticity. These characteristics were chosen as they can be either readily measured with reasonable precision or estimated with sufficient accuracy for descriptive purposes.

(ii) Colour.

Although this property is quite easy to appreciate it is difficult to quantify as a physical property. However, for identification purposes it can be highly significant, especially when used in conjunction with a rock or soil colour chart.

(iii) Stratigraphy.

Local geology is described in terms of stratigraphic units, and both geological and geotechnical information tend to be collated in stratigraphic units rather than in lithological units. It is therefore essential that the stratigraphy is included in any description.

(iv) Genesis.

Lithotypes may have the same name but if the genesis is known the association of certain elements with such a lithology due to the sedimentary environment can be anticipated e.g. sulphates in marine muds, layering in glacio-lacustrine muds etc.

The many different modes of genesis, such as lacustrine, aeolian, fluviatile etc. each of which will induce a different particle assemblage of size, shape and mineralogy, result through diagenesis in rocks and soils of similar appearance but of different engineering properties.

(v) Texture and Fabric.

The texture and fabric of a rock refer to the characteristics of individual grains and their arrangement in the rock or soil mass. The texture and fabric resulting from the nature of the primary sedimentation and subsequent diagenesis, diastrophism, and even metamorphism, has a considerable influence on the engineering behaviour of the soil or rock.

In general, well graded, non-cohesive, granular soils, i.e. those with high uniformity coefficients (D_{60}/D_{10}), possess a higher frictional strength and are certainly much less compressible than poorly graded soils. A soil or rock with preferred particle orientation will have a greater strength in a direction normal to the orientation of the particles. This can also apply to rocks and soils with segregated layers of different grain size or mineral content.

(vi) Weathering.

The processes of weathering, especially of clays, have been shown to result in a progressive change in the relationship between strength and water content, and a loss of strength with increasing weathering has been observed in both the Lias clays and the Keuper Marl (Chandler, 1972, 1969).

The engineer is not only concerned with the results of weathering over long periods of time, but also with the durability of materials which may continue to weather in slopes, tunnels or during their use as construction materials. It was concluded by Chandler (1972) that because weathering is so slow a process on an engineering time scale it is probably not an important factor leading to slope failure, although weathering probably contributes to a reduction in the effective shear strength parameters.

Several weathering grade classifications have now been set up and these are discussed later.

(vii) Strength.

A necessary component of the lithological description is a simple qualitative assessment of compaction or consistency in soils and compressive strength in rocks. A manual assessment of the strength of soils or the determination of uniaxial compressive strength can improve a lithological description.

(viii) Discontinuities.

The presence of discontinuities can impose design constraints and may have considerable influence on the construction. It is essential where these are evident to examine and record their nature, frequency and orientation. For example where discontinuities are extremely closely spaced a very highly permeable material can result; or where a rock is highly jointed the excavatability may be increased but slope stability could be seriously reduced.

(ix) Groundwater.

Deep groundwater tables are generally of no concern in building foundations; conversely a high water table can influence the design of foundations to provide measures for waterproofing and against possible damage by hydrostatic uplift, as well as creating problems during construction.

3.1.3.2. Geotechnical information.

Geotechnical tests are designed to provide quantified parameters on which the behaviour of the material during and after construction can be based, and such parameters are therefore of supreme importance.

Such information is commonly divided into two groups, (e.g. Horton, 1975). The first consists of tests which indicate the natural condition of the material, its physical properties; e.g. moisture content, bulk density, permeability, specific gravity of the solid phase, the particle size distribution, the particle shape and composition (coarse grained soils), clay mineralogy and pore water chemistry (cohesive soils). The second group is made up of those tests which show how the soil behaves in response to changes in stress conditions, the mechanical properties:- undrained and drained shear strength, compressibility characteristics etc.

3.1.3.2.1. Physical properties.

(i) Natural Moisture Content.

This is expressed as the ratio of the weight of water present in the sample to the dry weight of the solid soil particles.

The natural moisture content is of prime importance since it influences both the strength and consolidation characteristics of the soil and provides an immediate indication of the general nature of the soil.

(ii) Compaction and Consistency.

Compaction is the qualitative term applied to cohesionless soils to describe their density, or more specifically their relative density. The behaviour of cohesionless soils can be predicted from a knowledge of their degree of compaction whereas for cohesive soils their behaviour depends on the state of consistency. Wilun and Starzewski (1972) state that, for practical purposes, the mechanical properties of cohesive soils may be taken to depend mainly on the mineralogical composition of the clay fraction and on the type of the adsorbed cations as well as the moisture content (this excludes the influence of the structure of the soil and any diagenetic effects and really refers to a remoulded soil). As the first two factors influence the Atterberg Limits (commonly referred to as consistency limits or index parameters), the state of consistency may be expressed quantitatively as:

$$I_c = \frac{w_L - w}{w_L - w_p}$$

where w = natural water content in %

w_p = plastic limit in %

w_L = liquid limit in %

or qualitatively in terms such as soft, firm, stiff and hard.

The liquid limit, w_L, is defined as the minimum moisture content at which the soil will flow under its own weight.

The plastic limit is the minimum moisture content at which the soil can be rolled into a thread 3 mm in diameter without breaking.

(iii) Bulk density.

The bulk density of a soil, i.e. when the soil is in its natural state, whether saturated or otherwise, indicates the state of compaction of the material and hence its resistance to deformation under load either in situ or in a re-use situation.

From the recording of this property, with moisture content and specific gravity of the solids, a number of other important parameters can be derived, e.g. dry density, void ratio, degree of saturation etc.

(iv) Chemical analysis.

Certain chemical conditions in the ground may result in attack on buried concrete, mortar, and in some cases steel. The chemicals which are of the most concern are the sulphates, commonly found in clay soils, and acidic waters i.e. those with a low pH, found in association with peat soils. Some soils have a corrosive action on metals due to either an electro-chemical or bacterial agency and certain chemicals, such as the chlorides, can also affect foundation materials. Although the actual effects of the last are still debateable, information on the chloride content of a soil or groundwater may prove invaluable. It is therefore desirable to obtain a chemical analysis of the soil and groundwater to assess the necessity for special precautions.

(v) Mineralogy.

At the present time, relationships between the mineralogy and engineering properties have not been established, except in the case of the activity of clays (Chandler et al, 1968). However, the mineralogical composition of a material is thought by many to be of considerable importance. Franklin (1970) suggested that rocks could be assigned to one of five mineral assemblages for engineering purposes (see 3.2.5.). Kenney (1967) has demonstrated that the residual angle of shearing resistance

ϕ'_r is a function of both clay content and mineralogy.

(vi) Particle Size Distribution.

The mechanical analysis of particle size expresses quantitatively the proportions by weight of the various sizes of particles present in a soil and forms the basis for the classification of coarse grained soils.

The result of an analysis is plotted as a grading curve (cumulative percentage finer than the particle size), which indicates immediately the type of material. The general slope of the curve is an indication of the grading or range of particle sizes of which the soil is composed. The shape of a curve can present to the engineer a mental picture of the material, aiding assessment of its suitability for aggregate, fill and other applications.

The particle size distribution influences other geotechnical properties, e.g. porosity, permeability, strength and compressibility characteristics.

3.1.3.2.2. Mechanical properties.

(i) Shear strength.

The shear strength of a soil is the maximum available resistance that it can offer to shear stress at any given point within itself. For the construction of any structure the shear strengths of the materials upon which the structure is to be founded have to be known. The shear strength values have to be determined for the in situ conditions; the choice of test conditions therefore, depends on the purpose for which the shear strength is required. For example, tests on sands are usually carried out under drained conditions because of their high permeability and relatively rapid consolidation.

Undrained tests are used for problems relating to saturated clay soils when relatively rapid changes in stress are anticipated and there is little or no drainage (i.e. no consolidation) taking place. Such problems include the stability of foundations and short term stability of clay slopes.

Consolidated - undrained tests are used where changes in moisture content are expected to take place, due to consolidation, before the soil is fully loaded, and give total stress parameters c_u and ϕ_u relevant to the anticipated stress conditions. If pore water pressure measurements are made then the effective stress parameters c' and ϕ' can be determined. These latter parameters can be used in the analysis of the stability of earth dams, during construction, under full head or, rapid drawdown conditions.

Drained tests are used where long term stability problems are being assessed, but because of the long duration of these tests consolidated-undrained tests with pore water pressure measurement, now tend to be used in preference.

The variety of test conditions under which the shear strength may be determined can be briefly summarised as follows:

(a) Undrained: - the samples are subjected to an applied loading under conditions in which drainage is prevented or has insufficient time to take place.

(b) Consolidated-Undrained: - samples are allowed to consolidate, or soften, under an applied pressure and are then sheared under conditions of no drainage with or without pore pressure measurement.

(c) Drained:- samples are consolidated or softened, as in the previous test, but the shearing is carried out slowly under conditions of free drainage.

(ii) Compressibility characteristics.

Deformations in soils can be due to volumetric and shear strains induced by the applied stresses. The rate of deformation depends on the degree of saturation and permeability of the soils. In the case of a fully saturated soil the latter property controls the rate of deformation which is then referred to as consolidation.

The one-dimensional deformation modulus E (equivalent to the Young's modulus) is becoming more commonly used than the better known coefficient of volume compressibility, m_v, ($E = m_v^{-1}$), and is more easily applied to rocks and soils under a high state of stress, such as in tunnel constructions.

The Standard Penetration Test determines the number of blows, N, of a standard weight (65 kg), falling through a distance of 760 mm, which is required to drive a standard 50 mm diameter split spoon sampler into the soil, a distance of 305 mm after an initial penetration of 150 mm. The number of blows required is assumed to give an indication of the relative density of the soil (see Table 3.1) which has a decisive influence on the compressibility and angle of internal shearing resistance of a cohesionless soil.

(iii) Resistivity and P wave velocity.

Duncan (1969) suggests that with the increasing use of geophysical surveys these properties may be of some usefulness when a sufficient volume of data has been acquired.

At the present time resistivity and shallow seismic methods may be successful in determining the thickness of superficial deposits or weathered rocks and also in the location or detection of buried channels, faults, mine workings (shafts), swallow holes, solution caverns and groundwater assessment.

3.2. Classification.

3.2.1. Introduction.

It is clear that much of the information required by an engineer for a site investigation is common to nearly all investigations. It is unfortunate that no single set of universally accepted terminology exists to communicate such basic information. For most of the properties a multiplicity of classifications exist, e.g. weathering, where different classifications have been devised to describe the degree of weathering for different problems, Moye (1955), Ruxton and Berry (1957), Knill and Jones (1965), Ward, Burland and Gallois (1968), Chandler (1969, 1972).

Many of these existing classifications employ ambiguous terminology and such ambiguity must be removed rather than perpetuated. For these reasons it was decided to follow the suggestions of the Geological Society of London Engineering Group Working Party on the 'Preparation of Maps and Plans in terms of Engineering Geology' (Anon.,1972).

3.2.2. Lithology.

A classification has been developed to describe a soil in terms of its particle size distribution based on the smallest three particles: sand, silt and clay.

To illustrate this Feret's triangle can be used as in fig 3.1. The first version of the classification of soils within the triangle is that devised by the United States Bureau of Soils

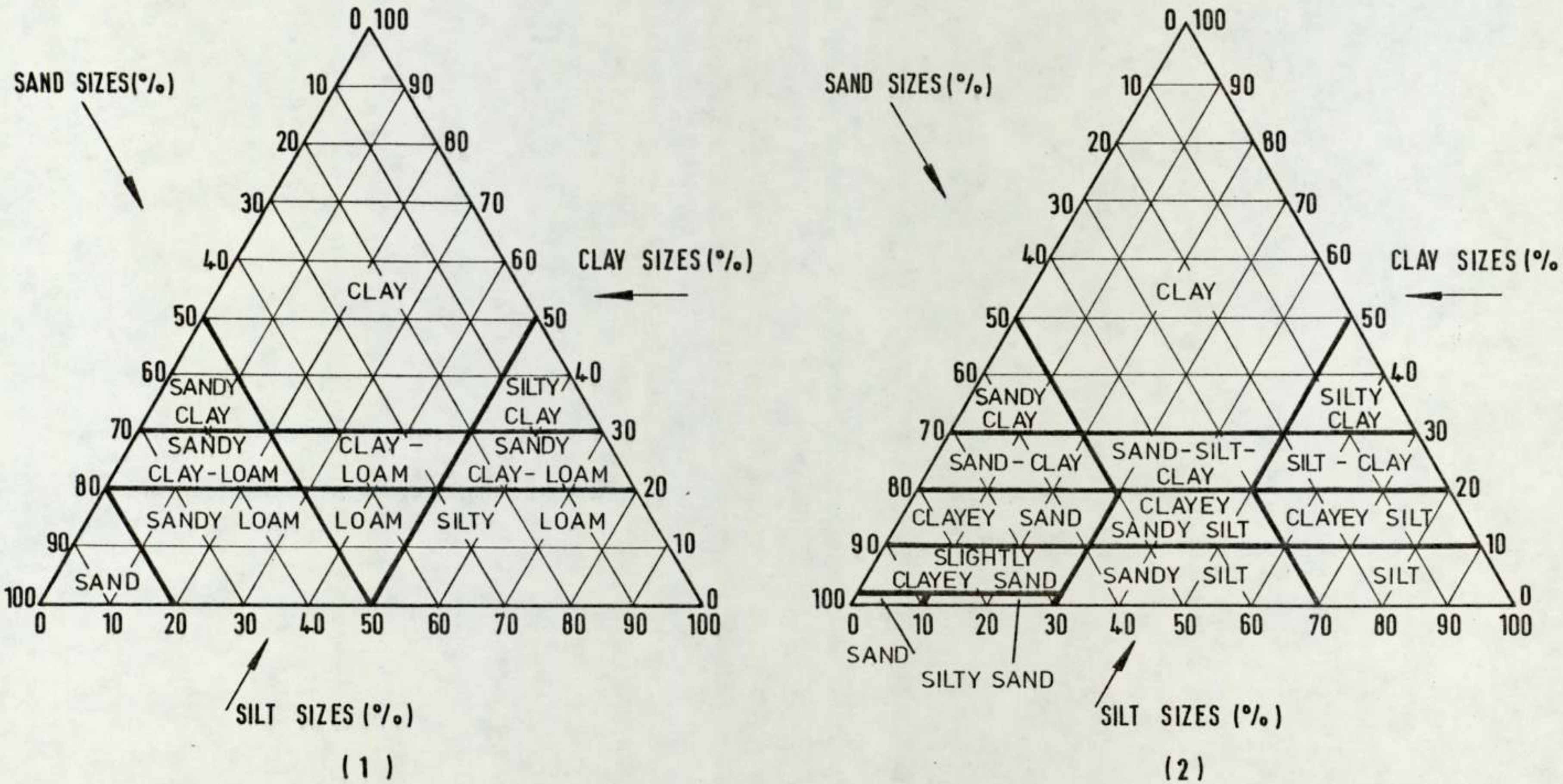


FIG. 3.1. CLASSIFICATION OF FINE-GRAINED SOILS BY MEANS OF FERET'S TRIANGLE :

(1) U.S. BUREAU OF SOILS AND PUBLIC ROAD ADMINISTRATION; (2) BASED ON THE POLISH STANDARD PN-54/B-02480 (1954)

and Public Road Administration (fig 3.1.1). The use of the ambiguous term 'loam' (a mixture of sand, silt, and clay in variable, but approximately equal amounts) in this version assisted the choice of the second version (fig 3.1.2). This latter version, based on the Polish Standard PN-54/B-02480 (1954) avoids the ambiguous term loam and defines the soils in terms of the basic components only (Wilun and Starzewski, 1972).

To facilitate the use of this classification lithological descriptions from borehole records were separated into their three basic components, each with a percentage qualifier enabling any fine grained soil or rock to be classified by the percentage of its three basic particles: sand, silt and clay.

A subsidiary classification of soils and rocks whose composition included particle sizes of: gravel (60 mm to 2 mm), cobbles (60 mm to 200 mm) and boulders (greater than 200 mm), was obviously required.

This was achieved by classifying soils or rocks which contain a percentage of these coarser elements into the following broad divisions (see fig 3.2).

(i) Very coarse gravel

(ii) Concrete gravel

(iii) Clayey gravel

(iv) Gravelly clay

(v) Gravelly sand

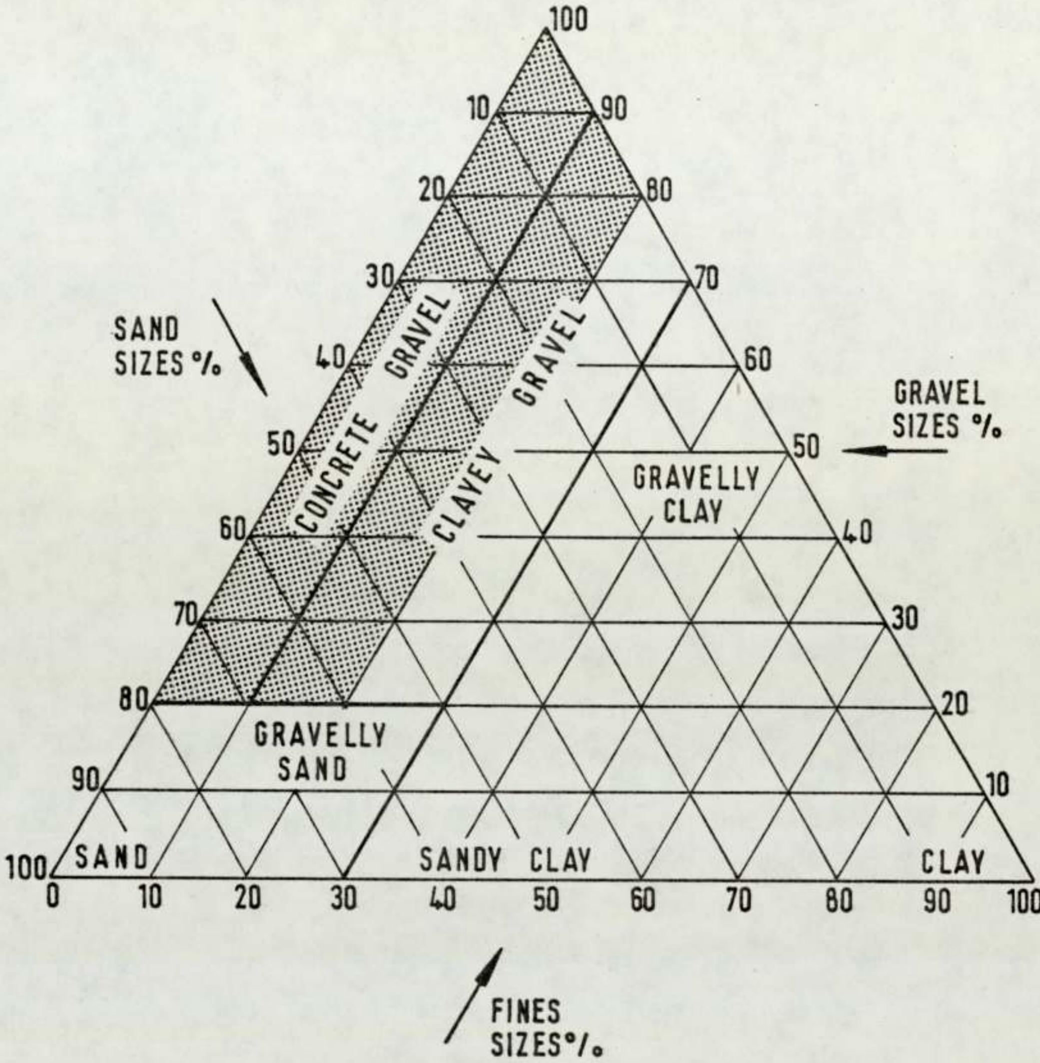
Gravelly deposits can be important to the engineer in two respects, firstly as a concrete aggregate (or similar construction material) and secondly as a foundation material. It was decided to classify such deposits in terms of their engineering suitability as aggregates. It was considered that a classification based almost on economic considerations alone, would in fact relate closely to the general engineering behaviour of the classes created.

After some discussion with practicing engineers and using the criteria suggested above, the divisions shown in fig 3.2 were chosen. The classes of concrete gravel, gravelly sand and clayey gravel represent the better aggregates with concrete gravel being as close to the ideal as possible.

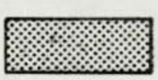
The concrete gravel is shown in fig 3.2 as having a fines content of less than 10% but in certain cases a gravel with a higher percentage of fines, 20%, can still be commercially useable if washed to obtain a clean concrete gravel as required by BS 882 (1965). These broad divisions allow for the possibility of good natural aggregate sources decreasing and the forced use of poorer aggregates such as clayey gravels in the future.

The major division of the diagram is along the 30% fines line. Soils with a fines percentage greater than this are classified as gravelly clays, containing a percentage of fines too high to be used commercially because of the added costs of washings etc. Samples falling into this grade with a high gravel percentage will be naturally strong, and a useful common fill material, unless they are very wet.

This coarse particle size classification was based purely on engineering requirements and hence cannot be compared with other 'particle size' classifications, such as that proposed by Folk (1968) based on particle size divisions in terms of ϕ where the particle diameters measured in millimetres is given as $2^{-\phi}$, a system employed dominantly by geologists.



SOILS WITH LESS THAN 5% GRAVEL ARE CONSIDERED IN THE FINE GRAINED SOILS CLASSIFICATIONS FIG. 3.1.



INDICATES SOILS WHICH CAN BE COMMERCIALLY WASHED TO OBTAIN CLEAN CONCRETE GRAVEL.

FIG. 3.2. CLASSIFICATION OF COARSE GRAINED SOILS

The problem of using a classification which employs three basic components and is then extended to include gravel, cobbles and boulders has been dealt with as follows: for soils and rocks which do not contain any components larger in size than 2 mm the Feret's triangle, fig 3.1.2. is applied, for those which include the coarser elements the above classification is used (fig 3.2). Obviously, for many soils there may be more than three components, e.g. 35% gravel, 30% clay, 25% sand, 10% silt, 5% cobbles, this would be classified as a gravelly clay on its two major constituents, gravel and clay. By incorporating the 5% cobbles as the third component, the system would record this example as a gravelly clay, with 5% cobbles recorded and the proportions of the other particle sizes being taken as read from fig 3.2.

This classification is also applicable to sedimentary rocks as well as for soils.

3.2.3. Colour.

The classification of colour is a difficult problem and initially the following system was tried (Anon., 1972). This simple subjective scheme, based on the Geological Society of America Rock Color Chart (1970), which was itself based on the original concept of Munsell (1941), involved a choice of colour from column 3 in the table below, supplemented, if necessary, by a term from column 2, and/or column 1.

1	2	3
light	pinkish	pink
dark	reddish	red
	yellowish	yellow
	brownish	brown
	olive	olive
	greenish	green
	bluish	blue
		white
	greyish	grey
		black

However, for clarity the complete Geological Society of America Rock Color Chart is used.

The system is based on a colour solid or approximately a colour sphere, which has a neutral grey axis grading from white at the north pole to black at the south pole (fig 3.3). This property of lightness is called "value". Around the circumference or equator of the solid are the ten major hues, designated by letters. Each is divided into ten numbered divisions, 5 is the middle of a hue and 10 the boundary between one hue and another. Thus any particular hue can be designated by a number and a letter such as "5R". A single vertical section through the neutral grey axis and a particular hue constitutes a colour chart on which colours grade in value from light at the top to dark at the bottom, and in chroma (degree of saturation) from grey at the left to the most vivid colours at the right. Both value and chroma are numbered and any particular colour can be given a numerical designation representing hue, value and chroma,

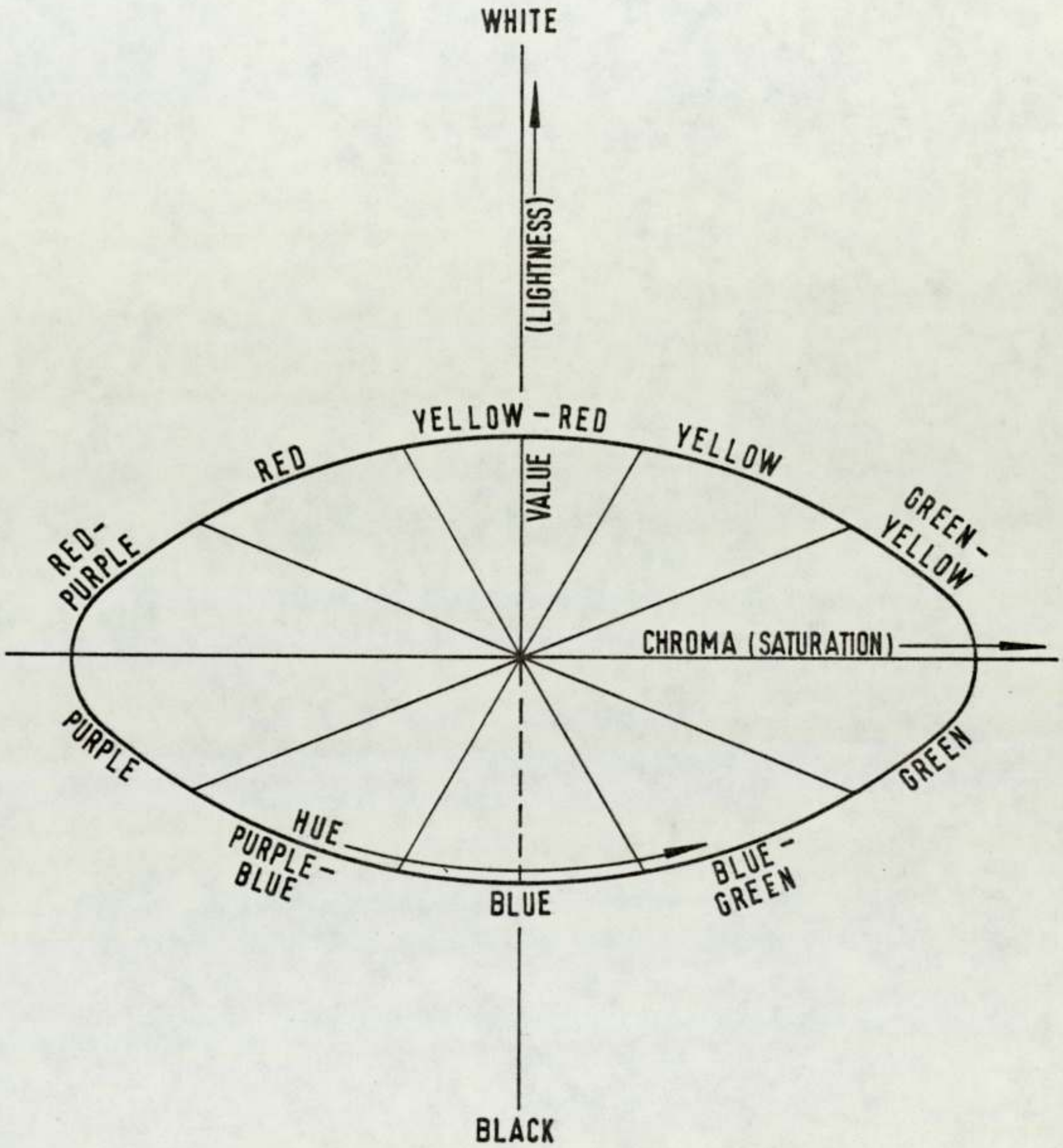


FIG. 3.3. THE COLOUR SOLID

e.g. 5R6/4 and 10YR 8/2. In order that combinations of colours can be recorded the colour scheme was duplicated to indicate a dominant colour and a secondary colour. This was enhanced by the use of a descriptive phrase between the two colours, e.g.

5R4/6	with mottles of	10 YR 8/2
5R4/6	with laminations of	10 YR 8/2
5R4/6	with vertical striations of	10 YR 8/2
5R4/6	spotted with	10 YR 8/2
5R4/6	grading into	10 YR 8/2
5R4/6	with lenses of	10 YR 8/2
5R4/6	and	10 YR 8/2

5R4/6 represents moderate red and 10YR8/2 a very pale orange.

With this scheme it was possible to reclassify lithological colour descriptions with reasonable confidence.

3.2.4. Strength.

Because of the varying nature of the soils different methods of classification have to be used. For cohesive soils, the consistency index (dependent on the amount of water present and Atterberg Limits), the manual moulding qualitative scale (soft to hard) or the quantified compressive or shear strength may be used. For cohesionless soils the density of packing determines the strength and is usually estimated in situ with a Standard Penetration Test. The approximate relationship between the number of blows applied in the test and the relative density of sands is shown in Table 3.1 (Terzaghi and Peck, 1967).

A scale of strength is also included for fine grained, cohesive soils based on unconfined undrained compressive

SOIL TYPE	STRENGTH		
	TERM	QUANTITATIVE VALUE	FIELD ASSESSMENT DEFINITION
		Number of blows	
Cohesionless (Coarse grained) soils	Very dense	>50	
	Dense	30-50	
	Medium dense	10-30	
	Loose	4-10	Can be excavated with a spade. 50mm wooden peg easily driven.
	Very loose	0-4	
		Compressive Strength, kN/m^2	
Cohesive (Fine grained) soils	Very hard	>288	Brittle or tough.
	Hard) Very stiff)	144-288	Cannot be moulded fingers.
	Stiff	72-144	
	Firm	36-72	Moulded only by strong pressure of fingers.
	Soft	18-36	Easily moulded with fingers.
	Very soft	<18	Exudes between fingers when squeezed.
Organic Soils (Peat)	Firm		Fibres compressed together.
	Spongy		Very compressible, open structure.

Table 3.1. A scale of strength for soils based on: the Standard Penetration Test, unconfined undrained compressive strength, and by field assessment (After Anon., 1972).

strength converted from the values of immediate shear strength of clays given in CP 2001, 1957, C232.

A field assessment definition is also included, enabling organic soils e.g. peat to be included (after Anon., 1972).

3.2.5. Mineralogy.

In practice the mineralogy is seldom considered important, but it has been included in the system as it has been shown recently by Franklin (1970) that most rocks can be assigned to one of five categories of mineral assemblage which provide a simple classification for engineering purposes, as follows:

(i) Quartzofeldspathic (e.g. acid igneous rocks, quartz and arkosic sandstone, gneisses and granulites). They are usually strong and brittle with important indexes such as porosity, quartz/feldspar ratio and feldspar freshness.

(ii) Lithic/basic (e.g. basic igneous rocks, lithic and greywacke sandstone, amphibolites). This group of mineral assemblage is usually strong and brittle with important indexes of porosity, texture, quartz content and the freshness of dark minerals.

(iii) Pelitic (clay) (e.g. mudstone, slate, phyllite).

This group is often viscous,plastic and weak with important indexes of durability, quartz and clay content, porosity and density.

(iv) Pelitic (mica) (e.g. schists). Often fissile and weak with important indexes of density, fissility, mica and quartz content, and porosity.

(v) Saline/carbonate (e.g. halite, gypsum, limestone, marble, dolomite). This group is sometimes viscous, often plastic and weak with important indexes of porosity, texture and mineral type.

In practice there is a gradation from one category to the next, and rather than placing a sample in one of the five categories it was thought that it would be better to estimate the content of the few minerals that determine this classification. Each should prove easy to identify and an abundance or lack of any one major constituent is of mechanical importance since each has characteristic mechanical properties. The classification used from Franklin's work shows the minerals likely to be of importance and are listed below in approximate order of mechanical quality.

1. Quartz.
2. Dark grains.
3. Fresh feldspars.
4. Salts and carbonates.
5. Altered minerals.
6. Micas and platy minerals.
7. Clay minerals.
8. Pores and cracks.

3.2.6. Weathering.

Several classifications have been devised for weathering grades. The first classification was proposed by Moye (1955) for the Snowy Mountain Scheme which covered the weathering grades from the completely altered state at the surface down through zones of decreasing weathering to fresh rock at depth. Ruxton and Berry (1957) working on granite in Hong Kong produced a similar scheme but excluded the ultimate weathering zone, soil.

Knill and Jones (1965) used a fourfold classification to describe stages of weathering of igneous rocks. Ward et al (1968) extended this to a fivefold grading scheme in the geotechnical assessment of chalk on a site at Mundford, Norfolk. A scheme for soft rock was adopted by Skempton and Davis when investigating the engineering behaviour of the Keuper Marl in the Midlands, and this was later used by Chandler (1969); a similar extended classification was used for the Lias clays (Chandler, 1972).

In 1970 a scheme broadly based on that developed by Moye (1955) was introduced, which had been adopted for a general range of rock types rather than simply for the granite rocks for which it was originally devised (Anon., 1970). This was later developed by the Geological Society of London Engineering Group Working Party (Anon., 1972), influenced by Fookes, Dearman and Franklin (1971), into two separate weathering schemes, one for soils and one for rocks.

It was decided to employ the former scheme (Anon., 1970) as this could be more easily applied to the conditions found in the information source area (Table 3.2.).

TERM	GRADE	DIAGNOSTICS FEATURES
Fresh	F	No visible sign of weathering.
Faintly weathered	FW	Weathering limited to the surface of major discontinuities.
Slightly weathered	SW	Penetrative weathering develops on open discontinuity surfaces but only slight weathering of rock material.
Moderately weathered	MW	Weathering extends throughout the rock mass but the rock material is not friable.
Highly weathered	HW	Weathering extends throughout the rock mass and the rock material is partially friable.
Completed weathered	CW	The rock is wholly decomposed and in a friable condition but the rock texture and structure are preserved.
Residual soil	RS	A soil material with the original texture,structure and mineralogy of the rock completely destroyed.

Table 3.2 Weathering Scheme (after Anon., 1970).

4. FILE MANAGEMENT SYSTEM.

4.1. Introduction.

During recent years many field data systems have been described; amongst those most relevant are Wynne-Edwards et al (1970), Roddick and Hutchinson (1972) and Reinhardt and Jackson (1973). They describe the data items, codes, input forms and various computer programs, to store, retrieve, manipulate and plot the calculated data. Many of these systems are only efficient when applied to the projects and problems for which they were designed. Computer programs written for storage, manipulation, retrieval and plotting will work only for the field data collected within the constraints of the system's specified forms and codes.

In all cases it is necessary to design a system which can handle all possible situations by separating the data recording from the data management, and the latter from the data manipulation and output. The data preparation form must be compatible with the current method of recording field observations and the system must be designed to select, sort, manipulate, print and plot information independently of the storage format. To meet these requirements a file management system must be designed.

Gordon and Martin (1974) described the basic steps in building a file and in the use of a management system:

(i) File definition, the organisation of the form of the data and its description in computer terms.

(ii) Data loading, the transference of data from their initial form to the storage medium.

(iii) Data validation, the checking of the data for gross errors, incorrect codes, numeric values out of the expected ranges, misspellings or keypunch errors.

(iv) Updating, the adding to, the deletion of or changing of data in the files.

(v) Retrieval, the extraction of the desired data items from the file.

4.2. Card Presentation.

4.2.1. General.

For the purpose of this system a borehole is represented as a single record. Each of these records consists of a set of data items corresponding to a single, identifiable observation, such as a test result for a lithological unit. Because these data items are highly variable and numerous it was decided to organise related items into groups. It is important to note that in the arrangement of these groups, and subsequently their different storage files, the greater the number of files, the more complex the retrieval system would become. A format had to be found which would limit the number of files, yet allow for the recording of all the available associated data together and also allow the files to be indexed to enable information from a particular borehole to be cross-referenced from one file to another.

The eleven different card types, and hence files, used are shown in Appendix I. The last two columns of each card type are occupied by the card type Code e.g. Borehole information, '01'. Further card types can be included into the system to record, for example, types of fossils located in a specific lithological unit, as required.

The card types are:

(i) Borehole information.

(ii) Groundwater levels.

(iii) Lithology.

(iv) Subsidiary lithology.

(v) Mineralogy.

(vi) Sample information.

(vii) Sample lithology.

(viii) Test card 1.

(ix) Test card 2.

(x) Particle size analysis.

(xi) Consolidation analysis.

The interconnecting link between all card types of a particular borehole record is the borehole's grid reference number. Separate sequencing features also occur within each card type, e.g. for lithology the lithological layers are numbered down the borehole

Grid reference.	Litho-unit.	Lithology.
SP12345678	001	Fill
SP12345678	002	Clay with occasional gravel
		etc.

The important feature of each card type is that it is based on the Standard IBM 80 column punch card, these columns are divided into a number of fields, i.e. one or more columns are used for a particular item of information. The alpha-numeric data are recorded in fixed format, that is the card types are all divided into fixed divisions so that any particular item of information always occurs in the same place on a particular card type. This feature is particularly useful for retrieval purposes as enquiries can be made on the bases of the values required occurring in specific fields as indicated by the parameter requested.

The use of free format, for example for the recording of lithology in words and not in code, was considered at this point but thought to be unsuitable for this particular study for reasons to be discussed later.

4.2.2. Borehole Information.

The primary information stored on this card is the location of a particular borehole, recorded in the form of an eight figure National Grid Reference, preceded by the code letters for the major grid square. The location is thus defined by ten characters to an accuracy of ± 5m. Following the National Grid Reference is 'the borehole number', this is a number unique to each borehole and is allocated to the borehole at the time of recording the information.

Basic drilling information, which includes: the borehole completion date, drilling method, surface Ordnance Datum level, first encountered and rest water levels, and also the confidentiality and reliability of the data are recorded. The total number of subsequent cards derived from the borehole is also recorded.

4.2.3. Groundwater Levels.

A record of the groundwater levels encountered during drilling operations are stored on this card. During the drilling of a borehole, several water levels may be encountered. Each water level is recorded, with the time and date of encounter, as a depth below surface level in metres, and referenced using the borehole's National Grid Reference. Each card contains the borehole grid reference number, four water levels, each of which includes the time and date of the encounter, and the number of subsequent groundwater level cards for the particular borehole.

4.2.4. Lithology.

The lithologic log of a borehole is recorded on this card. A complete log for a particular borehole is made up of a number of cards, each card giving information on a particular lithological unit, in sequence.

The information shown on this card type is preceded by the National Grid Reference unique to each borehole. Each lithological unit is numbered down the borehole and the depth from the surface to the top and bottom of each unit is recorded in metres. The type and lithology of each unit are described in accordance with the lithological classification (see 3.2.2.). Numerical data are recorded on this card in fixed format and codes are used to describe the lithology, stratigraphy, genesis, texture, fabric, colour, weathering and a qualitative strength estimation, for each lithological unit (see Appendix II). The card also includes provision for recording the number of: subsidiary lithology, mineralogy, and sample cards for the particular lithological unit.

4.2.5. Subsidiary Lithology.

This card is included to allow for the borehole records which include detailed observations of lithology within the major lithological units. The card is similar to the Lithology Card, except for the card type code.

4.2.6. Mineralogy.

This card type is merely an extension of the Lithology Card. Each record on this card refers to a particular lithological unit within a borehole. This is indicated by the same National Grid Reference and the same Litho-unit number as that recorded on the Lithology Card.

The object of this card is to record additional data, not only of the mineralogy, but also of the mesofabric. The latter includes descriptions of the bedding, bedding disturbance, laminations, bottom structures and information concerning the type, intensity and orientation of any discontinuities found in the unit. The number of subsequent mineralogy cards for a single lithological unit can also be recorded.

4.2.7. Sample Information.

This card serves the same purpose as the Borehole Information Card, containing information on the samples obtained from a particular borehole and referenced as in the previous cards. The samples are renumbered from the original borehole log for recording, commencing at the top of each borehole and omitting samples for which no data are available. The depths to the top and bottom of the sample are recorded in metres and a code is used to indicate the sample type (see Appendix II). The total number of subsequent sample card types, e.g. number of Sample Lithology cards, number of Particle Size Analysis cards etc., for each sample is also recorded.

The presence of fauna, flora, trace fossils, thin sections, hand specimens, and the availability of information on the treatment of a sample, e.g. X-ray Diffraction, Differential Thermal Analysis etc. can also be indicated.

4.2.8. Sample Lithology.

A record of the lithology of each sample can be stored on this card, referenced as previously, together with the same reference number as that recorded on the Sample Information card.

The composition of this card is formed by a combination of the Lithology and Mineralogy cards enabling the recording of a detailed description of the sample lithology.

4.2.9. Test Card 1.

The results of laboratory and field tests to determine geotechnical properties (mainly physical) are recorded on this card. These are the moisture content to the nearest 0.1%, liquid limit and plastic limit to the nearest 1%, specific gravity to the nearest 0.01, bulk and dry density to the nearest 0.001 Mg/m^3 and Standard Penetration Test results, as the blow count, N and the depth of penetration in centimetres. There is also provision for the results of chemical analyses : pH to the nearest 0.01, organic content, soil sulphate, soil carbonate and chloride contents to the nearest 0.01%, and water sulphate and water carbonate to the nearest 0.01 g/l. The number of subsequent cards can also be indicated if multiple results are recorded for the same sample.

4.2.10. Test Card 2.

The information documented on this card is made up predominantly of laboratory shear strength test results for samples referenced as previously on the Sample Information card. This is given in the form of cohesion, kN/m^2 , and the angle of internal shearing resistance (Ø) or a shear strength, kN/m^2 (where Ø was not determined), with the test type indicated by codes (see Appendix II).

Values of resistivity in ohms, P-wave velocity, km/s, deformation moduli in MN/m^2 from field tests and permeability values to the nearest 0.1 mm/s from either laboratory or field tests, can also be recorded on this card if the data are available. As previously mentioned if further cards are required to record the data for a particular sample, the number of subsequent cards is also indicated.

4.2.11. Particle Size Analysis.

Values obtained from tables or grading curves when available are recorded in terms of the weight percentage of the sample finer than the particle sizes of: 0.002, 0.006, 0.02, 0.06, 0.2, 0.6, 2, 6, 20 and 60 mm.

As previously discussed the number of subsequent cards is also indicated, all referenced, as previously, to the Sample Information card.

4.2.12. Consolidation Analysis.

As previously the card is referenced to the Sample Information card and used to record the test results of consolidation analysis. The values are taken from consolidation curves (voids ratio/effective stress, log scale), at points on the curve which represent:-

(i) Overburden stress.

(ii) Overburden stress - 50 kN/m^2.

(iii) Overburden stress + 50 kN/m^2.

(iv) Overburden stress + 100 kN/m^2.

(v) Overburden stress + 200 kN/m^2.

(vi) Overburden stress + 400 kN/m^2.

The corresponding voids ratio values are recorded in a (1 + e) format for ease of use in calculations of the coefficient of volume compressibility or its reciprocal.

The coefficient of consolidation can also be recorded on this card if information is available.

4.3. Data Processing, Coding And Storage.

4.3.1. Processing and Validation.

Validation of all information is carried out prior to its addition to the magnetic disc file store. The input data (1)* initially recorded on the data preparation forms (see Appendix I), are checked for errors against the original sources (2) and then punched on to 80 column cards (3). As there is a likelihood of errors occurring at this stage the cards are used as input to ancillary programs which provide line printer listings of the records (5) which can be checked for errors (6). The amount of time invested at this stage can minimise delays caused by entering invalid data into the system.

4.3.2. Coding.

Coding is carried out when the data are first recorded (2) on the data preparation forms. By substituting codes for free text the lengths of the files are considerably reduced e.g. a description of a soil containing 45% sand, 40% silt and 15% clay according to the Polish Standard PN-54/B-02480 (1954) (see fig 3.1.2.), is classified as a clayey sandy silt, i.e. 17 character spaces, but condensed to code can be represented as 466488265. In this way a precise lithologic description can be recorded in only 9 characters and so coding provides the data storage system with enhanced capacity.

Codes are used to describe major data items such as

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* The numbers refer to the Geotechnical Storage and Retrieval System Flow Chart fig 4.1

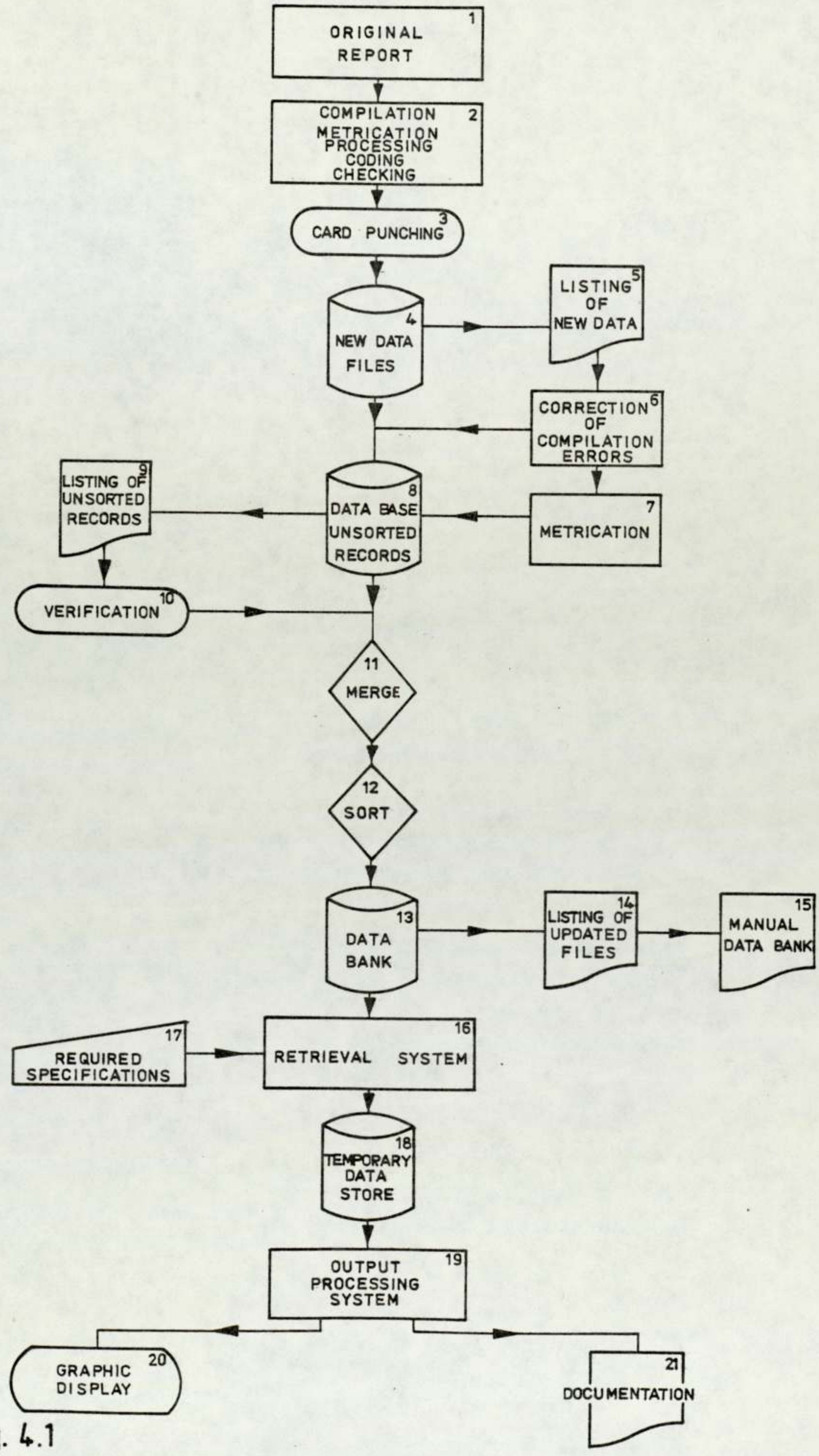


Fig. 4.1

FLOW CHART OF THE GEOTECHNICAL STORAGE AND RETRIEVAL SYSTEM lithology, stratigraphy, genesis, texture, fabric, weathering, strength, mineralogy, bedding structures, discontinuities and types of samples and tests. With the exception of lithology and colour the codes consist of either one or two digits. The code for lithology consists of three fields, representing the major, intermediate and minor components as described previously. Each field is composed of three digits: the first represents the percentage of a component and the remaining two indicate the class of the component e.g. gravel, sand or clay (see Appendix II). The colour codes are those recommended by the Geological Society of America (1970) as described previously.

These compound codes introduce a certain amount of complexity but are considered to be the necessary minimum for adequate description of the lithology.

4.3.3. S.I. Unit Conversions.

Much of the data supplied was in Imperial units and conversions had to be performed either manually before the data were added to the data preparation sheets (2) or by using ancillary programs after the data were input in the form of punched cards. It was found convenient to make use of a programmable calculator to do this before data are punched.

4.3.4. Data Storage.

As data became available they were added, in the form of punched cards, to the main data store, held on magnetic discs (8). The data cards are separated into individual card types before being added to their respective permanent files which form the data store. Ancillary programs are then used: to list newly added data (9), to check that the total number of cards in each record agree with the total recorded on the master cards, e.g. Borehole Information, Sample Information cards etc. When this stage has been completed the newly added data are merged with their existing respective card type files (11) and these files are then sorted (12) so that respective records in all the files occupy the same ordered position according to their grid reference, lithology unit or sample number for a particular borehole, creating an updated data bank (13).

Two generations of magnetic disc files are maintained so that in the event of data on the higher generation file becoming corrupt, then the file can be readily re-established by using the earlier generation file. Line printer listings of the files are kept up to date (14) and held in a manual data bank filing system (15); the original punched cards are also retained.

4.4 Retrieval System.

Fast retrieval of specific data items is the primary reason for using computer technology. The retrieval of data from the magnetic disc files is carried out using a number of 'find' programs (16).

A 'find' program generally consists of three parts: a qualifying clause, which specifies the records and files of interest, a selection clause which specifies the particular data items to be retrieved (17), and an output specification clause which is dependent on the type of retrieval required. The 'find' program retrieves the required information and writes the information to a temporary data store (18). A 'processing' or 'output' program (19), then retrieves this information to either manipulate the data for output, or produce directly the various types of output, such as: a reproduction of the information stored in the data bank in a tabulated format as in an engineering report (21), or as graphic displays of the data, or as an interpretation such as contour maps (20).

The graphic displays consist of location maps, graphs, histograms and contour maps. The location maps can be used to indicate positions and the nature of information stored in the data bank.

The contour maps are produced in three stages: a search of the data bank to retrieve the control points, the generation of a systematic grid by an interpolation algorithm, and the contouring of the gridded data.

Similar types of program are used to produce proximal maps, which for example can show the distribution of lithologies, or can be extended into isopleth and three dimensional maps. All of these programs will be discussed in greater detail in the following chapters.

5. USER REQUIREMENTS.

5.1. Introduction.

The presentation of information stored in this system must suit the requirements of a variety of projects and prospective users.

To enable the prediction of these requirements, several different projects are examined and these are illustrated in the following pages. However, before discussing the specific requirements of the different users, it must be demonstrated that the scheme satisfies certain basic demands. These are to show the user immediately: whether information is present for a particular area, what quantity of relevant information exists and the precise location of the information (i.e. borehole locations). Specimens of the computer outputs which demonstrate the presentation of such information are illustrated and discussed in Chapters 7 and 8.

5.2. Project Requirements.

To evaluate the requirements of the users, the different phases in the planning of a new project are considered and their respective information requirements outlined.

In general there are three phases in the development of new projects:

(i) assessment of site or route suitability;

(ii) a general investigation on which to base the planning of the project and a cost analysis for the budgeting of the site investigation;

(iii) the pre-design stage which involves the collation of technical information necessary for the design and construction of the works.

The requirements of these three phases of design and construction will be discussed in detail in the following sub-sections.

The 'in construction' stage may provide a feedback of information for the data bank when recordings are made of encountered conditions, which may, themselves lead to changes in design and construction.

5.2.1. Assessment of Site Suitability.

At present this stage of the investigation involves a study of the regional or local geology of possible routes or sites, with reference to as much detailed geological and geotechnical information as is available.

The regional data storage and retrieval system could provide the user with additional information in the form of small scale bedrock topographic contour maps, drift isopachs, fill thickness and distribution for the general area of investigation. It may also prove useful to have three dimensional pictures of the bed-rock as well as information on the general properties of the rocks and soils within the area.

5.2.2. Planning.

Detailed site utilization is decided mainly on aesthetic and socio-economic grounds with virtually no recourse to additional investigations of the ground conditions. Site layout is similarly decided. In the past this has led to many cases of severe settlement where buildings have been sited across the margins of poorly backfilled areas. The general information of the suitability stage (5.2.1.) has to be enhanced at this stage by critically examining all the specifically relevant available information.

At this stage the structure is decided and hence, the degree of involvement, or interaction, with the ground. There should be sufficient information available to assess whether such ground involvement will be economically viable or otherwise and the rapid availability of such information is obviously of considerable importance.

5.2.3. Pre-design.

A detailed investigation of the site is needed to establish the geological structure of the area, and to provide sufficient detailed information on the ground and groundwater conditions to enable the design of the most efficient foundations. This takes place on site and utilizes borings, trial pits, in situ testing, etc. It is important to realise that before this on-site investigation can take place the consultant or contractor must design an investigation which will meet his requirements both fully and economically. It follows then, that the collection of all relevant existing information is necessary for the planning and design of the investigation. Information derived from previous site investigations, within the immediate area, in forms suitable for the specific project would prove invaluable, if available, for the design of the most efficient site investigation.

In order to categorise the requirements of a potential user in this case the various types of schemes, with which they may be involved, have to be considered.

Typical construction schemes are: trenches (for water supply, sewerage, communications), tunnels, highways (with embankments, cuttings, bridge foundations), buildings (high and low rise domestic, and light and heavy industrial), re-use of waste materials (domestic, colliery, industrial etc.), material resources (concrete gravel, fill for embankments etc.), dams and reservoirs. These schemes can be roughly divided into two groups: compact sites for large and small structures, and extensive sites for linear surface structures and linear sub-surface structures.

It was decided to exclude dams and reservoirs at this point as these occur infrequently within urban areas and re-use of materials will be considered separately.

The special information necessary for the design of the investigation and, later, the design and construction of the structure can also be divided on the same basis.

5.2.3.1. Compact sites.

(i) Large structures.

These buildings are usually characterised by a heavy concentration of load, generally transmitted to the foundation by columns. Deep basements are often introduced to reduce bearing pressures and thus a careful investigation of the groundwater conditions must be considered along with the detailed evaluation of the ground conditions.

Information is required to indicate the bedrock depth and the position of any critical bearing materials which are likely to be influenced by the stresses imposed by the building. The availability of shear strength values for lithologies present within the immediate area can aid the assessment of a safe bearing capacity. The knowledge that critical bearing materials are present at depths within the site can influence the depth of the boreholes and a preliminary choice of foundation e.g. end bearing piles or friction piles can be made.

Geotechnical sections are usually produced across a site to show lithology, Standard Penetration test results, consistency, density and groundwater levels.

This category also includes industrial buildings, where manufacturing plant may induce dynamic loads or vibration effects. As this type of structure usually covers a large area it is often found that lateral variations in soil conditions exist. Loose sands and gravels (and some fills) are particularly sensitive to vibrations, which lead to compaction causing settlement. If the soil conditions alter laterally, differential settlement will be the result, which is generally more damaging than uniform settlement. An indication of the rate and magnitude of consolidation, and hence settlement,can be based on the compressibility of the lithologies present. For such reasons the subsurface distribution of lithologies within a specified area must be closely studied.

Groundwater conditions are also of great importance. High groundwater levels will give rise to bouyancy effects causing uplift on basement structures, and may also create problems during excavation.

The chemical composition of the groundwater or soil may cause deterioration of buried concrete, or affect the setting of such concrete. In particular, conditions where high concentrations of mobile sulphate or low pH values exist, careful assessment is required.

In cases where the heat from industrial processes (e.g. power plants and kilns) is sufficient to desiccate the subsoil, shrinkage may lead to significant settlement. In certain cases the heat from industrial processes has led to combustion of underlying coals. In other circumstances the construction may lead to an increase in the moisture content with consequent swelling of certain soils, or even loss of strength.

Existing groundwater records and chemical analyses are therefore extremely valuable in assessing whether the groundwater regime needs a more or less detailed investigation.

(ii) Small structures.

This category includes low rise residential and light industrial structures. Because of the light loadings involved their foundations are generally shallow, hence the geological and geotechnical investigations can be limited to shallow depths. These structures are generally founded on either spread or strip footings, or small piers and hence the near surface lithology of the site is important. In many cases the near surface materials vary rapidly and markedly in character, especially in areas of made ground where prediction of the variation is very difficult. In such cases, light structures are often founded on rafts to overcome the problem of differential settlement associated with a variable subsoil.

The depth to bedrock can also be a financial factor in the construction of such buildings. Shallow bedrock may provide an excellent foundation, but excavations into shallow bedrock could prove expensive.

Groundwater is less of a problem where light structures are concerned because the foundations are nearly always shallow. However, a number of industrial sites located on alluvial flats have encountered problems in groundwater control where foundations are bearing on the sands and gravels. Light structures are often founded on made ground (fill) and high concentrations of deleterious compounds are often found e.g. high sulphates in partially burnt shale fills.

To summarise, similar information is required for both small and large structures but for the former more attention must be given to the 'shallow' lithologies. The properties usually required for such structures are again bearing capacities, settlement etc. especially crucial where building foundations are on fills.

5.2.3.2. Extended sites.

(i) Surface structures.

For this category, which includes highways, railways, etc., a vertical profile along the proposed route must be established. In general the engineer is mainly concerned with the soil properties of the subgrade as this will bear both the dead and live loads. The soil property most commonly used as a guide to the thickness of a pavement is the bearing capacity of the subgrade, usually assessed by measuring the California Bearing Ratio. Another essential requirement for the subgrade is that the deformation produced by loads should not be sufficient to cause damage to the pavement, and thus its deformation modulus is of considerable importance. It has been found that the uniformity of the subgrade lithology is of perhaps more importance than its actual bearing capacity. As stated before, near surface materials may vary rapidly and prediction of the subgrade material is very difficult, and often the true nature of the subgrade is only revealed during construction, thus any additional information would be valuable.

Cuttings are often required to maintain low gradients and these may be in either rock or soil. The critical height of a rock slope (i.e. the slope of the sides of the cut) is roughly proportional to its shearing strength, although this must be modified by the strike and dip of the rock formation in relation to the excavation. For shallow cuts in cohesive soils the steepness of the slope is usually determined by comparing the proposed slope with existing slopes safely standing in similar materials. For steeper slopes, stability is usually determined on the basis of laboratory tests and a careful geotechnical appraisal of the situation should be made. This involves the determination of the variability of the shearing resistance of the material at various points in the cut and seasonal variations cannot be ignored. If the clays are heavily fissured, excavation relieves the stress and existing fissures may open and possibly fill with water. The subsequent softening of the material may cause a failure of the slope. On the basis of the geotechnical appraisal on site and using existing information the correct angle of slope can be chosen.

Embankments are also required for highways and railways. All modern embankments should be built of properly selected materials with proper compaction. It may be possible to use the material from nearby cuts for fill. Prior knowledge of the material types within the area would indicate the need to find spoil sites if the cut material was unusable or in excess of that needed for embankment constructions.

Embankments may fail because of defective foundations. It is therefore essential to know the properties and extent, both laterally and vertically, of the foundation materials. They may be soft to a limited or considerable depth before stronger strata are reached and they may consist of alternate layers of soft and stiff materials. These strata must be capable of supporting the dead and live loads they have to carry. Even if the bearing capacity is adequate, there may be a potential danger due to its decrease over a long period resulting from changes in groundwater conditions.

Structures such as bridges and retaining walls, which are often associated with these works can be considered as compact sites, discussed above.

A further problem which is often very important is road drainage. It is generally advisable to avoid wetting and drying of the sub-base and subgrade as this commonly leads to degradation, particularly of the latter. Both may be susceptible to damage during periods of frost.

(ii) Linear subsurface structures.

It is usual practice for this category, which includes tunnels and trenches, to establish the alignment, size and shape of the tunnel cross-section prior to any detailed geological survey. If any unfavourable geological conditions are disclosed the tunnel can be relocated.

A geological profile along the centre line of the tunnel is produced to show the detailed lithology, geological structures which are of extreme importance such as faults, joints and other discontinuities, and the groundwater conditions. Such information is usually obtained from a geological surface map showing the various formations, faults, joints, dips and strikes, contacts and any unusual water occurrences such as seeps or springs.

A number of factors which may influence construction methods and therefore costs can be qualitatively assessed on the basis of such preliminary surveys. These may include: the difficulty of excavation, degree of overbreak and caving, necessity for temporary supports, rate of water ingress, presence of swelling rock and the availability of concrete aggregate for tunnel lining. It is obvious that this type of assessment would be enhanced by the availability of additional information.

5.2.4. Research.

The very nature of this study is at least partly research orientated, whilst the collation and analysis of the information in large quantities is primarily for use in site investigations.

The scheme can also be used for research of a different nature such as the analysis of information concerning a particular geological or engineering topic. For example, a geologist might be interested in the composition of a particular stratigraphic horizon, unfortunately he will never be able to examine every grain or crystal of a rock body and so must derive geological generalisations for the whole horizon from the samples he has collected. An information retrieval system, such as this, may extend his information and allow multivariate methods of analysis, which may reveal clusterings of parameters which are at variance with accepted classifications or show relationships where none were expected.

The collation of information into this scheme should eventually enable regional trends of parameters (of more academic interest) to be diagnosed.

A good example would be the study of the sub-glacial drift topography of the Birmingham area, by the production of automated contour maps (which are discussed later) with the emphasis on the glacial history rather than geotechnical relevance.

The engineer, who may also be interested in this form of analysis, may be interested in the average properties or the variation of properties of certain soils. This may involve the production of histograms, graphs and other presentations to convey such information. Correlations or comparisons of vast quantities of various test values in this way may show such features as geographically separated deposits being of the same genesis.

5.2.5. Re-use of Material.

In many circumstances common materials derived from the site or elsewhere are needed on site in a re-use situation. In the majority of situations this re-use is as fill which may be required to perform various functions. Information on the bulk properties of such materials when used as fill will be of considerable value. The re-use of material is often dependent on basic constraints such as plasticity, organic content and sulphate content all of which are recorded in this scheme.

5.3. Summary.

Detailed investigations should accurately establish the geological nature of the area and should provide complete detail of both ground and groundwater conditions necessary for the design and construction of the structure. For foundation engineering purposes geotechnical sections should present both the geological and geotechnical data at the highest level of detail possible.

The in situ and laboratory test results should give sufficient quantitative and qualitative information on soils and groundwater to enable the foundation design and construction to be economically carried out. It is important to realise that any relevant information of this nature available before the pre-design stage, will enhance the design of a more specific site investigation and provide a more complete three dimensional picture of the subsurface environment.

From the above discussion it is apparent that all of the users require similar types of information, such as profile cross-sections, bedrock topography, groundwater conditions, etc. and it is to fulfill this need that the scheme has been designed. However, more specific information is needed for each particular type of structure, e.g. large structures require detailed information relating to the distribution of the lithology throughout the site and provisions for this have also been included.

This analysis of the user requirements has led to the development of the formats for information retrieval and presentation for this scheme to provide the greatest assistance towards the design of efficient site investigation.

6. THE SELECTED AREA.

6.1. Choice Of Area.

The choice of the area was influenced mainly by the need to obtain a large amount of data covering a relatively small area. To ensure the availability of a satisfactory density of information in the available time, it was desirable to use one main source of information. The local sources which could provide sufficient data in the time were the District and County Councils within the Midlands, and in particular the Birmingham and Telford authorities. Both of these are situated in areas of geological interest with bedrocks of similar type and age, overlain by complex Pleistocene drift deposits.

The decision to use data from the Birmingham area was made on the basis of the author's familiarity with the area, the location of the University of Aston in the centre of Birmingham, and the existence of a close liaison between Birmingham City Council and the University of Aston.

Having decided upon the most suitable source of information, the exact area to be studied was selected on the advice of the City Engineer of Birmingham. He also offered the use of the City's records, in particular those which would be useful for both planning and development, and hence be of commercial interest.

The area shown in fig 6.1, is situated in the centre of Birmingham, is roughly rectangular in shape and traversed by the Birmingham Fault. It lies within the major grid square SP and extends east from grid line '06' to grid line '12' and north from grid line '84' to grid line '92', following the line of the

GENERAL GEOLOGY OF BIRMINGHAM AND STUDY AREA

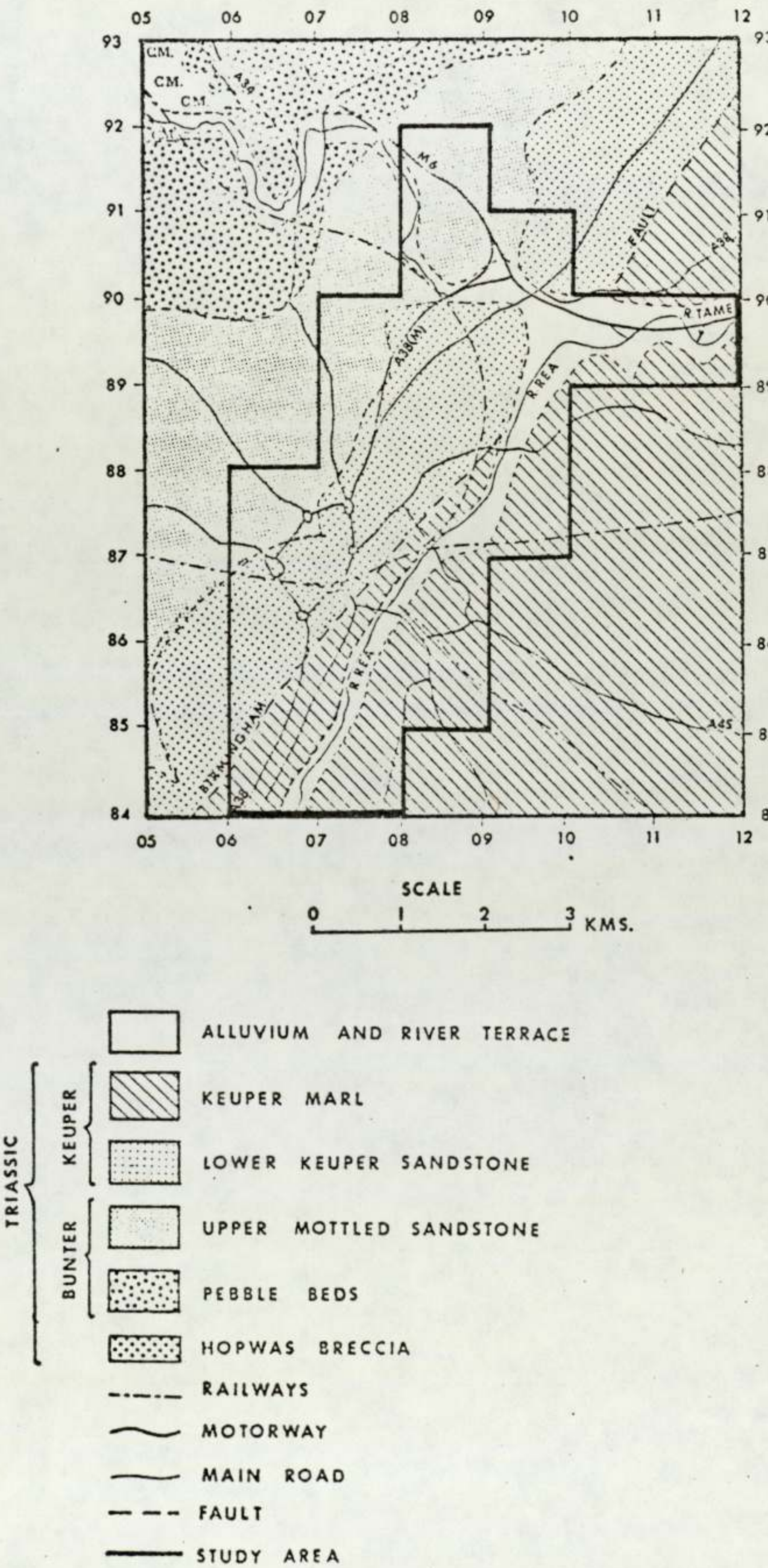


FIG. 6.1

Birmingham Fault.

The underlying bedrock within the area consists of the Keuper Marl, the Lower Keuper Sandstone and the Upper Mottled Sandstone. Overlying the bedrock is a complex sequence of glacial, interglacial and postglacial deposits, providing a wide variety of geotechnical properties.

A large percentage of the area is covered by Victorian residential and industrial sites, allocated to redevelopment, thus providing a relevant use for the project, to assist the future planning of the area.

6.2. Future Development.

6.2.1. Land Potential.

During a study of the City Centre of Birmingham by the West Midlands County Council and the City of Birmingham, an assessment of the opportunities for change was undertaken. Three main topics: land availability, buildings with potential for change, and transportation facilities were investigated with a view to their potential redevelopment.

The City Centre Study team, in an unpublished report established an area of 500 acres of 'Soft land', i.e. land available in some form or other for development, within an area enclosed by the Middle Ring Road shown in fig 6.2. Although 66% of this land is occupied by industrial and warehouse buildings, 22% is vacant land suitable for almost immediate development. Although this central area is only a small part of the study area it does reflect the possible potential redevelopment of the total study area.

6.2.2. Possible Development.

6.2.2.1. Office space.

Within the Inner Ring Road alone, 0.29 million square metres of office floor space was granted planning consent in the month of December 1974. Because of the availability of 'soft land' this current trend is expected to continue.

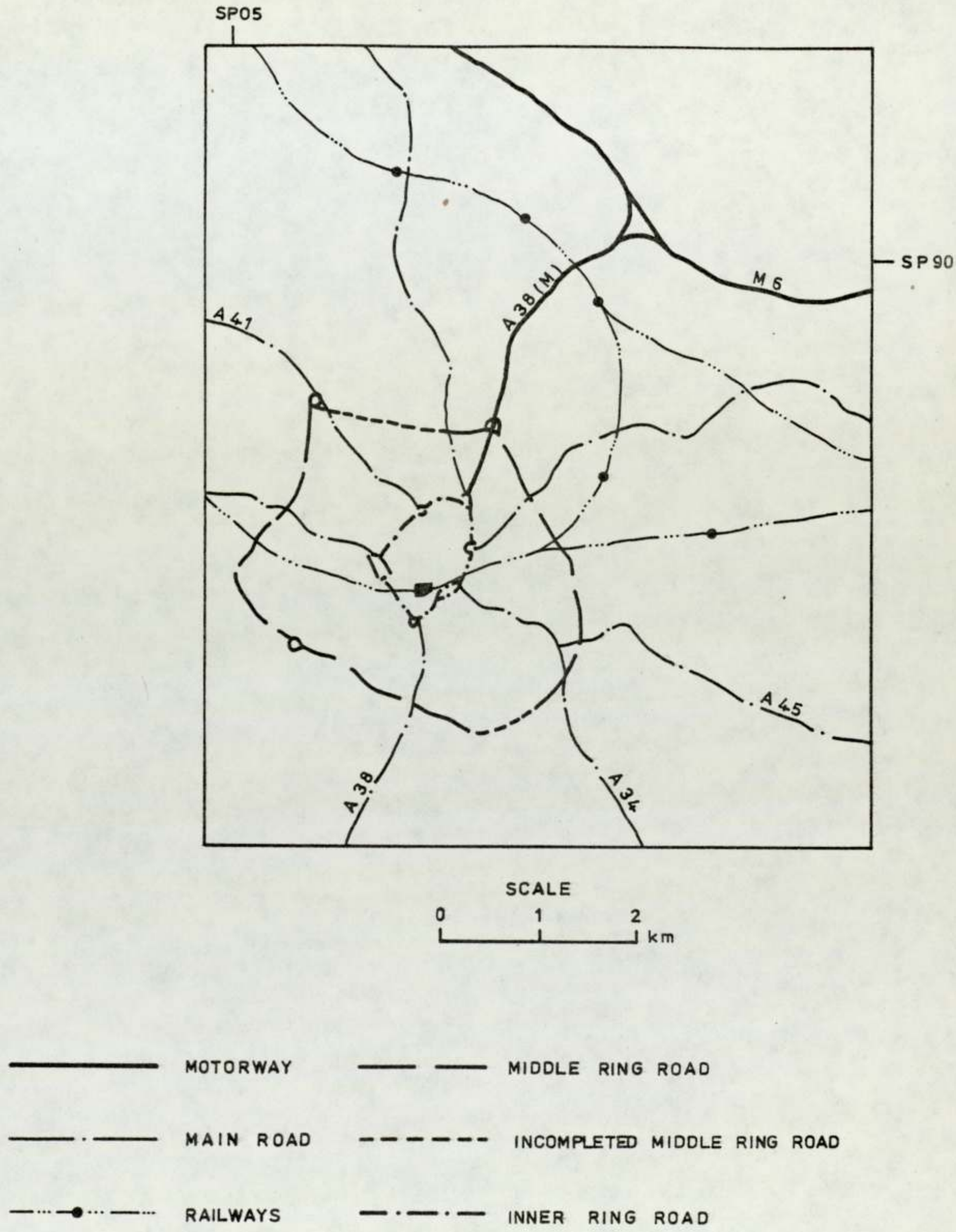


FIG. 6.2 LOCATION OF MIDDLE AND INNER RING ROADS, BIRMINGHAM.

6.2.2.2. Retail premises.

There have been many recent developments in the city, such as the Birmingham Shopping Centre, and the potential for further shopping developments would appear to be low. However, several proposals have been put forward for future developments of this type, within the Inner Ring Road. Amongst those being considered is the extension of the Birmingham Shopping Centre and the 'Rotunda' complex.

6.2.2.3. Residential.

Residential accommodation within the inner central area is limited to two tower blocks, even though there has been a demand for flat accommodation in the City Centre from higher income groups. This situation in Birmingham is not necessarily comparable to that of Central London where there appears to be an insatiable demand for luxury accommodation right in the centre. The demand in Birmingham does have alternative outlets, such as Edgbaston, and a considerable part of the central area, enclosed by the Middle Ring Road, has been designated by the City of Birmingham as a residential redevelopment area.

6.2.2.4. Transport.

The improvement of rail services in the West Midlands area, especially to Birmingham City Centre is envisaged by the development of certain railway lines focussing on the centre.

Preliminary investigations have commenced for an underground railway and interlinking facilities between New Street

Station and Snow Hill Station. This may be combined with an underground rail by-pass for main line through traffic.

The development of the road system has possibly reached a period of quiescence with the completion of the Inner Ring Road and the near completed Middle Ring Road.

6.2.3. Discussion.

It would appear from the evidence of the recent survey by the West Midland County Council and the City of Birmingham that the potential for redevelopment within the central area of Birmingham is high. After discussions with Birmingham City's Planning Department, it is believed that the study area, of which the central area is only a small part, does have a high potential for redevelopment which to some extent is reflected by the City Centre study.

6.3. The Geology.

6.3.1. Fill.

The study area, situated in central Birmingham, has been a developed area for at least 150 years. The natural deposits are now overlain by fills of highly variable thickness, constitution and quality. Many of the earlier buildings possessed basements which are now infilled predominantly with brick rubble. Elsewhere placed ash fill is present whilst areas exist which are underlain by domestic refuse and even sludges associated with earlier sewage treatment works.

Most areas have at least a thin cover of fill but locally the fill has been recorded up to 5 metres thick.

6.3.2. Superficial Deposits.

6.3.2.1. Postglacial.

The postglacial deposits which occur within the study area are associated with the Tame and Rea Valleys as shown on the Geological Survey Map of Birmingham (Eastwood et al , 1925). The alluvial deposits of the Tame Valley to the west of the Rea confluence, reach thicknesses of 8m near the confluence, and up to 4m further west. To the east of the confluence the alluvial deposits commonly reach thicknesses of 4m and contain deposits of interbedded peat. At the confluence of the Rea and Tame, 0.4m, and at Nechels Power Station 2.2m of inter-bedded peat have been recorded. Along the lower stretches of the Rea considerable thicknesses of alluvium have been recorded e.g. 10m at SP076863.

No evidence was available from the records collated to indicate the presence of river terrace gravels either along the Tame or the Rea, although both are indicated as having well defined terraces on the Geological Survey Map of Birmingham (Eastwood et al ,1925).

6.3.2.2. Glacial deposits.

Horton (1975) suggested that the glacial drift deposits of Birmingham were formed during at least two glacial periods separated by a long temperate interval, during which fluviatile and lacustrine sediments accumulated. The possibility that four glacial periods are recognisable was postulated by Wills (1950), who found dissected and patchy deposits of the first two periods and the deposits of two more recent periods. These more recent deposits dominate the landscape and have obviously influenced the development of the present river system.

From the information collected these glacial deposits appear complex and vary rapidly both vertically and laterally. Horton (1975) also found this to be the case and suggested that the Birmingham district may have been at the edge of a fluctuating ice sheet for at least part of a major glacial period. Hence, sediments of subglacial, englacial, supraglacial and extraglacial origin may have accumulated comtemporaneously in closely adjacent areas.

Deposits of a glacial advance cover the topography, and these are then partly eroded before the accumulation of interglacial sediments, which are, in turn, covered again by deposits associated with the advance of younger ice sheets. Since then, further erosion has taken place during the development of the present drainage system. The prediction, therefore, of the nature of the Pleistocene deposits particularly in terms of lithology and/or thickness at any particular locality is extremely difficult.

The thickness of the blanket of glacial deposits is illustrated in fig 6.3 which depicts the subglacial drift topography of north and west Birmingham, with the present surface shown by spot heights. The variation of drift thickness can be seen at: the Proto-Tame valley (SPO7708852) 35m, Highgate Park (SPO7798526) 2m, and in the vicinity of Aston Hall (SPO7958990) where there is no glacial drift.

The glacial deposits can be divided into four main lithological groups, although these have no stratigraphic correlation.

(i) Boulder Clay and Undifferentiated Drift.

These are probably the most widespread deposits, consisting of unsorted gravelly clays with rock fragments that range in size from large boulder to fine sand size. The matrix is usually a reddish brown clay occasionally mottled with greys and yellows. There is evidence to suggest the clay is derived from the Keuper, whilst the rock fragments are from several sources e.g. Carboniferous and Silurian rocks from the Wenlock and Coalbrookdale area, Welsh volcanics, and pebbles of Bunter derivation.

The undifferentiated deposits are lithologically very similar but include either more or less gravelly materials.

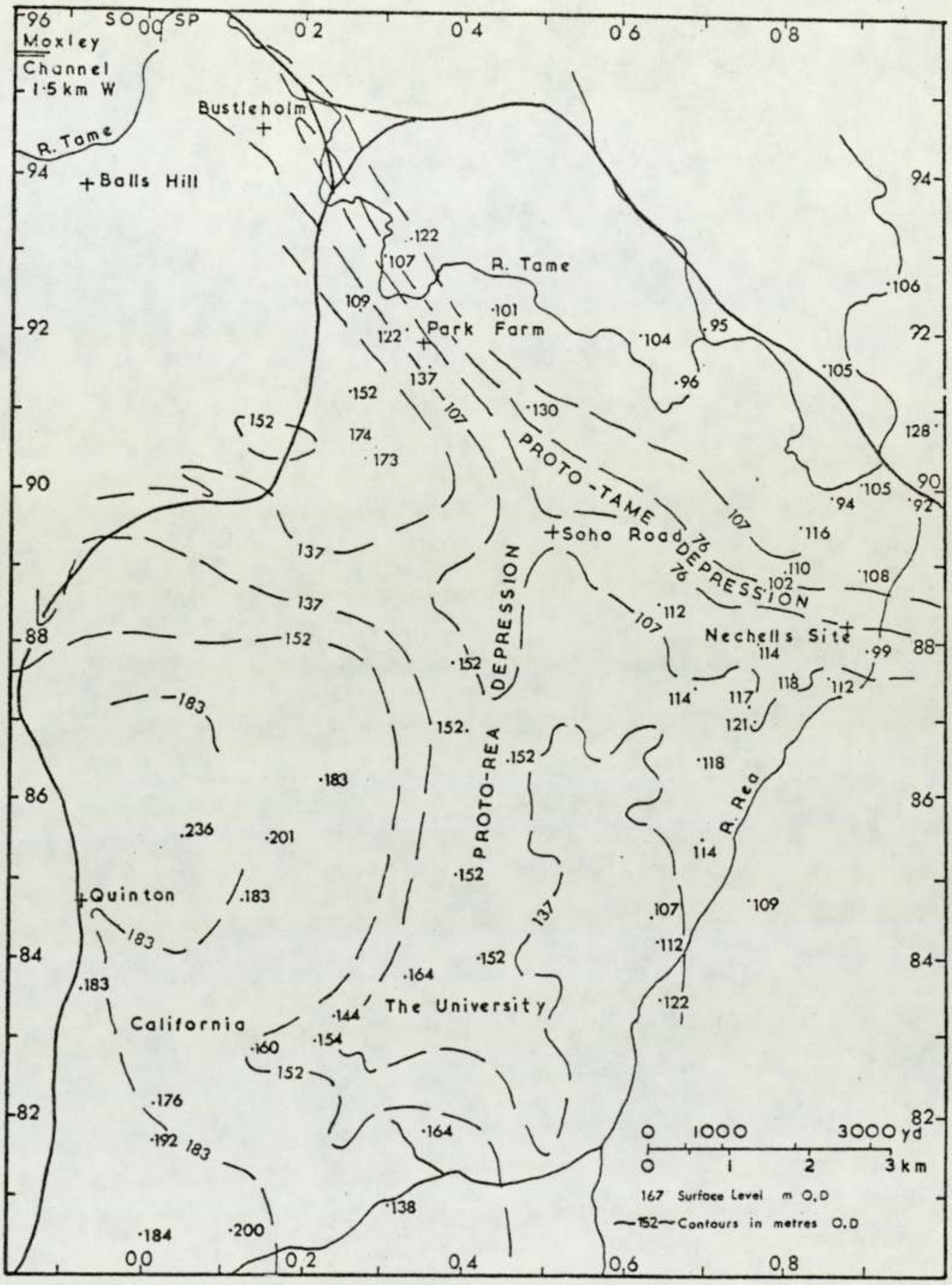


FIG. 6.3 GENERALISED CONTOURS ON THE SUBGLACIAL DRIFT TOPOGRAPHY OF THE BIRMINGHAM AREA (AFTER HORTON, 1975) INDICATING THE THICKNESS OF THE DRIFT.

(ii) Glacial Sands and Gravels.

These are mainly widely graded fine to coarse grained sands and gravels with a reddish brown matrix. The state of compaction of these deposits varies between loose to very dense.

(iii) Glacio-lacustrine deposits.

Consisting predominantly of reddish brown, or yellowish brown silts and clayey silts, and occasionally with fine sands and interbedded clays. They are often laminated and associated lenses of sand and gravel are not uncommon.

(iv) Interglacial deposits.

These sediments consist of peaty, commonly laminated, clays, silty clays and silts. In one of the major local occurences, in the Vauxhall-Nechells area, thicknesses of peat have been recorded at: SP08758806, 1.7m; SP0877880, 2m; SP0878881, 3m; and SP08808808, 2m.

These interglacial deposits are weak and highly compressible, and were deposited during a temperate interglacial period, possibly of the same age as the Nechells Interglacial series, described by Kelly (1964) as Hoxnian. They are found overlain by at least 13 m of younger glacial deposits whilst they can total 10 m in thickness as at SP08808808.

6.3.3. Trias.

The solid geology of the area is shown in fig 6.1. To the southeast of the Birmingham Fault, the Keuper Marl constitutes the bedrock. It is typically a dark red or reddish brown, very stiff to hard mudstone with bands of grey-green siltstone and occasional sandstones, often known as skerries. It is overlain by a variable thickness of drift and fills and where the drift cover is less than 5m a mature weathered profile has developed whilst elsewhere, where the drift cover is thicker, the weathered profile is attenuated.

To the northwest the Lower Keuper Sandstone, stratigraphically lying beneath the Keuper Marl, is present adjacent to the Birmingham Fault, buried under varying thicknesses of drift and fill. The Lower Keuper Sandstone consists of yellow-buff or red-brown, poorly cemented sandstones which may locally be pebbly or interbedded with red-brown mudstones up to 0.5m thick.

The only other bedrock present within the study area is the Upper Mottled Sandstone, lying stratigraphically beneath the Keuper Series, and belonging to the Bunter Series. This is a fine, weakly cemented, red sandstone with occasional bands of clay or silty clay. Unfortunately only a few of the boreholes collated, recorded the presence of this rock, which is also covered by varying thicknesses of drift and fill.

6.3.4. The Hydrogeology.

Although the permanent water table is at a considerable depth (in excess of 100m), the occurrence of low permeability deposits, within the glacial drift, can give rise to local perched water tables. The interglacial Proto-Tame and Rea channel infills constitute significant subsurface drainage channels, and in times of limited rainfall these deposits are not saturated.

The Upper Mottled Sandstone and the Lower Keuper Sandstone, to the west of the Birmingham Fault, are relatively permeable, and provide a necessary potable water supply. As these rocks possess an easterly dip there is a tendency for water to build up in these formations due to their juxtaposition against the much less permeable Keuper mudstones at the fault. Local perching of water also occurs in the sandstones where thin mudstones or clay seams are present.

6.4. Geotechnical Aspects Of The Lithologies.

6.4.1. Fill/Made Ground.

The variety of materials found in the made ground and fill is such that each particular site must be considered individually. This is especially the case if the suitability of the material for re-use is to be considered.

The made ground may contain large voids, from the many basements of nineteenth century buildings and elsewhere, significant thicknesses of organic debris. The latter is the case at Nechells Power Station where a thin topsoil overlies several metres of sewage sludge.

6.4.2. Postglacial Deposits.

The fine grained deposits normally associated with alluvial floodplains have been so disturbed by man's activities in this area that their properties have to be specifically considered for each particular site.

Sporadic occurrences of highly organic floodplain deposits necessitate careful geotechnical appraisals of sites where their presence is suspected. Their compressibility is high and they may be limited in lateral extent, thus leading to potential differential settlement.

It is important to note that the lower granular unit of the alluvium is very similar to that of the Devensian glacial deposits, both in character and properties. In general it is a reasonably dense sand and gravel and provides a suitable foundation for most structures unless it is waterlogged when groundwater control may be necessary in excavations.

6.4.3. Glacial and Interglacial Deposits.

The glacial deposits of the Devensian period consist mainly of outwash sheets of sands and gravels, and generally provide an adequate foundation.

These deposits may overlie low strength and highly compressible deposits laid down during earlier interglacial periods. The fact that such deposits are only locally preserved necessitates careful investigation of sites. The peats and glacio-lacustrine clays are typical of these compressible sediments. The unexpected occurrence of the interglacial Nechells peat during the investigation for a multi-storey residential development required a complete revision of the foundation design.

The coarse sands and gravels of the interglacials, derived from the Bunter sequence and sorted by fluvial action, form an excellent foundation. Construction problems may occur where these deposits have to be dewatered or when large diameter cast in situ piles are being installed.

The interglacial clays and peats which may occur in thicknesses of up to 17m (SP07658830) are often highly plastic in consistency with natural moisture contents nearer the liquid than the plastic limit.

Due to variations in permeability between different layers of these interglacial deposits significant seepage pressures can occur with artesian conditions arising in certain circumstances. Excavations in these deposits may encounter groundwater resulting in control problems of some magnitude.

In certain areas the glacio-lacustrine clays appear very similar to the weathered Keuper mudstones from which they are derived. They are, however, much more compressible and are not immediately underlain by significantly stronger material.

6.4.4. Pre-Hoxnian Deposits.

These are represented by tills (boulder clays), with a variable clastic content which is commonly low. Their matrix, to some extent, reflects the source material, i.e. the Keuper Marl, and has similar geotechnical properties to the weathered in situ source rock.

Seams of permeable sand and gravel within these tills may give rise to considerable water inflows into excavations. However, these deposits do provide suitable foundations for most structures.

6.4.5. Keuper Marl.

The geotechnical aspects of the Keuper Marl have now been well documented by Chandler et al (1968). Certain aspects though, such as weathering, consistency, aggregation, mineral activity are well worth comment.

The effect of weathering on Keuper Marl can be quite drastic where the drift cover is minimal or non-existent, and weathered zones can descend to 10 metres below the top of the Marl. Where the drift cover is greater, or has been recently removed, only the top 2 to 3 metres of the Marl may be affected. Fully weathered Keuper mudstones may often have markedly higher index properties and lower bulk densities than the unweathered material. Zone I unweathered Keuper mudstones may be considered as heavily overconsolidated soils, their dense state giving rise to high strength and low compressibility, and the more weathered mudstones as lightly overconsolidated soils (Chandler 1969). The latter may not be suitable for supporting heavy loads.

A further problem often caused by weathering is aggregate breakdown which results in a reduction of ϕ', the effective angle of shearing resistance and c', the effective cohesion, and also influences the clay activity. Skempton (1964) showed that in non-aggregated soils the residual strength was attained when enough movement on a shear surface had occured to orientate the component clay particles parallel to the slip surface. The value of the residual angle of shearing resistance, ϕ'_r, was seen to fall with increasing clay content.

Kenny (1967) demonstrated that ϕ'_r is a function both of clay content and mineralogy. A more detailed account of mineral activity and the aggregation ratio can be found in Chandler (1968).

Generally c', the effective cohesion, and ϕ', the effective angle of shearing resistance, are initially high for unweathered Keuper mudstones but decrease rapidly up the weathered profile with a consequent reduction in bearing capacity and a concomitant increase in compressibility.

Although the Keuper Marl consists of a series of red-brown mudstones with interspersed sandstones and frequent siltstones which possess different properties, the Keuper Marl can be considered, in general, as a homogeneous rock. Increased permeability will exist along the thin harder bands of sandstone and siltstone , known as skerries.

As the Keuper Marl is a shallow 'lacustrine' deposit, it commonly includes deposits of gypsum and other salts. Sulphate contents can often be high and deterioration of concrete in direct contact with these salts may occur. The problem is often magnified where relatively fast movement of groundwater occurs.

6.4.6. Lower Keuper Sandstone.

These sandstones provide excellent foundations and they are even sufficiently well cemented for underreamed piles to be constructed.

Silty clay bands, occurring quite frequently, have little or no effect on foundation performance, though they can lead to construction problems in subsurface works. Water perches can form and where these seams form tunnel roofs they may require support. Water flow along these seams into subsurface workings can cause erosion of the sandstone with resulting collapse and overbreak.

6.4.7. Upper Mottled Sandstone.

The Upper Mottled Sandstone has basically the same geotechnical properties as the Lower Keuper Sandstone and apart from a slightly higher permeability and less frequent clay seams can be considered identical.

6.5. Data Recorded.

Within the time available for the collation of borehole information a total of 520 boreholes were coded, logged and transferred to computer files. The distribution of these data is shown in fig 6.4. As a single, average length, borehole consumed between half an hour and an hour, with practice, to code and record onto the input data sheets for card punching, the total number was restricted. The time for each borehole was further increased by the complexity of the drift sequences, previously described, which required coding, and the numerous boreholes logged in Imperial units which needed converting to S.I. units.

The total number of lithological units recorded for drift, fill and bedrock, totalled 2,592 units, 148 necessitated additional mineralogical description. In all a total length of 6426.55 metres of borehole lithology was collated.

Groundwater was encountered and recorded 566 times and 4,894 samples provided information on the properties of the strata encountered within the area, Table 6.1.

It is apparent that the samples and test types reflect the lithologies encountered within the study area. As many structures have had to be founded on either the fill material or the considerable thicknesses of the drift deposits as much information as it is possible to obtain, is required to determine foundation designs. As a large proportion of the drift lithologies is predominantly granular, the Standard Penetration Test is employed far more frequently here than elsewhere.

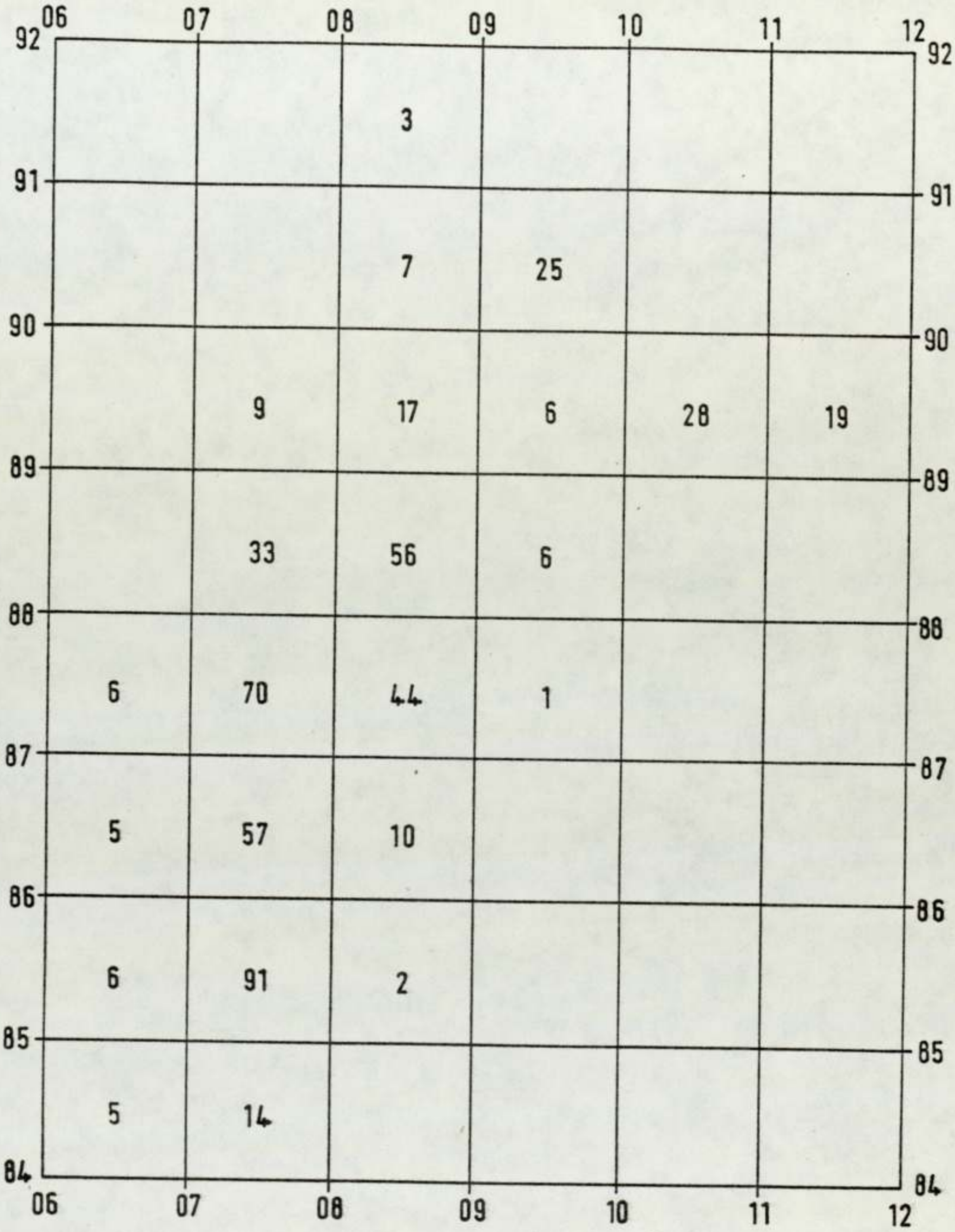


FIG. 6.4. BOREHOLE DISTRIBUTION WITHIN STUDY AREA

TYPE OF TEST	FILL	DRIFT	KEUPER MARL	LOWER KEUPER SANDSTONE	UPPER MOTTLED SANDSTONE	TOTAL
NUMBER OF BOREHOLES REACHING STRATIGRAPHY	6	103	192	208	11	520
MOISTURE CONTENT	173	399	810	62	55	1499
LIQUID LIMIT	48	57	247	15	4	371
PLASTIC LIMIT	48	57	246	15	4	370
SPECIFIC GRAVITY		3	1			4
DENSITY	31	275	487	9	7	809
STANDARD PENETRATION TEST	392	1774	580	544	43	3333
PH, SOIL	101	151	100	28		380
PH, WATER	19	25	52	20	4	120
ORGANIC CONTENT						
SOIL SULPHATE	100	150	97	27	2	376
WATER SULPHATE	21	26	56	18	2	123
SOIL CARBONATE						
WATER CARBONATE						
CHLORIDE						
SHEAR STRENGTH	36	254	487	16	5	798
GRADING CURVE ANALYSIS	80	146		57	33	316
CONSOLIDATION	5	20	50	1	-	76

TABLE 6.1. SUMMARY OF TEST RESULTS

The major lithologies designate the frequency and the type of tests performed. There is a lack of consolidation results because of the generally gravelly nature of the glacial deposits or, on the other hand, the presence of such highly compressible deposits, such as the alluvial clays, peats,etc. which are unlikely to have been tested. Furthermore, oedometer tests are expensive and during the period in which most of the boreholes were sunk a certain amount of controversy existed concerning the reliability of results in materials such as the Keuper Marl mudstones.

Particle size distributions, mainly used to classify materials, also indicate the permeability of such deposits for dewatering purposes. Further, they enable the assessment of such material for re-use purposes, though such re-use is limited in the study area.

The frequency of the tests such as moisture content, plastic limit etc. reflect the proportion of cohesive soils present. These tests being more frequent for the Keuper Marl than for the drift deposits. Some results have been recorded for the cohesive lithologies within the Upper Mottled Sandstone and the Lower Keuper Sandstone.

Chemical analyses, only necessary where sulphates may be expected to be concentrated, are quite numerous for the clays and silty clays of the Keuper Marl, drift and fill deposits where such concentrations may be detrimental to the buried concrete of a proposed structure.

As already discussed the drift deposits are predominantly granular and this is reflected in the number of tests for non-cohesive soils e.g. Standard Penetration Test. There are also many cohesive drift deposits which are too soft to even consider founding on them and consequently they have not been tested.

7. FACTUAL DATA PRESENTATION.

7.1. Introduction.

This chapter considers the presentation of factual data in a form that is easily understood, informative and usable. Basic search programs, written in Fortran IV, retrieve information from the data files in order that standard I.C.L. graph plotting routines can be used to present the information in the desired manner. This is commonly performed by searching the data files for a predetermined geographical area and withdrawing the required parameter for plotting. These programs were designed to show the capabilities of the system and extent of the data bank. A series of graphical plots and line printer documents are used to illustrate the potential of the study to the user. No attempt has been made to predict the full variety of user requests, and only a selection of presentations is illustrated. Many of the programs are amenable to minor changes which will allow the data presented to be varied at will. Presentation of the data in the majority of cases is for an area of one square kilometre, though any area can be designated by the user. However, where data are limited different areas are used, large areas showing the whole study area have been used to present, not only, low density information but also to provide the user with an overall picture to illustrate regional trends or identify local anomalies.

The presentation is considered under three headings, two of which, General and Geology, are most effectively presented in plan form. These plans reflect the amount of information stored at any particular time and will constitute permanent reference records. The third group of information, Geotechnical, also lends itself to presentation in a similar manner, with tabulation of data and geotechnical sections also having considerable value, as have certain graphical presentations e.g. Casagrande plots and particle size distribution curves.

7.2. General Information.

As it is essential to show immediately whether data are available for an area specified by a user, a graphical display is used to show the locations of any boreholes within a specified area. Such a presentation for the kilometre square SP072871 is shown in fig 7.1, where the borehole locations are denoted by a symbol and an adjacent reference number. The reference number is allocated by the author to each borehole, and hence is unique to each borehole, on collation into the file store. Further reference numbers are used in some of the following presentations (e.g. fig 7.31, 7.32 etc.), these are for the benefit of the user and facilitate correlation of one type of presentation with another, and are unique to the specific user request. The correlation of the different forms of computer outputs will be discussed later. The reference number used in these presentations can be omitted or replaced by other information such as surface levels, depth of borehole or even age of the boring.

A similar plan, fig 7.2, for the kilometre square SP070860 shows the stratigraphic level reached by each of the boreholes, indicated by symbols and produced with an attached legend. Again the reference numbers shown are solely for correlation of a number of computer outputs by the user.

These first two examples provide the user with an immediate knowledge of the quantity and possible extent of available information, thus enabling the user either to terminate or continue the request.

DISTRIBUTION OF BOREHOLES

WITHIN THE SPECIFIED AREA

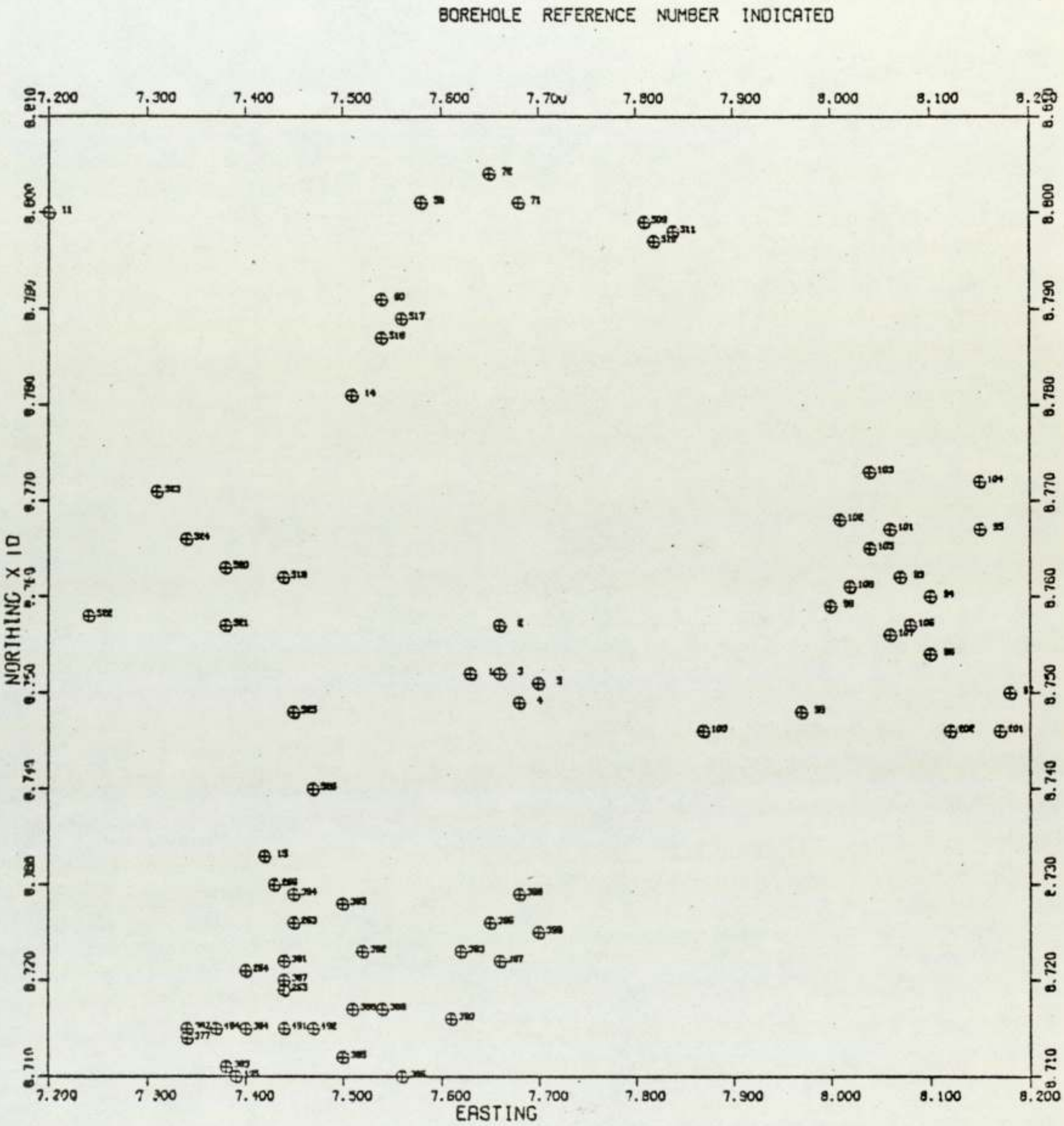


FIG. 7.1.

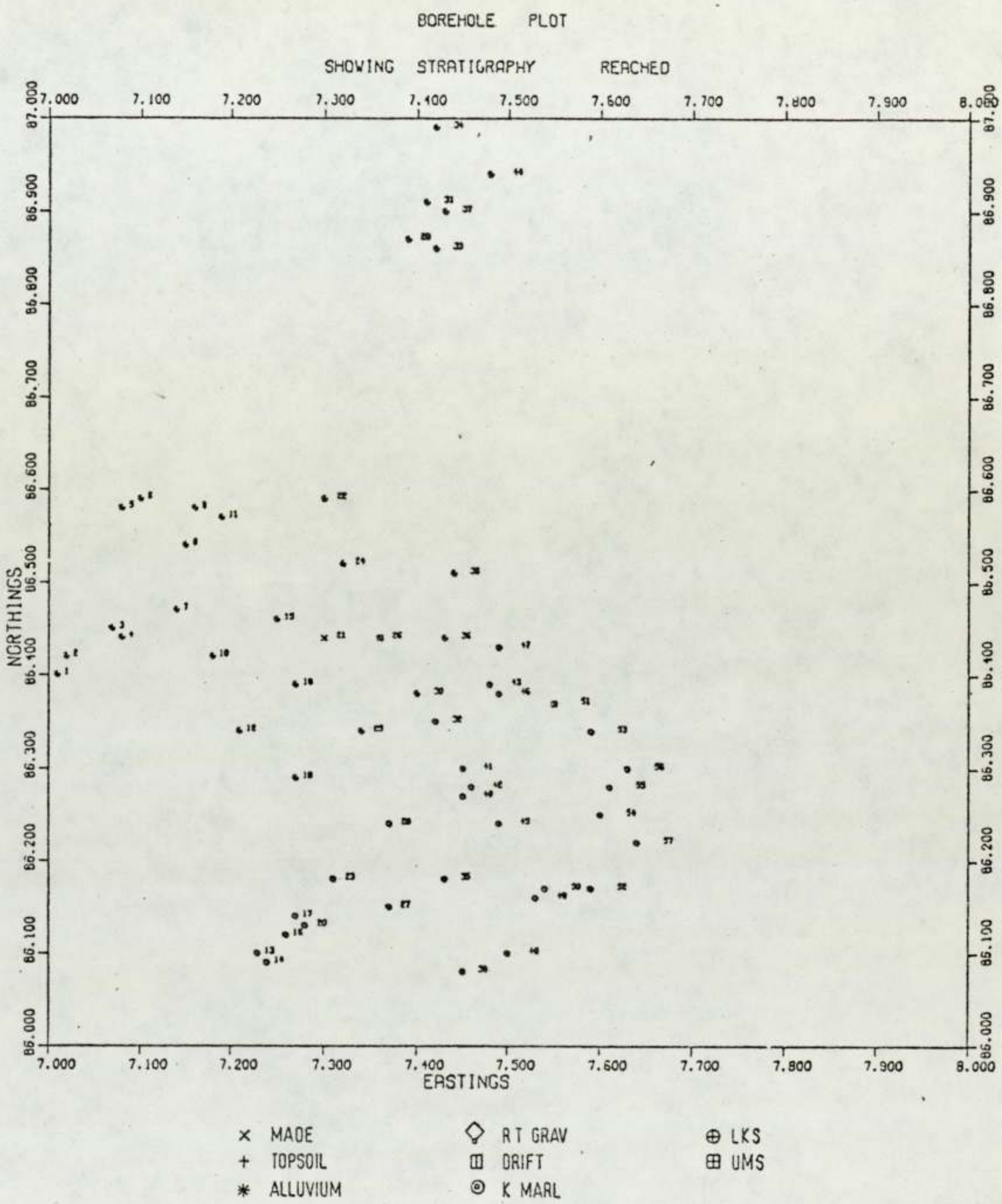


FIG. 7.2 PLAN SHOWING THE STRATIGRAPHY AT THE BASE OF THE BOREHOLES.

7.3. Geological Information.

As the study area is covered by large accumulations of complex and variable drift lithologies, and therefore variable engineering properties, any site needs a critical and detailed investigation utilizing all the available information.

After considering a number of different output designs, it was decided to use a series of plans using alphacodes to indicate the lithology present at the borehole position for specific depths. The series, fig 7.3.1. to 7.3.10, provides a simple representation of the lithologies intercepted by the boreholes descending at 1m and 5m intervals below surface level.

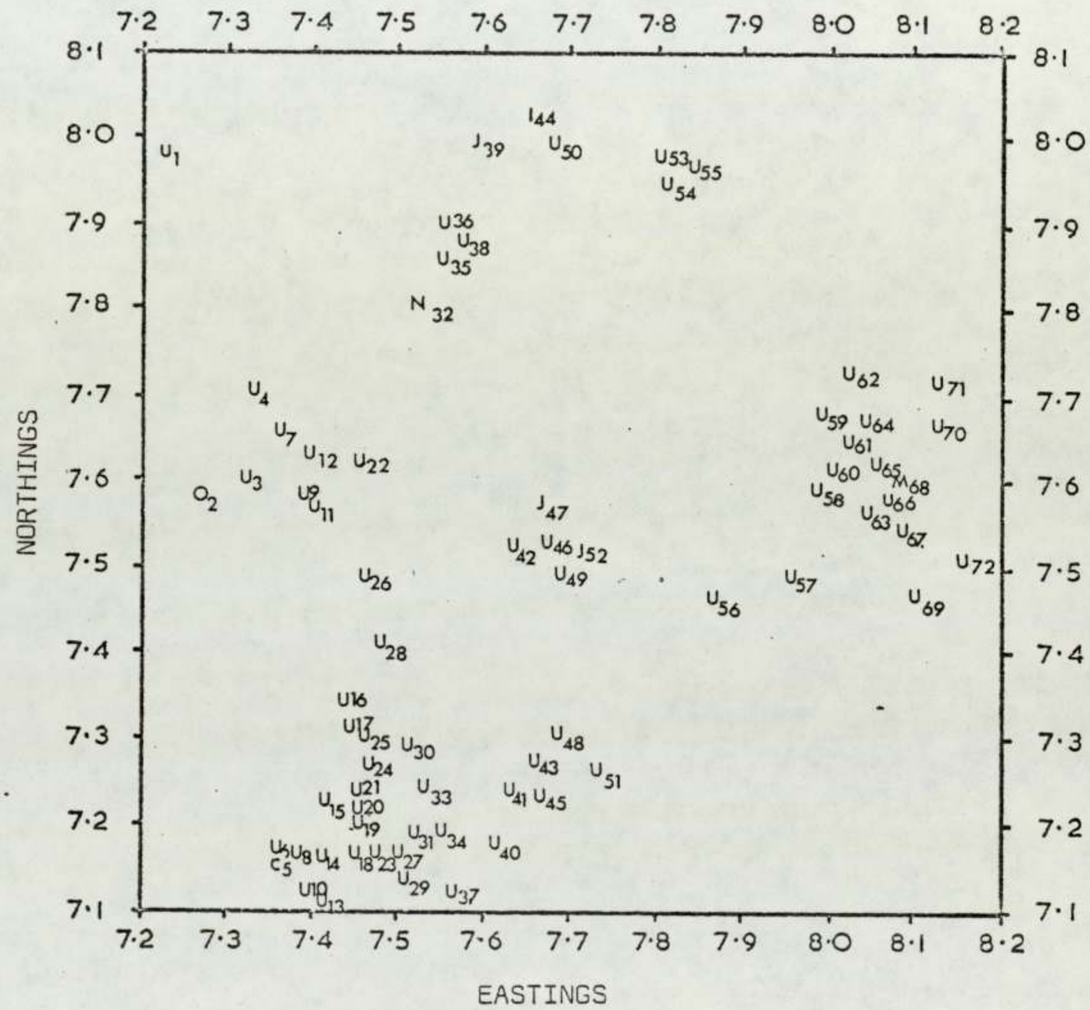
Three computer routines, written in Fortran IV, are used to select, classify and present the information. Initially a search is carried out on a geographical basis, and the lithology at a particular depth is found for each borehole within a specified area. The lithology, stored on file using the ternary descriptive system (see 3.2.2.) was decoded using the soil classifications, figs 3.1 and 3.2 and an alphacode selected to represent the particular lithology. Although basic I.C.L. graph plotter routines are used to produce the final output as an X - Y plot, an arithmetic counter is included to provide the reference numbers shown adjacent to the lithology alphacode. As the boreholes are sorted geographically counting always commences from the southwest corner of a user requested area, and is unique to that request.

This type of presentation is purely a soil classification below surface level and does not include a provision to illustrate bedrock. However, adaptations could easily show:

FIG. 7.3 BOREHOLE LITHOLOGY AT VARIOUS DEPTHS BELOW SURFACE LEVEL FOR THE AREA SP 072871

BOREHOLE LITHOLOGY

AT A DEPTH BELOW SURFACE LEVEL OF 1 METRES



A SAND

B CLAYEY SAND

C SLIGHTLY CLAYEY SAND

D SILTY SAND

E SILT

F CLAYEY SANDY SILT

G SANDY SILT

H CLAYEY SILT

I CLAY

J SANDY CLAY

K SAND-CLAY

L SILT-CLAY

M SAND-SILT CLAY

N CONCRETE GRAVEL

O PEBBLY SAND

P PEAT

Q VERY COARSE GRAVEL

R CLAYEY GRAVEL

S GRAVELLY CLAY

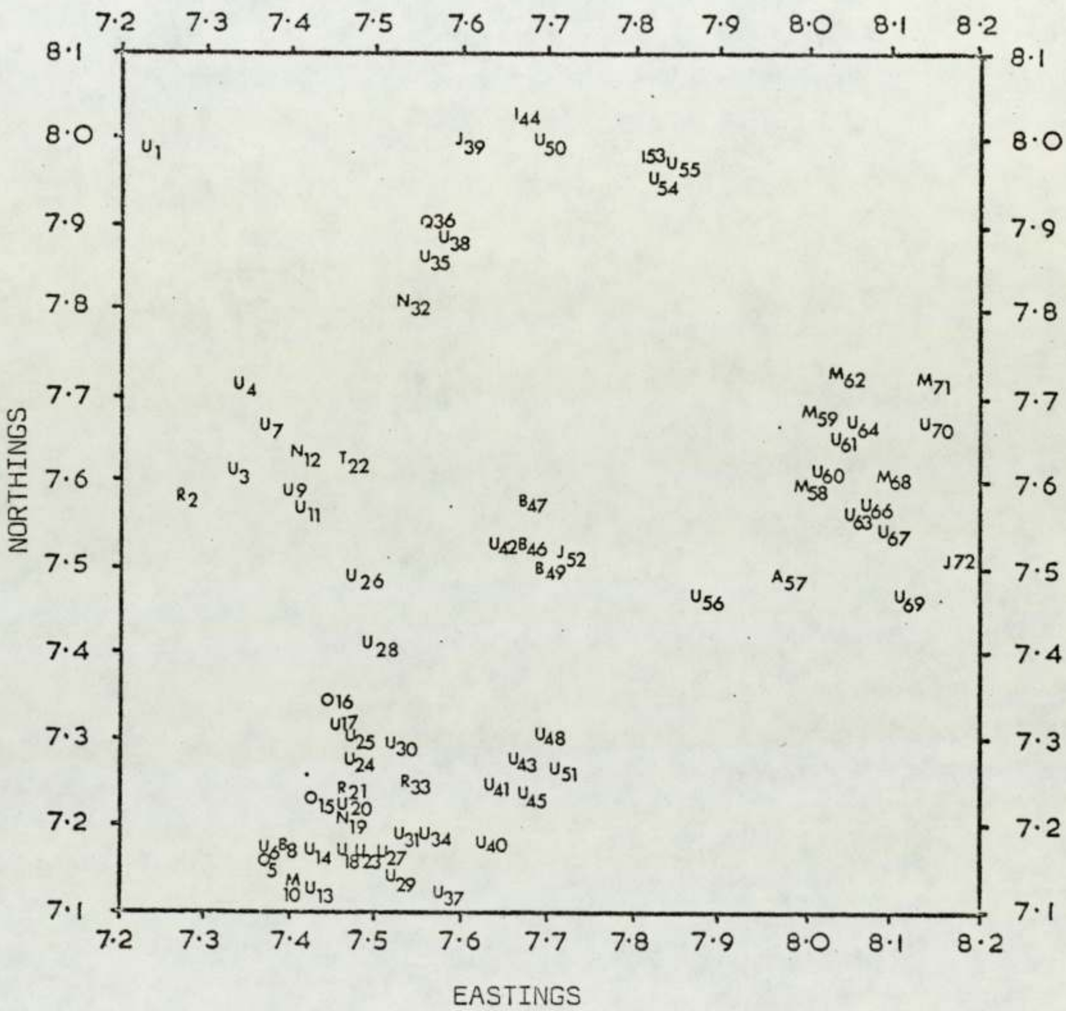
T SILTY CLAY

U MADE GROUND

FIG. 7. 3. 1

BOREHOLE LITHOLOGY

AT A DEPTH BELOW SURFACE LEVEL OF 2 METRES

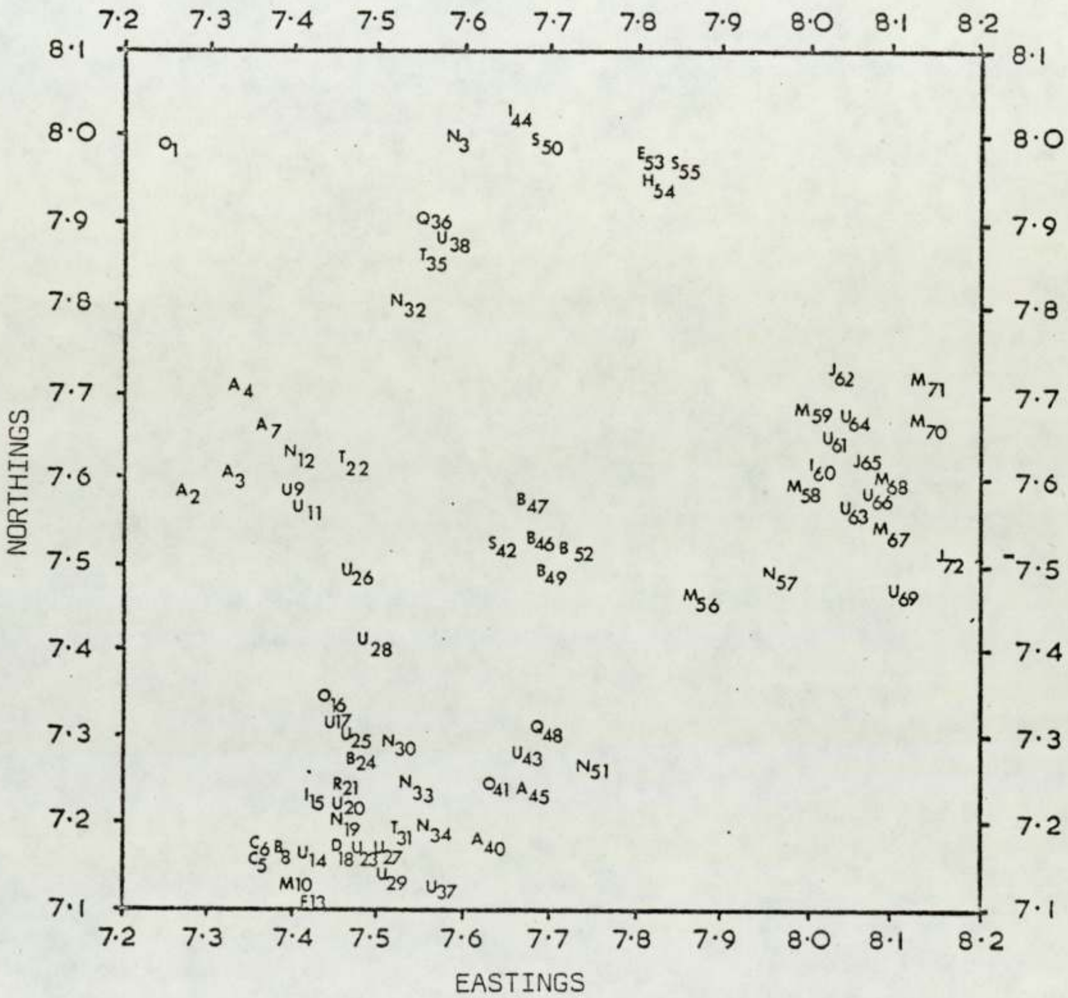


A SAND
B CLAYEY SAND
C SLIGHTLY CLAYEY SAND
D SILTY SAND
E SILT
F CLAYEY SANDY SILT
G SANDY SILT
H CLAYEY SILT
I CLAY
J SANDY CLAY
K SAND-CLAY
L SILT-CLAY
M SAND-SILT CLAY
N CONCRETE GRAVEL
O PEBBLY SAND
P PEAT
Q VERY COARSE GRAVEL
R CLAYEY GRAVEL
S GRAVELLY CLAY
T SILTY CLAY
U MADE GROUND

FIG. 7. 3. 2

BOREHOLE LITHOLOGY

AT A DEPTH BELOW SURFACE LEVEL OF 3 METRES

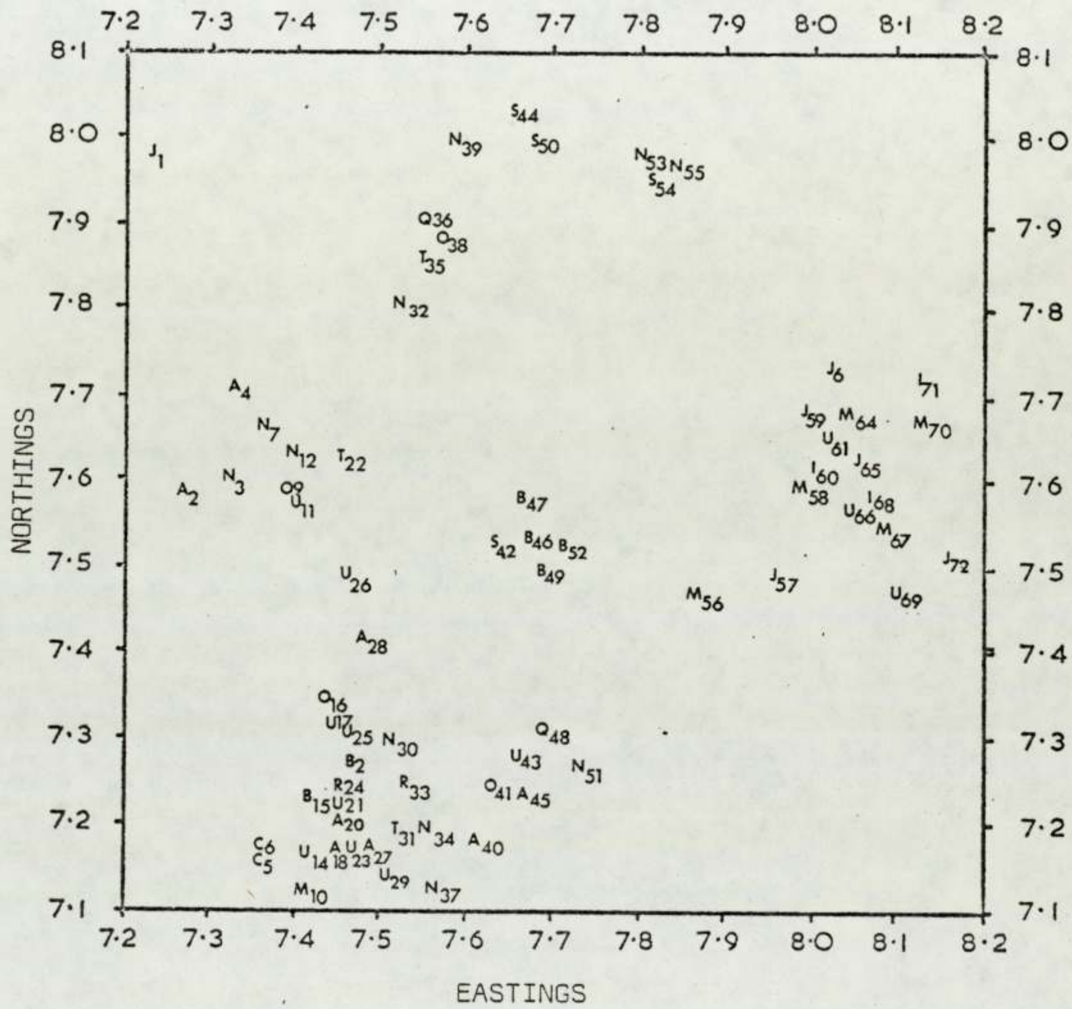


A SAND	H CLAYEY SILT	O PEBBLY SAND
B CLAYEY SAND	I CLAY	P PEAT
C SLIGHTLY CLAYEY SAND	J SANDY CLAY	Q VERY COARSE GRAVEL
D SILTY SAND	K SAND-CLAY	R CLAYEY GRAVEL
E SILT	L SILT-CLAY	S GRAVELLY CLAY
F CLAYEY SANDY SILT	M SAND-SILT CLAY	T SILTY CLAY
G SANDY SILT	N CONCRETE GRAVEL	U MADE GROUND

FIG. 7. 3. 3

BOREHOLE LITHOLOGY

AT A DEPTH BELOW SURFACE LEVEL OF 4 METRES



A SAND
B CLAYEY SAND
C SLIGHTLY CLAYEY SAND
D SILTY SAND
E SILT
F CLAYEY SANDY SILT
G SANDY SILT

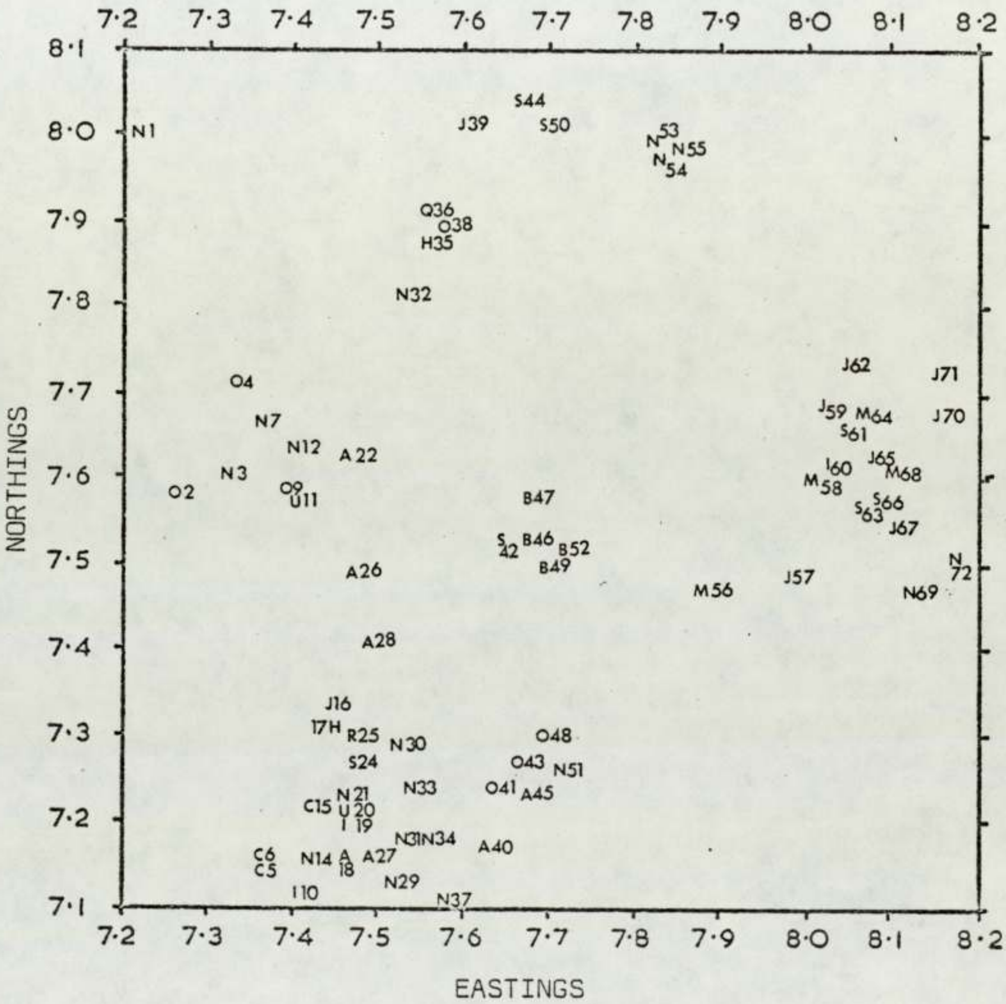
H CLAYEY SILT
I CLAY
J SANDY CLAY
K SAND-CLAY
L SILT-CLAY
M SAND-SILT CLAY
N CONCRETE GRAVEL

O PEBBLY SAND
P PEAT
Q VERY COARSE GRAVEL
R CLAYEY GRAVEL
S GRAVELLY CLAY
T SILTY CLAY
U MADE GROUND

FIG. 7. 3. 4

BOREHOLE LITHOLOGY

AT A DEPTH BELOW SURFACE LEVEL OF 5 METRES

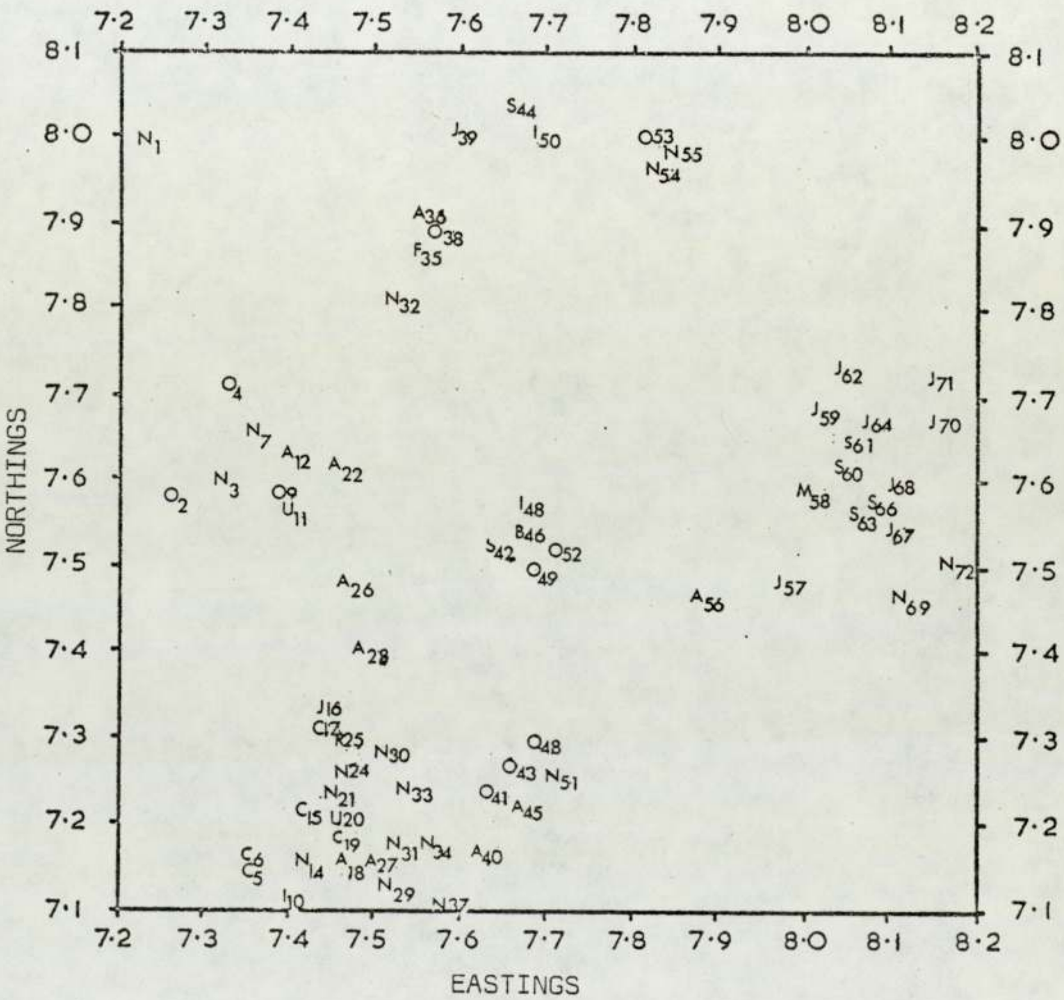


A SAND
B CLAYEY SAND
C SLIGHTLY CLAYEY SAND
D SILTY SAND
E SILT
F CLAYEY SANDY SILT
G SANDY SILT
H CLAYEY SILT
I CLAY
J SANDY CLAY
K SAND-CLAY
L SILT-CLAY
M SAND-SILT CLAY
N CONCRETE GRAVEL
O PEBBLY SAND
P PEAT
Q VERY COARSE GRAVEL
R CLAYEY GRAVEL
S GRAVELLY CLAY
T SILTY CLAY
U MADE GROUND

FIG. 7. 3. 5

BOREHOLE LITHOLOGY

AT A DEPTH BELOW SURFACE LEVEL OF 6 METRES

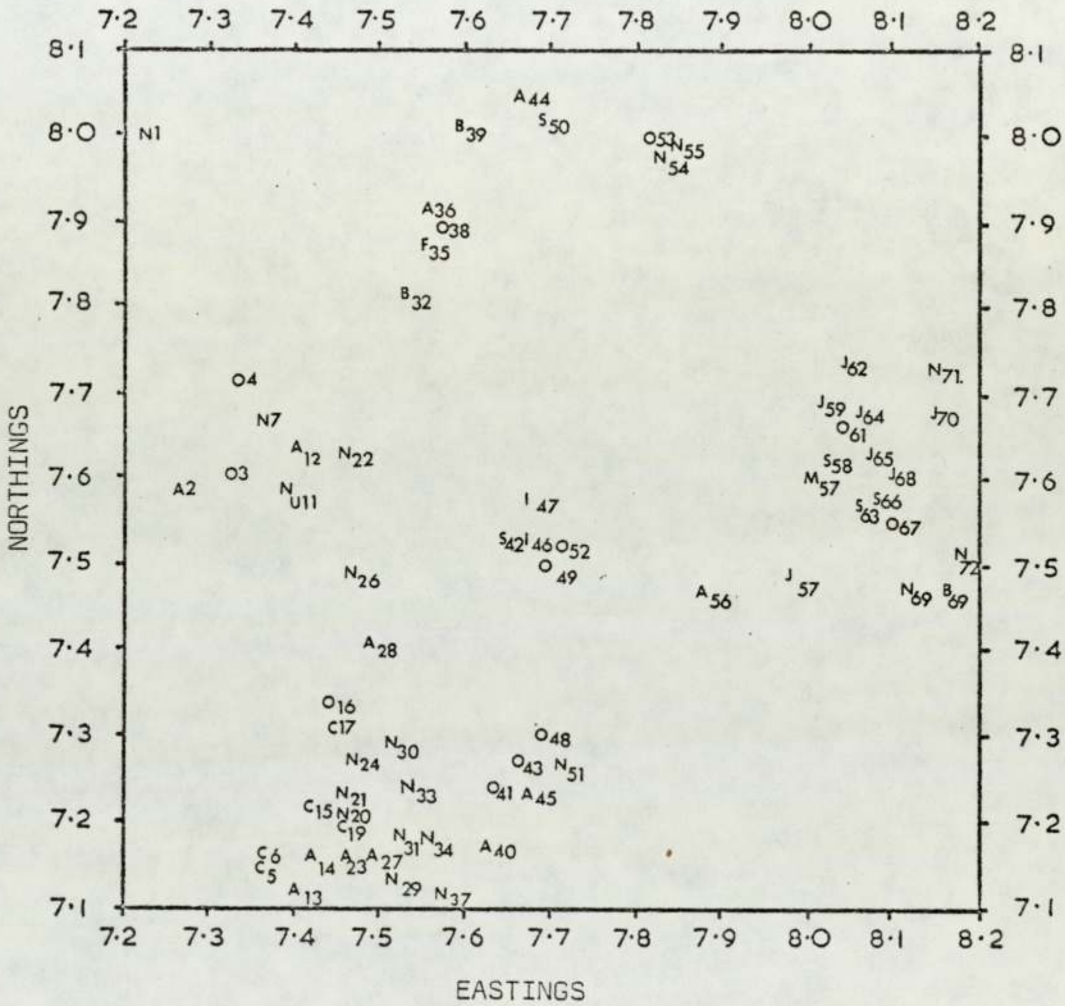


A SAND	H CLAYEY SILT	O PEBBLY SAND
B CLAYEY SAND	I CLAY	P PEAT
C SLIGHTLY CLAYEY SAND	J SANDY CLAY	Q VERY COARSE GRAVEL
D SILTY SAND	K SAND-CLAY	R CLAYEY GRAVEL
E SILT	L SILT-CLAY	S GRAVELLY CLAY
F CLAYEY SANDY SILT	M SAND-SILT CLAY	T SILTY CLAY
G SANDY SILT	N CONCRETE GRAVEL	U MADE GROUND

FIG. 7. 3. 6

BOREHOLE LITHOLOGY

AT A DEPTH BELOW SURFACE LEVEL OF 7 METRES

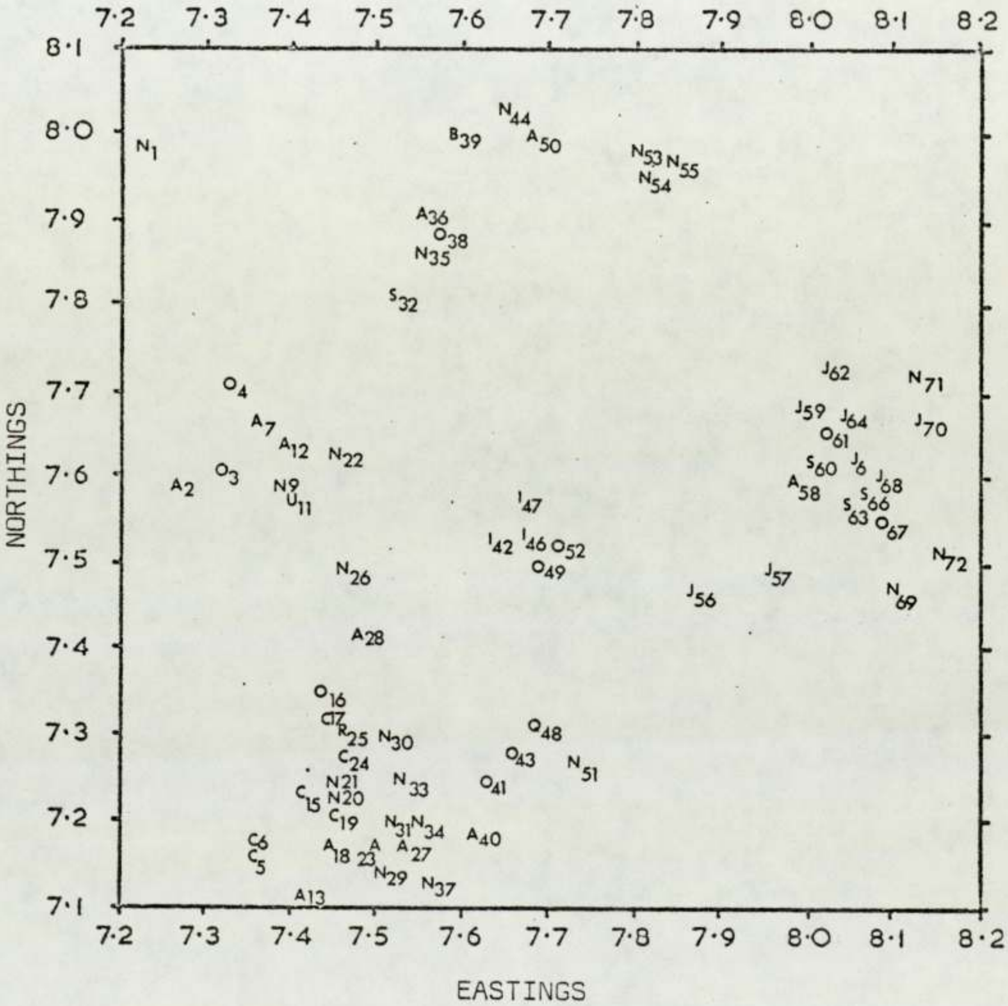


A SAND
B CLAYEY SAND
C SLIGHTLY CLAYEY SAND
D SILTY SAND
E SILT
F CLAYEY SANDY SILT
G SANDY SILT
H CLAYEY SILT
I CLAY
J SANDY CLAY
K SAND-CLAY
L SILT-CLAY
M SAND-SILT CLAY
N CONCRETE GRAVEL
O PEBBLY SAND
P PEAT
Q VERY COARSE GRAVEL
R CLAYEY GRAVEL
S GRAVELLY CLAY
T SILTY CLAY
U MADE GROUND

FIG. 7. 3. 7

BOREHOLE LITHOLOGY.

AT A DEPTH BELOW SURFACE LEVEL OF 8 METRES

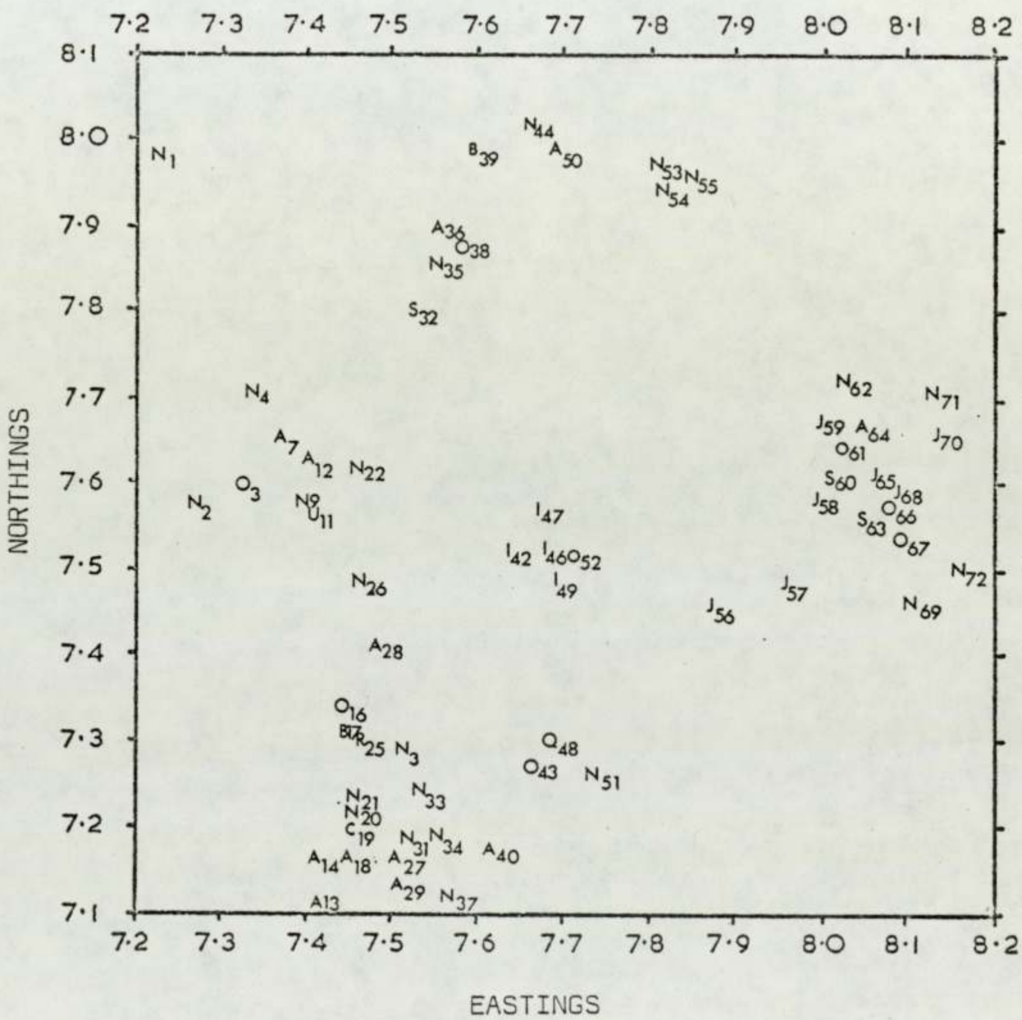


A SAND
B CLAYEY SAND
C SLIGHTLY CLAYEY SAND
D SILTY SAND
E SILT
F CLAYEY SANDY SILT
G SANDY SILT
H CLAYEY SILT
I CLAY
J SANDY CLAY
K SAND-CLAY
L SILT-CLAY
M SAND-SILT CLAY
N CONCRETE GRAVEL
O PEBBLY SAND
P PEAT
Q VERY COARSE GRAVEL
R CLAYEY GRAVEL
S GRAVELLY CLAY
T SILTY CLAY
U MADE GROUND

FIG. 7. 3. 8

BOREHOLE LITHOLOGY

AT A DEPTH BELOW SURFACE LEVEL OF 9 METRES

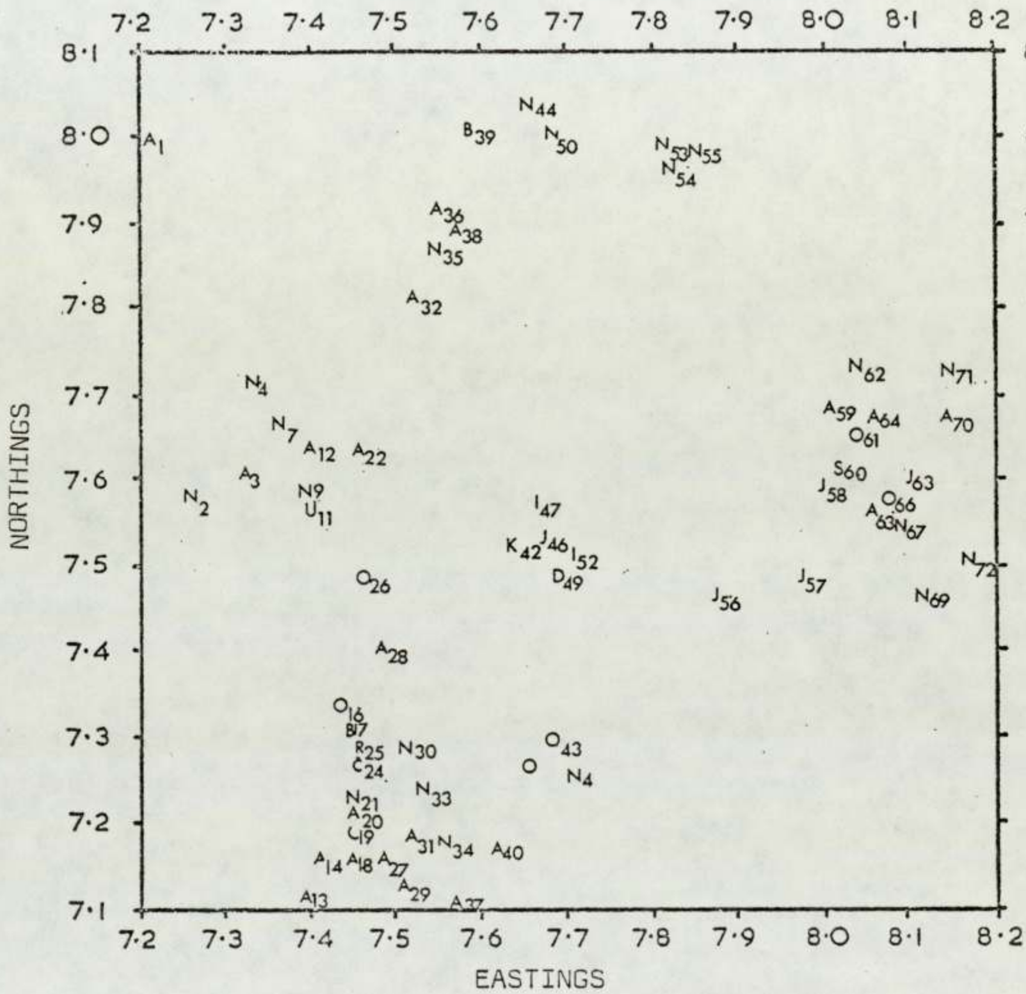


A SAND	H CLAYEY SILT	O PEBBLY SAND
B CLAYEY SAND	I CLAY	P PEAT
C SLIGHTLY CLAYEY SAND	J SANDY CLAY	Q VERY COARSE GRAVEL
D SILTY SAND	K SAND-CLAY	R CLAYEY GRAVEL
E SILT	L SILT-CLAY	S GRAVELLY CLAY
F CLAYEY SANDY SILT	M SAND-SILT CLAY	T SILTY CLAY
G SANDY SILT	N CONCRETE GRAVEL	U MADE GROUND

FIG. 7. 3. 9

BOREHOLE LITHOLOGY

AT A DEPTH BELOW SURFACE LEVEL OF 10 METRES



A SAND	H CLAYEY SILT	O PEBBLY SAND
B CLAYEY SAND	I CLAY	P PEAT
C SLIGHTLY CLAYEY SAND	J SANDY CLAY	Q VERY COARSE GRAVEL
D SILTY SAND	K SAND-CLAY	R CLAYEY GRAVEL
E SILT	L SILT-CLAY	S GRAVELLY CLAY
F CLAYEY SANDY SILT	M SAND-SILT CLAY	T SILTY CLAY
G SANDY SILT	N CONCRETE GRAVEL	U MADE GROUND

FIG. 7. 3. 10

the depth of bedrock below surface level, or to O.D. level, thickness of drift and fill etc. by the use of numbers distinct from the borehole reference numbers.

A more complete picture of the geology of an area is aided by groundwater level information. Data are presented for the first encountered water levels, fig 7.4.1 and the rest water levels, fig 7.4.2, for a user specified area. It is rare that boreholes are left open after completion for final rest water levels to be established. First encountered levels are highly dependent on the lithologies penetrated and unless the permeability is very high the level at which the water enters the borehole is often not apparent.

In this area, underlain by highly variable sequences of fill and drift deposits, groundwater conditions will always have to be assessed at any individual site. The value of these water level plans is thus somewhat limited, and it is only intended that they should indicate areas where groundwater could potentially be a problem, that is areas of anomalously high water levels where groundwater interference with construction may arise.

Where numerical data are printed out for boreholes located in close proximity, overlapping of the printed data often occurs. A further development is necessary to amend the plotting routine for a clearer presentation. Selection of information, averaging or the use of alphacodes to express a range of levels could be employed to eliminate at least the majority of any such overlapping.

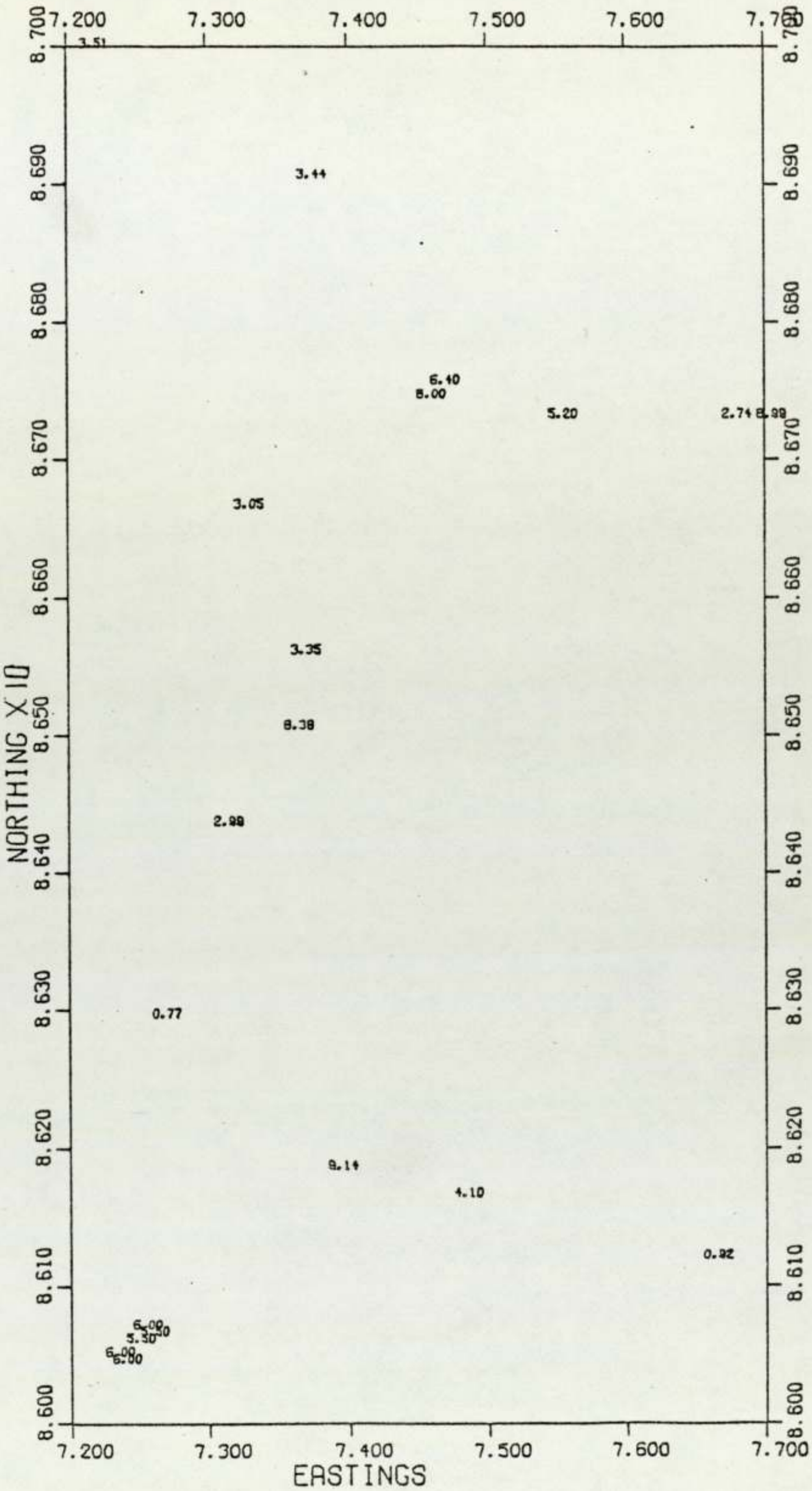


FIG. 7.4.1 FIRST ENCOUNTERED WATER LEVELS BELOW SURFACE LEVEL

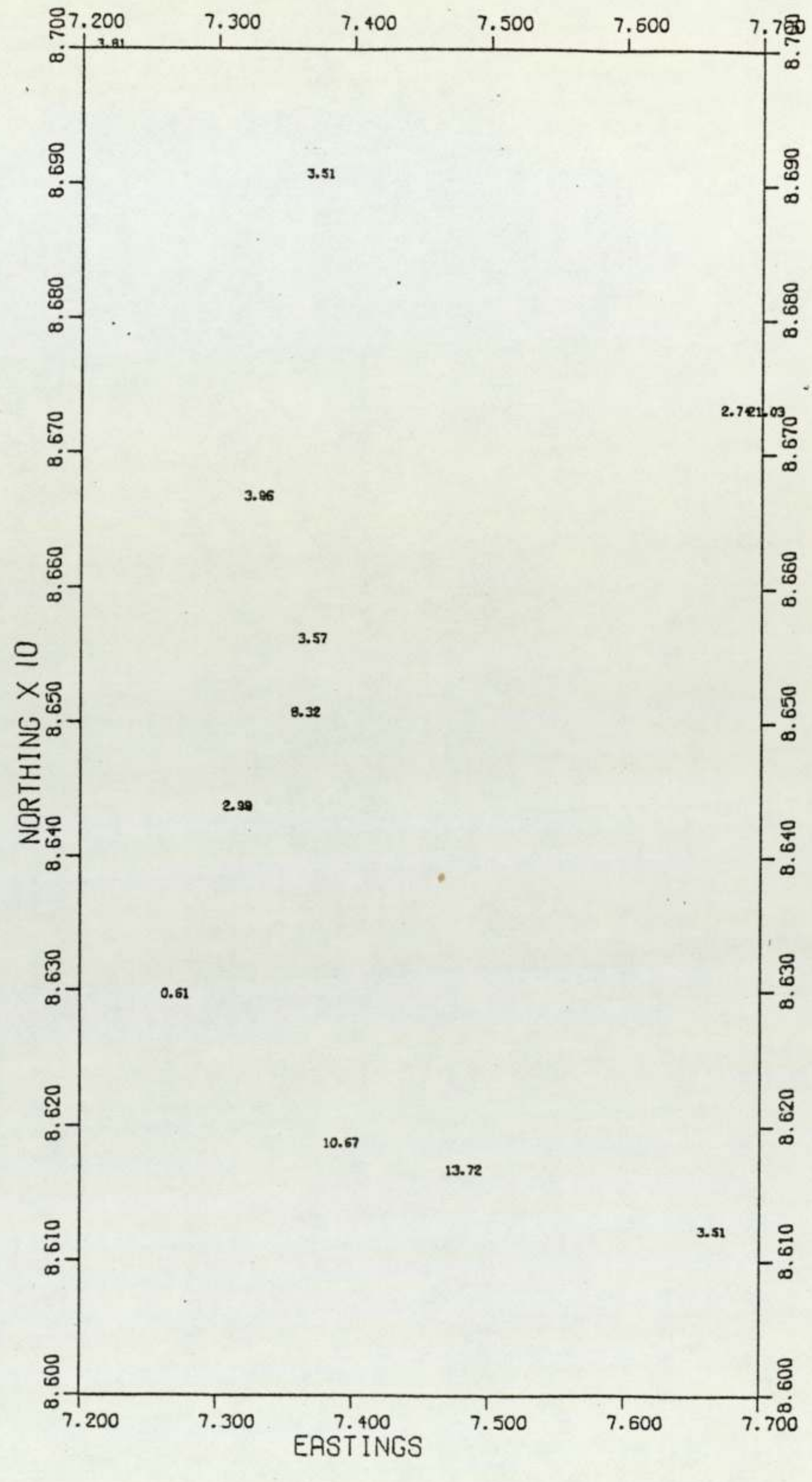


FIG. 7. 4. 2 REST WATER LEVELS BELOW SURFACE LEVEL

7.4. Geotechnical Information.

The available geotechnical information was considered and, as before, simple presentations were sought to convey basic factual information.

The selection of the geotechnical parameters is based on geographical location i.e. the user specified area, and the particular parameter is then sought for a certain stratigraphic horizon within each borehole. Further computer manipulations determine the most relevant value of the parameter, for example the highest value of plasticity index is found for the specific stratigraphic unit in each borehole to highlight material possibly unsuitable for engineering purposes. Calculations may be included at this stage where parameters, not stored, are determined directly from data on file e.g. plasticity index. The values found, or calculated, are then plotted using the basic I.C.L. graph plotter routines discussed earlier.

In the series of examples following, data were selected for the Undifferentiated Drift and Keuper Marl deposits. These units provide the lithologies for which these properties are most commonly determined. The cohesive element of the Undifferentiated Drift deposits provides most of the data for this stratigraphic unit, and the dominantly cohesive Keuper Marl providing similar information. These were preferred as they provided much more data than the remaining coarse grained lithologies.

Data are presented, in the majority of examples, for the whole of the study area, illustrating the diverse properties present. Where the data are sufficient in quantity, smaller areas are chosen to enhance the data display and demonstrate the flexibility of the system.

7.4.1. Plasticity Index.

In general, materials with high plasticity are less suitable for engineering purposes. To emphasize this, the highest values for the plasticity index have been identified, from calculation using the plastic and liquid limits.

Alphacodes, representing the ranges of plasticity index values and chosen to coincide with the fine grained soils plasticity chart after Casagrande (1948), were then plotted at each borehole location within the user specified area for Undifferentiated Drift, fig 7.5.1 and Keuper Marl, fig 7.5.2, deposits.

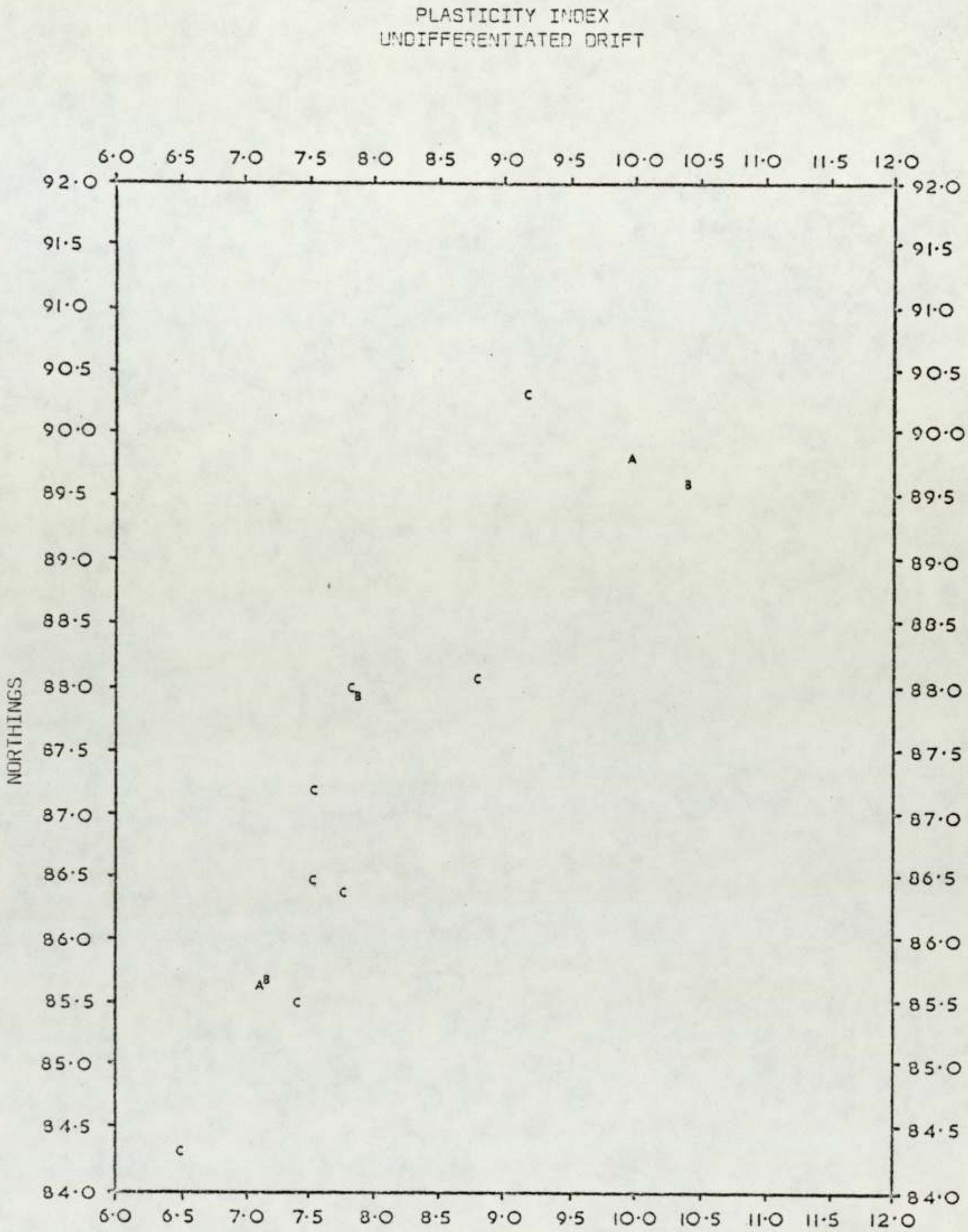
The ranges of values for the plasticity index are described in Table 7.1, with the vast majority of soils encountered in the Midland region falling in the low to medium plasticity category. Soils of high plasticity, 20 - 30% are of rare occurrence in this locality.

These presentations clearly demonstrate that for the Undifferentiated Drift deposits the plasticity index ranges from less than 5% to 20%, with an average near to 15%. The Keuper Marl deposits illustrate a similar range of values as the drift deposits, though with an average plasticity index of 10%.

The Keuper Marl data, fig 7.5.2, are divided into a northern cluster, representing information obtained from the M6 motorway, and a southern one, with data recorded for a new market develop-

ALPHACODE	PLASTICITY INDEX (%)	DESCRIPTION OF SOIL.
A	< 5	Non-plastic
B	5 - 10	Low plasticity
C	10 - 20	Medium plasticity
D	20 - 30	High plasticity

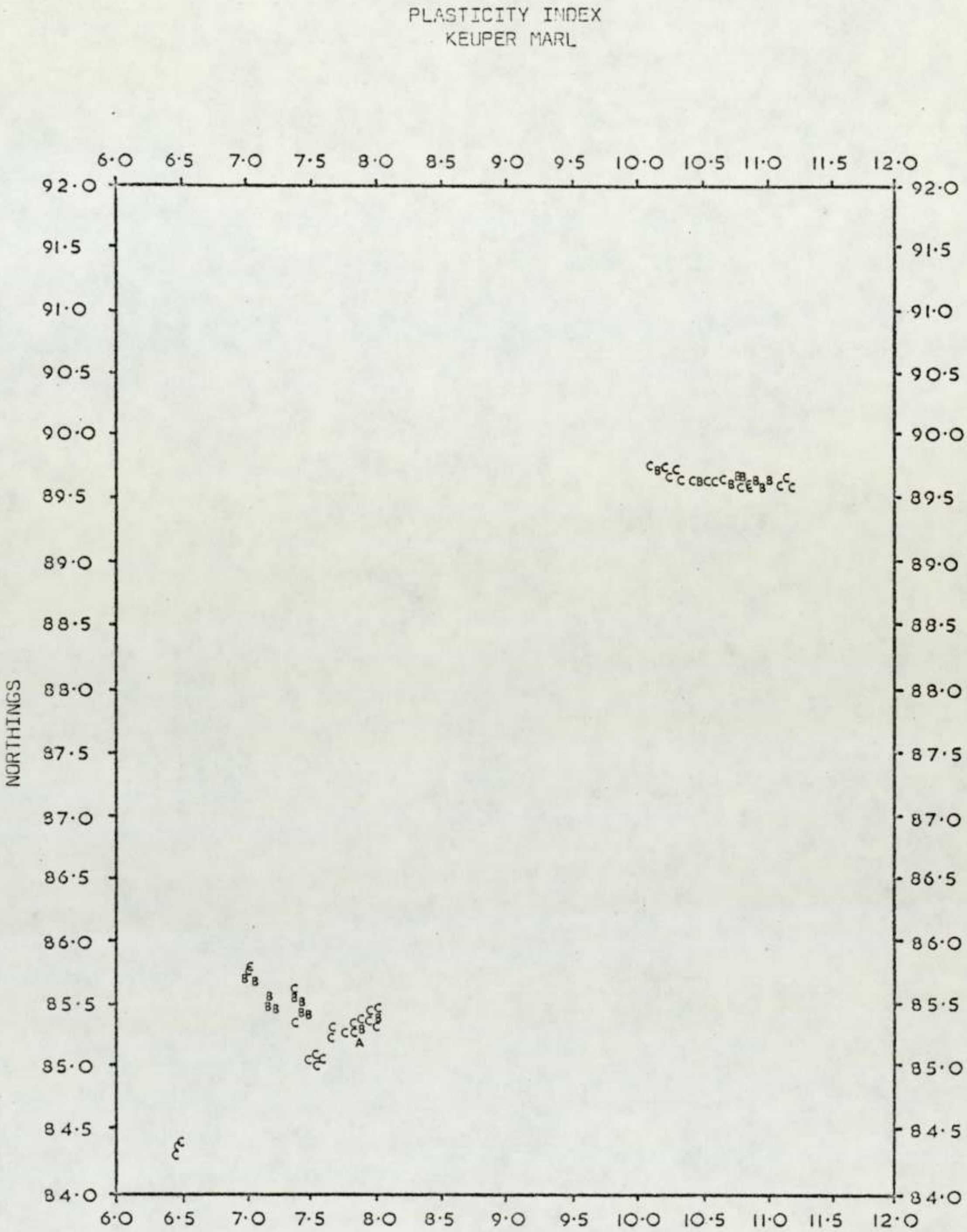
Table 7.1 Plasticity Index Values.



PLASTICITY INDEX RANGES

A	<5 %
B	5-10 %
C	10-20 %
D	20-30 %
E	30-40 %
F	40-50 %
G	>50 %

FIG. 7.5.1



PLASTICITY INDEX RANGES

A	<5 %
B	5-10 %
C	10-20 %
D	20-30 %
E	30-40 %
F	40-50 %
G	>50 %

FIG. 7. 5. 2

ment area. These clusters are further emphasized as it appears that the consistency limits were only recorded for the more recent investigations and data does not exist between the clusters even though boreholes in these areas do reach the bedrock.

7.4.2. Consistency Index.

The consistency index, defined as the ratio of the difference between liquid limit and natural moisture content and the difference between the liquid limit and plastic limit, provides further information on the physical nature of the soils. To illustrate this, very hard clays have a consistency index of one or more and the lower the value of the consistency index the greater the moisture content.

Average values have been retrieved from the boreholes within the study area for both of the clay dominated strata i.e. the Undifferentiated Drift, fig 7.6.1 and the Keuper Marl, fig 7.6.2, deposits to indicate the general nature of the strata. However, as the Undifferentiated Drift deposits usually consist of alternating sands and clays, the sands would have lower plasticity index and higher consistency index values. The lowest consistency index values recorded will provide the engineer with a clear indication of the presence of any soft clays. This is similarly so for the Keuper Marl deposits, although in many construction excavations any suspect weathered Keuper Marl, which would have lower consistency index values, would be removed and hence the average values give a clearer indication of the general character of the Keuper Marl.

The relevance of highest, average etc. values depends

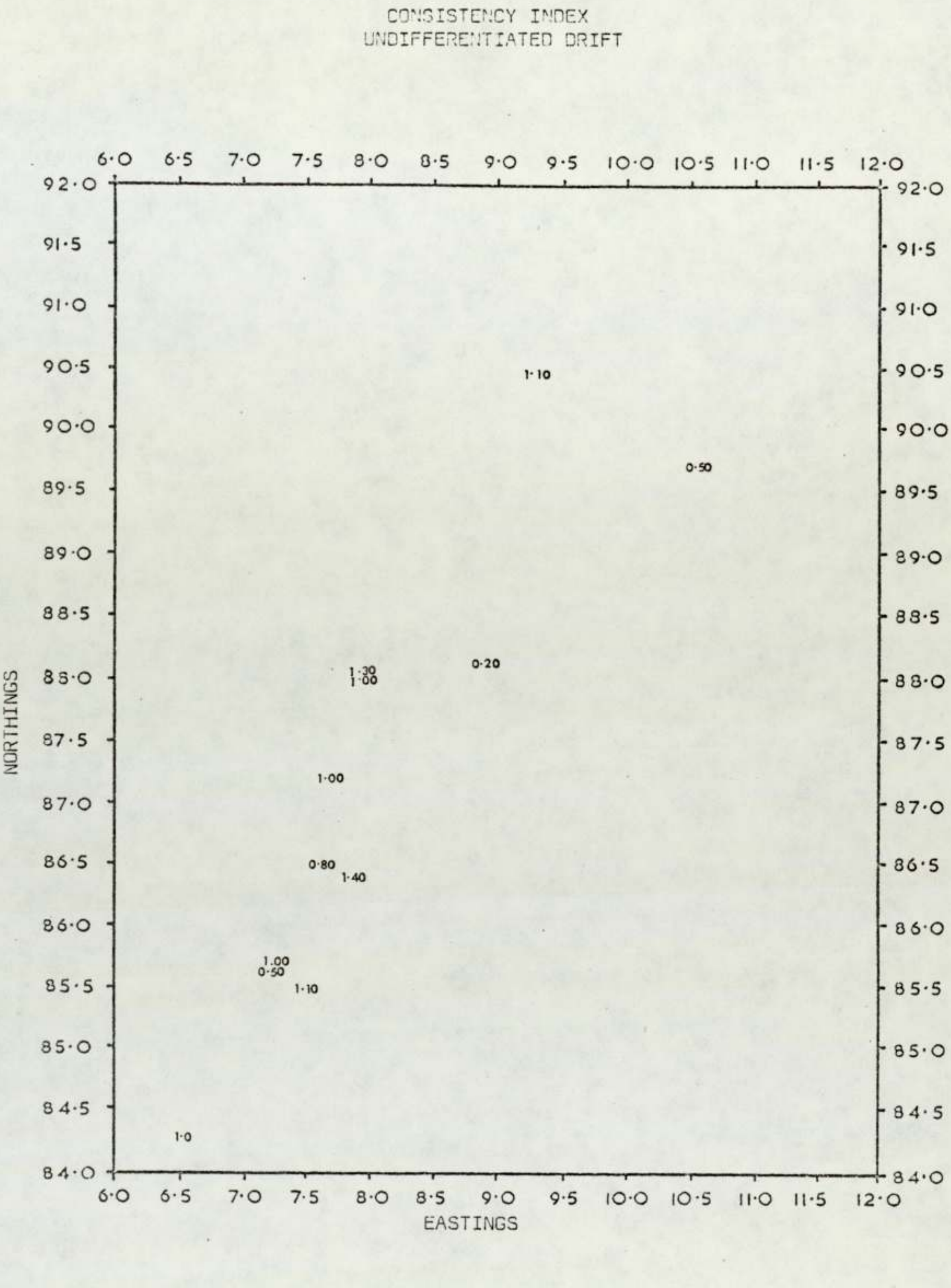

CONSISTENCY INDEX
UNDIFFERENTIATED DRIFT
NORTHINGS
EASTINGS
6·0
6·5
7·0
7·5
8·0
8·5
9·0
9·5
10·0
10·5
11·0
11·5
12·0
92·0
91·5
91·0
90·5
90·0
89·5
89·0
88·5
88·0
87·5
87·0
86·5
86·0
85·5
85·0
84·5
84·0
1·10
0·50
0·20
1·30
1·00
1·00
0·80
1·40
1.00
0·50
1·10
1·0

FIG. 7. 6. 1

CONSISTENCY INDEX
KEUPER MARL

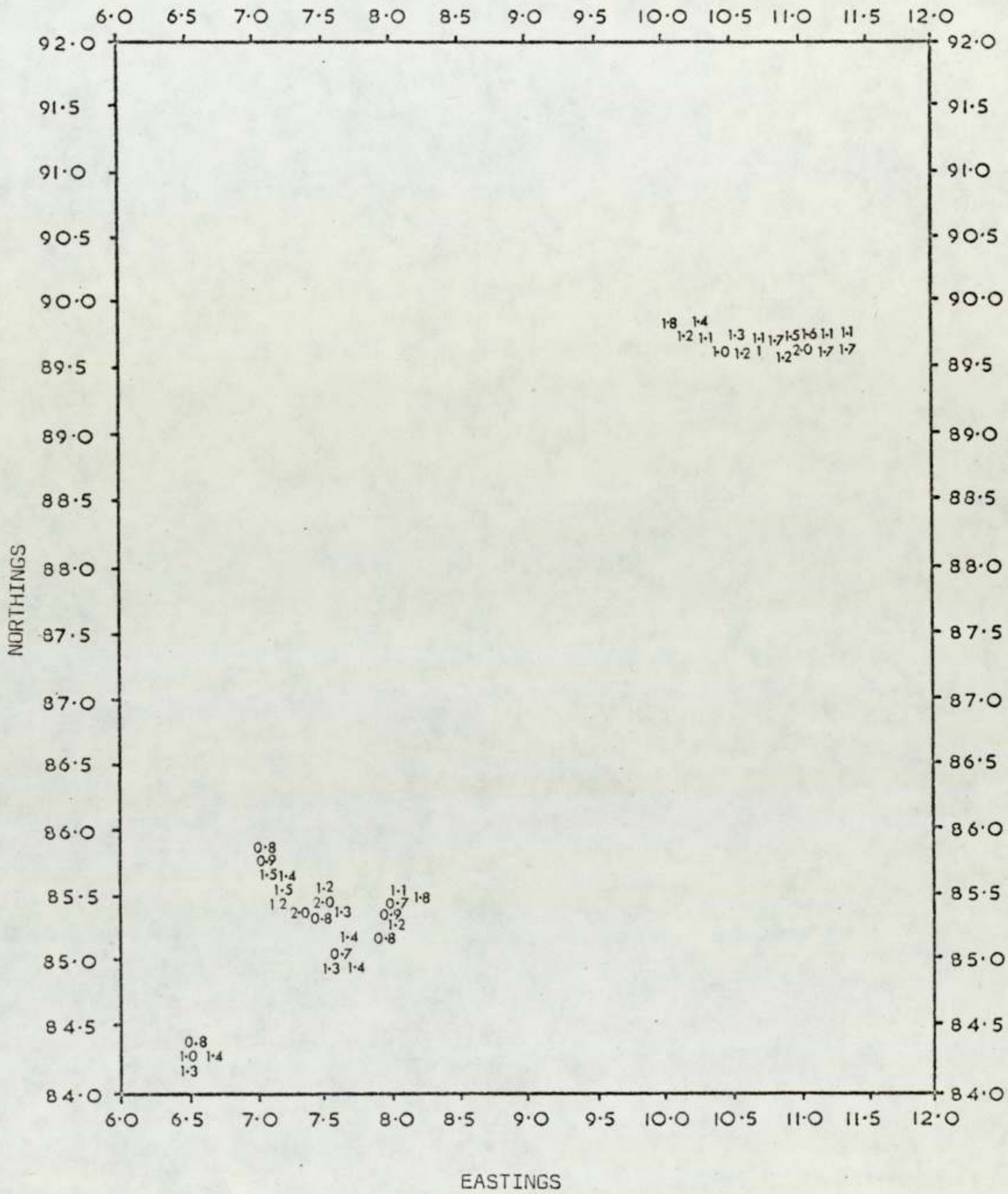


FIG. 7.6.2

to some extent on the user's reasons for requiring the information and hence a variety of computer outputs could be designed to illustrate worst values, near bedrock surface values, etc. for Keuper Marl deposits. Plans showing average or maximum and minimum values for Undifferentiated Drift deposits or where thicknesses of drift are great, showing variation with depth could also be of value.

7.4.3 pH.

The nature and concentration of deleterious chemicals that may be present within the strata or groundwater must be taken into account when considering constructions involving buried concrete. Where concentrations of chemicals are suspected, for instance in dark grey clay dominated soils, pH determinations are essential. The extreme values indicating acidity or alkalinity may be critical in foundation design, especially the former.

Unfortunately most boreholes only produced a single pH value, recorded from either a soil or groundwater sample (see Table 6.1). In the example fig 7.7, the sample type is not differentiated.

There is a need to show both high and low pH values to illustrate extreme conditions, and also the ranges of the values recorded where more than one analysis is present per borehole. Fig 7.7 illustrates the highest pH values recorded for each borehole, located at the position of the borehole, as

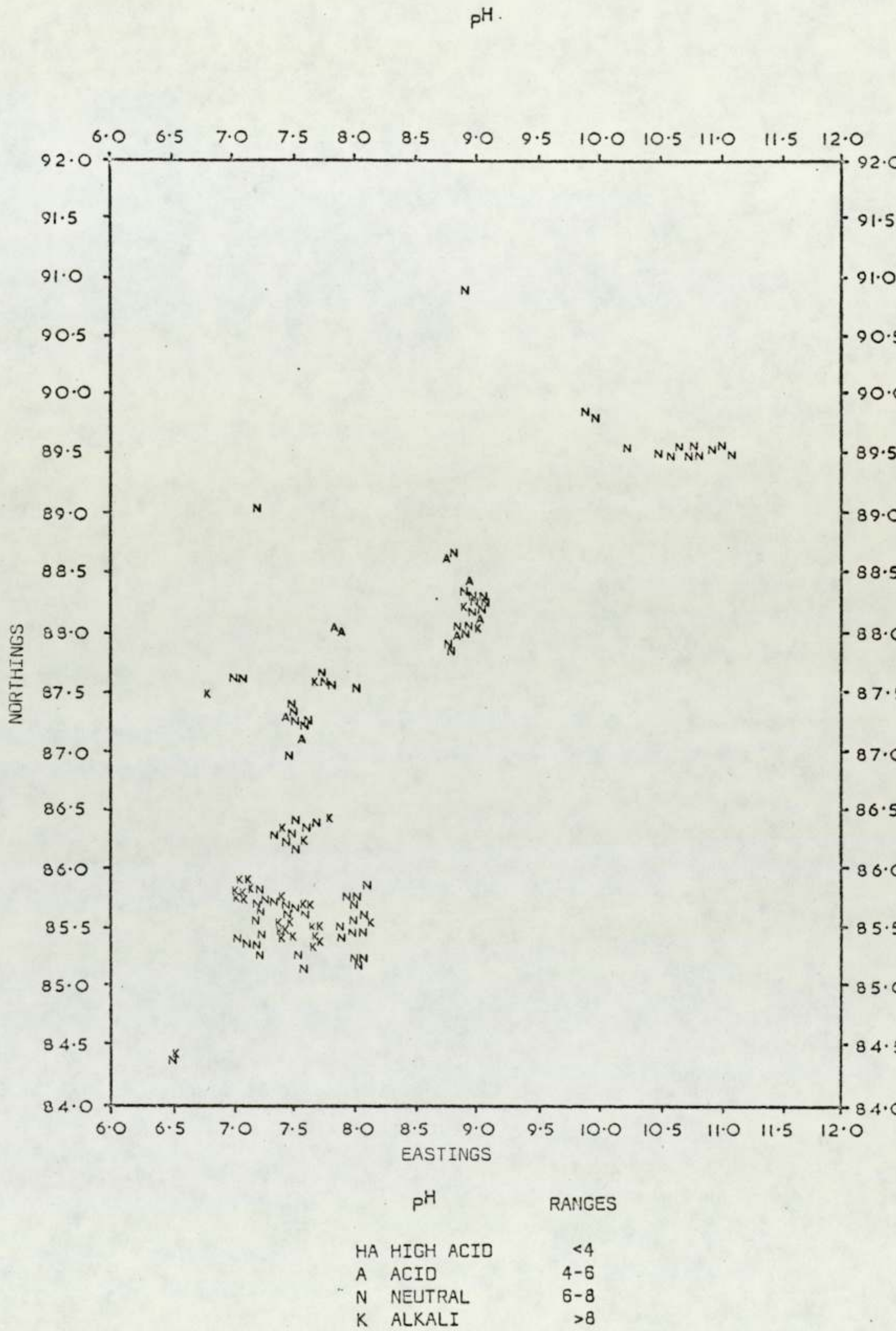

pH
NORTHINGS
EASTINGS
pH RANGES
HA HIGH ACID <4
A ACID 4-6
N NEUTRAL 6-8
K ALKALI >8

FIG. 7. 7

discussed previously, highlighting areas of alkalinity.

The values are denoted by an alphacode which represents an arbitarily chosen range as shown on fig 7.7. A similar plot for the minimum values is also available.

Ranges of values can be illustrated by increasing the number of codes and assigning a single code to, not only a single value, but also to large ranges of values e.g. B = pH range 4 to 8, the maximum difference between pH value and 7 (neutral), at each location.

7.4.4. Soil Sulphate.

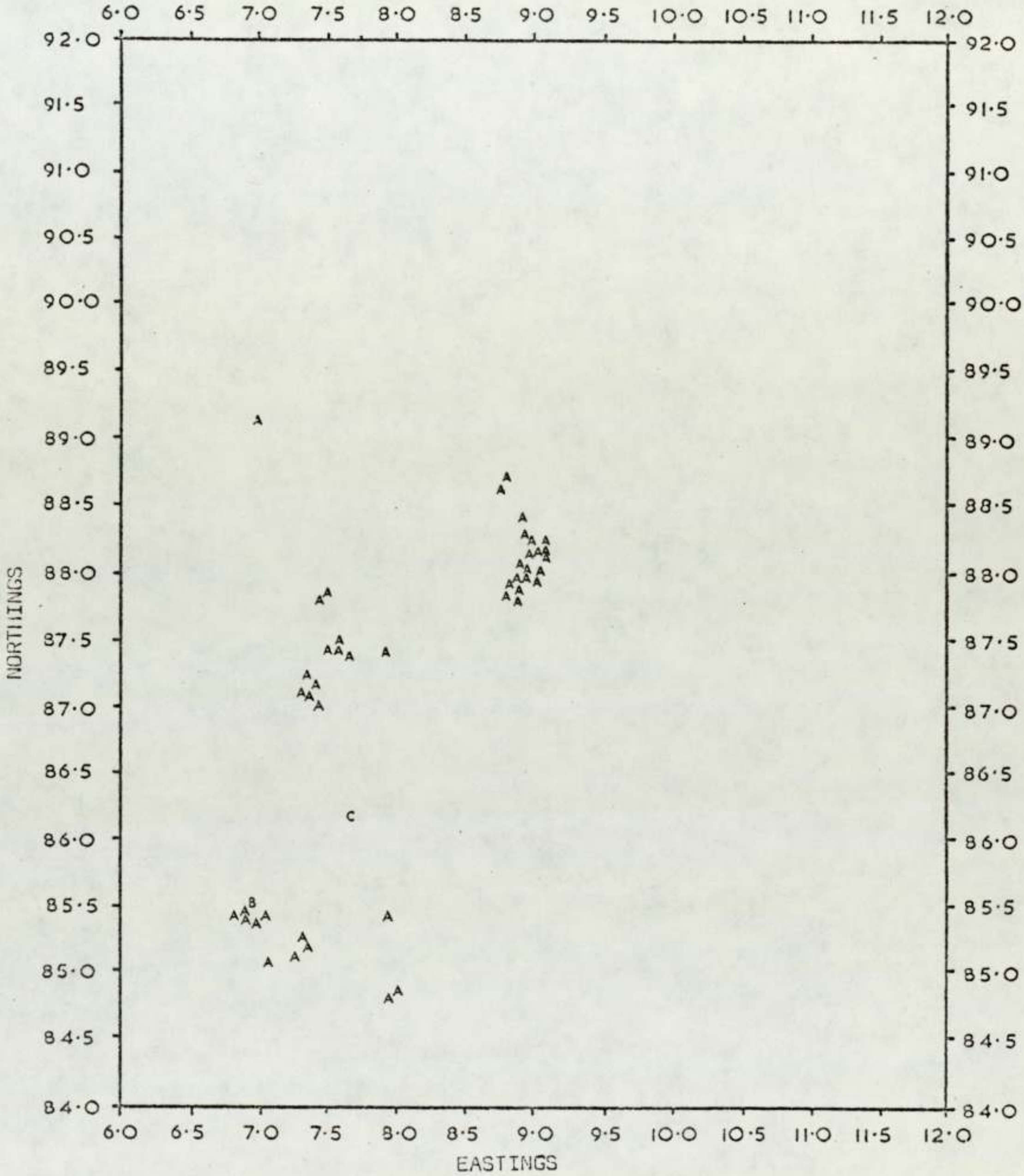
The greatest soil sulphate values encountered are illustrated for the whole study area to identify potential problem areas. Soil sulphate values are presented for the Undifferentiated Drift, fig 7.8.1, and Keuper Marl, fig 7.8.2, deposits, and are seen to have reasonably uniform values. Values recorded for fill materials, however, exhibit a wide range of concentrations and the value of a similar output for fill material is dubious.

The sulphate ranges used in this example are those currently employed by cement manufacturers when recommending cements for use in special soil conditions (Appendix III).

The plots indicate a reasonable distribution of data collated for the Undifferentiated Drift deposits, where sulphate concentrations are generally less than 0.2%. Information for the Keuper Marl deposits is unfortunately limited to the new

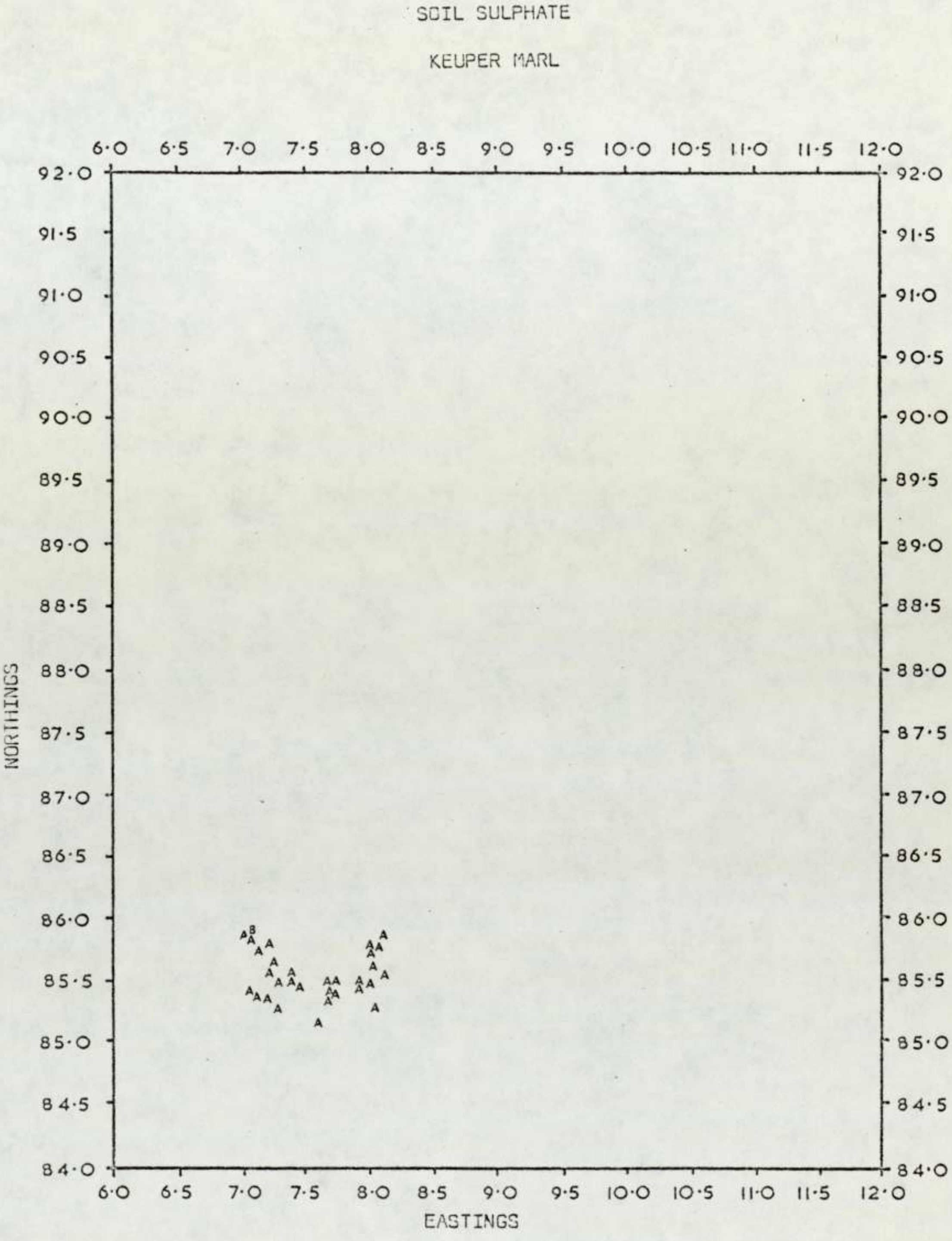
SOIL SULPHATE

UNDIFFERENTIATED DRIFT



SULPHATE	RANGES
A	0.2%
B	0.2-0.5%
C	0.5-1.0%
D	1.0-2.0%
E	2.0%

FIG. 7.8.1



SULPHATE RANGES

A	0.2%
B	0.2-0.5%
C	0.5-1.0%
D	1.0-2.0%
E	2.0%

FIG. 7.8.2

market development area, mentioned above. It is noticeable that whilst the Keuper Marl mudstones in this area have known inclusions of gypsum, only one sulphate concentration in excess of 0.2% has been recorded.

7.4.5. Water Sulphate.

As it is normal practice to take water samples at the end of a drilling period, or commonly the end of drilling, and hence usually from the bottom of the borehole, it is not possible to assign any results obtained from water samples to any specific horizon.

The highest values for the water sulphate content were taken for each borehole and presented for the total study area, fig 7.9, although more than one analysis per borehole was rarely recorded. These values were allocated to ranges of values designated in a similar manner to the soil sulphate values, and denoted by a single alphacode. In general these sulphate concentrations were found to be generally less than 1.2 g/l.

7.4.6. Dry Density.

The number of dry density determinations collated on file considerably exceeds that of the other parameters discussed above and accordingly,smaller areas were chosen to demonstrate the variations present within both the Undifferentiated Drift, fig 7.10.1 and the Keuper Marl, fig 7.10.2, deposits.

The search routine selects the lowest values from each

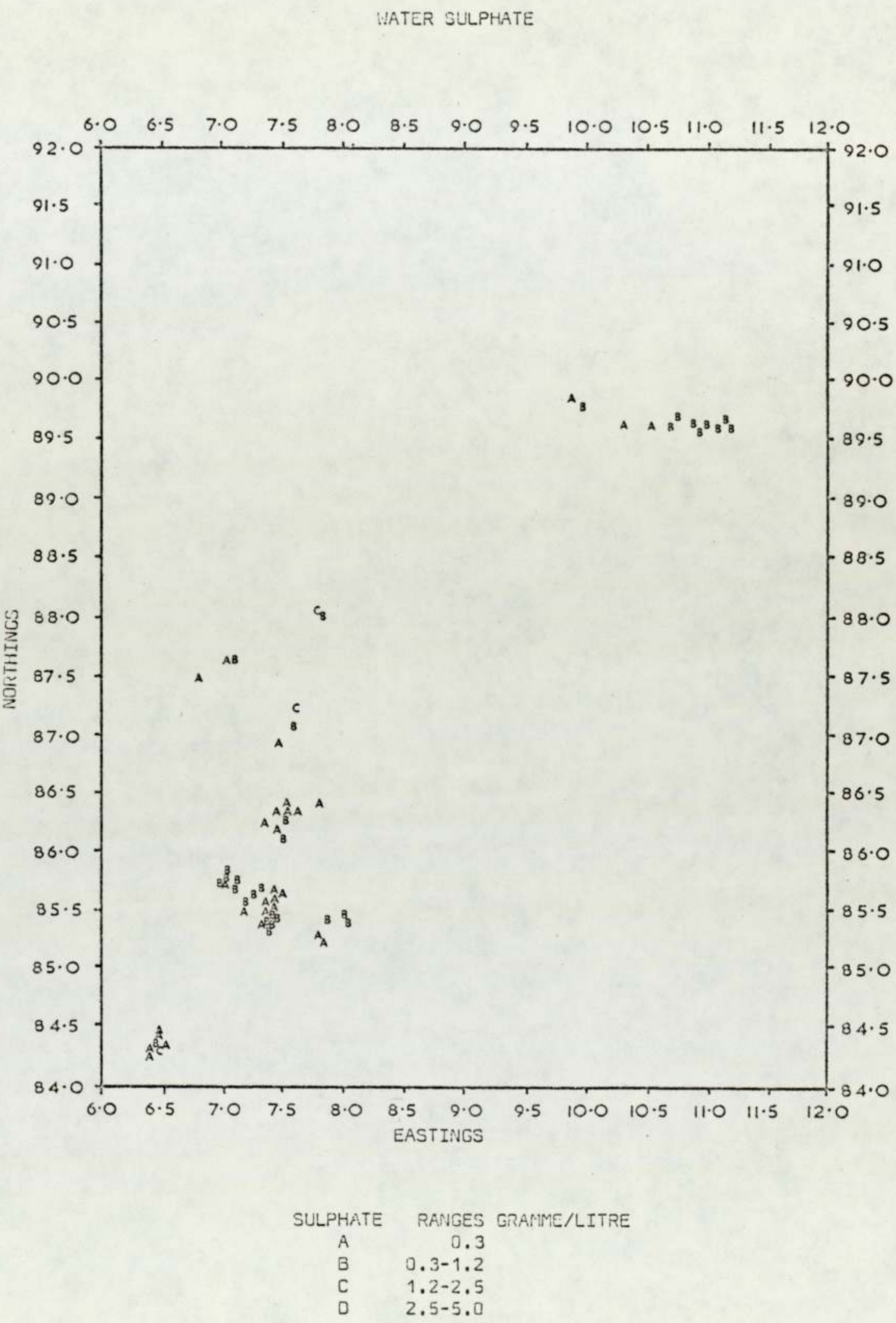
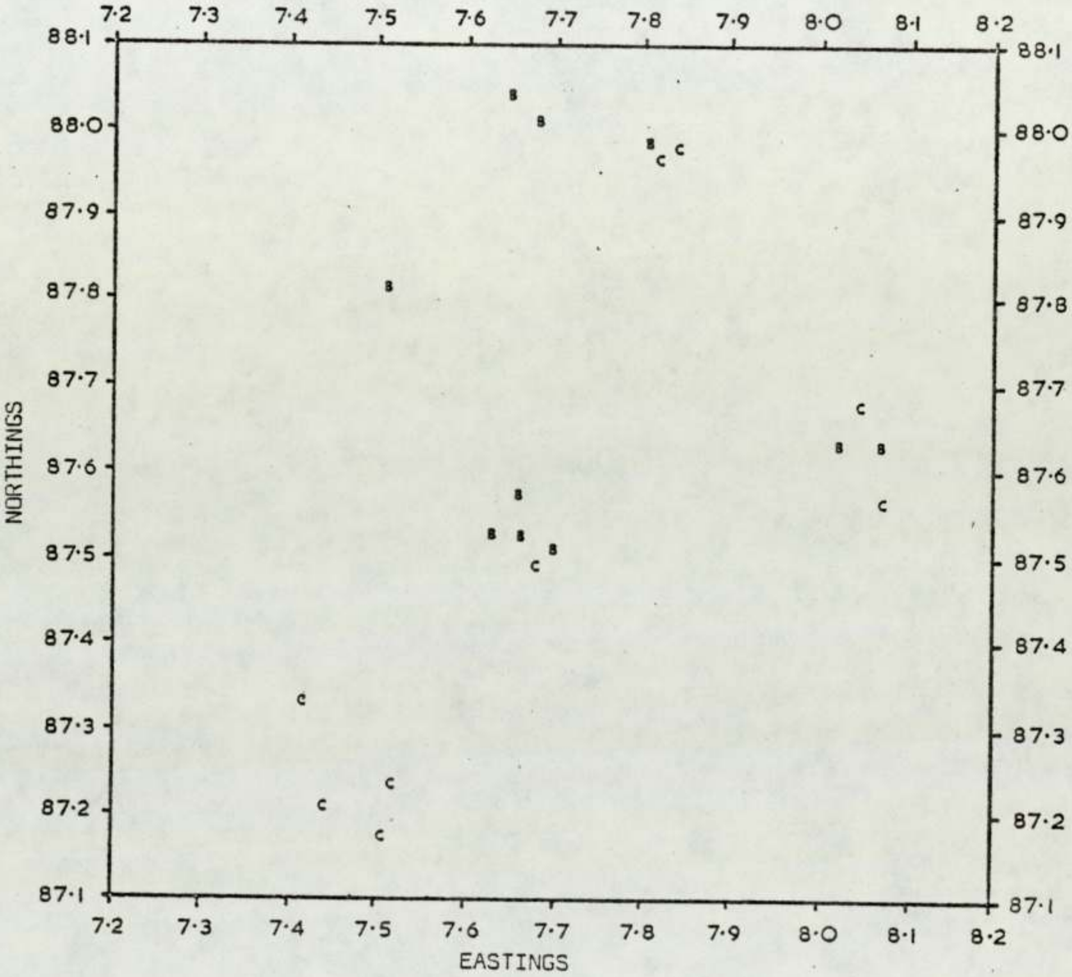

WATER SULPHATE
NORTHINGS
EASTINGS
6·0 6·5 7·0 7·5 8·0 8·5 9·0 9·5 10·0 10·5 11·0 11·5 12·0
84·0 84·5 85·0 85·5 86·0 86·5 87·0 87·5 88·0 88·5 89·0 89·5 90·0 90·5 91·0 91·5 92·0
SULPHATE RANGES GRAMME/LITRE
A 0.3
B 0.3-1.2
C 1.2-2.5
D 2.5-5.0

FIG. 7.9

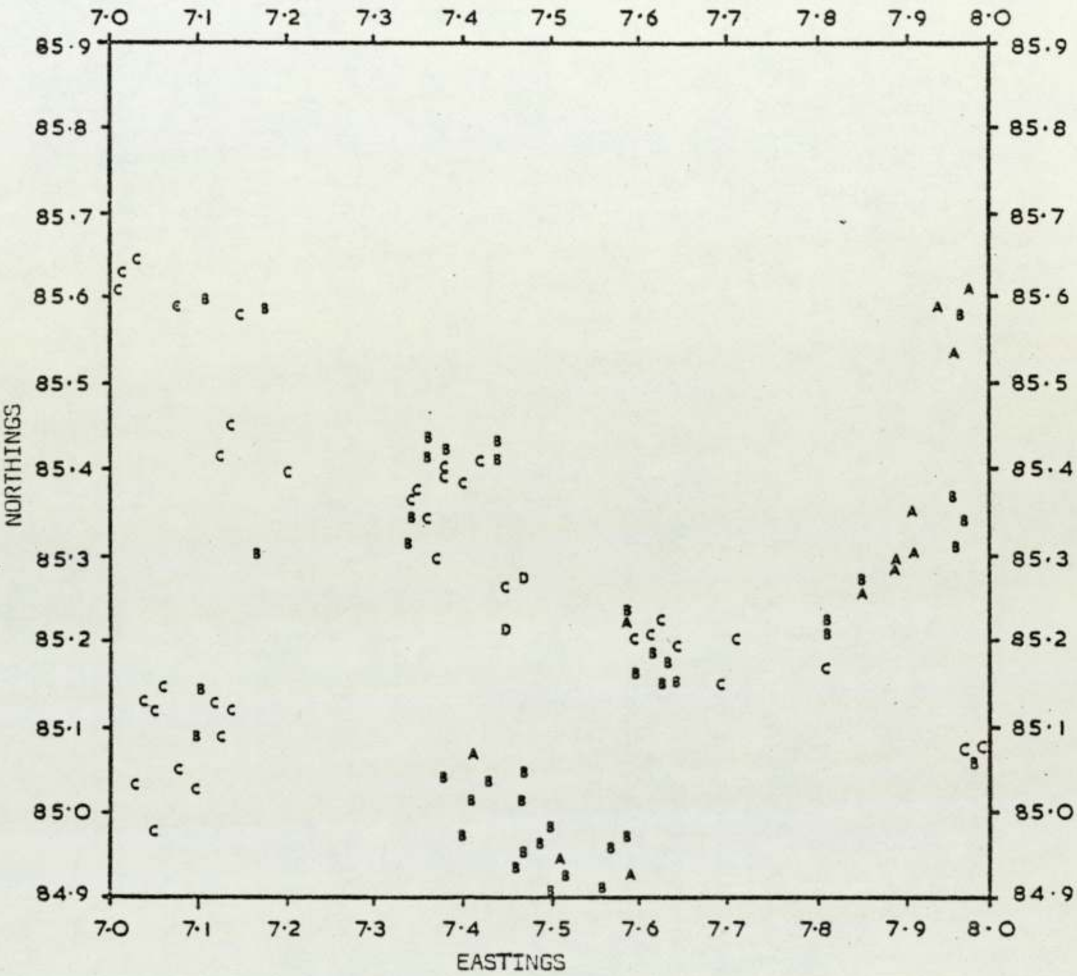
DRY DENSITY
UNDIFFERENTIATED DRIFT



DENSITY	RANGES MG/CU M.
A	<1.50
B	1.50-1.75
C	1.75-2.00
D	2.00-2.25
E	2.25-2.50
F	>2.50

FIG. 7. 10. 1

DRY DENSITY
KEUPER MARL



DENSITY	RANGES	MG/CU M.
A	<1.50	
B	1.50-1.75	
C	1.75-2.00	
D	2.00-2.25	
E	2.25-2.50	
F	>2.50	

FIG. 7. 10. 2

unit either directly from the borehole data recorded or by calculation using the bulk density and moisture content. These values are then given a single alphacode denoting one of an arbitary range of values. In the examples the lowest density values are illustrated, indicating the poorest material i.e. the less consolidated material with higher void ratios.

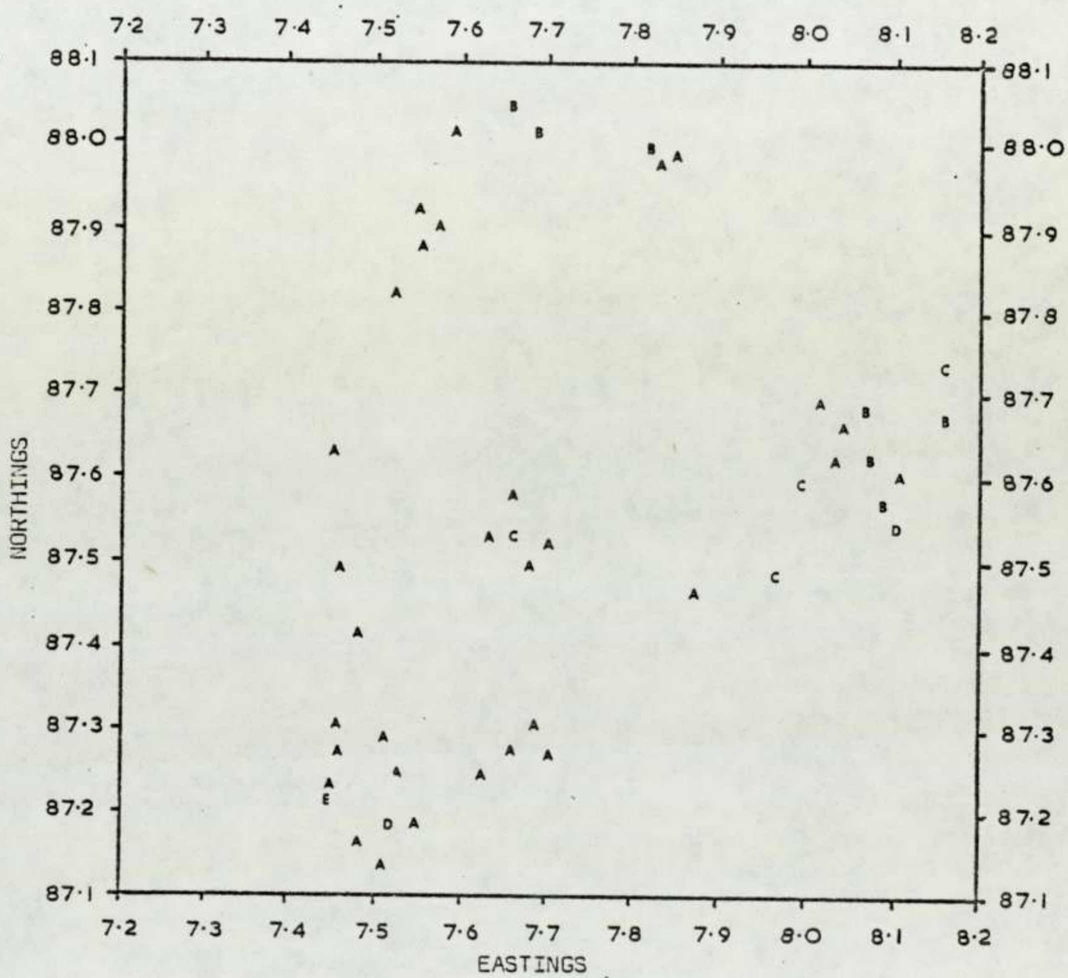
7.4.7. Shear Strength.

The cohesion values, c_u, have been extracted from undrained triaxial test results where the value of ϕ_u, the angle of internal shearing resistance is less than 5^o. Where ϕ_u exceeds 5^o the c_u value is less meaningful and values of ϕ_u greater than 5^o may well indicate unsaturated samples where the strength criteria must be more carefully considered.

The geographical areas chosen are those used for the dry density for the same reasons. The lowest values were again selected for both Undifferentiated Drift, fig 7.11.1 and Keuper Marl, fig 7.11.2, deposits for these areas to show the poorest material. These values were allocated to a range of values, after Anon.(1972), each range denoted by a single alphacode. Although fewer values were obtained for the Undifferentiated Drift deposits than for the Keuper Marl deposits both illustrate wide ranges of values, ($c_u < 36kN/m^2$ to $> 288kN/m^2$). The Undifferentiated Drift deposits however, are commonly soft to firm whereas the Keuper Marl deposits are predominantly stiff to hard. Several samples illustrate values of less than $36kN/m^2$; these could indicate samples of severely weathered Keuper Marl mudstones or fissured material

COHESION CU

ØU <5 DEGREES
UNDIFFERENTIATED DRIFT

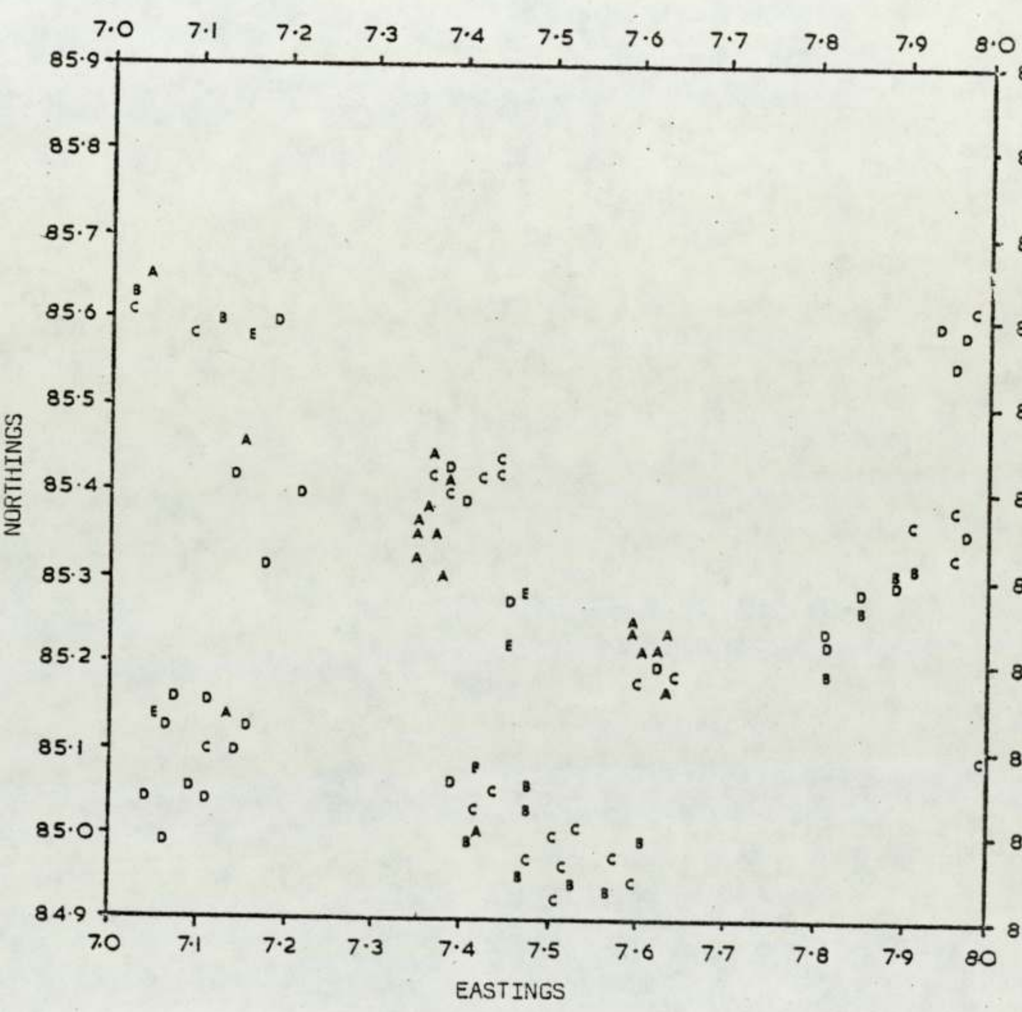


COHESION RANGES KN/SQ M

A SOFT	<36
B FIRM	36-72
C STIFF	72-144
D HARD	144-288
E VERY HARD	>288

FIG. 7. 11 . 1

COHESION CU
ØU <5 DEGREES
KEUPER MARL



COHESION RANGES KN/SQ M

A	SOFT	<36
B	FIRM	36-72
C	STIFF	72-144
D	HARD	144-288
E	VERY HARD	>288

FIG. 7. 11. 2

which often give spuriously low results.

It is pointed out that in the titles of these plots no lower case or subscripts have been used because this facility does not exist with the type of computer routines employed.

7.4.8. Compressibility.

Because of the relatively few consolidation test results collated, data are presented for the total study area for both Undifferentiated Drift, fig 7.12.1 and Keuper Marl, fig 7.12.2, deposits.

Compressibility moduli (m_v^{-1}) values are calculated from oedometer consolidation test results plotted as a graph in terms of voids ratio and vertical stress using the following relationship:

$$m_v^{-1} = \frac{(P_1 - P_o)(1 + e_o)}{(e_o - e_1)}$$

where:-

P_o = the overburden pressure

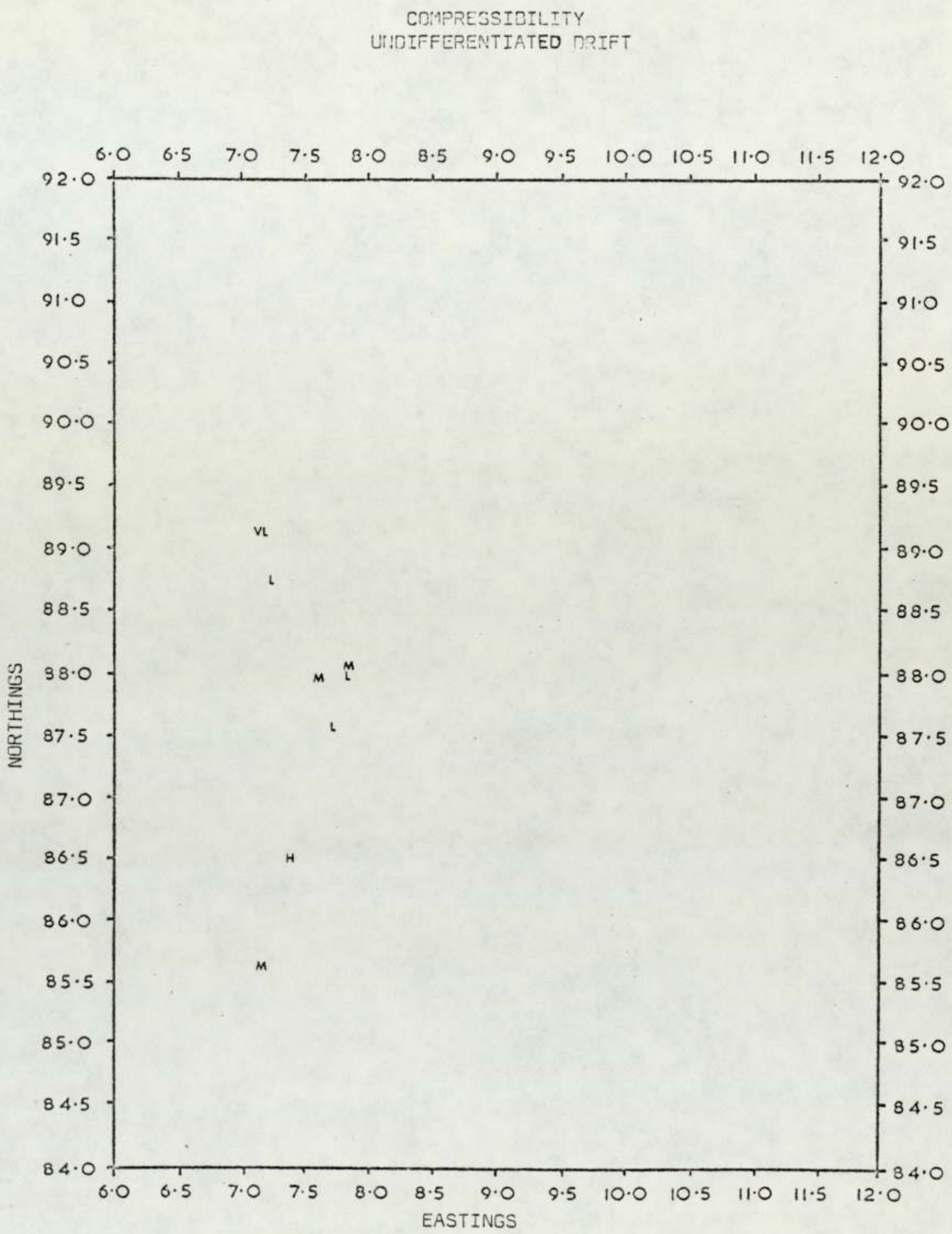
P_1 = the overburden pressure + 107 kN/m^2 (1 ton/sq ft)

e_o = the voids ratio at the overburden pressure P_o

e_1 = the voids ratio at pressure P_1

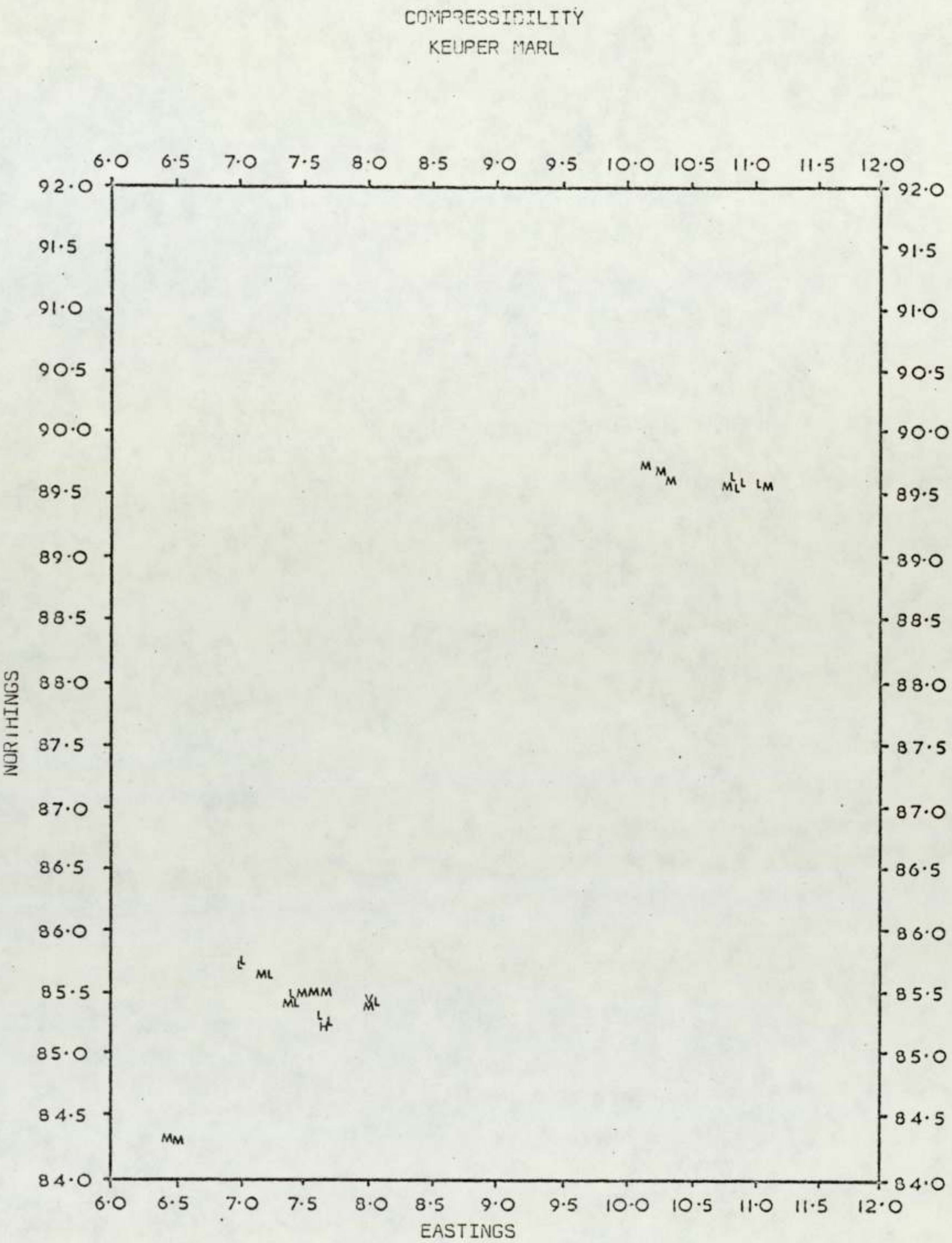
For simplicity the above relationship has been used to calculate the moduli plotted on the examples shown. As the lower the value obtained for the moduli reflects the higher the compressibility, this reflects the poorer material in terms of load carrying performance and where more than one value is recorded the lower value is taken.

The values representing the Undifferentiated Drift deposits



COMPRESSIBILITY	MODULI MN/SQ M.
VH VERY HIGH	<1
H HIGH	1-4
M MEDIUM	4-11
L LOW	11-22
VL VERY LOW	>22

FIG. 7.12.1



COMPRESSIBILITY	MODULI MN/SQ M.
VH VERY HIGH	<1
H HIGH	1-4
M MEDIUM	4-11
L LOW	11-22
VL VERY LOW	>22

FIG. 7. 12. 2

show a wide range from high to very low compressibility. Those expressed for the Keuper Marl deposits are predominantly medium to low compressibility.

The Keuper Marl data again reflects the two clusters of information as described previously.

7.4.9. Particle Size Analysis.

The data, initially recorded as percentages of the sample finer than sizes of 0.002, 0.006, 0.02, 0.06, 0.2, 0.6, 2, 6, 20, 60 mm are retrieved purely on geographical location to produce particle size distribution curves for each set of data for complete boreholes, fig 7.13.

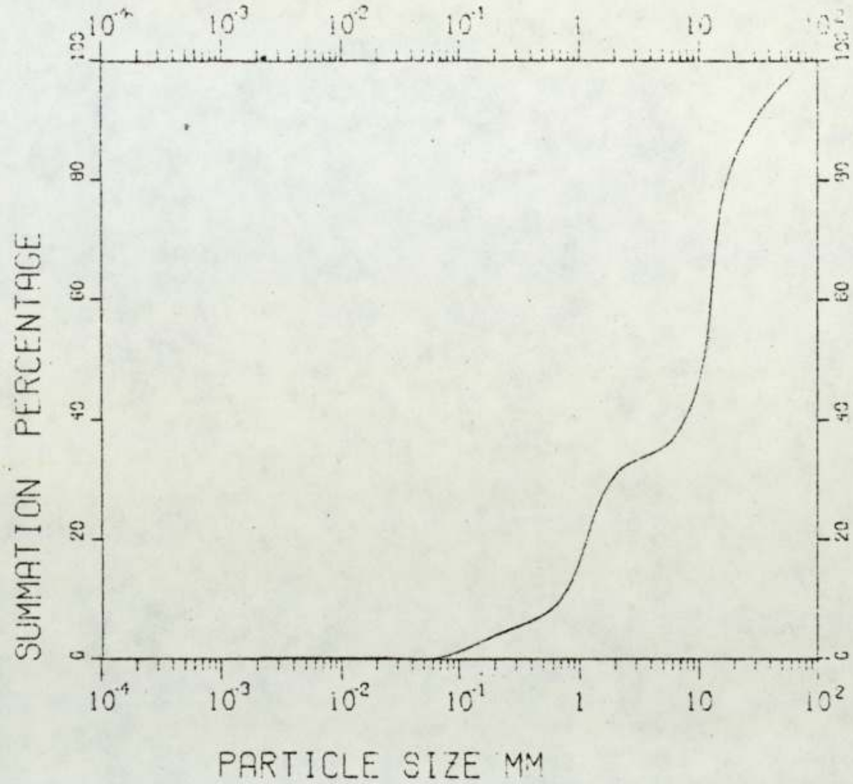
The data are plotted in the standard semi logarithmic format of a particle size distribution curve, with the particle diameter size (mm) plotted along the abscissae (the log scale) and the percentages along the ordinate (a linear scale). Standard I.C.L. graph plotter routines are used to plot these axes, titles and also the smooth curve passing through each set of size/percentage data points. The subroutine which draws this smooth curve, determines the curve as a cubic polynomial between two points (X_i, Y_i) and (X_{i+1}, Y_{i+1}) by employing the data points (X_{i-1}, Y_{i-1}), (X_i, Y_i), (X_{i+1}, Y_{i+1}) and (X_{i+2}, Y_{i+2}). The resulting smooth curve passes through each point in turn. However, to complete the curve the desired initial and/or final slope of the curve has to be specified; for the examples illustrated this has been assumed to be always zero.

The series of particle size distribution curves shown,

FIG. 7. 13 TYPICAL PARTICLE SIZE DISTRIBUTION CURVES

PARTICLE SIZE DISTRIBUTION

BOREHOLE NO 1 GRID REF SP720 8900
SAMPLE NO 5 DEPTH OF SAMPLE 4.5 5.1



PARTICLE SIZE DISTRIBUTION

BOREHOLE NO 2 GRID REF SP721 8750
SAMPLE NO 6 DEPTH OF SAMPLE 10.2 10.5

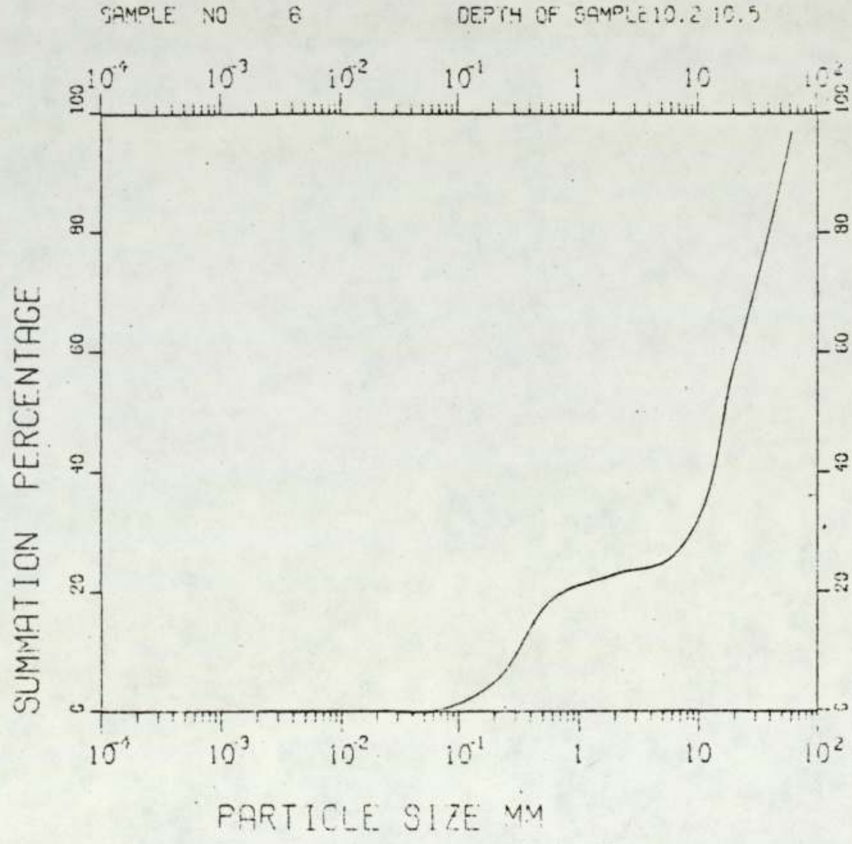
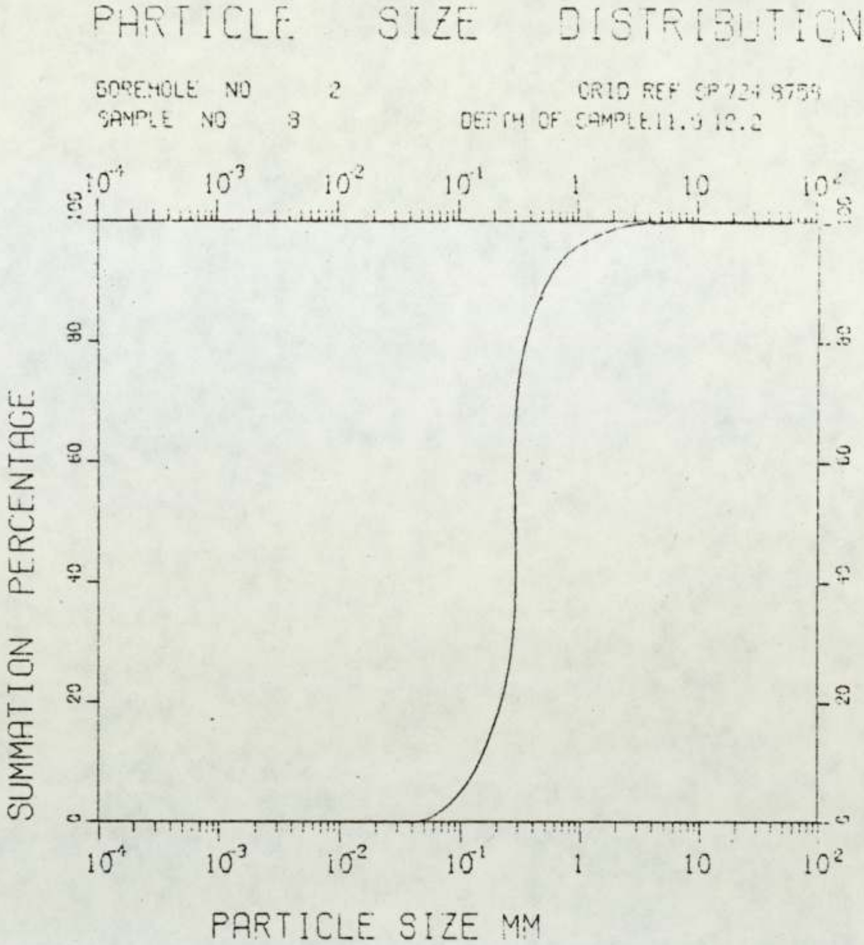


FIG. 7.13.1


PARTICLE SIZE DISTRIBUTION
BOREHOLE NO 2
GRID REF SP724 8758
SAMPLE NO 8
DEPTH OF SAMPLE11.9 12.2
SUMMATION PERCENTAGE
PARTICLE SIZE MM

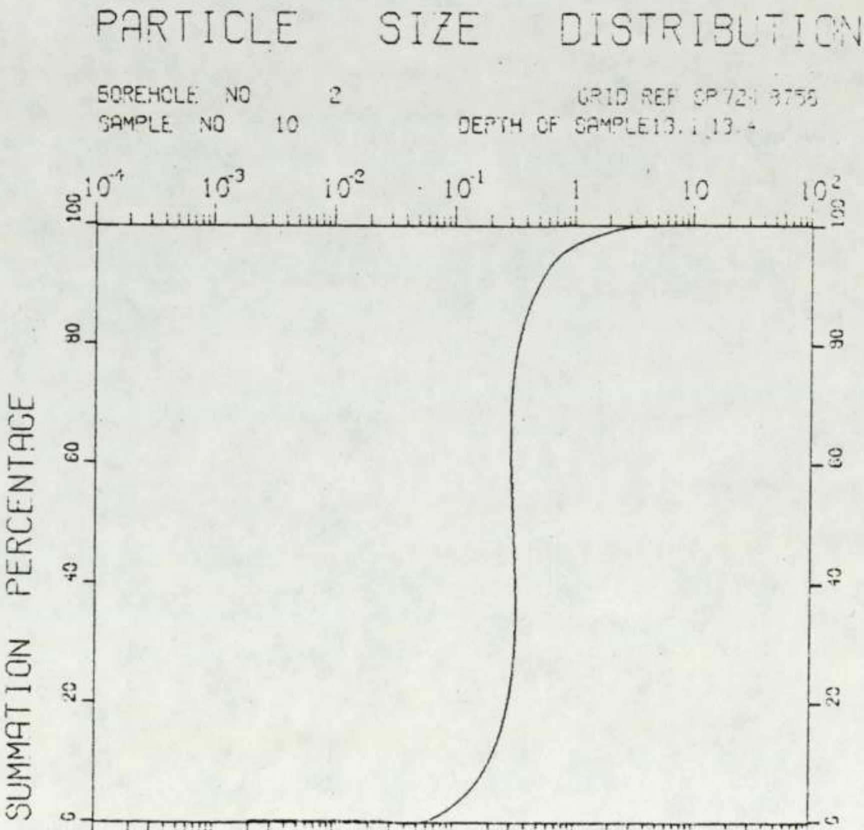
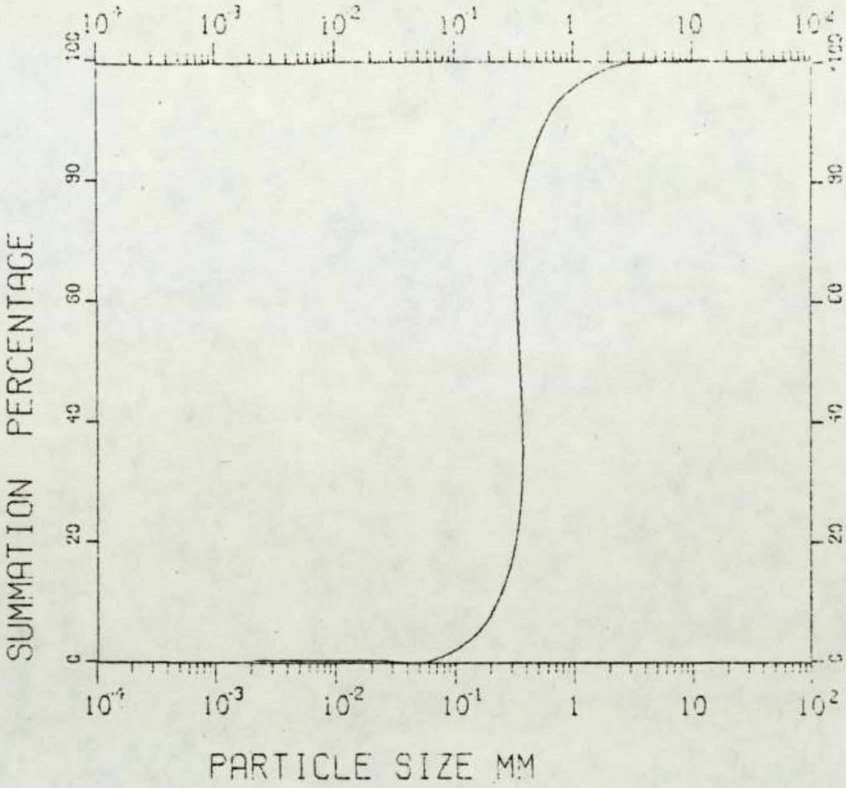

PARTICLE SIZE DISTRIBUTION
BOREHOLE NO 2
GRID REF SP724 8758
SAMPLE NO 10
DEPTH OF SAMPLE13.1 13.4
SUMMATION PERCENTAGE
PARTICLE SIZE MM

FIG. 7.13.2

PARTICLE SIZE DISTRIBUTION

BOREHOLE NO 2 GRID REF SP 724 8756
SAMPLE NO 12 DEPTH OF SAMPLE 14.8 15.1



PARTICLE SIZE DISTRIBUTION

BOREHOLE NO 2 GRID REF SP 724 8756
SAMPLE NO 14 DEPTH OF SAMPLE 16.6 16.9

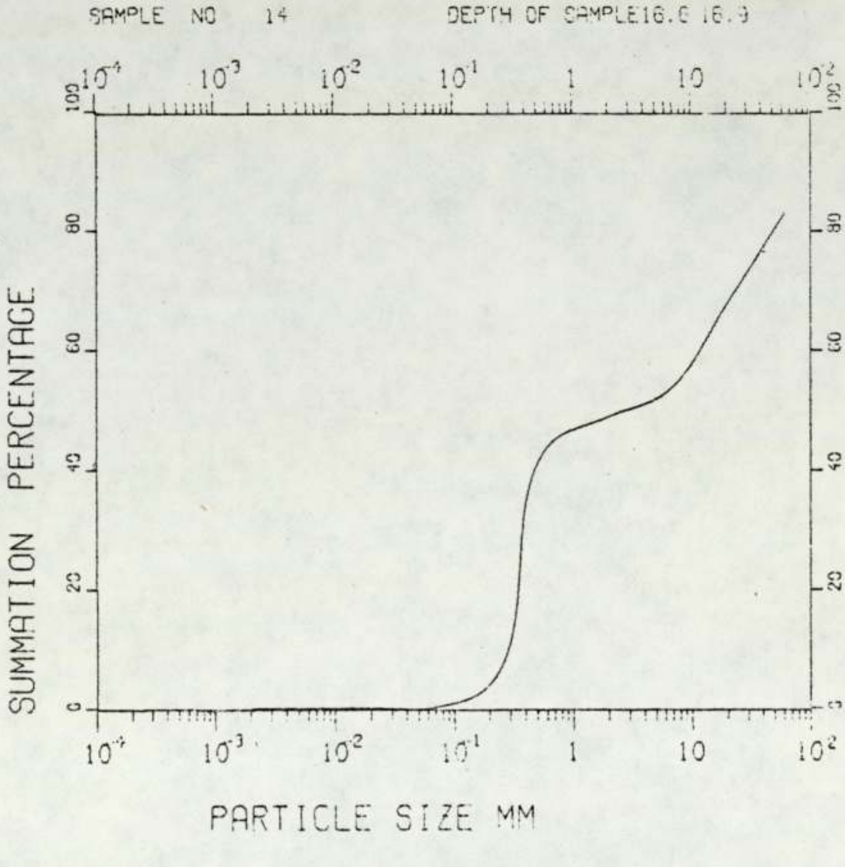
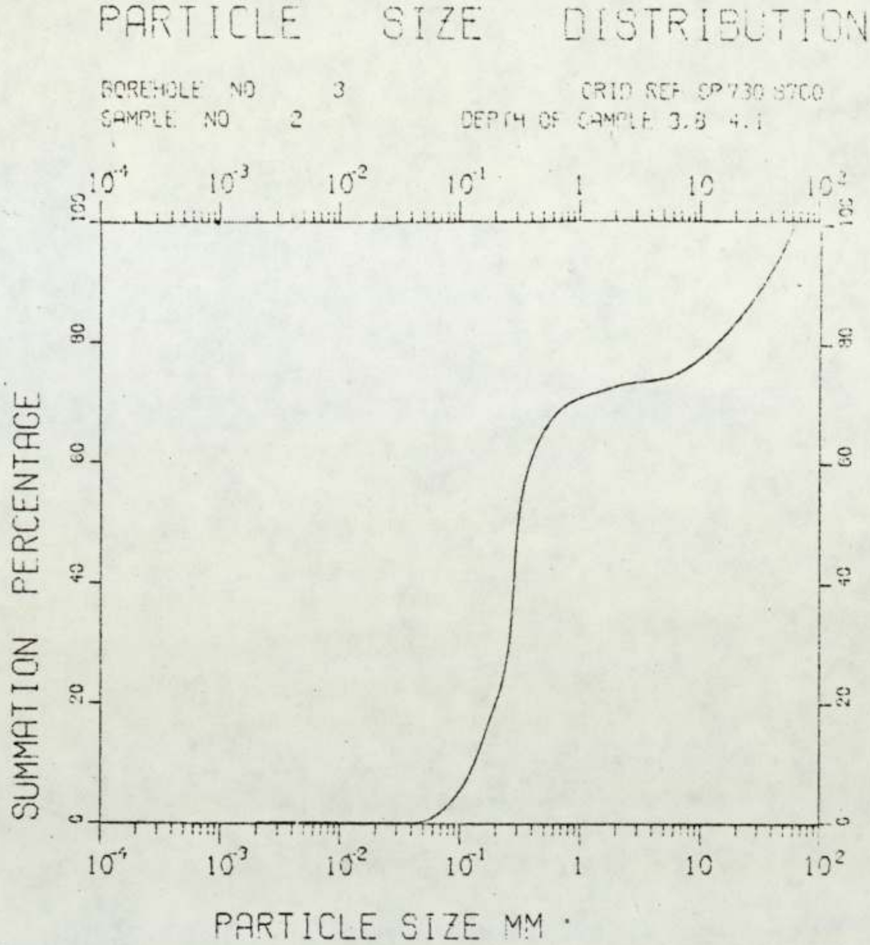


FIG. 7. 13. 3


PARTICLE SIZE DISTRIBUTION
BOREHOLE NO 3
GRID REF SP730 8700
SAMPLE NO 2
DEPTH OF SAMPLE 3.8 4.1
SUMMATION PERCENTAGE
PARTICLE SIZE MM

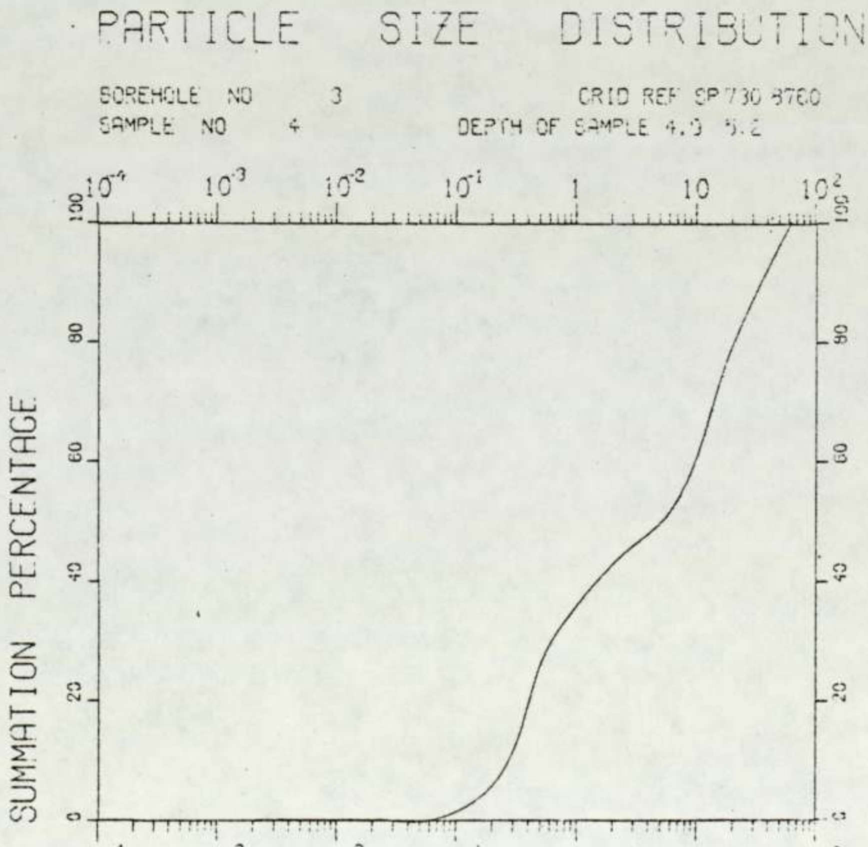

PARTICLE SIZE DISTRIBUTION
BOREHOLE NO 3
GRID REF SP730 8700
SAMPLE NO 4
DEPTH OF SAMPLE 4.9 5.2
SUMMATION PERCENTAGE
PARTICLE SIZE MM

FIG. 7. 13. 4

fig 7.13.1 to fig 7.13.4, can be correlated to previously illustrated data presentations. For example fig 7.13.1 is for a sample obtained from borehole, reference number '1', grid reference SP07208800, from a depth of 4.5 to 5.1m below surface level and the curve for this sample represents a coarse gravel. This can be compared with the borehole lithology, fig 7.3.5, where the lithology is illustrated for a depth of 5m below surface level. The lithology for the borehole, reference number '1', grid reference SP07208800, is represented by the alphacode 'N', a concrete gravel (or coarse gravel).

In view of the common occurrence of bimodal distributions in sand and gravel drift deposits, mean size and uniformity coefficients were not added to these plots as they have limited relevance in describing anything other than near normal distributions.

7.5. Collated Information.

The data discussed above are basically and simply presented to provide the user with as much information as is available; to form a sufficiently detailed background upon which to base further investigations. As the intention of this study was to facilitate proposed site investigations, it was thought necessary to be able to present data to the user in a format similar to that of a site investigation report. The findings from a given area, such as the geology, results of boreholes, in situ and laboratory tests,etc. should be combined into typical geotechnical logs.

The geological log, fig 7.14.1, presents the logs of several boreholes, referenced as discussed previously, and produced direct from a line printer computer terminal. The section includes the lithology description, stratigraphy, colour (see 3.2.3.), the depth below surface level of each lithological unit, and the number of samples present in each lithological unit. An extension of this type of format presents information obtained from in situ and laboratory tests for the same boreholes, fig 7.14.2. Both of these computer line printouts are easily and simply produced and serve only as examples of the straightforward printouts, of the data collated, which can be provided.

The logical development from this is the production of a geotechnical section. To facilitate such a construction, the format in fig 7.15 has been produced. Three boreholes, each illustrating lithology, stratigraphy, groundwater levels and consistency index are all adjusted to Ordnance Datum level

BOREHOLE 53 GRID REFERENCE SP7818799

LUN	DEPTH	LITHOLOGY	STRAT	COLOR1	Q	COLOR2	SAMPLES
1	0.0	MADE	MADE				0
2	1.7	CLAY	HOX	5 Y76	1	5YR41	0
3	2.4	SILT	U DRIFT	5YR34	1	10 Y52	1
4	3.8	CONC GRAVEL	U DRIFT				3
5	5.4	PEBBLY SAND	U DRIFT				1
6	7.9	CONC GRAVEL	U DRIFT				0
7	10.5	SAND	L K S	10 R46			2
8	11.9	CLAY	L K S	10 R46			1
9	12.5	SAND	L K S	5YR34			1
10	13.3	SILTY SAND	L K S	5YR22			0
11	14.5	SAND	L K S	5YR34			0

BOREHOLE 54 GRID REFERENCE SP7828797

LUN	DEPTH	LITHOLOGY	STRAT	COLOR1	Q	COLOR2	SAMPLES
1	0.0	MADE	MADE				0
2	2.4	CLAYEY SILT	U DRIFT	5YR34	1	5YR22	1
3	3.5	GRAVELY CLAY	U DRIFT	5YR34	1	5YR22	2
4	4.8	CONC GRAVEL	U DRIFT				0
5	5.0	SILTY SAND	U DRIFT	5YR56			0
6	5.3	CONC GRAVEL	U DRIFT	10YR54			1
7	7.3	SILTY CLAY	U DRIFT	5YR34			1
8	7.5	CONC GRAVEL	U DRIFT	5YR34			0

BOREHOLE 55 GRID REFERENCE SP7848798

LUN	DEPTH	LITHOLOGY	STRAT	COLOR1	Q	COLOR2	SAMPLES
1	0.0	MADE	MADE				0
2	2.2	GRAVELY CLAY	U DRIFT	5YR34			4
3	4.0	CONC GRAVEL	U DRIFT				1
4	10.4	SAND	U DRIFT	5YR56			0

BOREHOLE 56 GRID REFERENCE SP7878746

LUN	DEPTH	LITHOLOGY	STRAT	COLOR1	Q	COLOR2	SAMPLES
1	0.0	MADE	MADE				1
2	2.1	SAND-SILT CLAY	U DRIFT	5YR46			2
3	5.2	SAND	U DRIFT	5YR46			2
4	7.3	SANDY CLAY	U DRIFT	5YR46			3
5	11.9	SAND	U DRIFT	5YR46			2
6	14.0	CONC GRAVEL	U DRIFT				3
7	18.6	SAND	L K S	5 R46			2

BOREHOLE 57 GRID REFERENCE SP7978748

LUN	DEPTH	LITHOLOGY	STRAT	COLOR1	Q	COLOR2	SAMPLES
1	0.0	MADE	MADE				0
2	1.8	SAND	U DRIFT	N 5			2
3	2.4	CONC GRAVEL	U DRIFT				1
4	3.2	SANDY CLAY	U DRIFT				6
5	11.3	SAND	U DRIFT	5 R46			1
6	12.5	CONC GRAVEL	U DRIFT	5 R46			3
7	17.1	SAND	L K S	5 R46			2

FIG.7.14.1 LINE PRINTER LISTING LITHOLOGIC LOG

BOREHOLE 53 GRID REFERENCE SP7818799

SAMPLE NO	SAMPLE DEPTH		MC	LL	PL	BUD	SG	SPT/CM	CU	Ø	EC
1	2.3	2.7	22.0	36	20	2.050			54	0	
2	3.1	3.5	12.0	30	17	2.240			38	0	
3	3.7	3.5	17.0	34	19	2.020			67	20	8.232
4	4.3	4.4									
5	5.0	5.2									
6	6.3	6.7									
7	10.5	10.7						234/15			
8	10.7	10.8		25	27						
9	12.0	12.2	20.0	33	20						
10	12.7	12.9						250/15			

BOREHOLE 54 GRID REFERENCE SP7828797

SAMPLE NO	SAMPLE DEPTH		MC	LL	PL	BUD	SG	SPT/CM	CU	Ø	EC
1	3.1	3.5	15.0	23	15	2.130			47	20	11.295
2	3.7	4.1	16.0	26	17	2.190			53	12	
3	4.3	4.8	18.0	25	17	2.160			35	6	
4	6.4	6.7						99/30			
5	7.3	7.6						278/30			

BOREHOLE 55 GRID REFERENCE SP7848798

SAMPLE NO	SAMPLE DEPTH		MC	LL	PL	BUD	SG	SPT/CM	CU	Ø	EC
1	2.5	3.0	20.0	29	20	2.110			47	10	
2	3.1	3.6	12.0	31	18	2.240			143	21	
3	3.6	3.7	26.0	32	18	2.150			4	0	
4	3.7	4.0	15.0			2.230			21	0	
5	10.1	10.7	18.1			2.370			20	15	

BOREHOLE 56 GRID REFERENCE SP7878746

SAMPLE NO	SAMPLE DEPTH		MC	LL	PL	BUD	SG	SPT/CM	CU	Ø	EC
1	1.8	1.9						80/10			
2	2.1	2.6						40/45			
3	3.5	4.0	22.0					38/45	133	0	
4	5.5	5.9						17/30			
5	6.7	7.2						21/30			
6	7.6	7.9						50/45			
7	9.3	9.6						55/45			
8	11.0	11.4	15.0					66/45	234	0	
9	12.5	13.0						19/30			
10	13.4	14.0						20/30			
11	14.8	15.2						26/30			
12	16.3	16.8						28/30			
13	17.8	18.3						28/30			
14	19.2	19.3						70/10			
15	20.1	20.2						100/12			

(CONT.)

(CONT.)

BOREHOLE 57 GRID REFERENCE SP79787̸48

SAMPLE NO	SAMPLE DEPTH		MC	LL	PL	BUD	SG	SPT/CM	CU	Ø	EC
1	1.8	2.4						16/30			
2	2.4	2.4									
3	3.0	3.1						70/ 5			
4	3.4	3.8	20.0					45/45	97	0	
5	4.9	5.3						57/45			
6	6.6	7.0						48/45	79	0	
7	8.1	8.5	13.0					60/45	193	0	
8	9.3	9.8	12.0					100/45	60	2	
9	10.8	11.3						35/45			
10	11.9	12.3						19/30			
11	13.3	13.7						28/30			
12	14.6	15.2						23/30			
13	16.2	16.6						28/30			
14	17.7	17.8						70/10			
15	18.3	18.4						60/ 9			

FIG. 7.14.2 LINE PRINTER LISTING INSITU AND LABORATORY TEST RESULTS

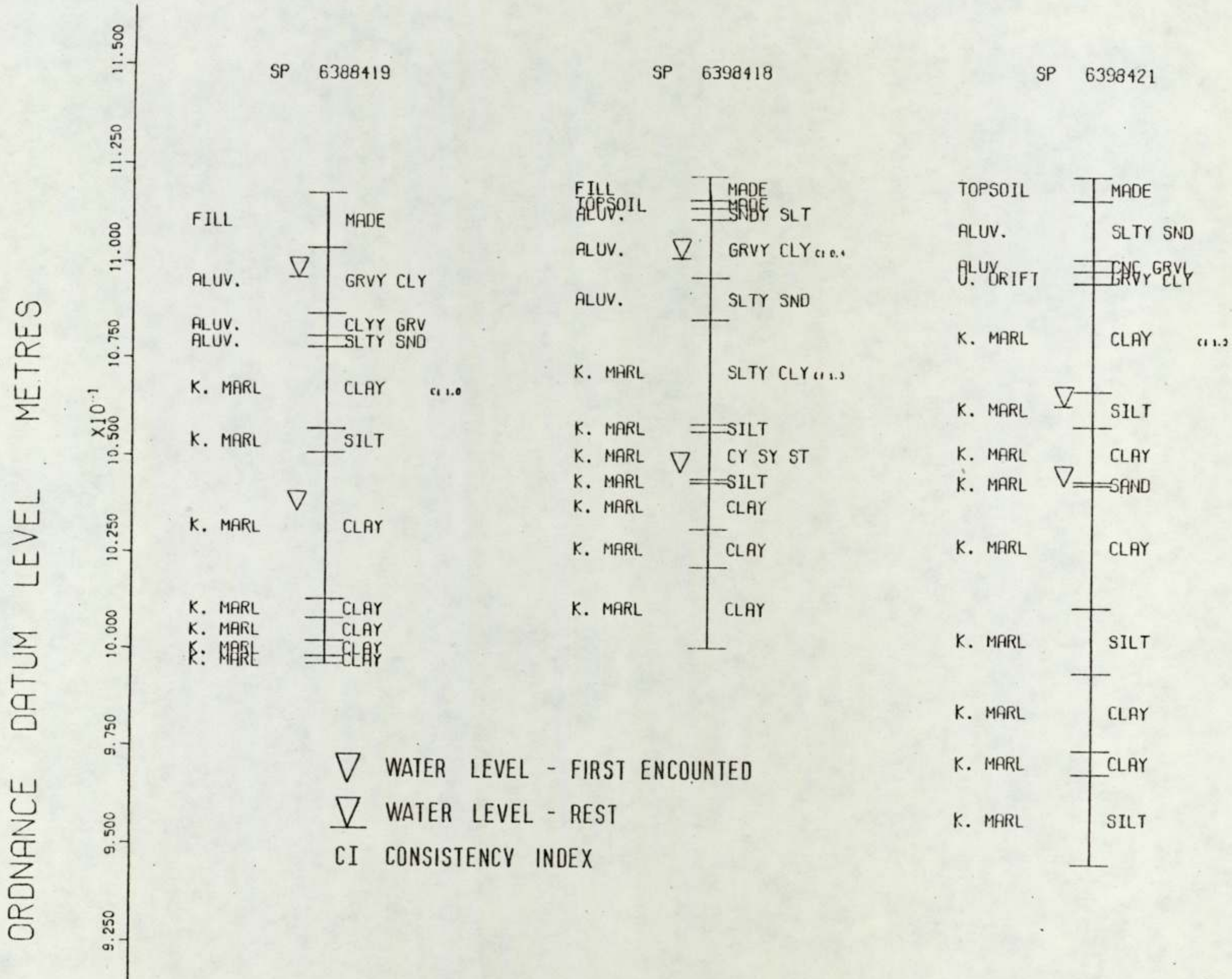


FIG. 7.15. BOREHOLE LOGS ALONG LINE SECTION

with a scale provided on the left. At this stage the boreholes have not been scaled horizontally, but this could be achieved with ease for boreholes along a line section and in close proximity of each other by a simple scaling procedure. The consistency index, Ic, given here is only an example and any test parameter could be presented, and simple manipulations could provide any derived parameter in the relevant position.

For broader evaluation of the properties of any particular unit, further collations can be provided. These may allow generalisations to be made about materials throughout a region rather than at a specific locality.

Histograms provide a means of showing the characteristic properties of a particular stratum. The apparent cohesion values for the Undifferentiated Drift, fig 7.16.1 and for the Keuper Marl, fig 7.16.2, deposits are presented as examples here in the form of histograms. Although every individual value could have been utilized, the values presented are the average values obtained for each borehole. A large range of values is exhibited for the Undifferentiated Drift deposits varying from soft to stiff, whereas the Keuper Marl deposits are typically stiff to hard clays. The samples providing cohesion results of less than $72kN/m^2$ are probable indicative of samples obtained from the weathered or fissured Keuper Marl mudstones and a bimodal distribution might have been expected.

A further collation is illustrated by the use of the Plasticity Chart, where the plasticity index is plotted against liquid limit for both the Undifferentiated Drift, fig 7.17.1 and for the Keuper Marl, fig 7.17.2, deposits. This Plasticity

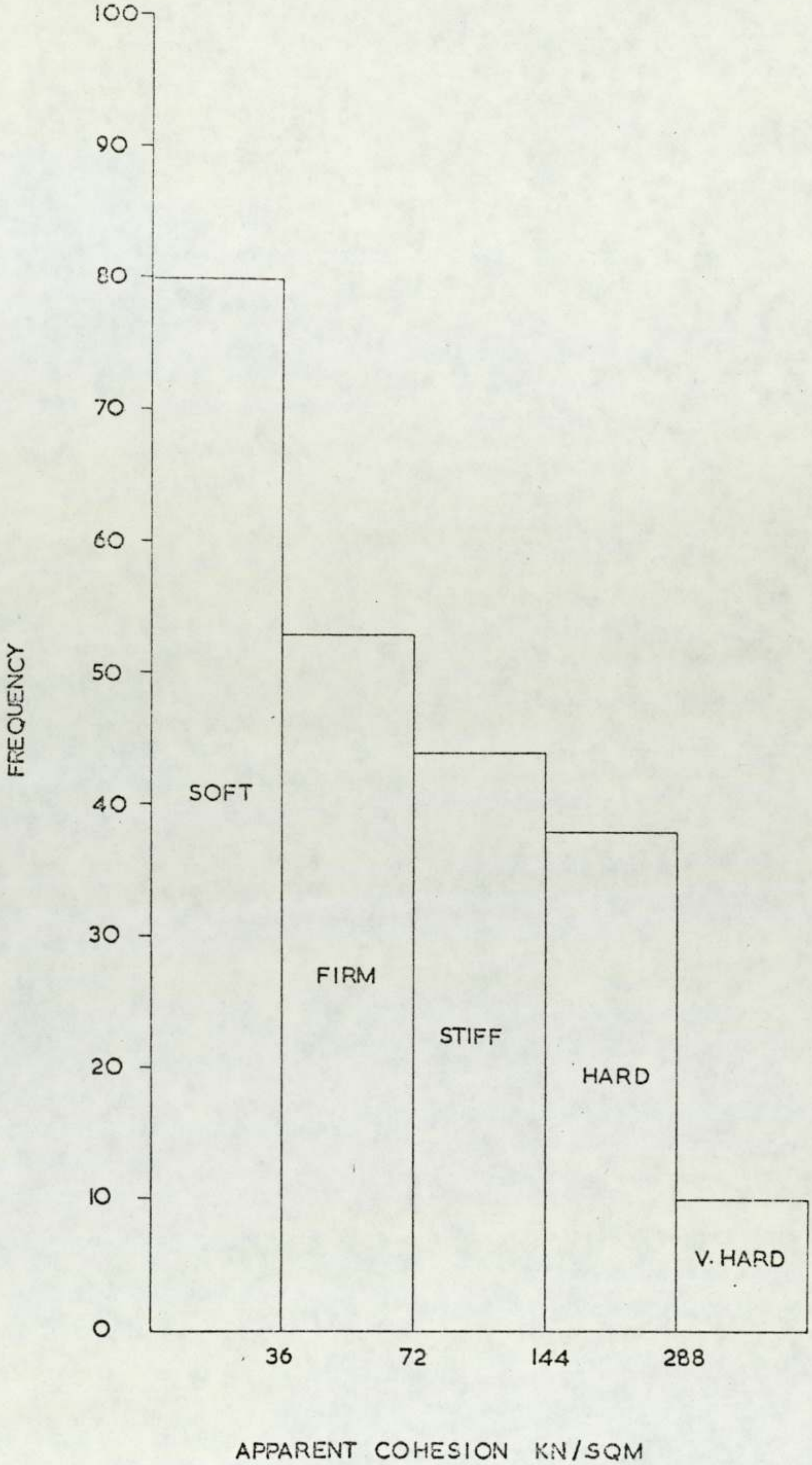


FIG. 7. 16. 1 DISTRIBUTION OF APPARENT COHESION FOR UNDIFFERENTIATED DRIFT

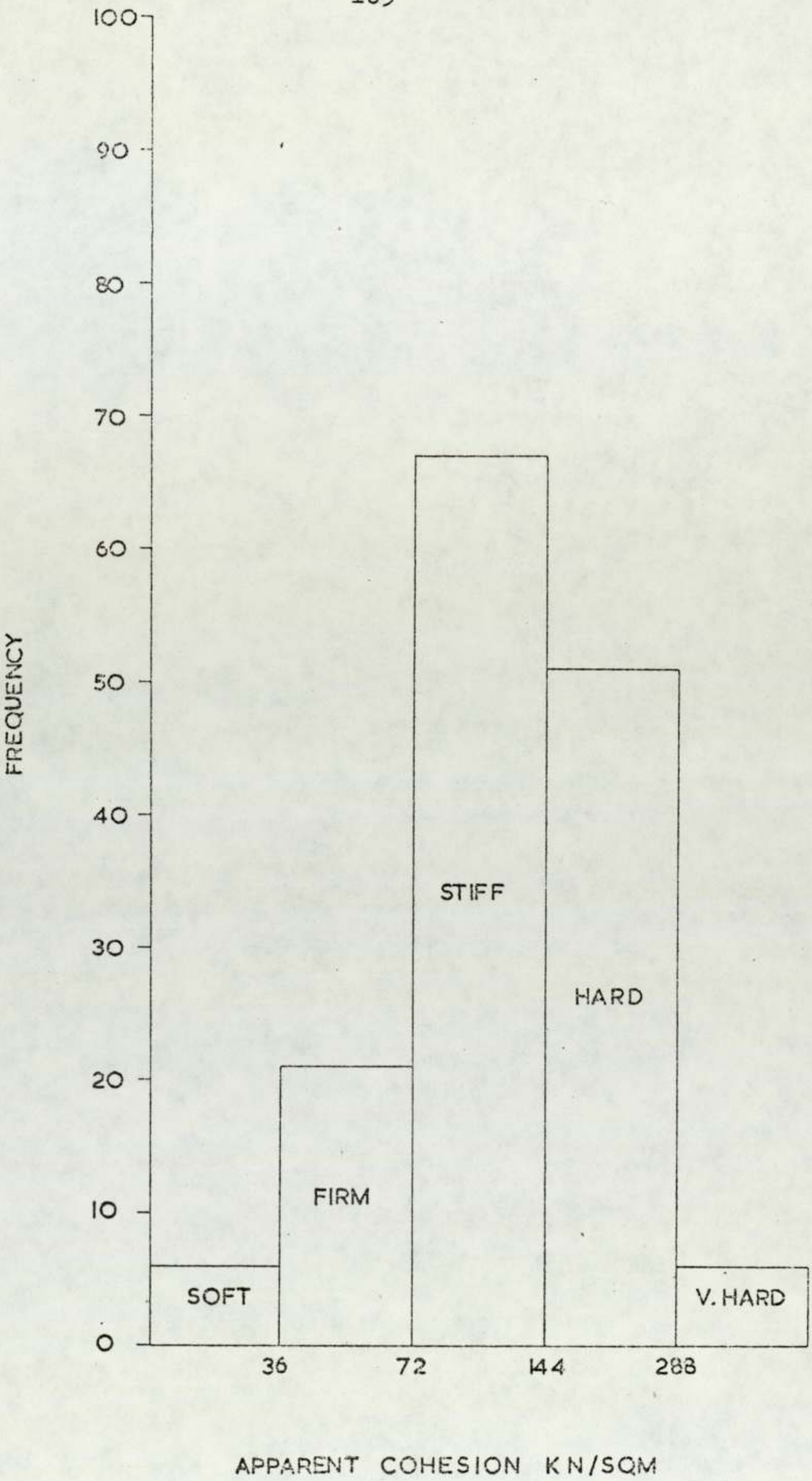


FIG. 7. 16. 2 DISTRIBUTION OF APPARENT COHESION FOR KEUPER MARL

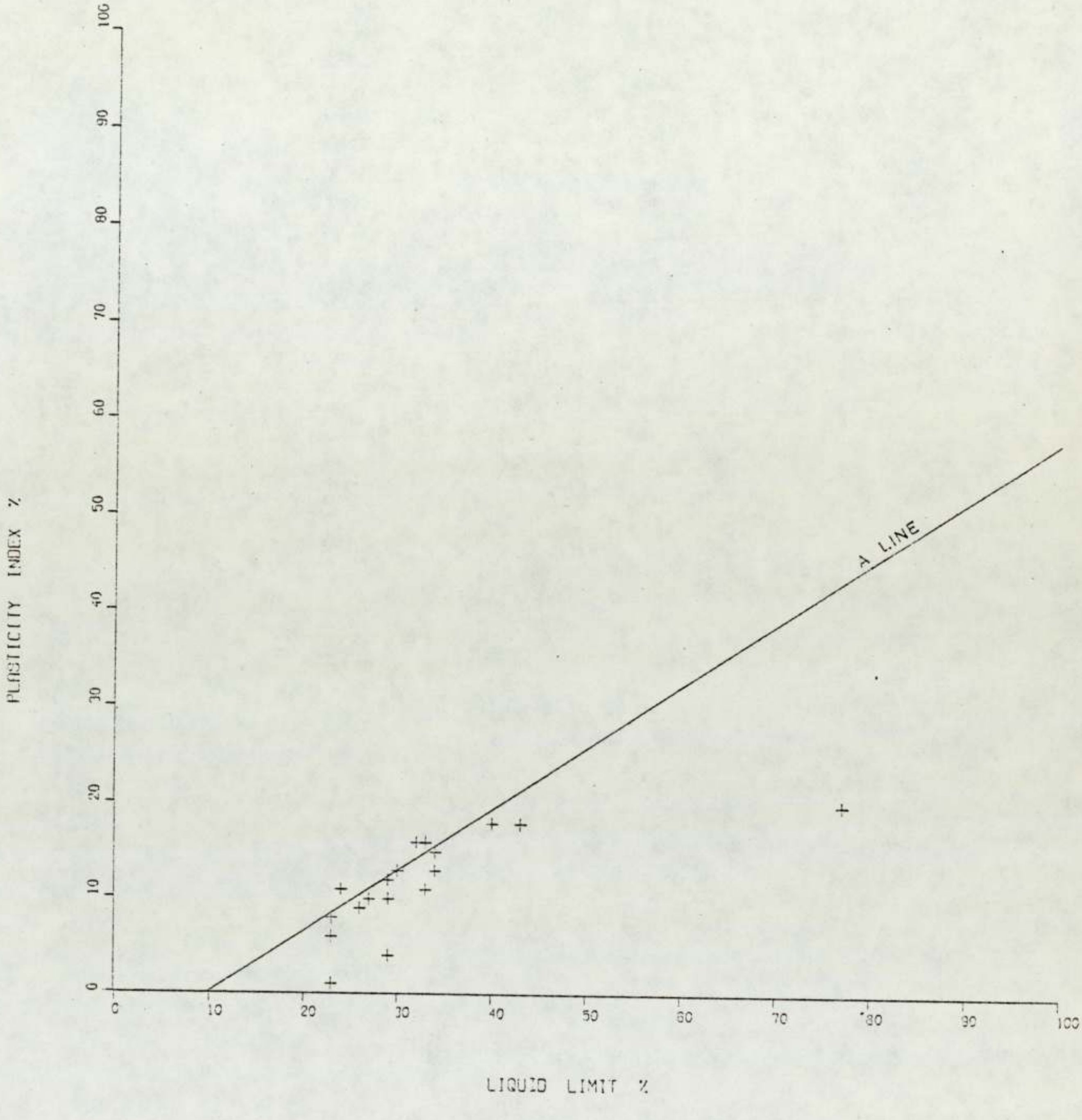


FIG. 7. 17. 1 CASAGRANDE PLASTICITY INDEX CHART FOR UNDIFFERENTIATED DRIFT

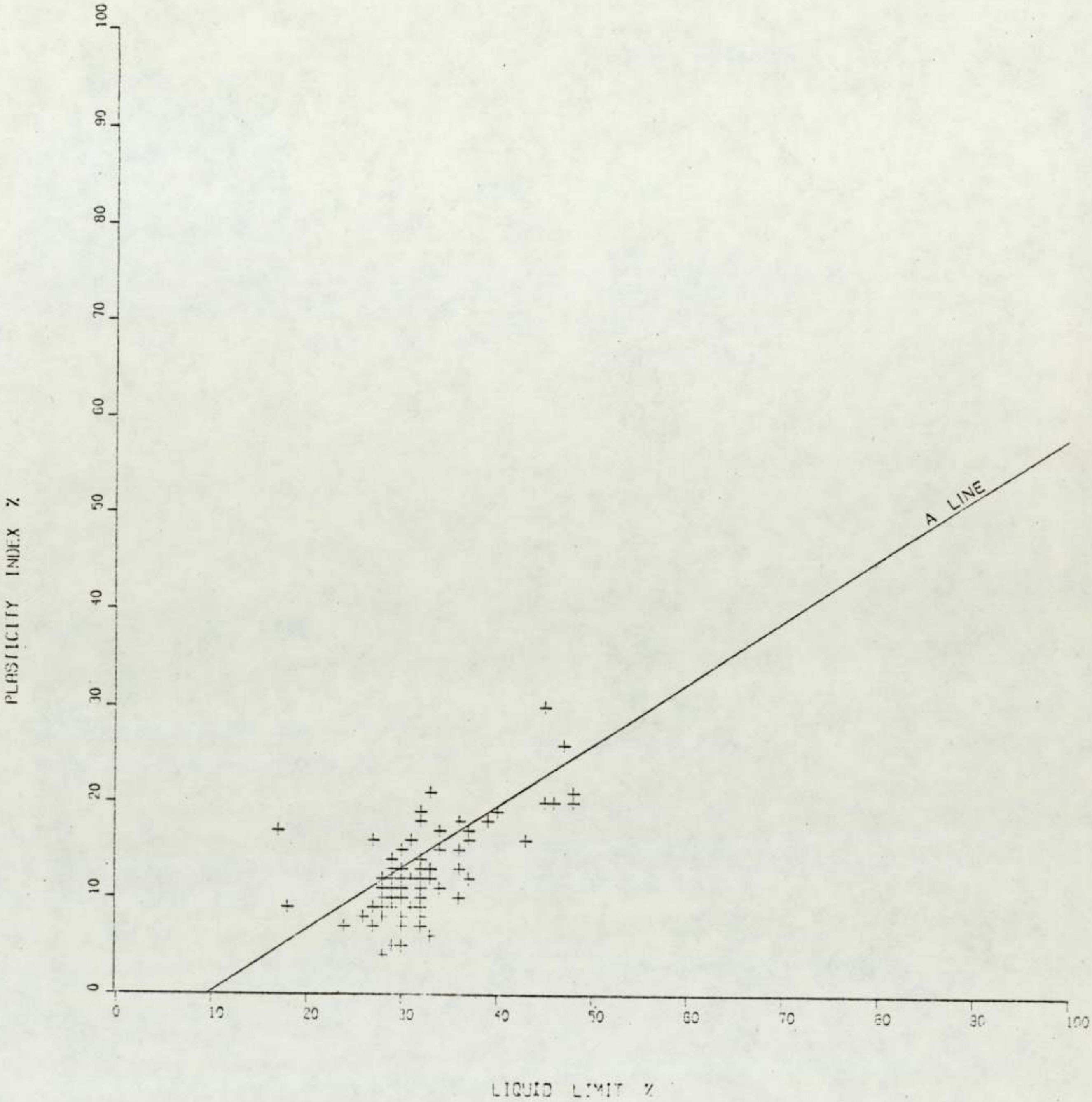


FIG. 7. 17. 2 CASAGRANDE PLASTICITY INDEX CHART FOR KEUPER MARL

Chart has been produced for comparison with the soil classification system developed by Casagrande (1948). The 'A-line' is taken as a boundary between the organic and inorganic soils, the latter lying above the line. By comparing the distributions for both the Undifferentiated Drift and Keuper Marl deposits their lithologies can be classified. The drift deposits are characteristically inorganic clays of low to medium plasticity, gravelly clays, sandy clays, inorganic silts, fine sands, and clayey silts with slight plasticity. Similar characteristics are shown by the Keuper Marl deposits though with higher plasticity index values.

These presentations are of considerable value for research purposes and similar presentations can easily be produced for other parameters to provide regional information.

The type of parameters which could be produced to present regional information could follow the format used by Horton (1975).

8. INTERPRETED DATA PRESENTATION.

8.1. Introduction.

Maps can be utilized by both geologists and engineers to express the spatial relationships of any data. The most common is the topographic map where contour lines represent points of equal elevation. With present day technology, digital computers are now being used to produce contour maps automatically.

It is important that if two maps are produced, one automatically, the other manually contoured using the same data and the same rational processes, the end results should be identical with only the time factor being different. Although computer contour methods are totally consistent the accuracy and quality of a produced contour map depend on the algorithm selected, and as many are now available, the selection of the most suitable for a particular job is difficult. This is especially so where no previous experience of the different algorithms is available.

It is also necessary to select a suitable computer output method. For this study the graph plotter and the line printer were available, with the latter method chosen on economic grounds and because remote terminals can be utilized.

Although computer contouring programs which employ the line printer may need verification and actual contour lines may have to be drawn by hand, their production speed is such that any system requests can be answered with speed, and maps can be produced within minutes. Contour lines have to be drawn by hand when contours are close and spatially adjacent value characters are not consecutive in value.

Computer methods may produce geomorphologically impossible interpretations. Manual verification will be required to identify and rectify such anomalies which may arise from erroneous data, lack of data or the nature of the algorithm employed.

The reliability and accuracy of computer contour map is dependent upon the distribution of the data points. The distribution may be classified into three categories, namely, regular, random and clustered; and may also be described as uniform when the density of points in any subarea of the map is similar. The distributions of data points have been well documented by: Davis (1973), Koch and Link (1971), Harbaugh and Merriam (1968), Krumbein and Graybill (1965), and so will not be discussed in detail. However, it is worth noting that Davis (1973) stated that most geologic researchers have been content with qualitative assessments of the adequacy of their data distribution.

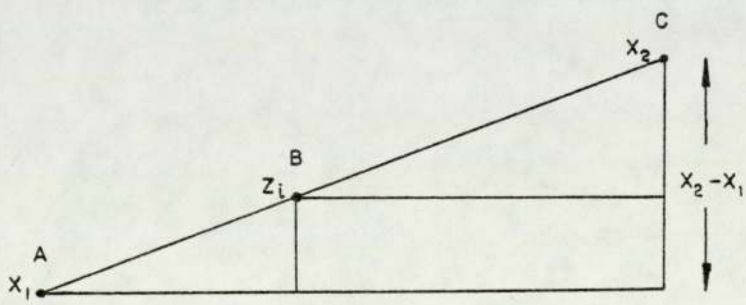
Two computer contouring programs have been used in this study: CONTUR based on two programs devised by Davis (1973), and SYMAP (Fisher, 1968). Although these programs have both been used to produce contour maps of various types such as bedrock topography, drift lithology distributions at desired depths etc., the former has been used to produce a sub-glacial drift topographic map for most of the study area. This map has been compared with manually produced maps of the same area and the statistical parameters describing the data distribution have been calculated.

The examples presented in the following sections were chosen purely to illustrate the types of map that can be produced. It is also possible to produce contour maps of: moisture content, plasticity indexes, densities, weathering ranges at certain depths or for particular stratigraphic units and as mentioned previously, groundwater contour maps may also be produced.

8.2. Line Printer Contour Maps.

8.2.1. 'CONTUR'.

The program 'CONTUR' (Appendix lV) based on routines developed by Davis (1973) is designed to output a contour map to a line printer. Each character or space represents an interpolated value calculated from the six nearest data points and was used to produce the computer printouts included in the next section. It consists of a routine MAP based on routine GRID given by Davis (1973), which uses a simple yet comparatively unrefined algorithm, and a subroutine SPCONT, based on a subroutine PLOT also given by Davis (1973). It employs a weighted average technique, the 'weights' of a number of data points (six in this case) are added together and averaged. These 'weights' are proportioned to the inverse of the distance between the data point and the point for which the value is to be interpolated. This can be illustrated by the following example: the value Z_i is required for the point B, situated between the two data points A and C whose values are X_1 and X_2 respectively.



The distances between A and B, and B and C are D_{i1} and D_{i2} respectively.

The elevation or value at B can be expressed by:

$$Z_i = X_1 + \frac{(X_2 - X_1)\, D_{i1}}{D_{i1} + D_{i2}}$$

$$Z_i = \frac{D_{i2} X_1 + D_{i1} X_1 + D_{i1} X_2 - D_{i1} X_1}{D_{i1} + D_{i2}}$$

$$Z_i = \frac{D_{i2} X_1 + D_{i1} X_2}{D_{i1} + D_{i2}}$$

$$Z_i = \frac{\dfrac{X_1}{D_{i1}} + \dfrac{X_2}{D_{i2}}}{\dfrac{1}{D_{i2}} + \dfrac{1}{D_{i1}}}$$

This can be expressed for a number of data points as:

$$Z_i = \frac{\sum_{i=1}^{n} X_i/d_i}{\sum_{i=1}^{n} 1/d_i} \qquad \text{Equation 8.1}$$

Where Z_i is the interpolated value, X_i is the value of the data points and d_i the distance from the interpolated point to the data points. This is the interpolation formula used by program CONTUR, for which a detailed listing is given in Appendix IV

The data are entered as a 3 x n array where n is the number of data points, each comprising the dependent variable and its grid reference co-ordinates X_1 and X_2. These data are selected from the data bank by a simple search routine for a specified source area.

The map area to be contoured, although lying within the data source area does not have to be the same area i.e. data can be drawn from outside the area to be contoured, this is illustrated later in the following section. The width of the map, WIDTH, and the co-ordinates of the four corners of the map, X_1MIN, X_2MIN, X_1MAX, X_2MAX are then entered. The program then calculates the map size and the number of line printer characters horizontally IW, and vertically IH. IW is evaluated by:

$$IW = WIDTH * 10.0$$

as there are ten line printer characters per inch across the page, and IH by:

$$IH = WIDTH * 6.0 * \underbrace{(X_2MAX - X_2MIN)}_{\text{height of map.}} / \underbrace{(X_1MAX - X_1MIN)}_{\text{width of map.}}$$

as there are six line printer characters per inch vertically.

Interpolation commences from the top left hand corner of the map i.e. at X_2MAX, X_1MIN, and the distances to all the data points in the source area are calculated using the following statement:

$$DIST(K) = (X_1MIN - X_1(K))**2 + (X_2MAX - X_2(K))**2$$

these values are then stored in the linear array DIST(K).

This is, in effect, the evaluation of the Pythagorean equation, with the exception that the square root is not taken into consideration at this stage in the program generalised to:

$$D_{ik} = \sqrt{(X_{1k} - X_{1i})^2 + (X_{2k} - X_{2i})^2}$$

where D_{ik} is the distance from data points (1 to i) to any interpolated point (1 to k).

The six closest points are then found and the value of the interpolated point is estimated using equation 8.1. The interpolated values are stored in an array AMAP (I, J) where J is a column counter and I a row counter. AMAP (I, J) is filled row by row and column by column until I = IW and J = IH and the data for the map are complete.

Contouring is achieved by subroutine SPCONT, which is an algorithm for printing contour maps on the line printer. It assumes that the grid spacing corresponds to the mosaic which the line printer carriage establishes. This is ten characters to the inch horizontally and six lines to the inch vertically. The finished map will then contain 60 grid points per square inch and the maps produced in this study for a kilometre square will contain 6,000 grid points.

Subroutine SPCONT is called by MAP when it has finished interpolating all the values for AMAP (I, J). To each of the interpolated values stored in AMAP (I, J) a contour character is assigned by a simple elimination procedure which compares the interpolated grid point value with CONTOUR (K), the contour lines elevation values, which are calculated using the following equation:-

CONTOUR (K) = BASE + (CINT K)

where BASE is the minimum elevation value and CINT the contour interval, both are pre-designated. In this study a possible thirty contour characters, i.e. K = 1 to 30, were available and from this comparison a particular character can be selected from DATA CH which holds a number of line printer characters which are representative of the values of K, e.g.

DATA CH = '-' , '1' , '+' , '2' etc.
where K = 2 3 4 5

Thus when a value is found from the comparison of the interpolated grid point value and CONTOUR (K) a character is selected from DATA CH and held in the array PR (J) by the statement

PR (J) = CH (K)

This process is carried out for each row i.e. for J = 1 to IH. When a row is completed a line of characters is printed out i.e. one line of the finished map. This is then repeated for each row until the map is complete.

This program has been successfully used to produce several contour maps. However, the program can only interpolate; it cannot perform any form of extrapolation. This has the effect of forming for example, raised plateaux instead of rounded hills etc. and therefore, subdues the parametric topography.

In the following examples the values contoured are levels illustrating bedrock topography, but as mentioned above it is possible to contour the values for any specific parameter in this way.

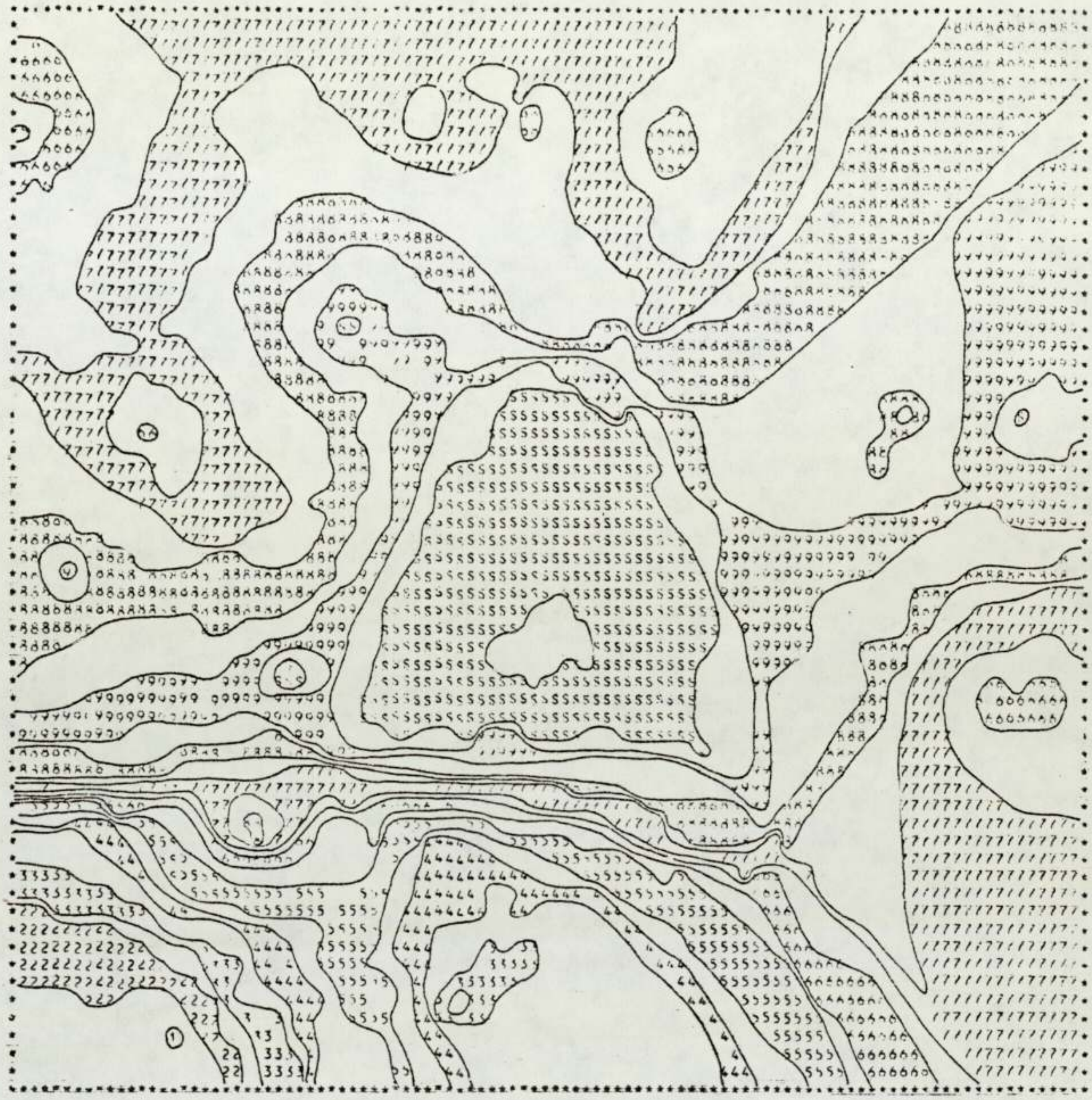
8.2.1.1. Bedrock depth below surface level.

Several examples have been produced with the contours illustrating the bedrock depth below surface level. These maps are only of use when produced for small areas where there are no significant surface topographic changes. They are then of value whilst tendering for contracts or for the design of site investigations as they enable estimation of borehole depths.

One of the first computer contour maps, fig 8.1, to be produced for this study, illustrates the depth of bedrock below surface level for the kilometre square SP072871. It was produced by the program CONTUR as described above, evaluating the grid points from a total of 54 data points within that kilometre square and producing contours at intervals of 2 metres. If the number of data points are compared to those illustrated in fig 7.1, the distribution of boreholes in the kilometre square SP072871 it is obvious that there are more boreholes or data points than the number used in evaluating the contours for fig 8.1. The difference in this instance being composed of boreholes which do not reach bedrock and hence have been ignored by the program.

Difficulty was experienced at this stage in the manual plotting of the contours where a symbol which represents a certain depth lies adjacent to a symbol representing a far greater or lesser depth. Several contour lines have to be drawn between the symbols, and where this occurs frequently throughout a map, hand 'contouring' of the computer contour map can become very intricate.

To overcome this the number of characters was increased thus allowing the contour interval to be reduced to 1 metre, thereby increasing the precision.



DEPTH M	SYMBOL	DEPTH M	SYMBOL	DEPTH M	SYMBOL
1.		11.		21.	
2.	1	12.	6	22.	A
3.		13.		23.	
4.	2	14.	7	24.	B
5.		15.		25.	
6.	3	16.	8	26.	C
7.		17.		27.	
8.	4	18.	9	28.	D
9.		19.		29.	
10.	5	20.	S		

FIG. 8.1 'CONTUR' MAP OF DEPTH TO BEDROCK FOR THE KILOMETRE SQUARE SP 072871, WITH INFORMATION DRAWN FROM WITHIN THAT AREA

In order to assess the effect caused by the lack of information in certain areas of the kilometre square SP072871, a series of four maps, fig 8.3.1 to fig 8.3.4, was produced. Each map overlaps the original square, SP072871, by approximately a quarter, see fig 8.2.

The four contour maps illustrate how the contour patterns at the edges of the original square, SP072871, are altered by utilizing data from differing areas. The four areas, each one kilometre square with their origins at A, B, C, D respectively, see fig 8.2, cover a common area (shaded on the diagram). Each map produced utilizes data only from that kilometre square as defined by their origins. Thus the map produced for the kilometre square with origin A, SP070873 (fig 8.3.1) is produced from 31 data points from within that kilometre square, similarly for B, SP074873 (fig 8.3.2), 38 data points, C, SP074868 (fig 8.3.3) , 54 data points, and D, SP070868 (fig 8.3.4) , 60 data points.

A study of the common areas, outlined on each of these four maps, shows the same general contour pattern dominant throughout. The pattern is made the more obvious by the features shown for example in fig 8.3.1 in the south-east corner of the map (i.e. the common area), where a central 'basin' with a depth of 21m, denoted by the symbol '.', is surrounded by values of 20m, denoted by the symbol 'S', and is repeated in the other maps. On closer examination of the four maps, each one expresses a greater detail of information towards the centre of the map. The centre of say fig 8.3.1 although still covered by fig 8.3.2, is of a greater detail than the latter. It can also be noticed with these same maps that the contours in the centre of fig 8.3.1 are

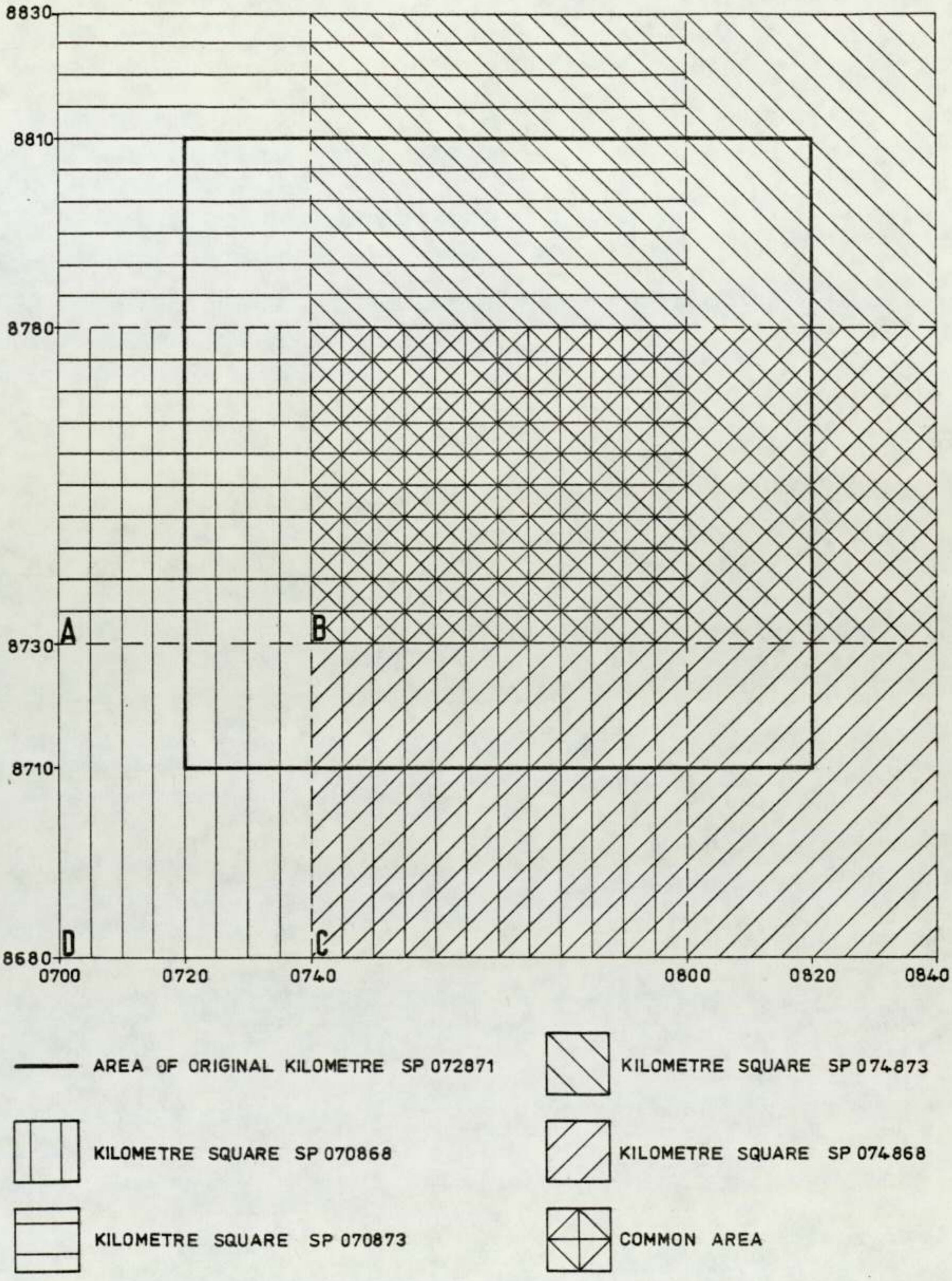
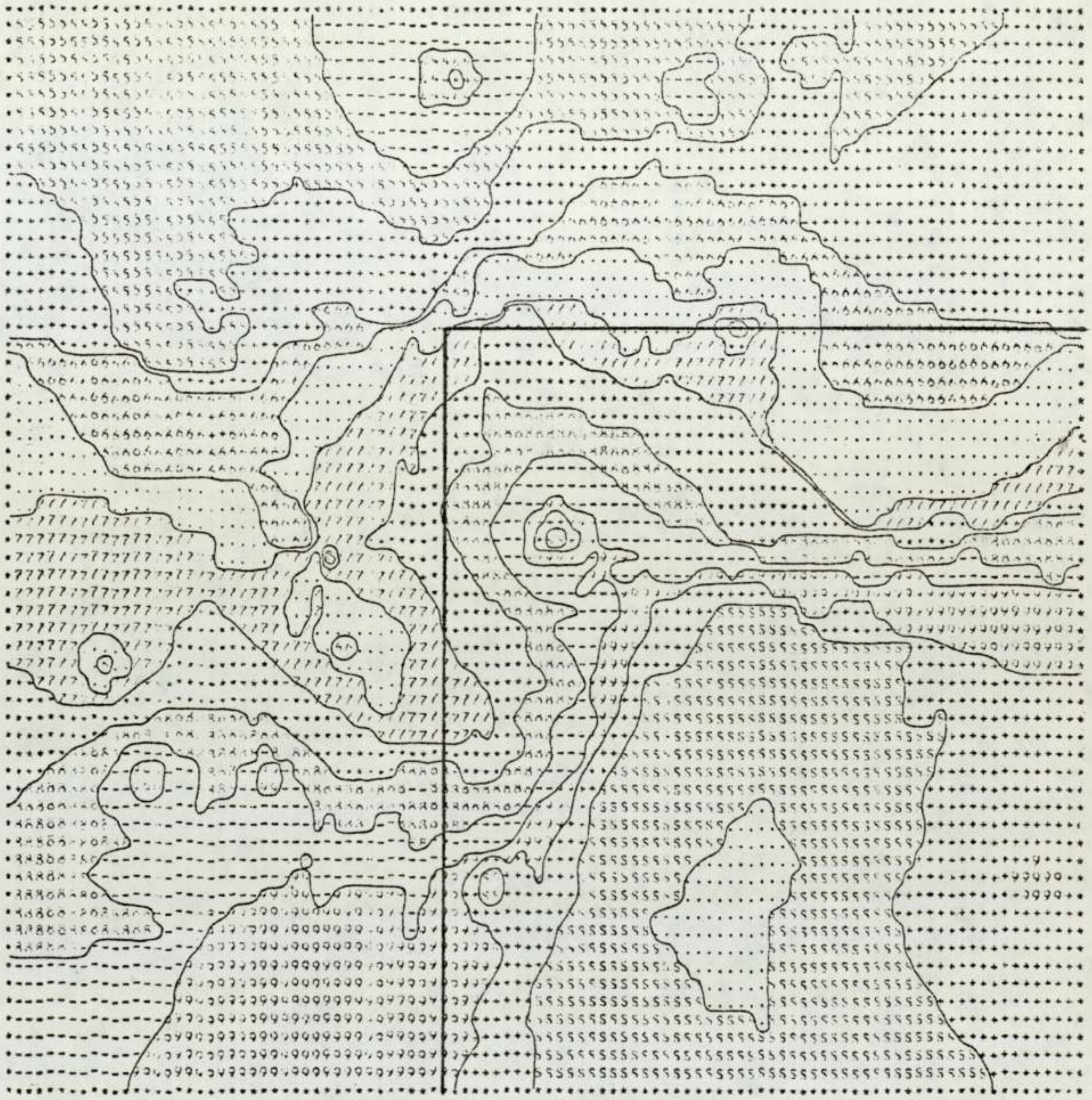


FIG. 8.2. A DIAGRAM TO ILLUSTRATE THE DEGREE OF OVERLAP OF THE COMPUTER CONTOUR MAPS USED TO INVESTIGATE CONTOUR VARIATIONS PRODUCED BY DIFFERING DATA CATCHMENT AREAS.

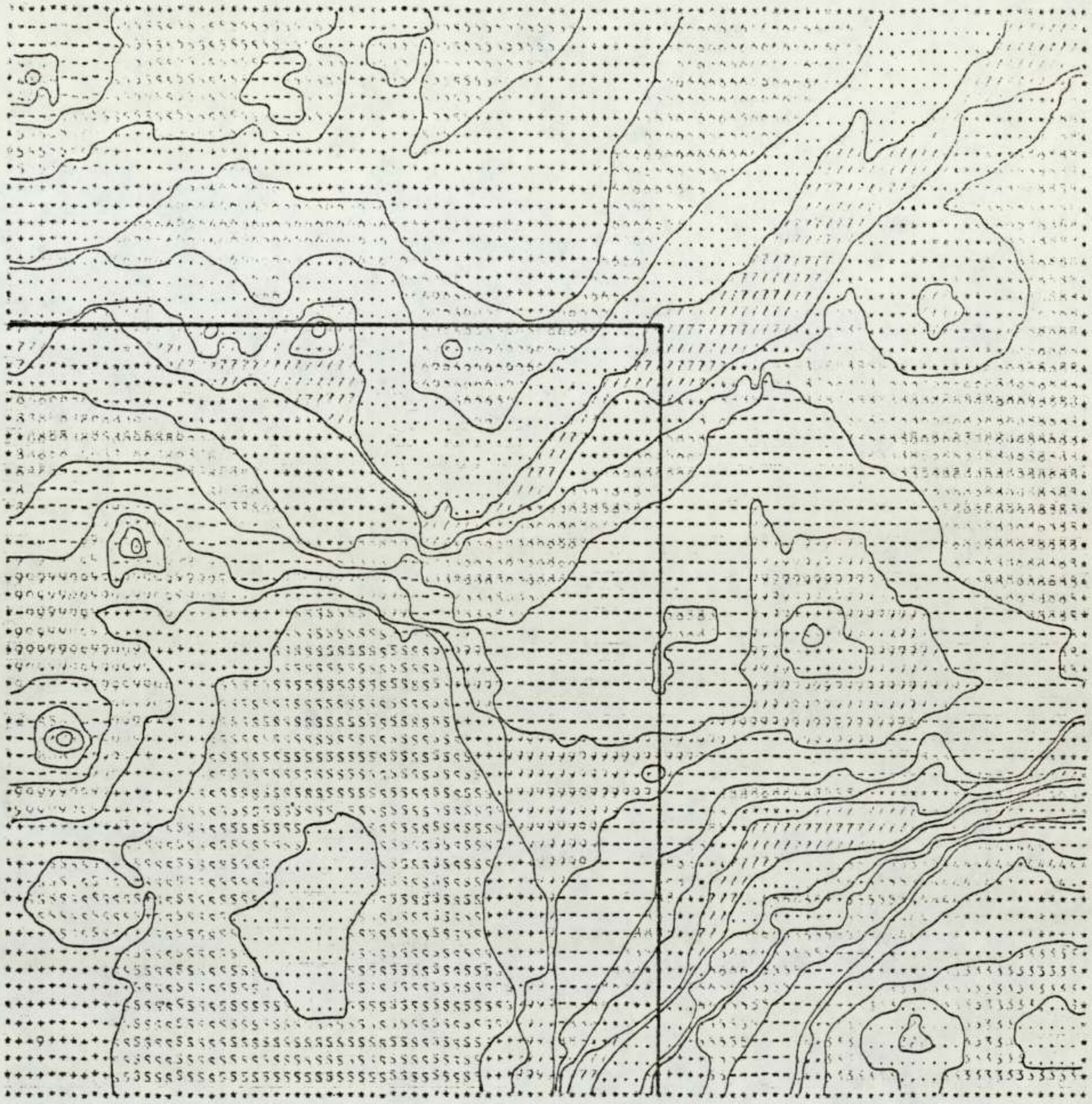


KILOMETRE SQUARE SP070873

DEPTH M	SYMBOL	DEPTH M	SYMBOL	DEPTH M	SYMBOL
1.	-	11.	+	21.	.
2.	1	12.	6	22.	A
3.	+	13.	.	23.	+
4.	2	14.	7	24.	B
5.	.	15.	*	25.	-
6.	3	16.	8	26.	C
7.	*	17.	-	27.	+
8.	4	18.	9	28.	D
9.	-	19.	+	29.	.
10.	5	20.	S		

——— COMMON AREA

FIG. 8.3.1 'CONTUR' MAP OF DEPTH TO BEDROCK FOR THE KILOMETRE SQUARE SP 070873, WITH INFORMATION DRAWN FROM WITHIN THAT AREA

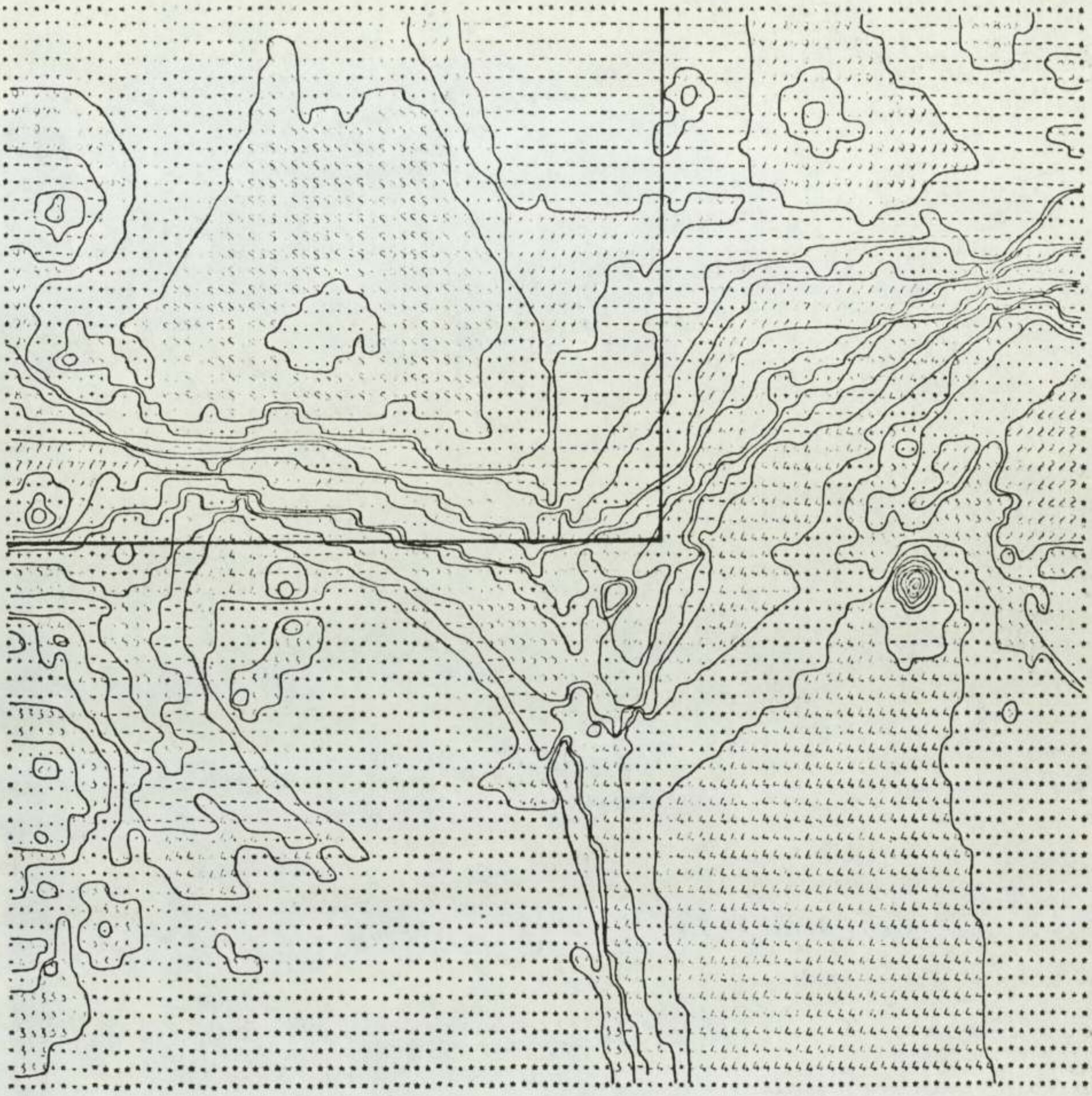


KILOMETRE SQUARE SP074873

DEPTH M	SYMBOL	DEPTH M	SYMBOL	DEPTH M	SYMBOL
1.	-	11.	+	21.	.
2.	1	12.	6	22.	A
3.	+	13.	.	23.	+
4.	2	14.	7	24.	B
5.	.	15.	*	25.	-
6.	3	16.	8	26.	C
7.	*	17.	-	27.	+
8.	4	18.	9	28.	D
9.	=	19.	+	29.	.
10.	5	20.	S		

——— COMMON AREA

FIG. 8.3.2 'CONTUR' MAP OF DEPTH TO BEDROCK FOR THE KILOMETRE SQUARE SP 074873, WITH INFORMATION DRAWN FROM WITHIN THAT AREA

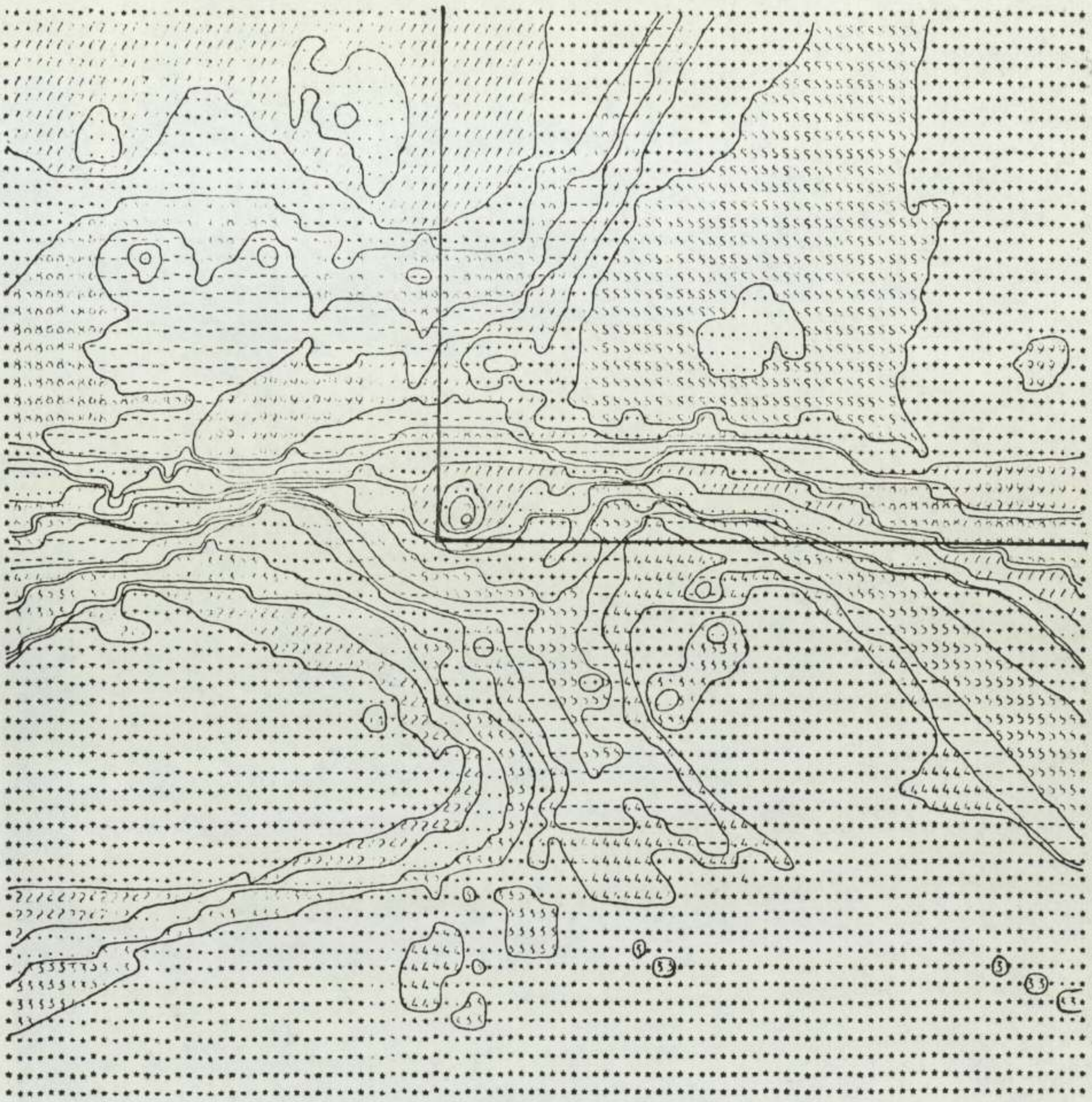


KILOMETRE SQUARE SP074868

DEPTH M	SYMBOL	DEPTH M	SYMBOL	DEPTH M	SYMBOL
1.	-	11.	+	21.	.
2.	1	12.	6	22.	A
3.	+	13.	.	23.	*
4.	2	14.	7	24.	B
5.	.	15.	*	25.	-
6.	3	16.	8	26.	C
7.	*	17.	-	27.	+
8.	4	18.	9	28.	D
9.	-	19.	+	29.	.
10.	5	20.	S		

——— COMMON AREA

FIG. 8.3.3 'CONTUR' MAP OF DEPTH TO BEDROCK FOR THE KILOMETRE SQUARE SP 074868, WITH INFORMATION DRAWN FROM WITHIN THAT AREA



KILOMETRE SQUARE SP070868

DEPTH M	SYMBOL	DEPTH M	SYMBOL	DEPTH M	SYMBOL
1.	-	11.	+	21.	.
2.	1	12.	6	22.	A
3.	+	13.	.	23.	'
4.	2	14.	7	24.	B
5.	.	15.	*	25.	-
6.	3	16.	8	26.	C
7.	*	17.	-	27.	+
8.	4	18.	9	28.	D
9.	-	19.	+	29.	.
10	5	20.	S		

——— COMMON AREA

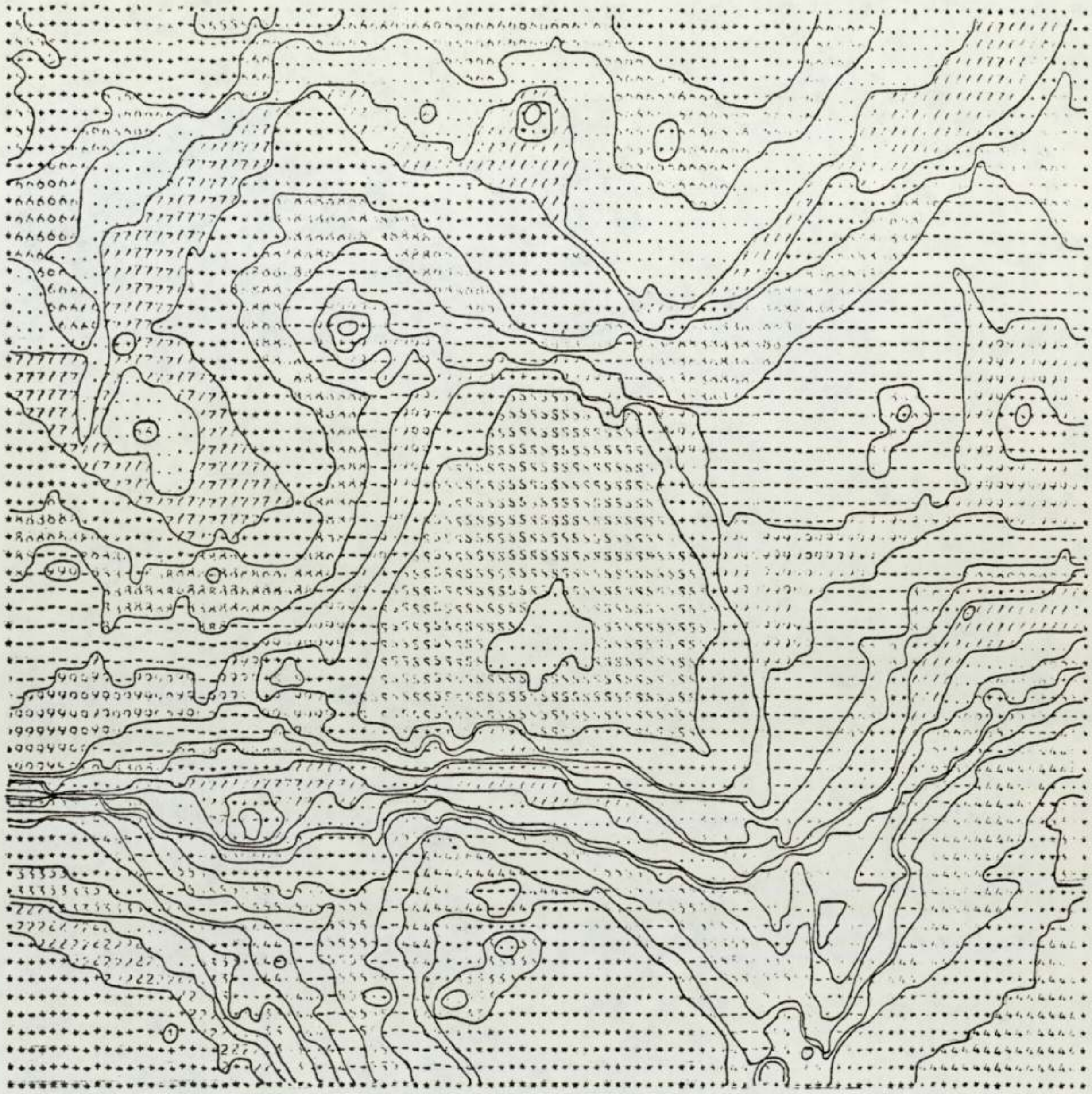
FIG. 8.3.4 'CONTUR' MAP OF DEPTH TO BEDROCK FOR THE KILOMETRE SQUARE SP 070868, WITH INFORMATION DRAWN FROM WITHIN THAT AREA

continuous whereas, in comparison, the contours of the same location in fig 8.3.2 extend towards the map border. This illustrates the point made previously, that this program can only interpolate and where no data are available, say at the edge of an area required to be contoured, the averaging effect becomes even more apparent.

From these examples the observation can be made that the outputs are directly dependent on the amount of data available and the location of that data. Where the density of data is high little variation exists between the four maps and conversely where there are areas of low density considerable variations are present. However, general contour maps can be produced with relatively few data points as illustrated.

Although no definite relationship can be obtained from this particular study, between this type of computer contour map and the data distribution and density, the examples do illustrate the need to produce maps which can draw on data from a source area within which is situated the area to be contoured. The size of the 'fringe' area required is obviously dependent on the availability of adjacent data and therefore will be variable.

To demonstrate the use of a fringe area a computer contour map showing the depth of bedrock below surface level for the kilometre square SP072871, fig. 8.4 was produced. This utilized the facility of the program CONTUR to accept and use data which lie outside the area of the map to be produced. The map utilizes 91 data points extracted from a source map area of 1.5 km by 1.4 km, which is the total area covered by figs 8.3.1 to 8.3.4 as illustrated in fig 8.2. The contour pattern



DEPTH M	SYMBOL	DEPTH M	SYMBOL	DEPTH M	SYMBOL
1.	-	11.	+	21.	.
2.	1	12.	6	22.	A
3.	+	13.	.	23.	+
4.	2	14.	7	24.	B
5.	.	15.	+	25.	-
6.	3	16.	8	26.	C
7.	+	17.	-	27.	+
8.	4	18.	9	28.	D
9.	-	19.	+	29.	.
10.	5	20.	S		

FIG. 8.4 'CONTUR' MAP OF DEPTH TO BEDROCK FOR THE KILOMETRE SQUARE SP 072871, WITH INFORMATION DRAWN FROM THE TOTAL AREA SHOWN ON FIG. 8.2

illustrated at the centres of the map is again very similar to the contour patterns dominating the centres of the common areas of the last four maps, figs 8.3.1 to 8.3.4.

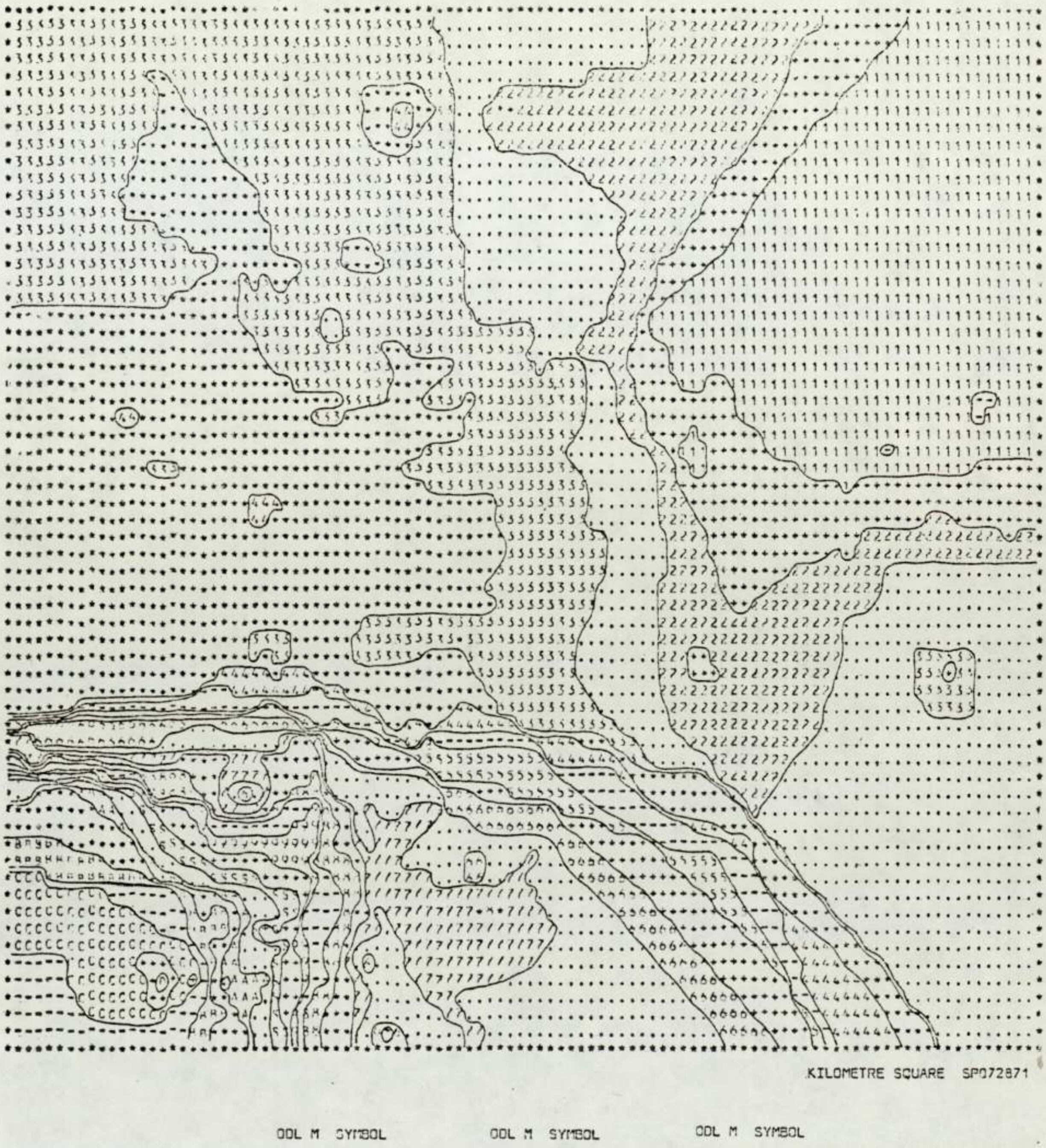
With the utilization of all available data, a simple computer contour map can be produced which although interpolative is of considerable value. Its value however, will depend on data density and distribution and thus it may be of value to the user to have a map which includes the location of the data. The evaluation of data density and distribution and their effect on the validity of such contour maps is discussed below where a comparison with manually produced maps is also made.

8.2.1.2. Bedrock topography to Ordnance Datum.

One of the first requirements in the design of any scheme is the depth of the bedrock below ground level. In many cases this is better expressed with reference to the Ordnance Datum level, and may also be of benefit to other categories of user e.g. for research in civil engineering or geology.

A computer contour map was produced illustrating the sub-glacial drift topography to Ordnance Datum, fig 8.5 employing the same data and source area as for the map described above, fig 8.4., for the kilometre square SP072871. Comparison of the two maps, figs 8.4 and 8.5, show many broad agreements, but the minor differences must reflect changes in topography.

This single map is not described here as it is incorporated into a map illustrating the sub-glacial drift topography to Ordnance Datum of the whole study area. This map was compiled from individual one kilometre square maps provided from data within a source area 1.5 x 1.4 km. Minor disparities arose



KILOMETRE SQUARE SP072871

ODL M	SYMBOL	ODL M	SYMBOL	ODL M	SYMBOL
99.	-	109.	+	119.	.
100.	1	110.	6	120.	A
101.	+	111.	.	121.	+
102.	2	112.	7	122.	B
103.	.	113.	*	123.	-
104.	3	114.	3	124.	C
105.	+	115.	-	125.	+
106.	4	116.	9	126.	D
107.	-	117.	+	127.	.
108.	5	118.	$		

FIG. 8.5 'CONTUR' MAP OF THE SUBGLACIAL DRIFT TOPOGRAPHY TO ORDNANCE DATUM FOR THE KILOMETRE SQUARE SP 072871

in the contour patterns at the margins of some squares indicating that a 200 to 250 m wide 'fringe' was insufficient in these cases. This was overcome by incorporating a second series of one kilometre square maps offset by 500 m (north and east) into the compilation. Marginal portions of the study area, where data were very sparse, were omitted, fig .8.6.The final presentation, fig 8.7, was drafted directly from the computer printouts.

It is quite feasible for the computer to produce this map in one run. However, as data were only available for an area quite irregular in shape and the program developed only able to produce maps from a rectangular grid of values this was not possible at this stage of the study. It is worth noting in retrospect that SYMAP, although more costly, could be used to produce a similar type of map for an irregular shaped area. The final size of the map was defined by the need to show the contours at intervals of 2 m. In a smaller version these lines would become compressed and the resultant map would have to be produced with a greater contour interval and consequent loss of detail.

The map of the study area covers part of a large area for which similar maps have been produced manually (Pickering, 1957; Horton, 1975). The later map utilizes the larger amount of information derived from site investigations for the M5 and M6 motorway complex in the Birmingham area and effectively constitutes an updated version of the map produced by Pickering (1957). Comparison of the later map fig 8.8 with the computer contour map immediately shows that the major features are compatible. One of the most striking features illustrated is the valley running northwest to southeast (SP075895 to SP090885) and passing just north of the University of Aston. This valley

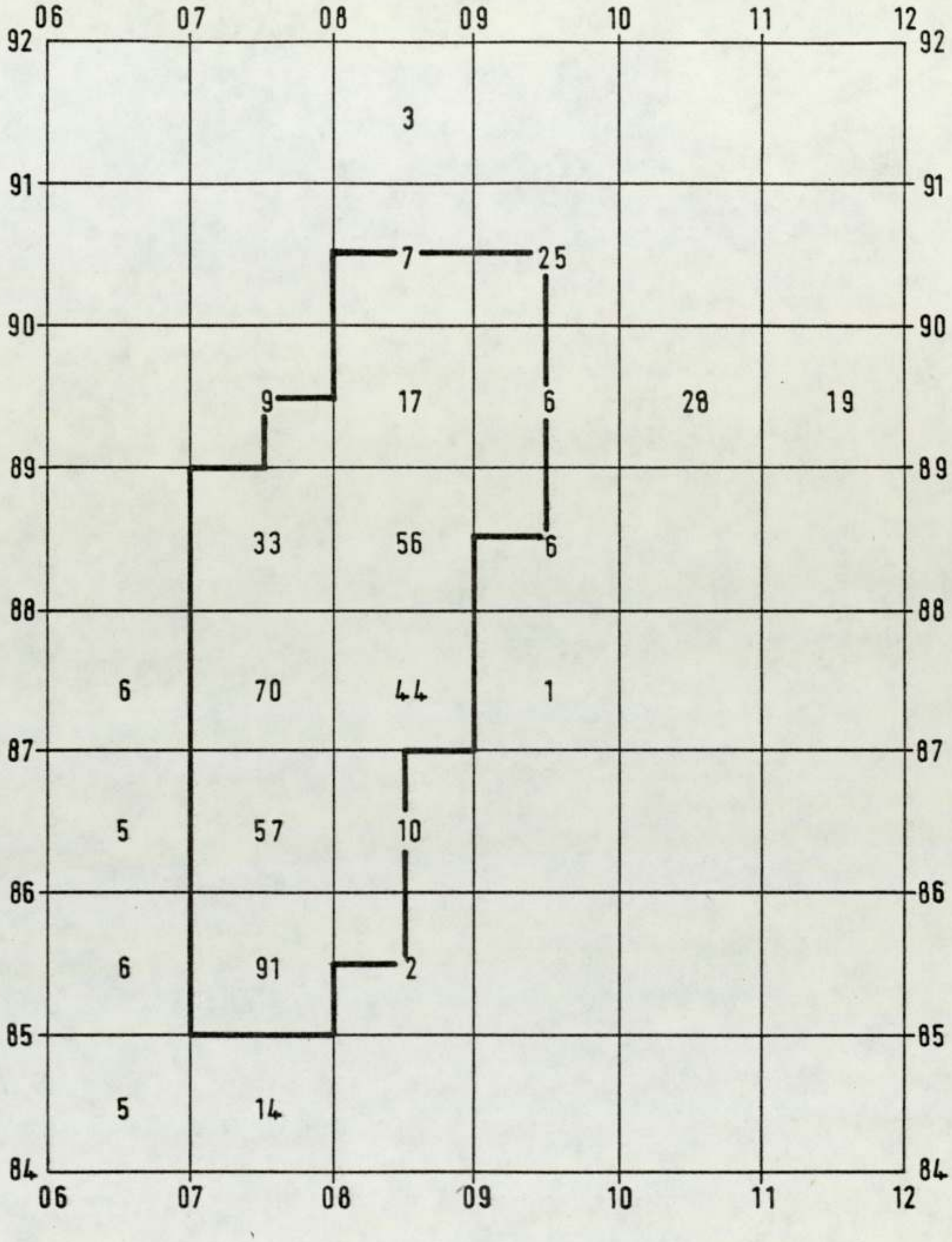


FIG. 8.6. BOREHOLE DISTRIBUTION WITHIN STUDY AREA SHOWING THE AREA REPRESENTED BY THE CONTOUR MAP, FIG. 8.7.

FIG. 8.7 BEDROCK TOPOGRAPHY OF THE BIRMINGHAM AREA
contained in back pocket

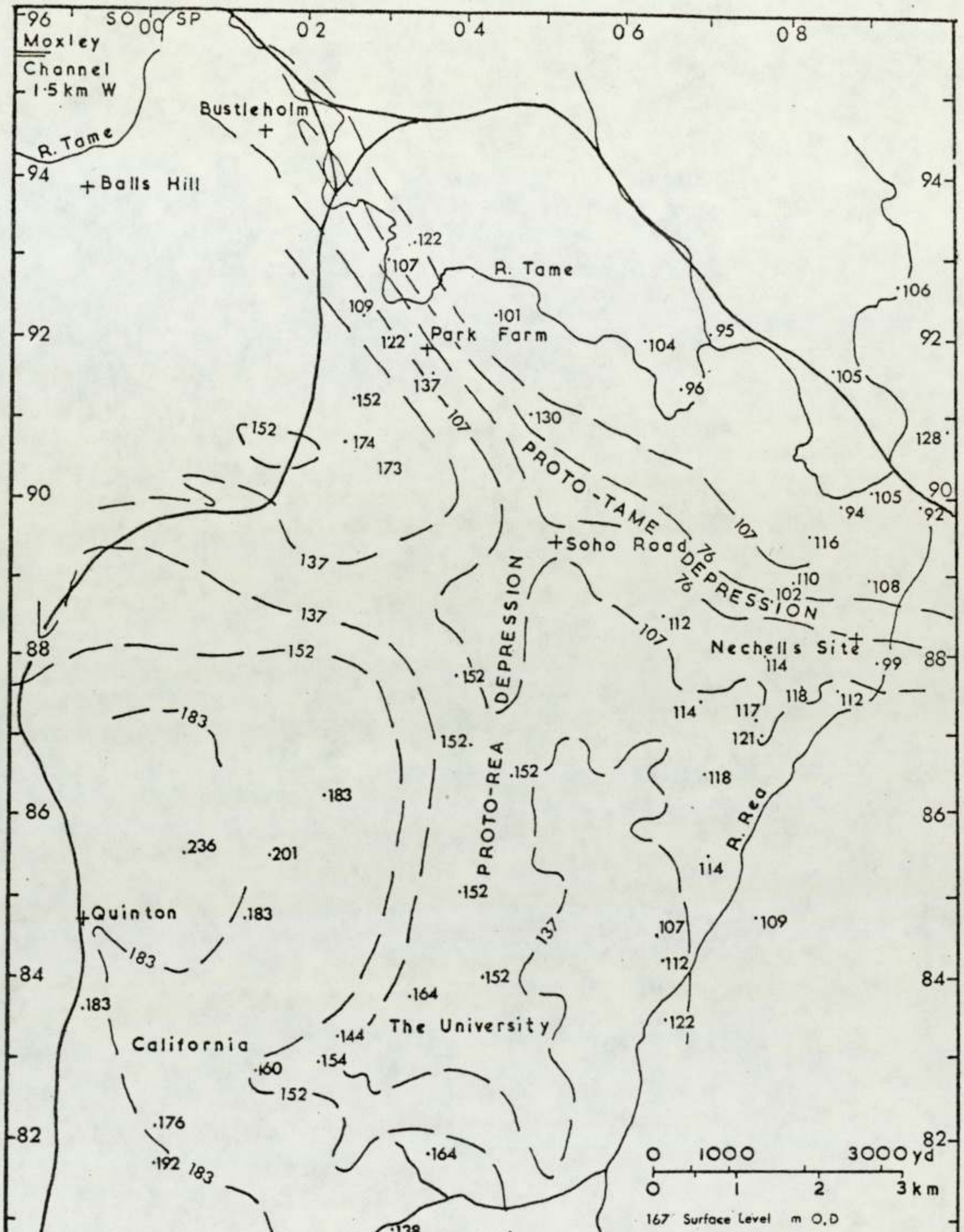


FIG. 8.8 GENERALISED CONTOURS ON THE SUBGLACIAL DRIFT TOPOGRAPHY OF THE BIRMINGHAM AREA (AFTER HORTON, 1975)

in the bedrock surface descends to below 74 m a.O.D. and is obviously the 'Proto-Tame depression' of Pickering (1957).

A much broader valley can be seen in the southwest of the study area (SP070850) running into the Proto-Tame depression. The present day course of the river Rea appears to follow this valley and the northern bank of this valley also runs sub-parallel to the line of the Birmingham Fault (Eastwood _et al_, 1925). The 'break' visible in the Proto-Tame depression along this same line (SP085884) may also indicate the position of the Birmingham Fault, although this point lies to the west of the line suggested by Eastwood _et al_ (1925). It is however possible, that this 'break' may be due to anomalous data and this aspect will be discussed later.

To the east of this broad tributary valley in the southeast of the study area, a steep ridge is clearly visible reaching an elevation of more than 126m a.O.D. at Highgate Park (SP084857). This feature also parallels the Birmingham Fault but lies to the east of the fault.

North of the Proto-Tame depression another shallow valley is apparent in the vicinity of the 'Spaghetti Junction' motorway interchange (SP088899). This valley runs southeast and appears to follow the present day course of the river Tame.

Although this detailed computer contour map was produced for the study to illustrate the comparability with manually produced maps, it is not easy to compare the generalised contours of fig 8.8 with the more complex contours, produced with the aid of a computer, in fig 8.7. However, the basic features of the bedrock topography illustrated by both of the maps are so similar that the computer contour map is equally as valid as the manual. However, on close examination of the computer contour map some unnatural computer interpretations can be observed. One of these lies in the central part of the Proto-Tame depression; here the valley is divided into two by a narrow strip of apparently higher topography rising to about 90m a.O.D. at SP08508850. Examination of the data recorded in this area revealed that none were available in the centre of the depression and consequently the interpolation has had to use data from the depression sides, giving an anomalously high value.

A further unnatural interpolation is found just north of Highgate Park, SP08258620 where a basin-like hollow can be seen in the valley running northeast. On examination of the data in this area, one borehole, located exactly at this point, was found to have a recorded bedrock level 12m below that recorded in the close vicinity and so casting doubt on the validity of this particular record.

With the occurrence of such anomalies a thorough knowledge of the data (values and locations) is required to identify the cause of the anomaly. Such anomalies resulting from lack of data, erroneous field data or input errors could then be rectified manually or merely qualified.

8.2.1.3. Assessment of the adequacy of the data distribution for use with CONTUR.

The necessity for assessing the data distribution for which computer contouring is performed is of special importance as the program CONTUR is designed to compute its final contours from irregularly spaced yet evenly distributed data.

The nature of the data distribution used to produce the contour map illustrating the sub-glacial drift topography for part of the study area, fig 8.7, was assessed using two methods: Subarea or Quadrat Analysis and the Nearest Neighbour Analysis. The former method tests for uniformity of data density by testing the hypothesis that there is no difference in the number of points per subarea; the latter tests for randomness of the data.

(i) Subarea or Quadrat Analysis.

A map area may be divided into a number of equal-sized subareas or quadrats, such that each subarea contains a number of points. If the data points are distributed uniformly, each subarea will contain the same number of points. The hypothesis of no difference in the number of points per subarea can be tested using a χ^2 method and is theoretically independent of the shape or orientation of the subareas. The test is most efficient if the number of subareas is a maximum (this increases the degree of freedom), subject to the restriction that no subarea contains less than five points.

This test was carried out by defining subareas of 1 km by 0.5 km for the area covered by the computer contour map, fig 8.7, to ensure that each subarea contained no less than five points as shown in Table 8.1.

The expected number of points in each subarea is

$$E = \frac{\text{total number of data points}}{\text{number of subareas}}$$

A χ^2 test of goodness-of-fit of the expected uniform distribution to the observed distribution is given by

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

Observed number of points.	$\frac{(O - E)^2}{E}$
53	40.84
47	26.31
43	18.38
38	10.47
11	5.96
16	1.93
20	0.30
29	1.80
11	5.96
37	9.16
19	0.58
19	0.58
14	3.28
9	8.19
5	13.72
9	8.19
8	9.44
19	0.58
Total = 407	$\chi^2 =$ 165.67

Table 8.1 Number of boreholes in eighteen subareas of the area represented by the contour map, fig 8.7.

where O is the observed number of data points in a subarea and E is the expected number. The test has $\nu = (m - 2)$ degrees of freedom, where m is the number of subareas, in this case $m = 18$.

The computed test value of $\chi^2 = 165.67$ far exceeds the critical value of χ^2 at the 5% significance level and confirms quantitatively that the quadrats are far from uniformly populated.

(ii) Nearest Neighbour Analysis.

The nature of the uniformity is not established by demonstrating that a pattern is uniform, and the use of a Poisson distribution as a test for randomness or a nearest neighbour analysis must be considered. The latter analysis was considered more applicable here than the Poisson distribution for several reasons e.g. the close similarity of this test and the method involved in the computer contouring program CONTUR, and the added advantage in that it provides an indication of the nature of the point distribution beyond a simple acceptance or rejection of a null hypothesis.

In a random distribution of points, the expected mean distance, $\bar{\Delta}$, between each point and its nearest neighbour is

$$\bar{\Delta} = \frac{1}{2\sqrt{p}}$$

where p is the density of points in the area. Point density is defined as the number of points per unit area, where the area is measured in the square of units used to measure distance between points. In this study the total area considered was 9 sq. km., and the unit area as 1 sq. km.

The density of points, $p = 45.22$ per sq. km.

and the expected mean distance $\bar{\Delta}$, between each point and its nearest neighbour was found to be 0.074 km. By measuring the distances between every point and its nearest neighbour the observed mean distance, $\bar{D}$, was calculated as 0.03877 km. The ratio of the observed mean distance D to the expected mean distance $\bar{\Delta}$ is expressed as the nearest neighbour statistic R where:-

$$R = \frac{\bar{D}}{\bar{\Delta}}$$

The ratio ranges from 0 for a distribution where all points coincide, to 1.0 for a random distribution of points, to a maximum value of 2.15 which characterizes a distribution in which the mean distance to the nearest neighbour is maximised. In this case :

$$R = \frac{\bar{D}}{\bar{\Delta}} = \frac{0.03877}{0.074} = 0.5239$$

This value of R is characteristic of a distribution of points which are grouped into clusters.

The very nature of the data in terms of their origin inevitably leads to an uneven clustered distribution. Individual site investigations are rarely carried out on large areas, particularly urban areas, and data are found to be clustered though the distribution of clusters may be reasonably uniform and random. The statistical parameters calculated above merely provide a quantified assessment of the distribution but only allow a qualitative evaluation of the validity of the maps produced.

8.2.2. SYMAP and SYMVU.

8.2.2.1. Program Description.

SYMAP (Synographic Mapping System) and SYMVU (Synographic Mapping View) (see Appendix V) are FORTRAN programs which depict spatially disposed quantitative and qualitative data, and are provided with numerous options to meet widely varying requirements.

Both SYMAP and SYMVU originate from the Laboratory of Computer Graphics at Harvard University, Massachusetts, U.S.A. The programs have been modified at Edinburgh Regional Computing Centre and it is these versions, further modified at the University of Manchester Regional Computer Centre to be compiled by the FTN compiler which have been used in this Thesis (Fisher, 1968).

SYMAP accepts data from points defined at irregularly spaced intervals in an area whose outline can be non-rectangular. The output is a line printer map and if required a file of interpolated data for use by SYMVU. These data, or data read from a card image file, are used by SYMVU to produce a three dimensional display of the data. Both SYMAP and SYMVU have been described fully in Fisher (1968) and in unpublished material such as technical newsletters issued by the University of Manchester Regional Computer Centre.

8.2.2.2. SYMAP.

The three types of map which can be produced by the SYMAP program are:-

(i) Proximal, consisting of spatial units defined by the nearest neighbour methods from point information, and is very similar in appearance to the conformant map (see below). Each character location on the output map is assigned the value of the data point nearest to it. The boundaries are assumed along the line where the values change and conformant mapping is applied. (see 8.2.2.2. (iii).). In the proximal 'shading' map system, the value for a particular area is envisaged as a 'spot height' located at a suitable 'character space' at the centre of that unit. SYMAP calculates the value or height of each character space by interpolating from a minimum of four and a maximum of ten data points, although an average of seven is common (this is specified in F-MAP package). A shading symbol, appropriate to the interpolated value, is then printed in that space or, alternatively, the program finds the 'character space' which most nearly coincides with the isoline value and prints a symbol there, leaving the rest of the map blank. This type of map is useful for displaying qualitative data, particularly when the precise definition of zonal boundaries is not of paramount importance (Fisher, 1968); examples of the possible uses of proximal maps are discussed later.

(ii) Contour, based on the use of contour lines, or closed curves which connect all points having the same numeric value or height. Between any two contour lines a continuous variation is assumed and therefore the use of contour lines should be restricted to the representation of continuous information, such as topography, rainfall, population density etc.

(iii) Conformant, or choropleth maps are suitable for data, either qualitative or quantitative, whose areal limits are of significance, and whose representation as a continuous surface is inappropriate.

In the production of any of these maps it is necessary to establish a source map with a designated top and left borders from which required measurements may be taken. For the examples illustrated the source map is unique to each map and its origin is located to the north and west of all the data locations considered to be of significance. The source map area was chosen to coincide with the source map discussed previously, see section 8.2.1.1.

Several packages are used to produce the maps illustrated, a brief explanation of their general purpose is included here and a more complete description is available in Fisher (1968).

The outline of the study area (i.e. output map) is specified in terms of the source map and stored in the A-OUTLINE package. National Grid reference co-ordinates of the data locations are extracted from the data bank and converted to the Equal Unit Measurement of SYMAP, i.e. the same scale of measurement is used to determine both vertical and horizontal co-ordinates, measured from the source map origin, and stored in the B-DATA POINTS package. Concomitantly the data values are stored in the E-VALUES package. The type of map is controlled by the F-MAP package which consists of a number of electives which control the form of the map. These electives provide a variety of options for obtaining maps to suit particular needs. This package is also used to specify titles etc. below each map. The D-BARRIERS package was also used for one of the presentations, fig 8.10, to provide a barrier to interpolation between data points; this facility is discussed later.

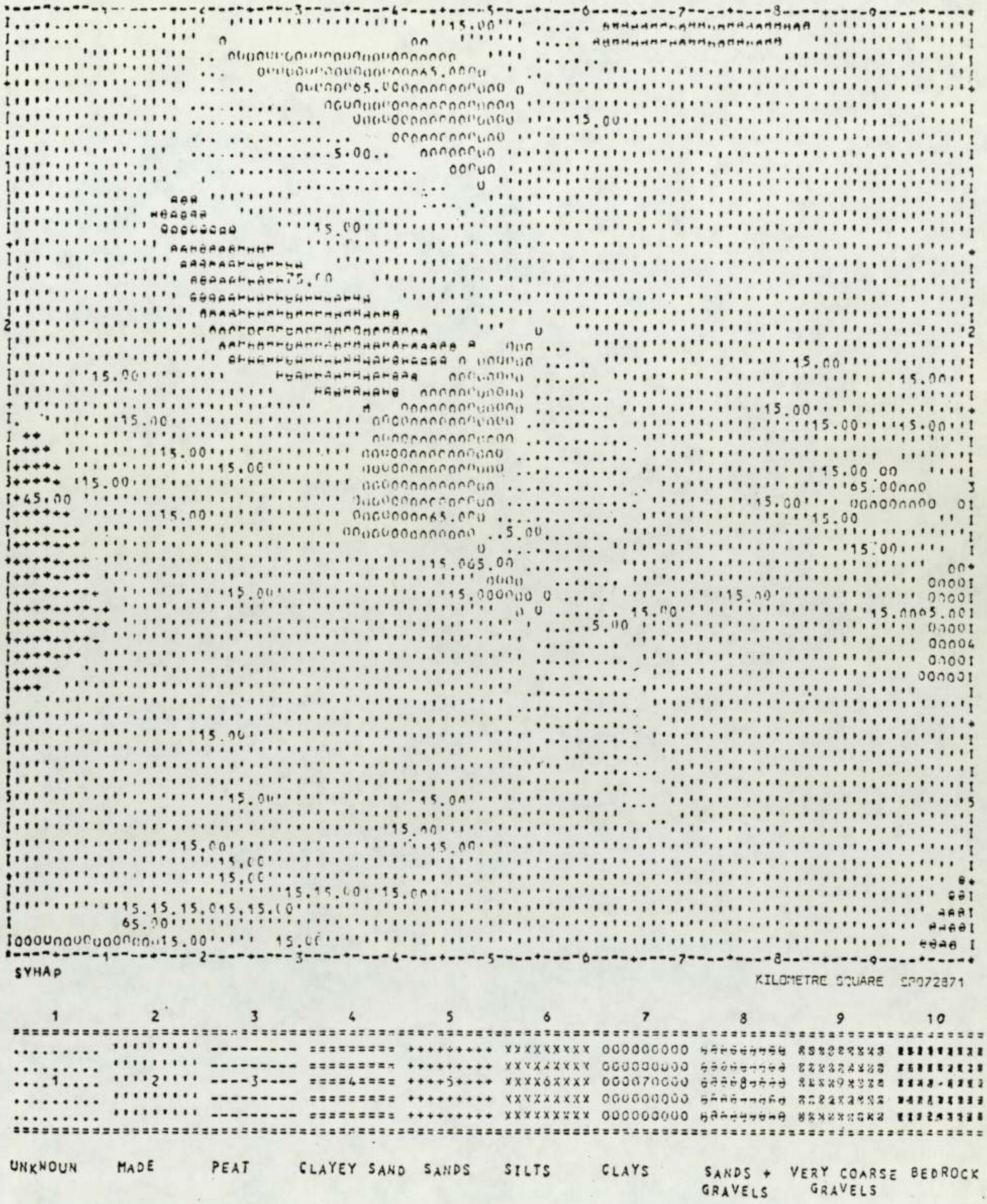
For the purpose of this study only two types of map were produced: proximal and contour.

(i) Proximal.

The proximal option in SYMAP produces maps shaded with symbols indicating the value of the 'nearest neighbour' data point, thus the geometrical figures defined by the boundaries of the area around each data point are close approximations to Thiessen polygons (Haggett, 1965). The use of this method is ideal where the data values, i.e. height etc., do not lie on an interval or ratio scale and the distribution cannot be considered continuous. For these reasons maps can be produced to show, for example, lithology at specified depths below the ground or at specified altitudes.

To illustrate this a series of proximal maps were produced to present a descending picture of the different lithologies below surface level for a one kilometre square SP072871, fig 8.9.1 to fig 8.9.9, with data drawn from the same area as discussed (for the contour maps produced) in section 8.2.1.1. In the area mapped the vast majority of values of overlapped data points reveal the same lithology at a particular depth. However, where two or more data points of different values lie within the area of one printout character, as indicated in some of the printouts fig 8.9.1 to fig 8.9.9, a mean value is determined.

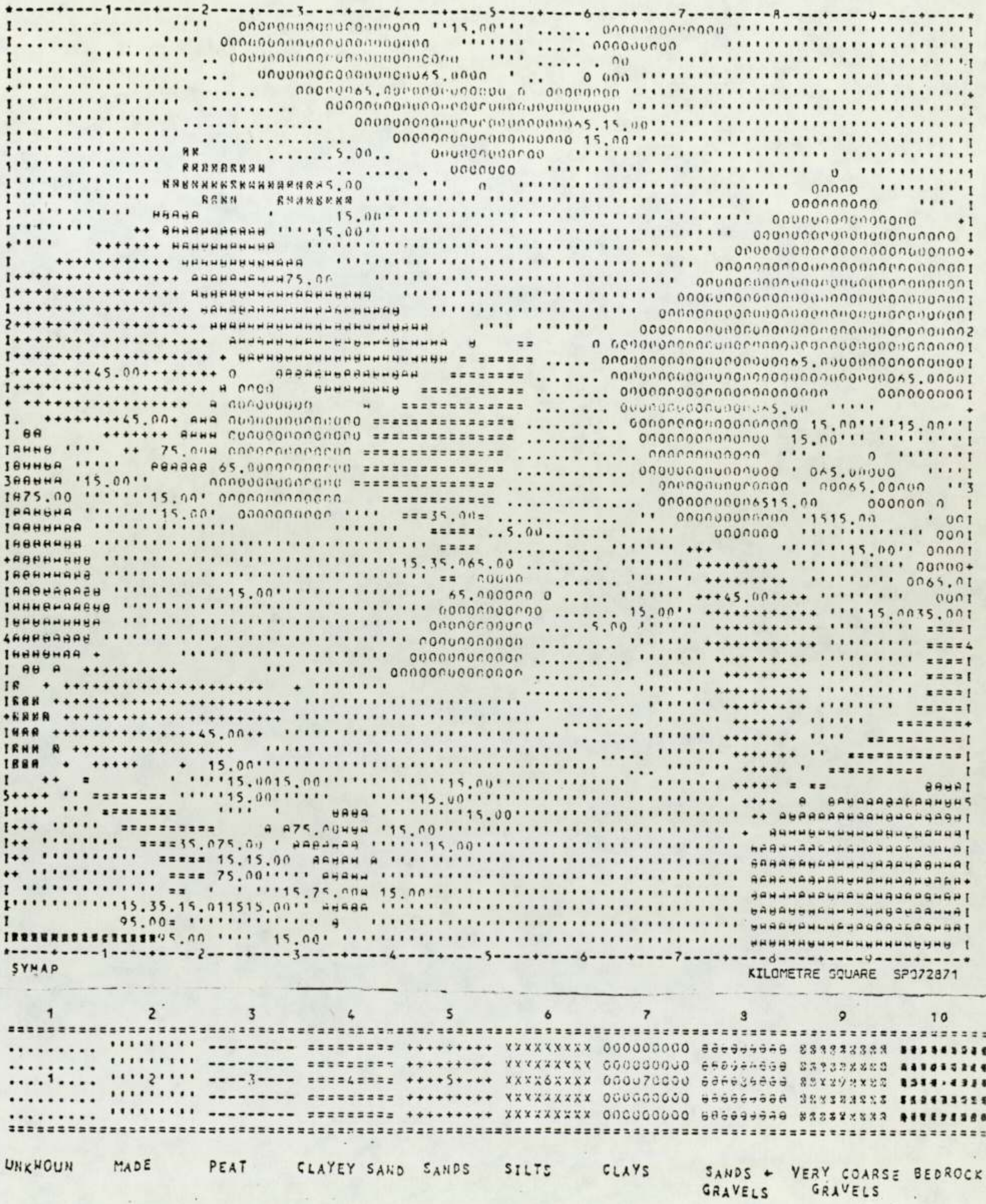
FIG. 8.9 DISTRIBUTION OF DRIFT LITHOLOGIES WITHIN THE KILOMETRE SQUARE SP 072871 AT VARIOUS DEPTHS.



DATA POINTS REPRESENT BOREHOLE LOCATIONS

UNKNOWN DATA POINTS ARE THOSE MORE THAN 0.1KM
AWAY FROM A KNOWN DATA POINT IN THE 1KM GRID SQUARE

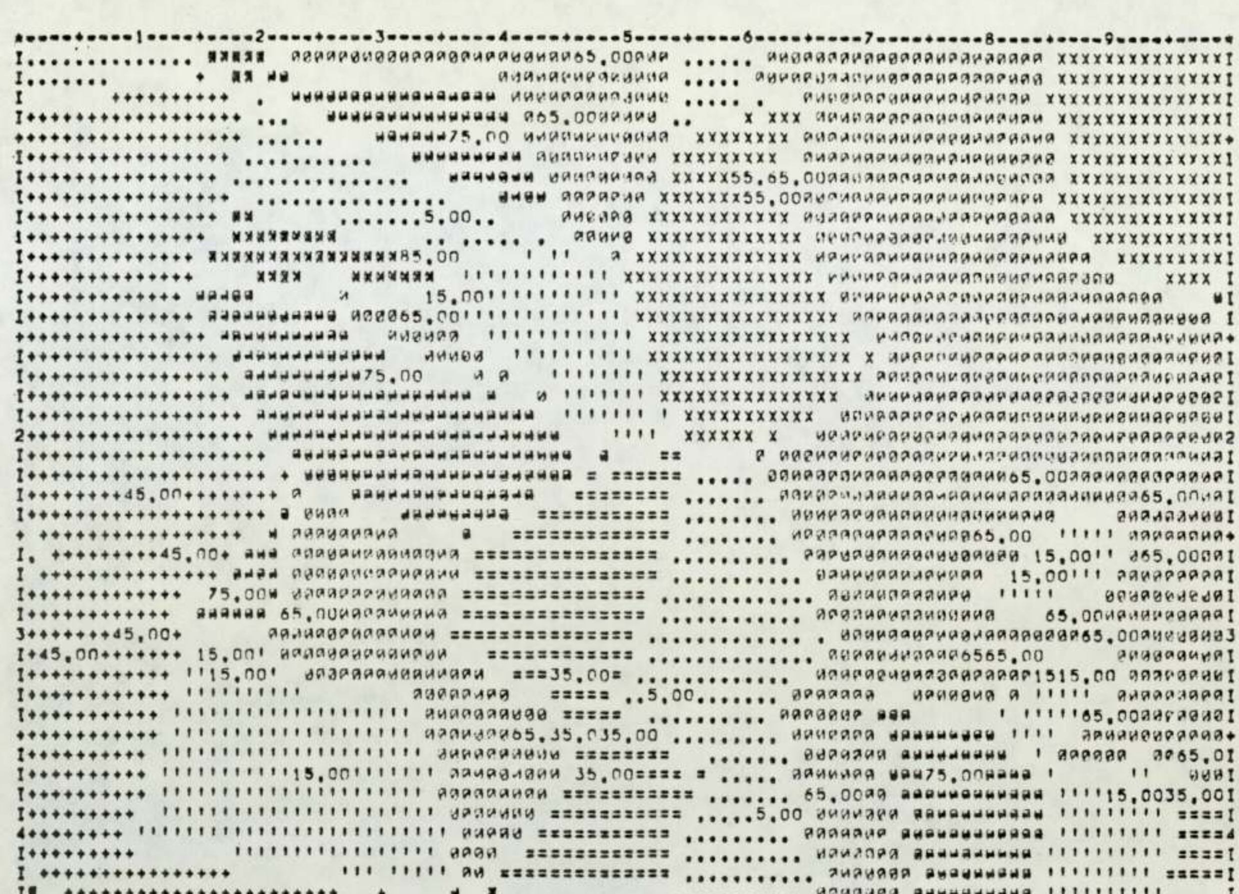
FIG. 8.9.1 DISTRIBUTION OF DRIFT LITHOLOGIES WITHIN THE KILOMETRE SQUARE SP 072871 AT A DEPTH OF 1.0m.



DATA POINTS REPRESENT BOREHOLE LOCATIONS

UNKNOWN DATA POINTS ARE THOSE MORE THAN 0.1KM AWAY FROM A KNOWN DATA POINT IN THE 1KM GRID SQUARE

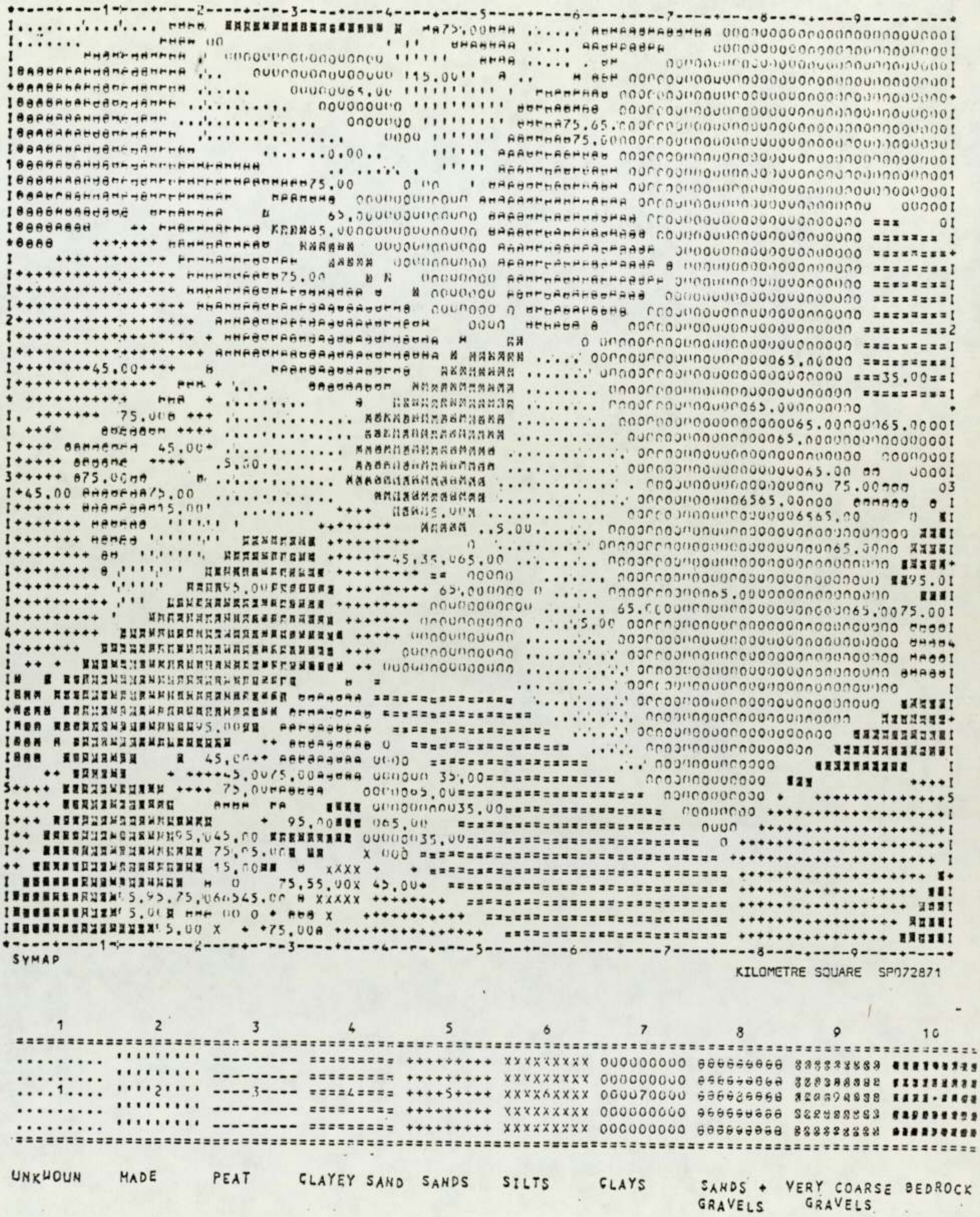
FIG. 8.9.2 DISTRIBUTION OF DRIFT LITHOLOGIES WITHIN THE KILOMETRE SQUARE SP072871 AT A DEPTH OF 2.0m.



DATA POINTS REPRESENT BOREHOLE LOCATIONS

UNKNOWN DATA POINTS ARE THOSE MORE THAN 0.1KM
AWAY FROM A KNOWN DATA POINT IN THE 1KM GRID SQUARE

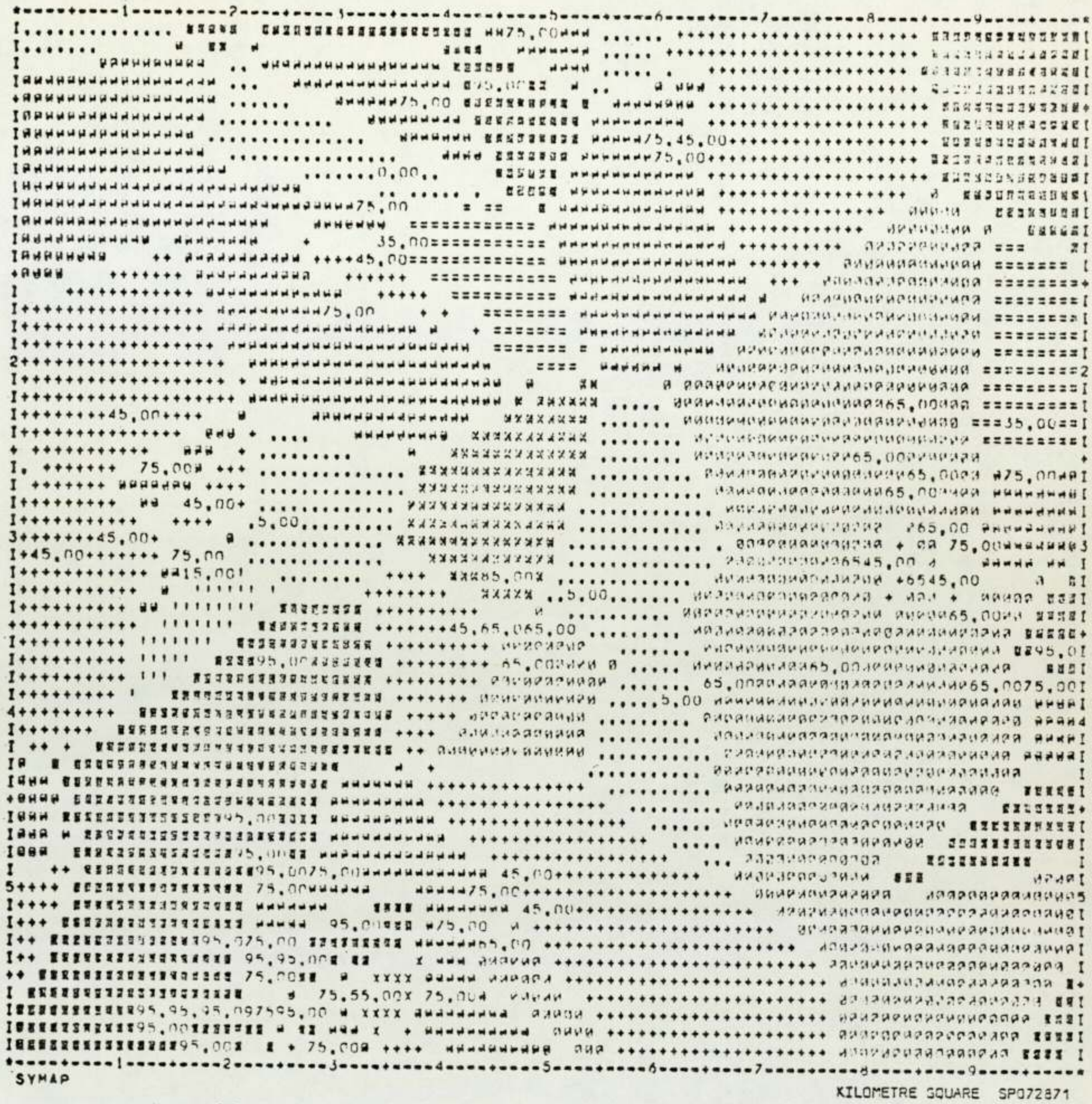
FIG. 8. 9. 3 DISTRIBUTION OF DRIFT LITHOLOGIES WITHIN THE KILOMETRE SQUARE SP 072871 AT A DEPTH OF 3.0m.

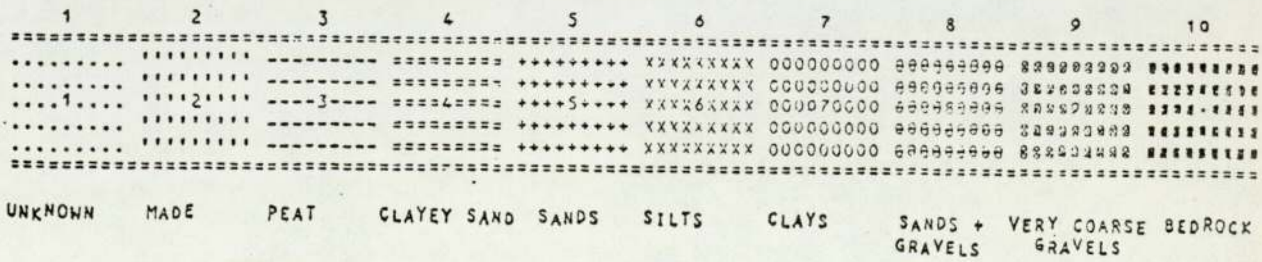


DATA POINTS REPRESENT BOREHOLE LOCATIONS

UNKNOWN DATA POINTS ARE THOSE MORE THAN 0.1KM AWAY FROM A KNOWN DATA POINT IN THE 1KM GRID SQUARE

FIG. 8.9.4 DISTRIBUTION OF DRIFT LITHOLOGIES WITHIN THE KILOMETRE SQUARE SP 072871 AT A DEPTH OF 5.0m.

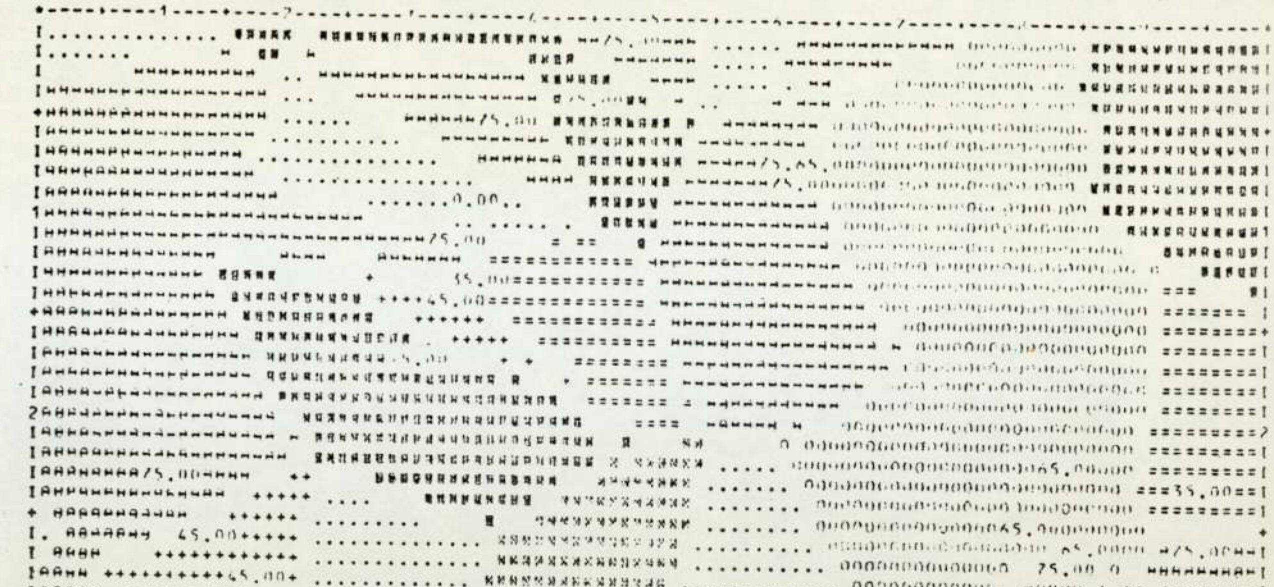


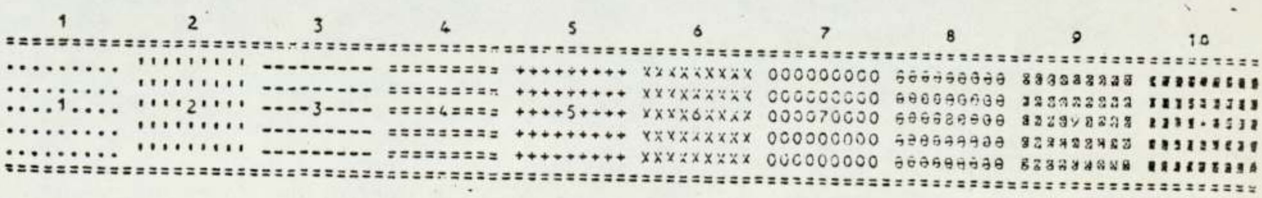


DATA POINTS REPRESENT BOREHOLE LOCATIONS

UNKNOWN DATA POINTS ARE THOSE MORE THAN 0.1KM AWAY FROM A KNOWN DATA POINT IN THE 1KM GRID SQUARE

FIG. 8.9.5 DISTRIBUTION OF DRIFT LITHOLOGIES WITHIN THE KILOMETRE SQUARE SP 072871 AT A DEPTH OF 7.0m.

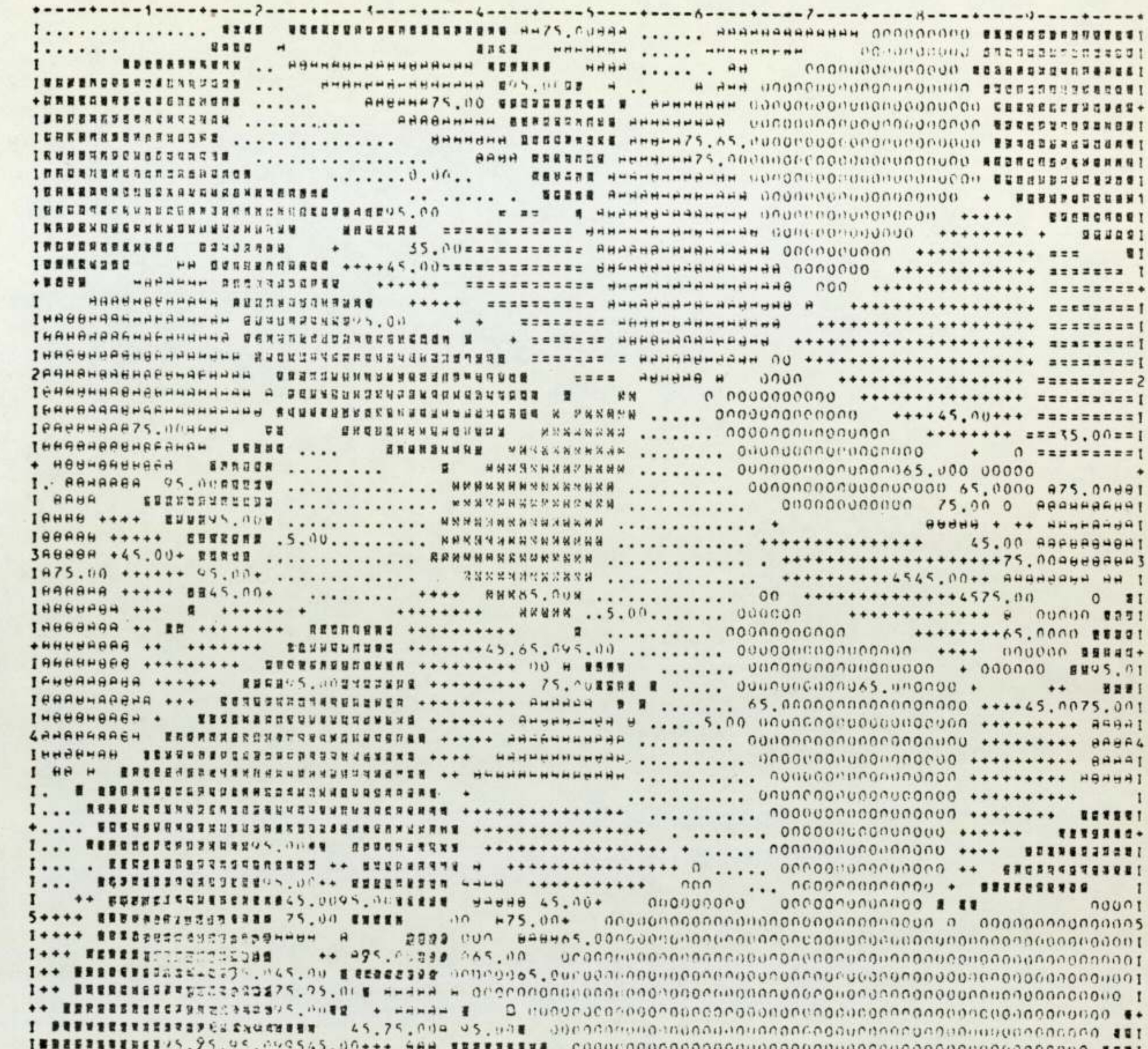




DATA POINTS REPRESENT BOREHOLE LOCATIONS

UNKNOWN DATA POINTS ARE THOSE MORE THAN 0.1KM AWAY FROM A KNOWN DATA POINT IN THE 1KM GRID SQUARE

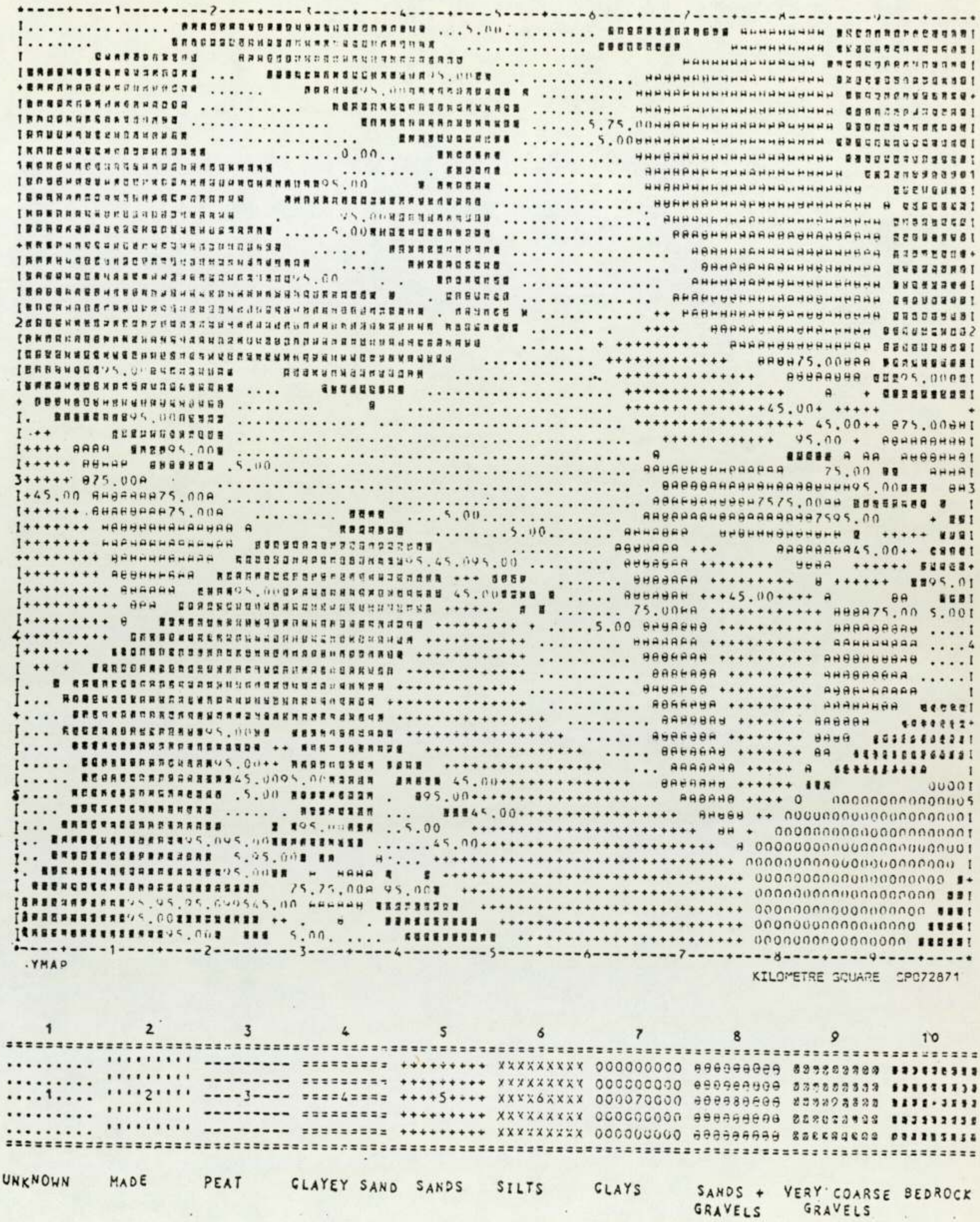
FIG. 8.9.6 DISTRIBUTION OF DRIFT LITHOLOGIES WITHIN THE KILOMETRE SQUARE SP 072871 AT A DEPTH OF 9.0m.



DATA POINTS REPRESENT BOREHOLE LOCATIONS

UNKNOWN DATA POINTS ARE THOSE MORE THAN 0.1KM
AWAY FROM A KNOWN DATA POINT IN THE 1KM GRID SQUARE

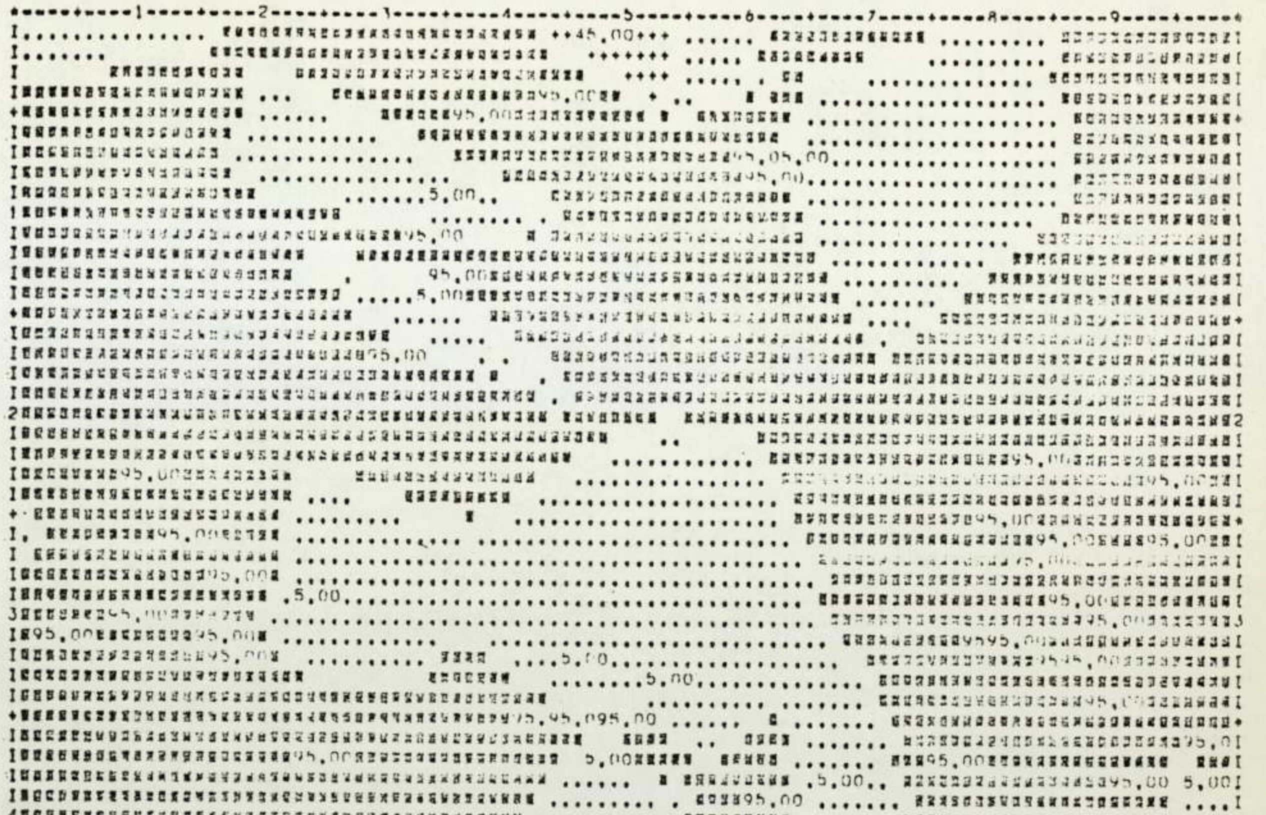
FIG. 8.9.7 DISTRIBUTION OF DRIFT LITHOLOGIES WITHIN THE KILOMETRE SQUARE SP 072871 AT A DEPTH OF 10.0m.



DATA POINTS REPRESENT BOREHOLE LOCATIONS

UNKNOWN DATA POINTS ARE THOSE MORE THAN 0.1KM AWAY FROM A KNOWN DATA POINT IN THE 1KM GRID SQUARE

FIG. 8.9.8 DISTRIBUTION OF DRIFT LITHOLOGIES WITHIN THE KILOMETRE SQUARE SP 072871 AT A DEPTH OF 15.0m.



UNKNOWN | MADE | PEAT | CLAYEY SAND | SANDS | SILTS | CLAYS | SANDS + GRAVELS | VERY COARSE GRAVELS | BEDROCK

DATA POINTS REPRESENT BOREHOLE LOCATIONS

UNKNOWN DATA POINTS ARE THOSE MORE THAN 0.1KM AWAY FROM A KNOWN DATA POINT IN THE 1KM GRID SQUARE

FIG. 8.9.9 DISTRIBUTION OF DRIFT LITHOLOGIES WITHIN THE KILOMETRE SQUARE SP 072871 AT A DEPTH OF 20.0m

The SYMAP program is only capable of categorising data in 10 groups, known as levels. The lithological types were restricted to nine with the first level, '0', used to designate unknown data points, the use of which is discussed below. A level code is automatically printed out at each data point and symbols are employed between data points.

Level	Code	Symbols	Lithological groups
1	5.0	....1....	Unknown
2	15.0	''''2''''	Made
3	25.0	----3----	Peat
4	35.0	====4====	Clayey sand
5	45.0	++++5++++	Sands
6	55.0	XXXX6XXXX	Silts
7	65.0	000070000	Clays
8	75.0	θθθθ8θθθθ	Sands and gravels
9	85.0	[illegible]	Very coarse gravels
10	95.0	[illegible]	Bedrock

Table 8.2 Levels, Codes, Symbols and Lithological groups used for the proximal maps, fig 8.9.1 to fig 8.9.9.

By varying the groupings emphasis could be transferred from one lithology characteristic to another e.g. 3 or 4 symbols could be used to designate clays of differing consistency.

As maps are produced for greater and greater depths the number of data points diminish as the boreholes do not reach the depth. Consequently the reliability of the map diminishes, although the probability of encountering bedrock increases with depth. No attempt has been made to evaluate the adequacy of the data distribution but an 'unknown' category has been included to overcome the problem of data points disappearing with depth. In line with a similar usage by Rhind (1973), areas which are more than 0.1 km away from a borehole are also indicated by this code.

The examples used to illustrate proximal maps, fig 8.9.1 to fig 8.9.9, infer the distributions of lithologies at depths of 1m, 2m, 3m, 5m, 7m, 9m, 10m, 15m and 20m below surface level.

This facility of SYMAP was thought to be suitable for the production of lithological cross sections. A very simplified version is illustrated in fig 8.10, where the vertical logs of ten boreholes, defined by their recorded borehole reference numbers, are presented as a ribbon section. The same symbols are used for this version of the proximal type maps as discussed above, with one exception. In this case no 'unknown' value has been included, instead this value has been used to differentiate surface level. The vertical scale, Ordnance Datum levels in metres, is obviously exaggerated; which accounts for the steep 'steps' between boreholes. No attempt has been made here to introduce a smoothing factor to these 'steps' although a D-BARRIER has been employed.

The D-BARRIER package was used in fig 8.10 to provide a

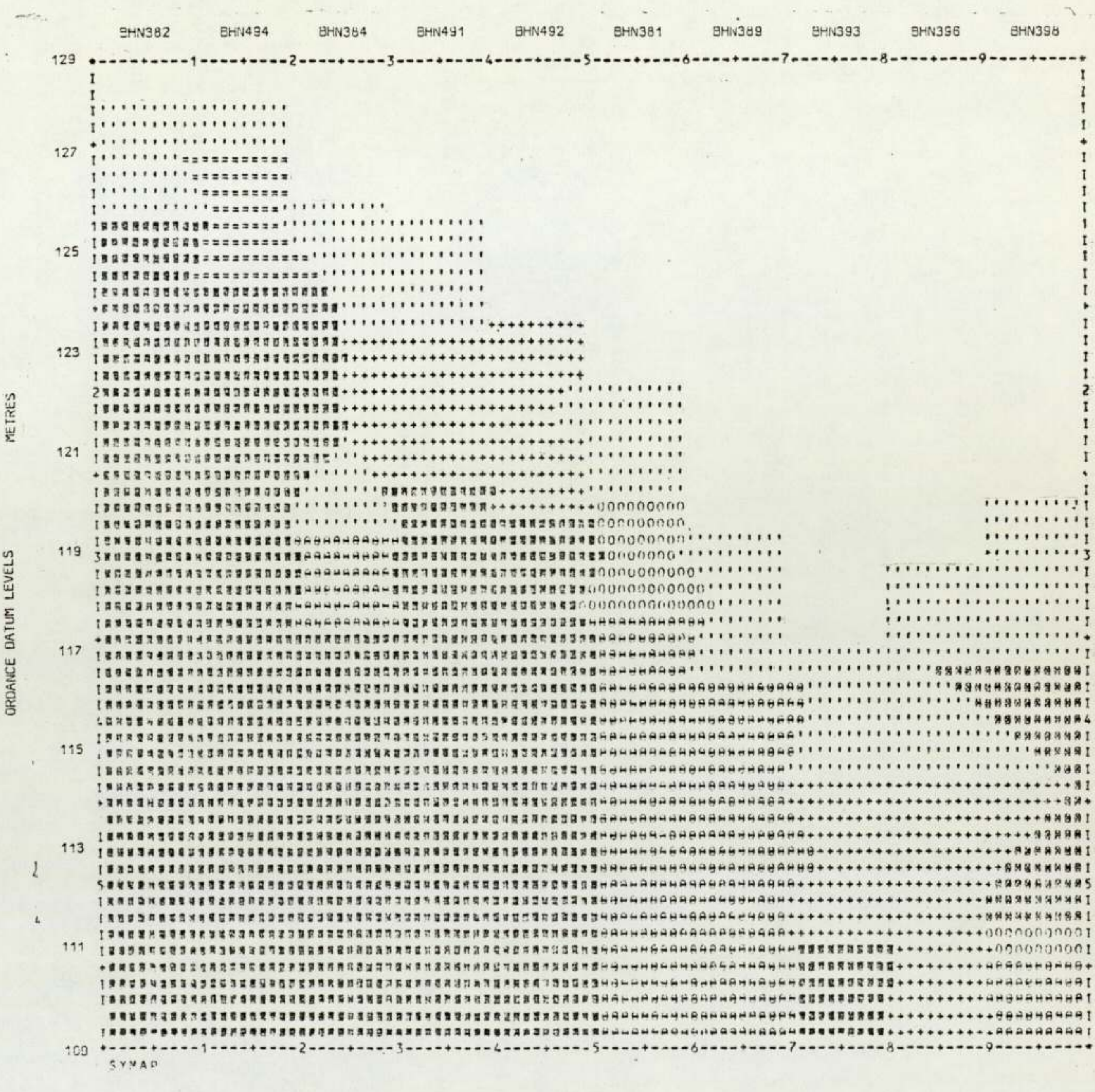


FIG. 8.10 A LITHOLOGICAL SECTION

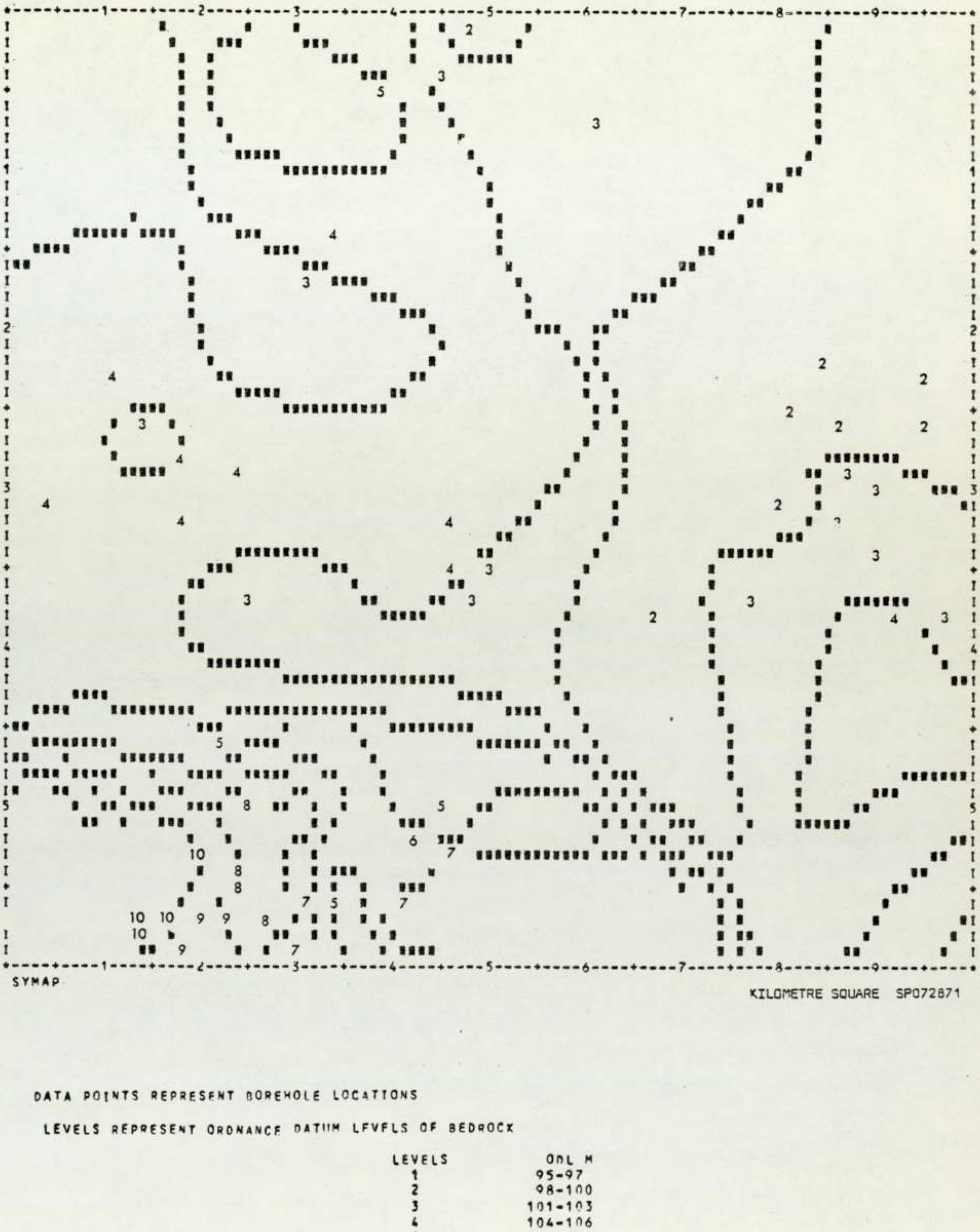
barrier to interpolation between certain data points. A barrier may be used to modify the computers distance - orientated interpolation in order to reflect the probable effect of an obstacle, such as a body of water, a geological fault etc. To allow no interpolation to be made between the atmosphere and the borehole lithologies an impermeable barrier was used, preventing 'overhanging cliffs' of the surface profile, which may have been produced due to interpolation between the atmosphere and a lithology data point.

No allowance was made for the differing surface distances between each borehole and further work is required to investigate the use of the D-BARRIER package to impose barriers of varying permeabilities related to the distance between adjacent boreholes. The greater the distance the more impermeable the barrier should be. The size of the map could also be increased to allow scaling of the distances between boreholes. However, although there is no set limit to the dimensions which may be specified a safeguard is incorporated into the program to allow for user error and to prevent any dimension of the map exceeding 72.0 inches.

In this study the size of the final map was limited to ease reproduction problems and minimise the running costs, the latter to be discussed in the following chapter.

(ii) Contour.

As previously discussed this facility of SYMAP should be restricted to the representation of continuous information. To illustrate this a map was produced of the sub-glacial drift topography to Ordnance Datum, for the kilometre square SP072871, fig 8.11.



DATA POINTS REPRESENT BOREHOLE LOCATIONS

LEVELS REPRESENT ORDNANCE DATUM LEVELS OF BEDROCK

LEVELS	ODL M
1	95-97
2	98-100
3	101-103
4	104-106
5	107-109
6	110-112
7	113-115
8	116-119
9	120-122
10	123-126

FIG. 8.11 THE SUBGLACIAL DRIFT TOPOGRAPHY TO ORDNANCE DATUM FOR THE KILOMETRE SQUARE SP 072871

This map is to be compared with fig 8.5, produced by the program CONTUR (after Davis, 1973), from the same data source and for the same area. Although the production of this type of map using the SYMAP program is more costly than the CONTUR version, it can be produced as part of the procedure for the production of a three dimensional projection such as fig 8.12.

The close similarity of the contour patterns illustrated by the CONTUR and SYMAP versions is very noticeable. There are two major features illustrated clearly in each of the maps. The first a broad shallow valley running northeast and easily discernible in the northeast quarter of the kilometre square; and the second in the southwest corner of the kilometre square, where a rapid increase in gradient to the southwest is marked by the closeness of the contour lines which are also quite complex in form.

The SYMAP version appears, at first glance, the more simple and the more comprehensible. However, where contours are plotted close together it is not an easy task to discern one from another. With the CONTUR version, although complex, close contours can be differentiated.

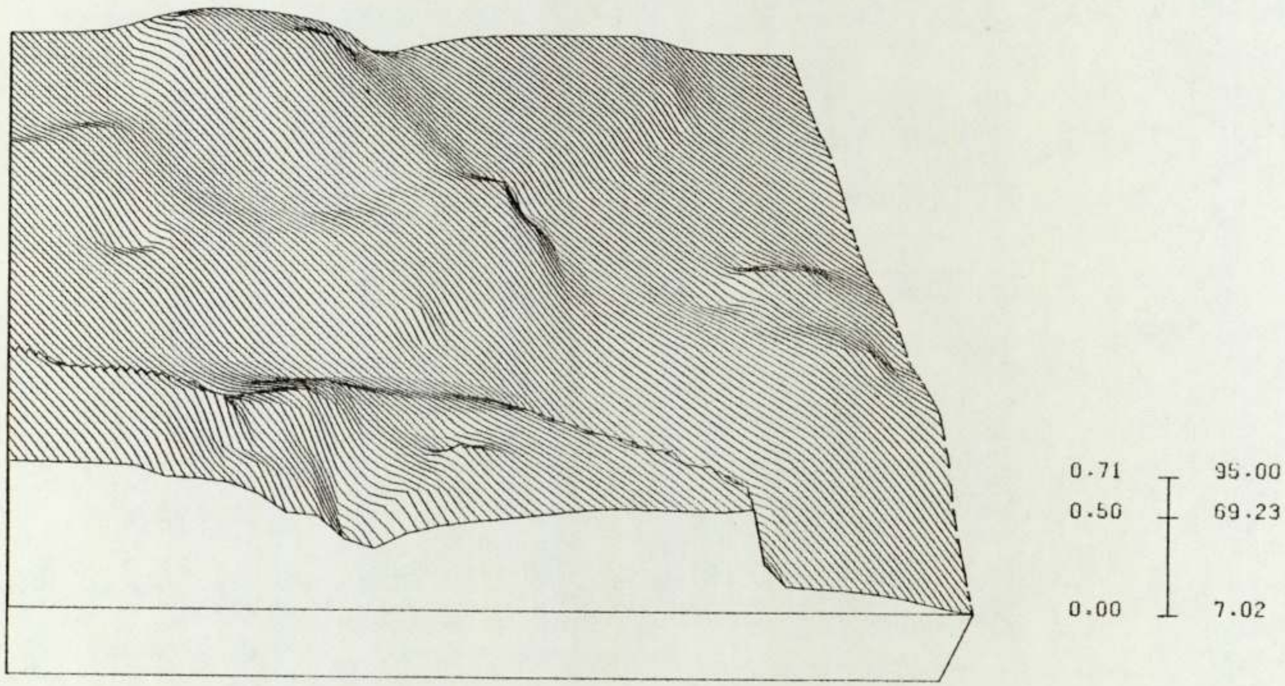
8.2.2.3. SYMVU.

The purpose of this program is to generate three dimensional line-drawing displays of data. It is commonly used for quantitative geographic mapping purposes and illustrates the absolute values of spatially continuous data, unlike contour maps which use rounded intervals for mapping displays of quantitative information. One of the major accomplishments of this program is that it can decide which parts of the object being viewed are seen and which are hidden from view.

The program utilizes information placed in the format of a grid matrix generated either by SYMAP or supplied directly in a matrix. The advantage of using SYMAP is that data are taken from point or area locations and interpolated producing spatially continuous surfaces organised into a grid format, which can then be immediately utilized by SYMVU.

The SYMVU program has three primary control cards which specify which of the thirty-five electives built into the program are required. The first card is the title card and is completely flexible using the 'A' format. The second card, using the 'I' format, specifies which of 25 electives are to be used to denote: the size of the data matrix, the type of drawing (orthographic projections or two point perspectives), direction of lines drawn across the matrix, symbols, scale factors etc. The third card has the four primary variables that control the size and viewing angles of the plot specified using the 'F' type format. There are a number of optional data cards which can also be used which enable the remaining electives to be used to define: the symbol point and type, legend specifications etc.

Utilizing the data supplied for the production of the contour map, fig 8.11, the three dimensional line drawing, fig 8.12 was generated. This illustrates the sub-glacial drift topography to Ordnance Datum, for the kilometre square SP072871 viewed at an altitude of 45° above the horizontal plane and at zero azimuth, i.e. looking north along grid line 077. The topographic surface is seen resting on a half inch block or base,



BEDROCK TOPOGRAPHL ODL OF NGR SP 0720 0820 8710 8810 VIEWED FROM SOUTH

AZIMUTH = 0 ALTITUDE = 45
*WIDTH = 5.00 *HEIGHT = 1.00

* BEFORE FORESHORTENING 04/11/75

FIG. 8. 12 A THREE - DIMENSIONAL LINE DRAWING OF THE SUBGLACIAL DRIFT TOPOGRAPHY TO ORDNANCE DATUM FOR THE KILOMETRE SQUARE SP 072871 VIEWED FROM THE SOUTH.

a purely arbitary choice illustrating one of the electives available.

Such three dimensional line drawings cannot be regarded as having the same precision as the maps but have substantial value as illustrations. The usefulness of this type of presentation is easily appreciated especially if the area of the map was extended, as intended, to cover an area such as the total study area. This could possibly be a useful tool for research, especially into preglacial geomorphology.

9. DISCUSSION AND EVALUATION.

9.1. Introduction.

At this stage in the development of the system certain advantages and disadvantages have become apparent and attention is drawn to the more important of these. The transference of the data onto the data preparation sheets highlighted many limitations in the original descriptions. Despite wide variations in terminology the classifications evolved were adequate to ensure no loss of detail. Particular attention is paid to the time involved in the collation of the data. These three items have inevitably restricted the total volume of data recorded and by the very nature of the origin of the data their distribution is sporadically clustered. The subsequent computer outputs by either line printer or graph plotter are used to present simple and collated factual data, and interpretations of the data.

Sufficient work has been done to indicate the effectiveness of the techniques, especially in the production of contour maps on the line printer and the simple location plans produced on the graph plotter. The commercial costs involved in the system have however, proved difficult to ascertain.

The extent of this study is also such that lines of further development can be suggested.

9.2. Aspects Of Data Handling.

9.2.1. Data Collation and Validation.

The data to be processed by a computer has to be stored in a form as congruous as possible to the processing and retrieval needs of the user, and at the same time compatible with current methods of recording field observations. The system developed allows data to be transferred from detailed borehole logs onto a series of data preparation sheets. These were the result of a modification of similar data preparation sheets proposed by the Institute of Geological Sciences at the commencement of this study. They were designed to simplify the transfer of data from a borehole log onto the data preparation sheets. Eleven types of data preparation sheet were evolved though some were more frequently used than others. The Mineralogy, Sample Lithology and Subsidiary Lithology preparation sheets were rarely used, but it was felt that valuable data could be lost if these were not included and they would be most certainly used in the future. These then enabled the data to be stored in such a way that retrieval can be rapidly and easily accomplished on a geographical basis or through a borehole reference number.

The standard and often the detail of the data collected could be related to the age of the record, the older records being more dubious in quality and certainly briefer. Many of these records had to be excluded from the system because they lacked a surface level measurement. However, many of the more recent records were also deficient in some respects and the inclusion of an indication of the reliability of the data is essential. Although no such indication is presented on the outputs included here, it would be a simple addition to either the line printer or graphic presentations.

From the records employed it is apparent that much more care is needed in the definition and recognition in the field, of stratigraphy, lithology, colour, and mineralogy as well as in the recording of numerical data such as surface level to Ordnance Datum.

A large proportion of the information collated required careful consideration in determining exactly what was meant by the use of certain terms. This applied in some cases to quite recent records although guidelines have been recently published on the logging of rock cores for engineering purposes (Anon., 1970) and on the preparation of maps and plans in terms of engineering geology (Anon., 1972) in this country. In Canada similar work has been carried out by Brisbin and Ediger (1967), to standardise definitions etc. for the Canadian National System for the Storage and Retrieval of Geological Data. As it will be some time before all such recommendations are fully implemented, some limitations in the recording of borehole information will continue to be present. If these are not recognised and suitably amended before information is transferred onto computer files, many discrepancies could arise.

The time involved in the collation of the data was not only increased by the necessary close scrutiny of all the records, but also, as much of the data was recorded in Imperial Units, metrication was required. The coding of the descriptive part of the borehole then had to be carefully performed.

It can be argued that the time needed to transfer a borehole log from a site investigation report onto a computer file through the various process stages of validation, metrication, and coding could be reduced by the use of recognisable words instead of codes (see 9.4.1.). However, towards the end of the research period, when the author was completely familiar with the codes, an average borehole of say 15m depth with a full lithological description and test results could be transferred onto the data preparation sheets in approximately 20 minutes, no longer than if the descriptive parts were transferred with the use of recognisable words. Obviously the time needed for this familiarisation has limited the total number of boreholes recorded.

9.2.2. Classification.

The necessity for uniform descriptions and standard terminology in the logging of boreholes soon became apparent during the collation and transfer of the data from the borehole logs onto the data preparation sheets. Many descriptions of the lithologies encountered employed locally derived terminology, which if retained in the system could only lead to confusion. The lithological nomenclature chosen was based on characteristics which can be precisely measured or accurately estimated for descriptive purposes to give a general indication of the physical properties of the soil, namely particle size distribution and plasticity. The conversion of these descriptions into the classifications described previously were found to be suitably exact, and with the use of the numeric codes every description was transcribed with no loss to that of the original. Where locally derived terms were encountered the author's 'local knowledge' had to be employed in an interpretative manner.

The recommendations of the Engineering Group Working Party of the Geological Society of London (Anon., 1972) were followed, with the exceptions of colour, and weathering, where the recommendations of the earlier working party (Anon., 1970) were accepted. No inadequacies in these classifications arose during the period of this study.

9.2.3. Data Distribution.

The area chosen for the study provided a sufficient density and variety of information to demonstrate the value of the system. The drift encountered provided a wide range of lithologies, which in turn provided numerous in situ and laboratory test results reflecting these differing lithologies. Of the three bedrock formations encountered, the Keuper Marl, the Lower Keuper Sandstone and the Bunter Sandstone, the former provided the larger proportion of the test results reflecting the amenability of the weathered zone to investigation by conventional sampling and laboratory testing.

Although it was not possible to provide a uniform distribution of data of a sufficient density for all presentation types to be illustrated for the whole of the study area, sufficient data have been collected for certain parts to be used to display the various outputs to their best advantage. It was also unfortunate that the data distribution throughout the study area was not of sufficient density and uniformity to validate the use of the contouring programs. However, because of the compatibility between the manually produced contour map, fig 8.8. (after Horton, 1975) and that produced by the computer program, CONTUR (after Davis, 1973), the viability of the techniques employed, although not proven statistically, appear well founded. It is likely that the statistical viability of the data distribution employed for the manual map is also very low.

9.3. Computer Techniques.

9.3.1. Introduction.

The two methods which were used for the pictorial presentation of data were the line printer and the graph plotter. The line printer is an obvious choice for the output device as most computer installations have linked, remote, line printer terminals and it is definitely the cheaper of the two. However for simple straightforward locational type outputs the graph plotter has been used.

9.3.2. Factual and Collated Data.

Data are easily located according to predefined requisites and extracted from the data bank using simple search routines. Different outputs are produced with the aid of the I.C.L. graph plotter routines, which are excellent for displaying properties by the use of symbols, numerals and letters. In the outputs produced, the availability of data is immediately apparent and the ease with which correlations can be made between one output and another is similarly clear. These outputs provide a complete geological and geotechnical representation of a required area with no interpretation of the data.

The need to be able to present data to a user in a form similar to that of a site investigation report is adequately satisfied by the use of the line printer geological log, fig 7.14.1, and the in situ and laboratory test log, fig 7.14.2. The natural extension of these two logs into the geotechnical section is cheaply and efficiently produced on the graph plotter. The parameters illustrated on the geotechnical section, fig 7.15, serve only as an example of what may be produced. It can be easily expanded to include any number of boreholes and could be scaled both laterally and vertically, and used to illustrate any predefined parameters.

Further collated information is presented using the graph plotter for histograms or x - y graphs, which can be used to illustrate regional characteristics.

Many of the data presentations, especially those illustrating the whole of the study area need only be produced once; photocopies can then be used to transmit the necessary information to the user. These will require updating following the addition of substantial data. In this way immediate verbal answers could be given to many requests by simply referring to a set of basic outputs which could include the following:

- (i) stratigraphy reached by each borehole;
- (ii) thickness of fill;
- (iii) thickness of drift;
- (iv) thickness of total cover to bedrock;
- (v) bedrock surface topography to O.D;
- (vi) drift lithology at various levels below the surface;
- (vii) chemical analysis - evidence of 'bad' spots;
- (viii) areas of high moisture content - soft areas.

There is really an almost unlimited scope for outputs of this type which can be considered in the future, these may even include qualitative bearing capacity and settlement maps for specific situations.

9.3.3. Interpreted Data.

Several display packages were investigated and from these, two were found to be more suitable to display data on a line printer output rather than the more expensive graph plotter. Data are extracted from the data bank according to predefined requisites in the same manner as for factual data and with the use of the programs CONTUR (after Davis, 1973) and SYMAP (Fisher, 1968), contour maps were produced which are excellent in terms of their clarity. Although, as described above, the data distribution available was not altogether suitable for the packages used, this type of computer output is perfectly viable provided the data distribution is evaluated and quoted. However, the production of the contour map for the study was paramount in illustrating the relative accuracy of the program CONTUR by the comparison with the manually produced maps. The same follows for the program SYMAP as this program accepts data from points at irregularly spaced intervals and similarly interpolates the contour values by the nearest neighbour method. In SYMAP each character space is calculated by interpolating from a minimum of five and a maximum of ten data points defined by a search radius, whereas CONTUR uses the six nearest data points. SYMAP holds a distinct advantage over CONTUR as it can deal with non-rectangular areas. It also has in addition the ability to produce three dimensional projections.

9.3.4. Commercial Costing.

Whilst investigations were made to assess the real cost of setting up this system commercially no organisation was willing to provide figures on which to base such an assessment. The University's internal rates of charges do not lend themselves readily comparable with those of a private organisation and are thus no guide.

In order to express these costs to a user the costs of the developed programs can be approximately determined. Simple search and location plots can be produced for a few pounds with the more complex contour maps being more expensive. However once any plots or maps are produced from existing programs, these can then become master copies with photocopies then providing a very inexpensive means of passing the information on to the user. This would not only minimise the running costs but costs of producing say one map could be proportioned between many users.

The larger part of the total manhours accumulated in reaching this stage of the study was involved in transferring the information from the original logs onto the data preparation sheets, the costs of which may possibly far outweigh the computer costs.

This could easily be saved, once the system is on a commercial footing, by the users (Civil Engineering Contractors) providing new information directly on the data preparation sheets. However, the time saved at the pre-investigation stage if data are retrieved from the computer in comparison to the amount of time involved in manual searches is obvious. Even where organisations have a significant amount of data in a well ordered filing system there would still be a time saving advantage plus the added benefit of access to a larger body of data.

It is felt therefore that there must be considerable cost advantages, especially if the data supplied leads to more economic site investigation, foundation design and construction.

9.4. Further Developments.

9.4.1. Future Research.

The immediate concern is to continue the build up of the system by collating data over larger areas to form a basis for a regional data bank. This can then be used to present collective data interpretations of the geotechnical properties of the materials present in a region. Some progress was made in this study, as is illustrated in figs 7.16.1 and 2, and 7.17.1 and 2, and it was hoped to be able to extend this work in a manner similar to that of Horton (1975).

Modifications of existing presentations would enable more detailed data to be illustrated. For example the geotechnical section, fig 7.15, could incorporate a scaling factor for the lateral separation of the boreholes, and more parameters included to bring it into line with currently accepted, manually produced, geotechnical sections.

Specialist information, such as extensive groundwater records could be obtained from the Institute of Geological Sciences and the Regional Water Authorities, to enable accurate regional groundwater contour maps to be produced. At this stage of the study the collated groundwater data only permits the levels to be plotted as in figs 7.4.1 and 2, to serve as an indication of areas where groundwater may be a problem. With this form of presentation there is always the possibility of overlapping of data values in areas of high data density. A system could be introduced to select information for averaging, or to utilize symbols which denote either a value or a range of values for the water level (either as depth below surface or to O.D.).

Several systems have been recently developed which utilize recognisable character strings or words (Gover et al., 1971, Rhind and Sissons, 1971). The latter experimented with coding and card punching, and showed that the operators, found the work much less demanding, proceeded more quickly, and made fewer mistakes where recognisable character strings (i.e. words) were employed. This confirmed Brisbin and Edigers (1967) contention that any computer time or storage saved by entering data using unfamiliar codes is more than offset by factors affecting the costs and accuracy of recording the data in the first place. However, fixed length mnemonics are easier to deal with, cost less and need less storage space in the computer than variable length words, and, as the author discovered, operators can soon become familiar with simple codes. One possibility may be the use of a standard set of recognisable abbreviations formulated by the omission of vowels, e.g. BLCK SHL for Black Shale. This may solve two problems; one the characters would be recognisable by the punch card operators, and two the optimization of available storage space. As one of the aims of this study is to produce a regional data bank which can be incorporated into a national system, work is obviously required to determine the best method of recording this type of descriptive data, and to ensure compatibility with other systems.

There is obviously a need to develop a field recording sheet, either compatible with the data preparation sheet used in this study, or one which will only require a minimum of time for information transfer onto data preparation sheets ready for computer processing. If such forms were used by Civil Engineering Contractors, etc., the financial savings would be advantageous to the user.

Considerable difficulties were encountered with the computer contouring systems CONTUR and SYMAP, which use data directly to produce contour maps of areas which may be of highly concentrated or unduly sparse in borehole information. This problem can be alleviated by devising a program to test the nature of data distribution to see whether it is acceptable for the production of contour maps. When sufficient information is available, with the necessary data distribution, it would be highly desirable to produce not only a computer contour map of the bedrock topography of the West Midlands region, but also a three dimensional projection. An apparent weakness of both programs is that they are unable to extrapolate beyond data points, and the contours, produced purely by interpolation, may provide a smoothed version of the topography (see section 8.2.1.). A program is obviously required which is capable of extrapolation and yet still be able to produce contour maps economically. Further developments of these contouring programs could produce presentations similar to fig 8.10, the lithology cross section, to illustrate geotechnical properties such as plasticity, strength, compressibility, etc.

Other desirable modifications would be the inclusion of routines for the calculation of parameters useful in lithofacies analysis and especially statistical analytical routines such as the ROCDOC package (Loudon, 1967).

Utilizing the recorded data variations in engineering properties with changes in elements of the lithology could be studied, e.g. the variation of shear strength with varying percentages of clay and sand; the variation of shear strength with mineral content.

Where regional trends are required to be determined, as opposed to local anomalies, trend surface analyses could provide a suitable form of contour plot for exploratory or academic purposes, especially where data points are thinly scattered. It would also be advantageous to present spatial orientation data in the form of stereograms for both regional and locally derived information. The author is fully aware of the benefits to industry in establishing this system on a commercial basis and the need to investigate fully the optimization of data storage facilities and retrieval mechanisms.

9.4.2. Commercial Use.

It is obvious that this system could not provide a free service, and any type of information retrieval would have to be charged to the client. However, where data are requested at the planning stage of a site investigation it could be expected that new data would be forthcoming as a result of the investigation and hence such information could be supplied at a suitably reduced rate.

The major supplier of information, Birmingham City Council, as well as the new West Midland County Council would be amongst the authorities who would benefit from the extension of the scheme and would no doubt supply information in the future. Problems may arise in the private sector where contractors or their clients may be unwilling to allow information produced at their expense to be made available to others at a comparatively cheap rate. This could be overcome, to some extent, by the assurance that only real data are used and no contractors' or consultants' interpretations or recommendations would ever be incorporated into the system.

It is essential that the user realises that data obtained from the system constitute only a small part of the pre-site investigation search. It is only intended to provide such data as it can, immediately, for consideration in the design of a specific investigation.

9.5. Conclusion.

A system has been developed which allows data derived from the logs of boreholes to be efficiently and rapidly stored and retrieved using computer data files. The data are recorded, with the aid of several classifications, in a similar form to that in which information is described and recorded in the field.

To demonstrate the feasibility of the system information was obtained from the most readily accessible source, and because of the length of time involved in obtaining this information the data are restricted to the Birmingham area. It can be argued that this present system is biassed towards the requirements of the records collected for the strata encountered in this area, but the system is flexible enough to incorporate records from any area.

If data are available the system provides background information to the user enabling clear objectives to be formulated for any site investigation. The information can be presented in many different ways, either in forms which clearly convey the factual information which the user can then interpret to meet his specific needs, or in forms involving the use of various interpretative routines.

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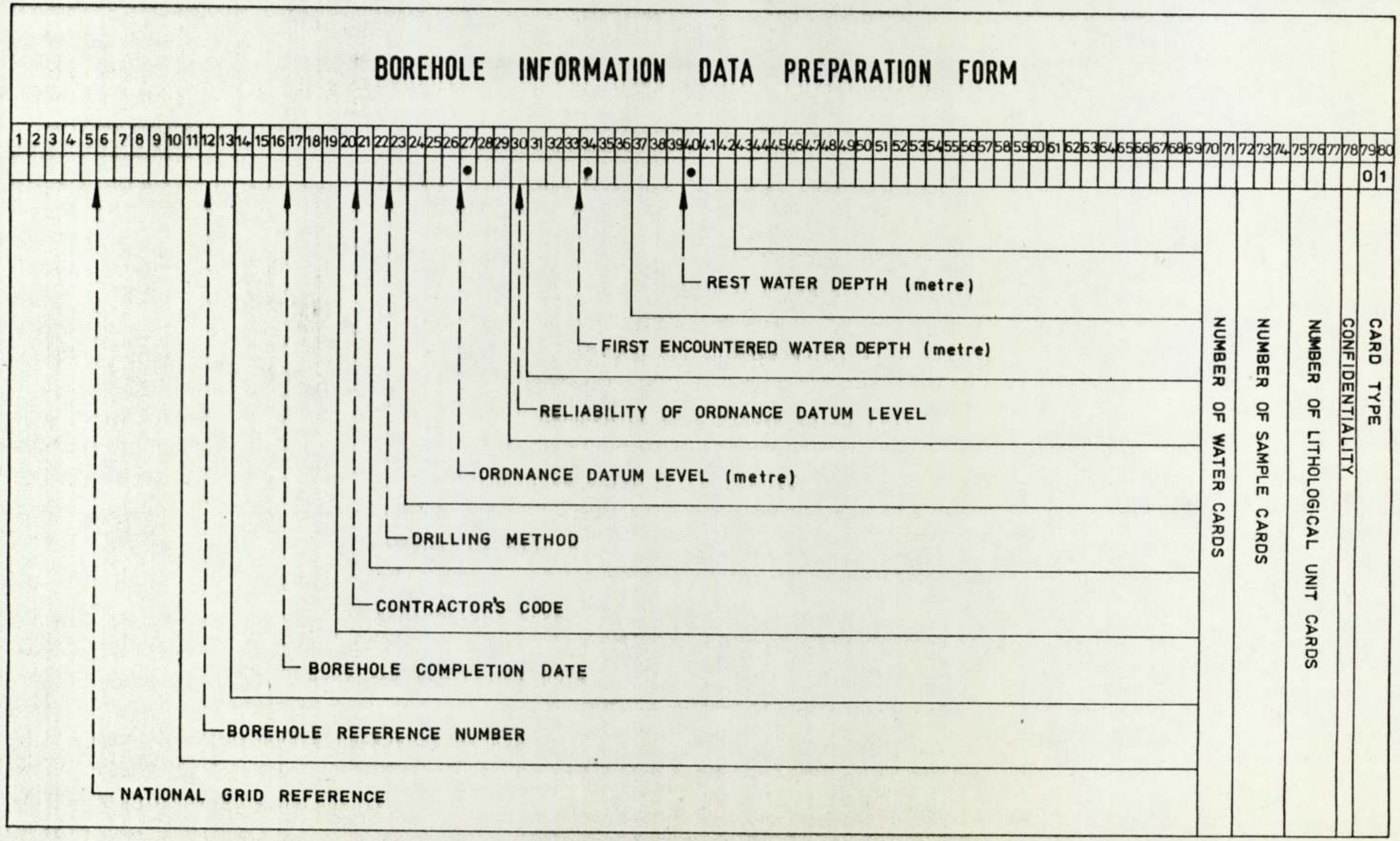
APPENDIX I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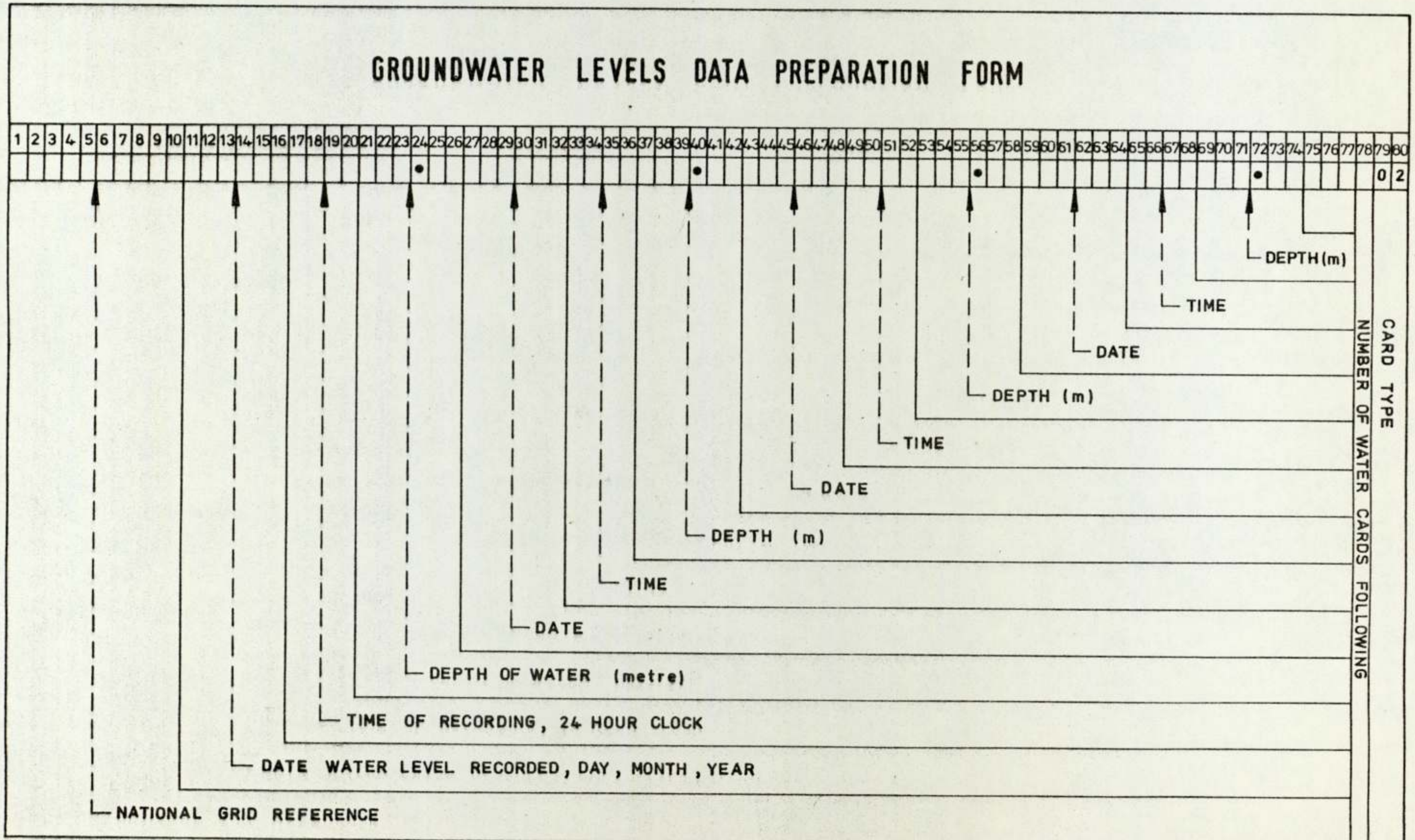
0 1
REST WATER DEPTH (metre)
FIRST ENCOUNTERED WATER DEPTH (metre)
RELIABILITY OF ORDNANCE DATUM LEVEL
ORDNANCE DATUM LEVEL (metre)
DRILLING METHOD
CONTRACTOR'S CODE
BOREHOLE COMPLETION DATE
BOREHOLE REFERENCE NUMBER
NATIONAL GRID REFERENCE
NUMBER OF WATER CARDS
NUMBER OF SAMPLE CARDS
NUMBER OF LITHOLOGICAL UNIT CARDS
CONFIDENTIALITY
CARD TYPE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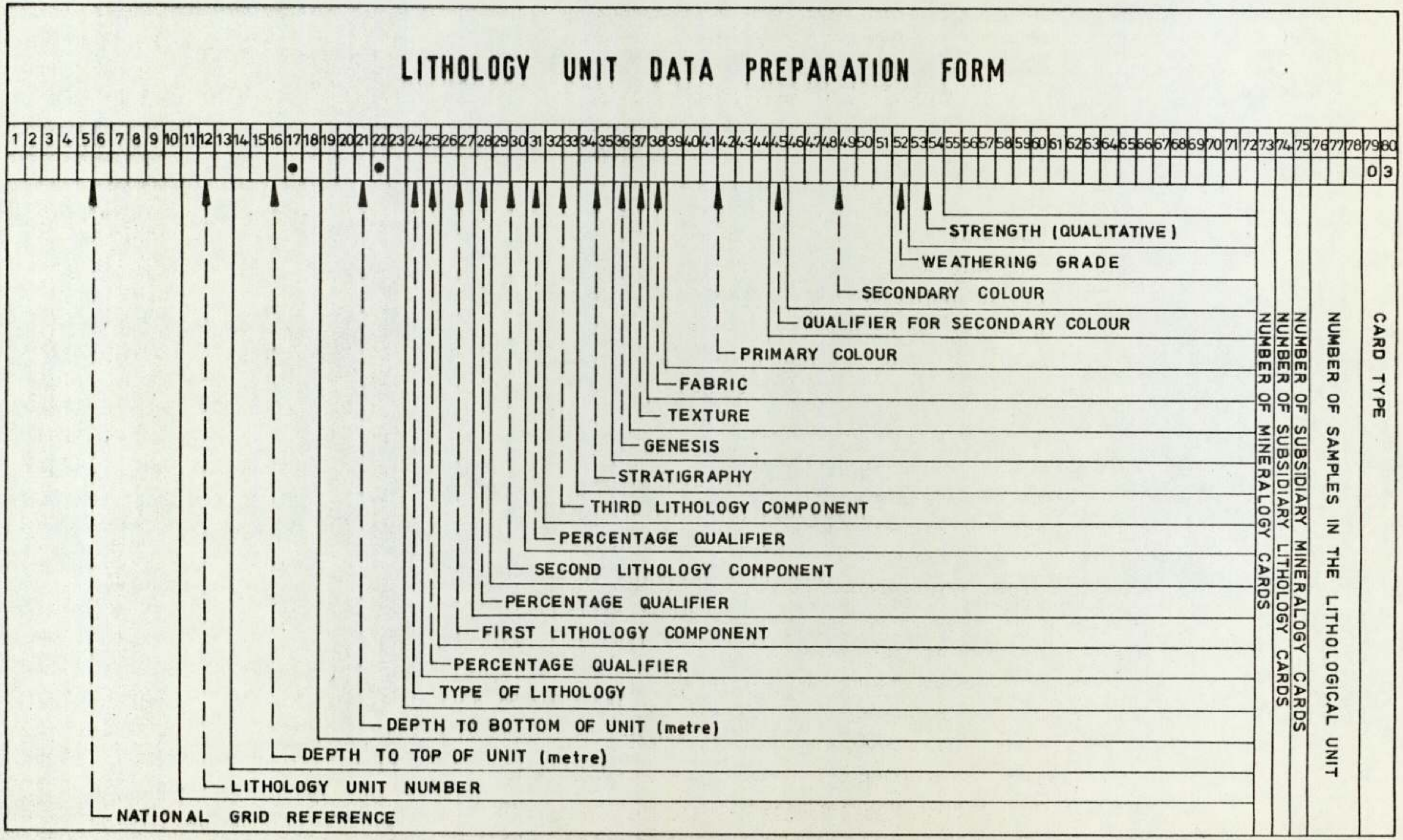
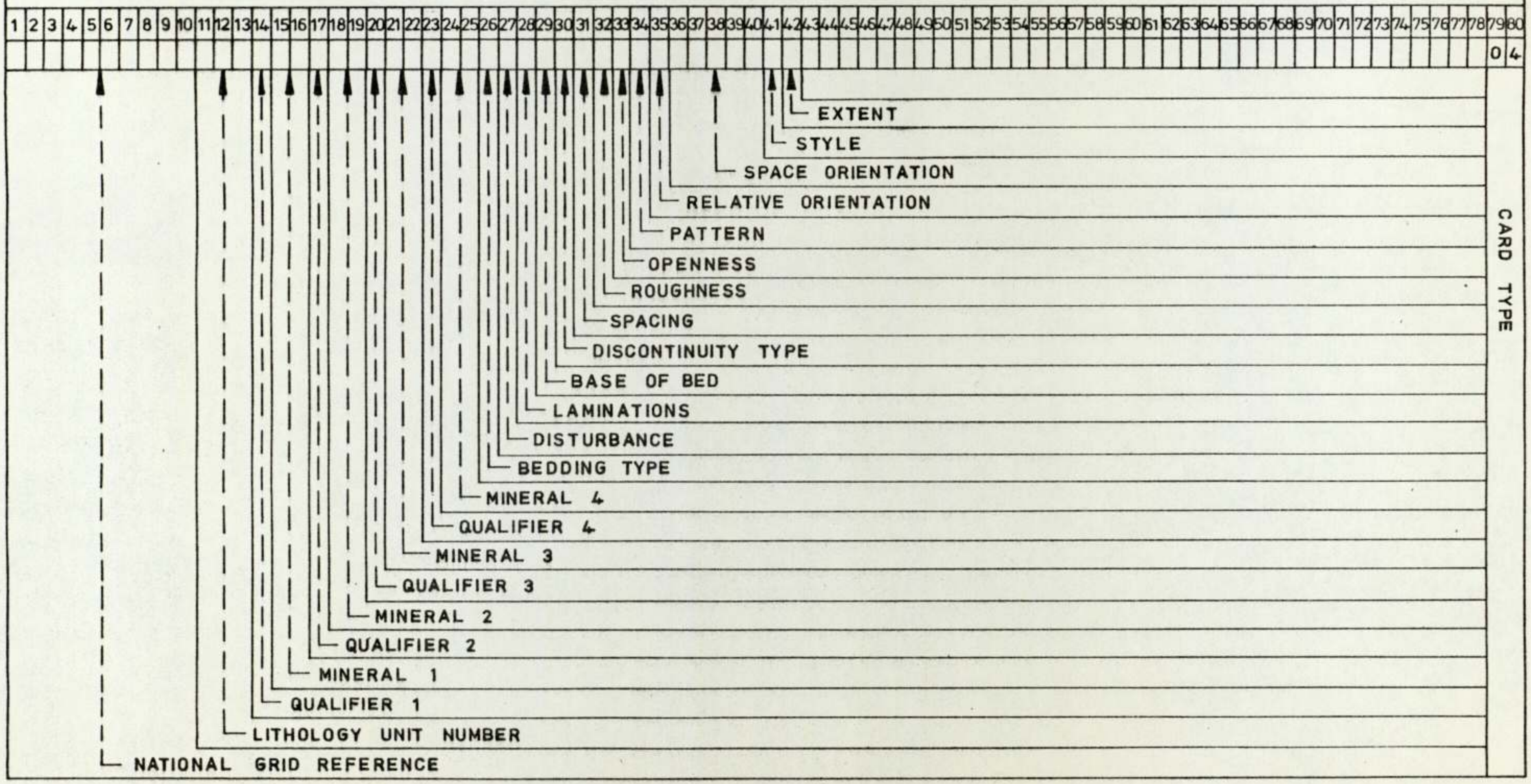
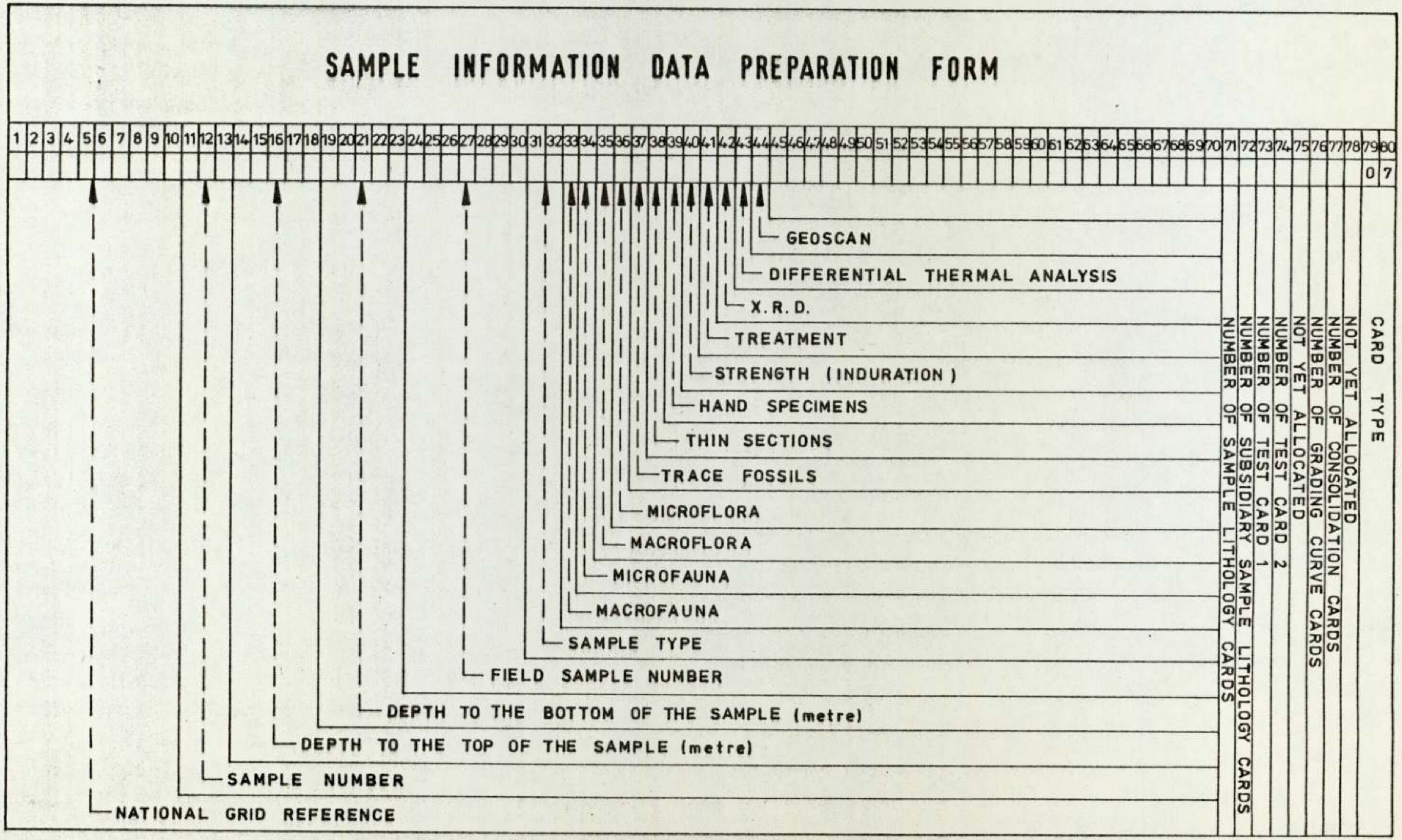
0 2
DEPTH (m)
TIME
DATE
DEPTH (m)
TIME
DATE
DEPTH (m)
TIME
DATE
DEPTH OF WATER (metre)
TIME OF RECORDING, 24 HOUR CLOCK
DATE WATER LEVEL RECORDED, DAY, MONTH, YEAR
NATIONAL GRID REFERENCE
CARD TYPE
NUMBER OF WATER CARDS FOLLOWING


LITHOLOGY UNIT DATA PREPARATION FORM
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
0 3
STRENGTH (QUALITATIVE)
WEATHERING GRADE
SECONDARY COLOUR
QUALIFIER FOR SECONDARY COLOUR
PRIMARY COLOUR
FABRIC
TEXTURE
GENESIS
STRATIGRAPHY
THIRD LITHOLOGY COMPONENT
PERCENTAGE QUALIFIER
SECOND LITHOLOGY COMPONENT
PERCENTAGE QUALIFIER
FIRST LITHOLOGY COMPONENT
PERCENTAGE QUALIFIER
TYPE OF LITHOLOGY
DEPTH TO BOTTOM OF UNIT (metre)
DEPTH TO TOP OF UNIT (metre)
LITHOLOGY UNIT NUMBER
NATIONAL GRID REFERENCE
NUMBER OF MINERALOGY CARDS
NUMBER OF SUBSIDIARY LITHOLOGY CARDS
NUMBER OF SUBSIDIARY MINERALOGY CARDS
NUMBER OF SAMPLES IN THE LITHOLOGICAL UNIT
CARD TYPE

MINERALOGY DATA PREPARATION FORM

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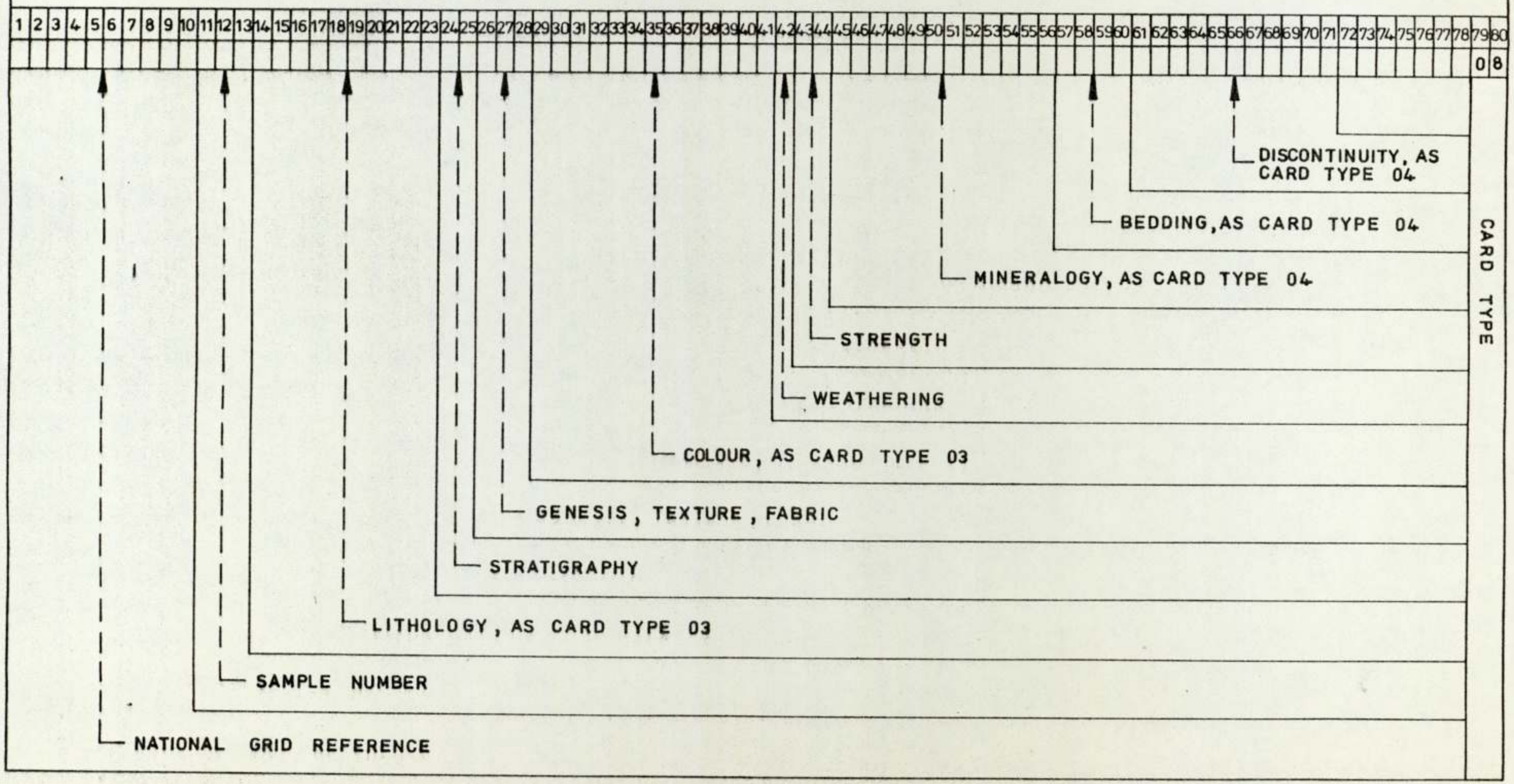
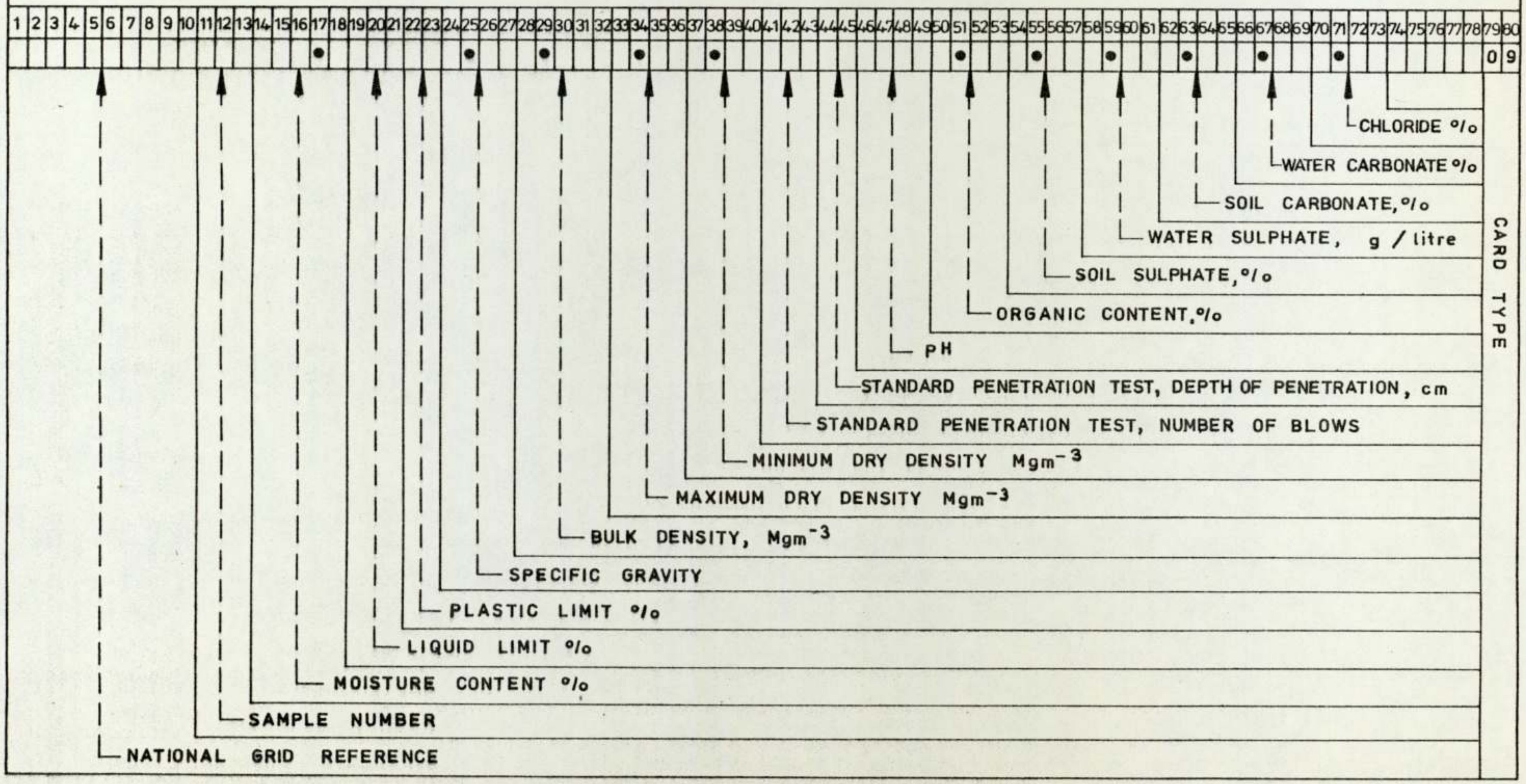
0 7
GEOSCAN
DIFFERENTIAL THERMAL ANALYSIS
X.R.D.
TREATMENT
STRENGTH (INDURATION)
HAND SPECIMENS
THIN SECTIONS
TRACE FOSSILS
MICROFLORA
MACROFLORA
MICROFAUNA
MACROFAUNA
SAMPLE TYPE
FIELD SAMPLE NUMBER
DEPTH TO THE BOTTOM OF THE SAMPLE (metre)
DEPTH TO THE TOP OF THE SAMPLE (metre)
SAMPLE NUMBER
NATIONAL GRID REFERENCE
NUMBER OF SAMPLE LITHOLOGY CARDS
NUMBER OF SUBSIDIARY SAMPLE LITHOLOGY CARDS
NUMBER OF TEST CARD 1
NUMBER OF TEST CARD 2
NOT YET ALLOCATED
NUMBER OF GRADING CURVE CARDS
NUMBER OF CONSOLIDATION CARDS
NOT YET ALLOCATED
CARD TYPE

SAMPLE LITHOLOGY DATA PREPARATION FORM



TEST CARD 1 DATA PREPARATION FORM



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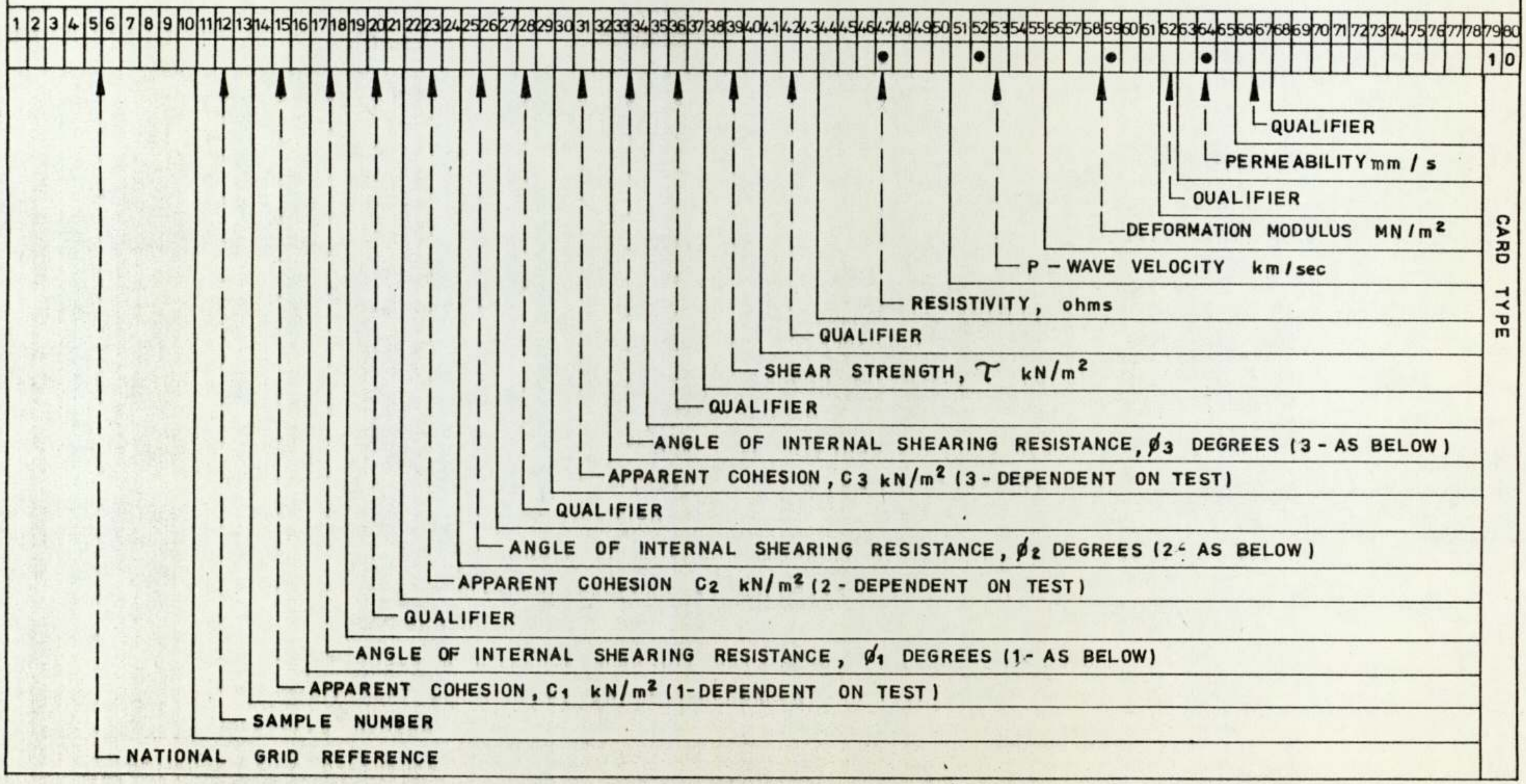
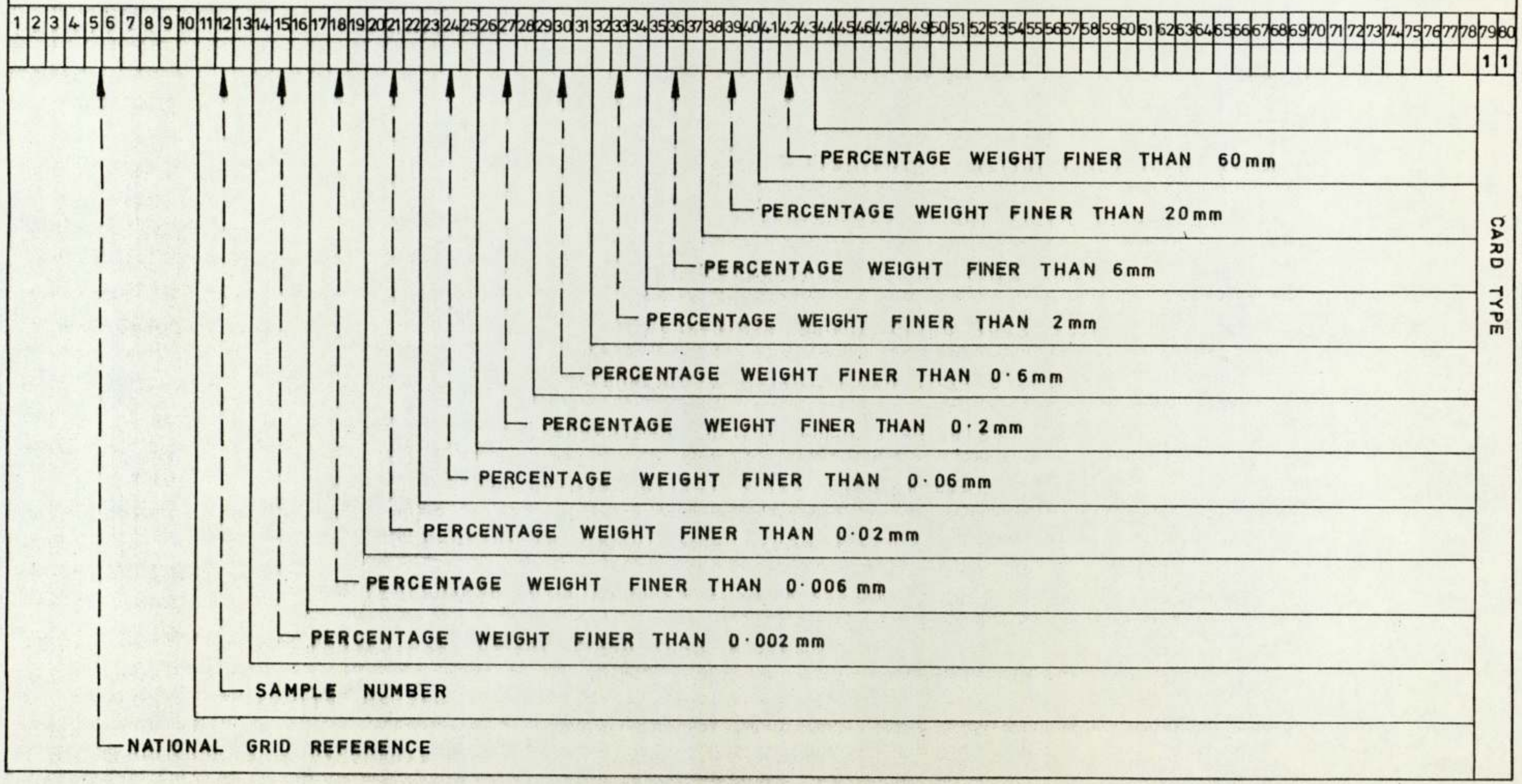
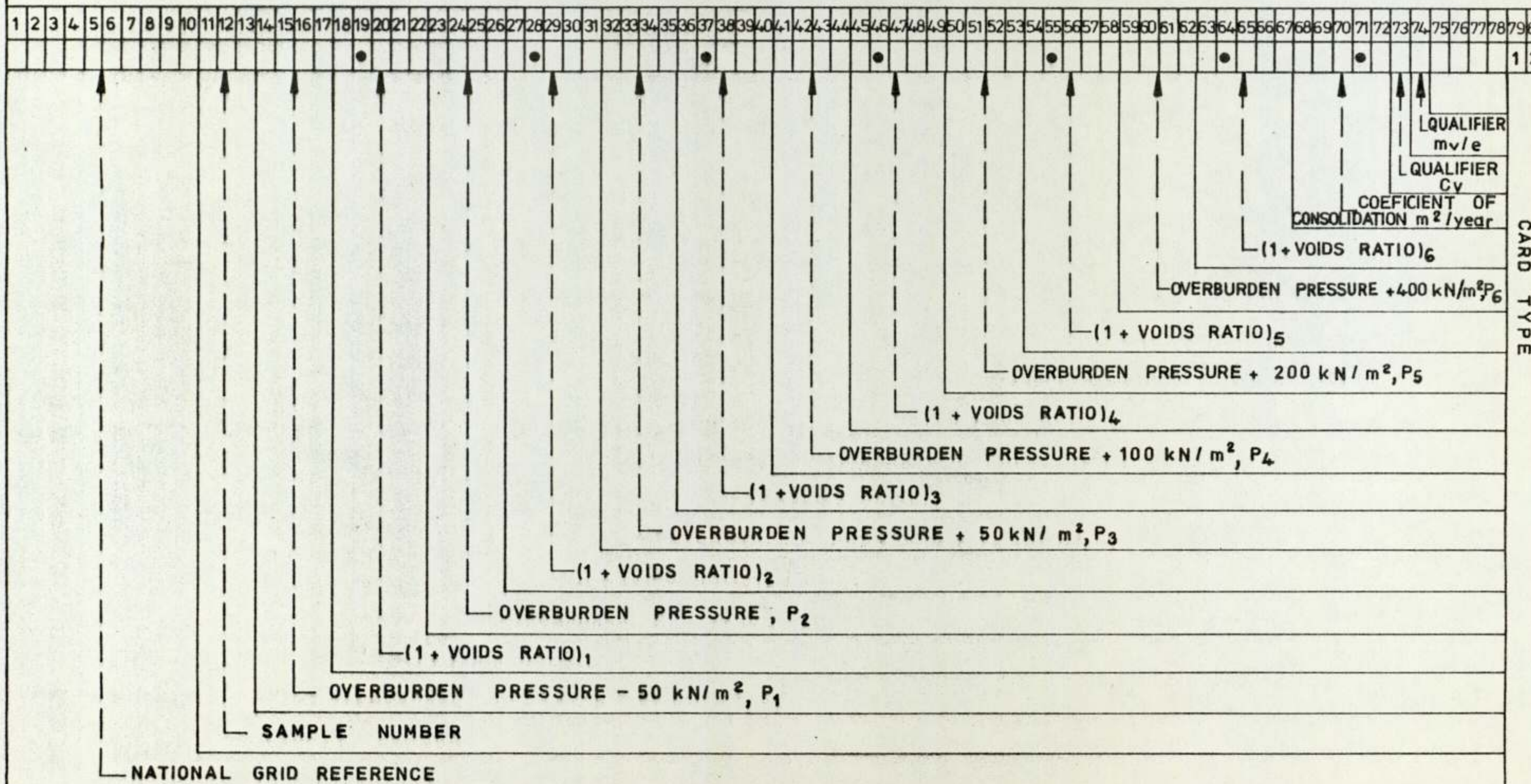


PARTICLE SIZE ANALYSIS DATA PREPARATION FORM



CONSOLIDATION ANALYSIS DATA PREPARATION FORM



APPENDIX 11

BOREHOLE INFORMATION DATA PREPARATION FORM, CARD TYPE 01

Col(s)	Heading	Coding
20-21	Contractor	e.g. 01 = City of Birmingham; 02 = Coulson Ltd etc.
22-23	Drilling method	01 = Wash boring; 02 = Shell and auger; 03 = Hand auger; 04 = Power auger; 05 = Delft sampling; 06 = Rotary core; 07 = Rotary open; 08 = Rotary percussive; 09 = Temporary excavation (Trial Pit); 10 = Shell and auger, some chisling < 5 hours; 11 = Shell and auger, extensive chisling > 5hours; 12 = Shell and auger with rotary; 13 = Shell and auger, and rotary, extensive chisling > 5 hours; 14 = Shell and auger, and rotary, some chisling < 5 hours; 15 = Hand percussion
30	Ordnance Datum reliability	1 = Accurate to < 0·01 m (i.e. levelled from nearby bench mark); 2 = Accurate from 0·01 – 0·1 m (i.e. levelled from distant bench mark); 3 = Accurate from 0·1 – 1 m (i.e. levelled from spot height); 4 = Accurate from 1 – 10 m (i.e. estimated from contours or from old records).

LITHOLOGY DATA PREPARATION FORM, CARD TYPE 03

Col(s)	Heading	Coding
24	Lithology type	1 = soil; 2 = sedimentary; 3 = metamorphic; 4 = igneous; 5 = organic; 6 = chemical; 7 = rock.
25	Percentage qualifier	1 = 0 – 10 %; 2 = 10 - 20 %; 3 = 20 – 30 %; 4 = 30 - 50 %; 5 = 50 - 60 %; 6 = 60 – 70 %; 7 = 70 - 80 %; 8 = 80 - 90 %; 9 = 90 - 100 %;
26-27	First lithology component	e.g. 01 = rounded gravel; 02 = subrounded gravel; 03 = angular gravel; 04 = subangular gravel; 05 = coarse rounded gravel; 06 = coarse subrounded gravel; 07 = coarse angular gravel; 08 = coarse subangular gravel; 09 = medium rounded gravel... 23 = medium & coarse angular gravel... 33 = rounded sand... 48 = fine subangular sand... 63 = fine, medium & coarse rounded sand... 65 = silt; 66 = clay; 80 = mudstone; 85 = siltstone; 99 = peat.
28	Percentage qualifier	As for col. 25
29 - 30	Second lithology component	As for cols. 26 - 27
31	Percentage qualifier	As for col. 25
32 - 33	Third lithology component	As for cols. 26 - 27
34 - 35	Stratigraphy	01 = Fossil soil; 02 = Made ground; 03 = Topsoil; 04 = Alluvium; 05 = Head; 06 = Brickearth; 07 = River Terrace Gravels... 21 = Undifferentiated Drift, sands and gravels... 42 = Arden Sandstone; 43 = Keuper Marl; 44 = Lower Keuper Sandstone; 45 = Upper Mottled Sandstone; 46 = Bunter Pebble Beds; 47 = Hopwas Breccia...
36	Genesis	0 = lacustrine / sabkhas; 1 = aeolian; 2 = fluvial; 3 = estuarine; 4 = intertidal; 5 = littoral; 6 = neritic; 7 = fluvioglacial; 8 = glacial; 9 = periglacial.
37	Texture	1 = v. well sorted; 2 = well sorted; 3 = moderately sorted; 4 = poorly sorted; 5 = bimodal.
38	Fabric	1 = random; 2 = orientated; 3 = matrix (mud) supported with 10% grains; 4 = matrix (mud) supported > 10% grains; 5 = grain supported with complete matrix; 6 = grain supported without complete matrix.
39 - 44	Primary colour	As the Geological Society of America Rock Color Chart. e.g. 10 YR 5/4 moderate yellowish brown.

(Cont.)

Col(s)	Heading	Coding
45	Colour qualifier	1 = mottles of ; 2 = laminations of ; 3 = vertical striations of ; 4 = spotted with ; 5 = grading into ; 6 = and ; 7 = lenses of.
46 - 51	Secondary colour	As cols. 39 - 44
52	Weathering	1 = fresh ; 2 = faintly weathered ; 3 = slightly weathered ; 4 = moderately weathered ; 5 = highly weathered ; 6 = completely weathered ; 7 = residual.
53 - 54	Strength	1 = very loose ; 2 = loose ; 3 = medium dense ; 4 = dense ; 5 = very dense ; 6 = very soft ; 7 = soft ; 8 = firm ; 9 = stiff ; 10 = very stiff ; 11 = hard ; 12 = very hard ; 13 = spongy.

MINERALOGY DATA PREPARATION FORM, CARD TYPE 04

Col(s)	Heading	Coding
14	Qualifier 1	1 = rare; 2 = scattered; 3 = common; 4 = abundant;
15-16	Mineral 1	01 = quartz; 02 = mica; 03 = clay minerals; 04 = calcite; 05 = gypsum; 06 = quartzite; 07 = carbonates; 08 = post-glacial organic material; 09 = glacial organic material; 10 = recent organic material; 11 = potassium feldspar; 12 = sodium feldspar; 13 = mafics; 14 = opaques; 15 = silica; 16 = dolomite; 17 = siderite; 18 = selenite; 19 = ferric oxides; 20 = coal; 21 = cherts; 22 = calcareous material; 23 = flint; 24 = acid igneous; 25 = basic igneous; 26 = metamorphics;
17	Qualifier 2	As col. 14.
18-19	Mineral 2	As cols. 15-16.
20	Qualifier 3	As col. 14.
21-22	Mineral 3	As cols 15-16.
23	Qualifier 4	As col. 14.
24-25	Mineral 4	As cols. 15-16.
26	Bedding Type	1 = bedded; 2 = cross bedded; 3 = plane bedded; 4 = unbedded.
27	Disturbance	1 = convolute; 2 = slumped; 3 = cryoturbed; 4 = bioturbed.
28	Laminations	1 = very thickly bedded, spacing > 2m; 2 = thickly bedded, spacing 600mm - 2m; 3 = medium bedded, spacing 200mm - 600mm; 4 = thinly bedded, spacing 60mm - 200mm; 5 = very thinly bedded, spacing 20mm - 60mm; 6 = laminated, spacing 6mm - 20mm; 7 = varved, spacing < 6 mm.
29	Base of bed	1 = erosive; 2 = unconformable; 3 = irregular; 4 = planar; 5 = transitional; 6 = rapid transitional; 7 = load cast; 8 = flute cast.
30	Discontinuity type	1 = fissures; 2 = faults; 3 = joints; 4 = shears; 5 = faults and joints; 6 = fissures and joints; 7 = undefined.

(Cont.)

Col(s)	Heading	Coding
31	Spacing	1 = extremely high, > 2m; 2 = very high, 0·6m – 2 m; 3 = high 0·2m – 0·6m; 4 = moderate, 0·06m – 0·2m; 5 = low 0·02m – 0·06m; 6 = very low, 0·006m – 0·02m; 7 = extremely low, < 0·006m.
32	Roughness	1 = slickensides; 2 = very smooth; 3 = smooth; 4 = slightly rough; 5 = rough; 6 = very rough; 7 = pock marked; 8 = pitted.
33	Openness	1 = open; 2 = partly open; 3 = closed (no effective tensile strength across it); 4 = tight (significant tensile strength across it); 5 = infilled; 6 = partly infilled.
34	Pattern	1 = systematic; 2 = non-systematic; 3 = en-echelon; 4 = peripheral; 5 = radial; 6 = orthogonal – parallel to strike; 7 = orthogonal — non-parallel to strike.
35	Relative orientation	1 = perpendicular or normal to bedding; 2 = oblique to bedding 30° – 70°; 3 = accute to bedding 10° – 30°; 4 = parallel to bedding ± 10°; 5 = vertical; 6 = subvertical; 7 = horizontal; 8 = subhorizontal; 9 = inclined.
36-40	Space orientation	discontinuity direction 0 – 360°; dip 0 – 90°.
41	Style	1 = planar; 2 = curved; 3 = irregular undulating; 4 = regular undulating; 5 = conchoidal fracture.
42	Extent	maximum linear distance 1 = 10 cm; 2 = 50 cm; 3 = 100 cm; 4 = 5m; 5 = 10 m; 6 = 50 m; 7 = > 100m.

SAMPLE INFORMATION DATA PREPARATION FORM, CARD TYPE 07

Col(s)	Heading	Coding
31-32	Sample type	1 = undisturbed; 2 = disturbed; 3 = bulk; 4 = U 4"; 5 = U 1½"; 6 = jar; 7 = con - can; 8 = block; 9 = ring; 10 = ground water; 11 = core; 12 = Raymond penetration; 13 = cone penetration; 14 = Terzaghi penetration; 15 = U3"; 16 = U 2";
33	Macrofauna	1 = present; 0 = absent.
34	Microfauna	1 = present; 0 = absent.
35	Macroflora	1 = present; 0 = absent.
36	Microflora	1 = present; 0 = absent.
37	Trace fossils	1 = present; 0 = absent.
38	Thin sections	1 = present; 0 = absent.
39	Hand specimens	1 = present; 0 = absent.
40	Strength (induration)	1 = unindurated; 2 = indurated; 3 = poorly cemented; 4 = well cemented.
41	Treatment	1 = unsealed; 2 = polythene; 3 = wax.
42	X. R. D.	X-Ray diffraction readings taken = 1; none = 0.
43	Differential thermal analysis	analysis available yes = 1 no = 0
44	Geoscan	records available yes = 1 no = 0

TEST CARD 2 DATA PREPARATION FORM, CARD TYPE 10

Col(s)	Heading	Coding
19 - 21	Qualifier (cohesion)	01 = undrained quick undisturbed, 38mm; 02 = undrained quick remoulded, 38 mm; 03 = undrained quick undisturbed, 38 mm, 3 sample; 04 = undrained quick undisturbed, 38 mm, 4 sample; 05 = undrained quick remoulded, 38 mm, 3 sample; 06 = undrained quick remoulded, 38 mm, 4 sample; 07 = undrained quick undisturbed, 100mm, cell pressure = -p; 08 = undrained quick undisturbed, 100 mm, cell pressure = po; 09 = undrained quick undisturbed, 100 mm, cell pressure = p+; 10 = undrained quick undisturbed, 100mm, cell pressure = ms; 11 = undrained quick remoulded, 100mm, cell pressure = -p; 12 = undrained quick remoulded, 100mm, cell pressure = po; 13 = undrained quick remoulded, 100mm, cell pressure = p+; 14 = undrained quick remoulded, 100 mm, cell pressure = ms; where ms = multistage, po = overburden pressure, -p = less than overburden pressure, and p+ = greater than overburden pressure. 31 = consolidated drained slow undisturbed, 38 mm, 3 sample; 32 = consolidated drained slow undisturbed, 38 mm, 4 sample; 33 = consolidated drained slow remoulded, 38 mm, 3 sample; 34 = consolidated drained slow remoulded, 38 mm, 4 sample; 35 = consolidated drained slow undisturbed, 100mm; 36 = consolidated drained slow remoulded, 100mm. 40 = consolidated undrained quick undisturbed, 38 mm, 3 sample; 41 = consolidated undrained quick undisturbed, 38 mm, 4 sample; 42 = consolidated undrained quick remoulded, 38 mm, 3 sample; 43 = consolidated undrained quick remoulded, 38 mm, 4 sample; 44 = consolidated undrained quick undisturbed, 100 mm; 45 = consolidated undrained quick remoulded, 100mm. 50 = undrained and pore water pressure, undisturbed, 38 mm, 3 samples; 51 = undrained and pore water pressure undisturbed, 38 mm, 4 samples; 52 = undrained and pore water pressure, remoulded, 38 mm, 3 samples; 53 = undrained and pore water pressure remoulded, 38 mm, 4 samples;

(Cont.)

Col(s)	Heading	Coding
		54 = undrained and pore water pressure undisturbed, 100mm;
		55 = undrained and pore water pressure remoulded, 100mm.
		60 = shear box (direct shear) drained 60 × 60 × 20, undisturbed;
		61 = shear box (direct shear) drained 60 × 60 × 20, remoulded;
		62 = shear box (direct shear) drained 305 × 305 × 102·5, undisturbed;
		63 = shear box (direct shear) drained 305 × 305 × 102·5, remoulded.
		70 = simple shear drained undisturbed;
		71 = simple shear drained remoulded.
		80 = ring shear undisturbed;
		81 = ring shear remoulded.
27-29	Qualifier (cohesion)	As cols. 19 - 21.
35-37	Qualifier (cohesion)	As cols 19 - 21.
41-43	Qualifier (shear strength)	01 = unconfined compression, undisturbed, rock, meganewtons/m^2
		02 = unconfined compression, undisturbed, soil, kilonewtons/m^2
		03 = unconfined compression, remoulded, soil, kilonewtons/m^2
		10 = unconfined compression, undisturbed;
		11 = unconfined compression, remoulded.
		20 = laboratory vane undrained undisturbed;
		21 = laboratory vane undrained remoulded.
		40 = situ vane undisturbed;
		41 = insitu vane remoulded.
		50 = insitu shear box drained, peak;
		51 = insitu shear box drained, longstrain.
62	Qualifier (deformation modulus)	1 = unconfined compression, rock, MN / m^2;
		2 = unconfined compression, soil, KN / m^2.
66-67	Qualifier (permeability)	01 = falling head, remoulded;
		02 = falling head, undisturbed;
		03 = constant head, remoulded;
		04 = constant head, undisturbed;
		05 = oedometer consolidation, remoulded;
		06 = oedometer consolidation, undisturbed.

CONSOLIDATION ANALYSIS DATA PREPARATION FORM, CARD TYPE 12

Col(s)	Heading	Coding
73	Qualifier (consolidation)	1 = average Cv ± 25%, no relationship with pressure; 2 = average Cv ± 50%, no relationship with pressure; 3 = average Cv ± 100%, no relationship with pressure; 4 = average Cv ± 200%, no relationship with pressure; 5 = average Cv ± 25%, declines with increase pressure; 6 = average Cv ± 50%, declines with increase pressure; 7 = average Cv ± 100%, declines with increase pressure; 8 = average Cv ± 200%, declines with increase pressure.
74	Qualifier	0 = (voids ratio + 1) recorded in cols. 18 - 22, 27 - 31, 36 - 40, 45 - 49, 54 - 58; 1 = coefficient of volume compressibility recorded in cols. 18 - 22, 27 - 31, 36 - 40, 45 - 49, 54 - 58, in m^2/KN.

APPENDIX III

SO_3 PARTS PER HUNDRED THOUSAND		MINIMUM SULFACRETE CONTENT	MAXIMUM FREE WATER / CEMENT RATIO
IN SOILS	IN GROUND WATER		
200 to 500	30 to 120	290 kg/m^3	0·55
500 to 1000	120 to 250	330 kg/m^3	0·50
1000 to 2000	250 to 500	370 kg/m^3	0·45

CLASSIFICATION OF SOIL CONDITIONS FOR CONCRETE AND MORTAR IN FOUNDATIONS IN CONTACT WITH SULPHATE BEARING SOIL AND GROUND WATER. BLUE CIRCLE CEMENTS DATA SHEET Yq^2 (B.S. 4027)

APPENDIX IV

```
      MASTER CONTUR
C     PROGRAM TO COMPUTE A RECTANGULAR GRID OF VALUES INTERPOLATED
C     FROM IRREGULARLY SPACED MAP DATA.MATR1X OF GRID VALUES IS
C     PRINTED OUT AND ALSO A LINE PRINTER CONTOUR MAP BY PLOT
C     FIRST CARD READ IS MAP CONTROL CARD
      DIMENSION X1(500),X2(500),DATA(500),AMAP(60,100),DIST(500)
      DEFINE FILE 3(100,100,U,IX)
C
C     READ MAP CONTROL CARD,WIDTH OF MAP IN INCHES
C
      READ (1,1001) WIDTH,X1MIN,X1MAX,X2MIN,X2MAX
      WRITE (2,1001) WIDTH,X1MIN,X1MAX,X2MIN,X2MAX
 1001 FORMAT (5F5.0)
C
C     CALCULATE MAP SIZE AND SCALE PARAMETERS
C
      IW=WIDTH*10.0
      IH=WIDTH*6.0*(X2MAX-X2MIN)/(X1MAX-X1MIN)
      DX1=(X1MAX-X1MIN)/FLOAT(IW-1)
      DX2=(X2MAX-X2MIN)/FLOAT(IH-1)
      SMALL=(DX1*DX1+DX2*DX2)/1000.0
      READ (4,1002)N

      WRITE(2,27)IW,IH
   27 FORMAT(1X,'IW AND IH = ',2X,I6,2X,I6)
      WRITE(2,28)DX1,DX2
   28 FORMAT(1X,'DX1 AND DX2 = ',2X,F9.3,2X,F9.3)
      WRITE(2,29)SMALL
   29 FORMAT(1X,'SMALL',2X,F9.3)
      WRITE(2,30)N
   30 FORMAT(1X,'N=',1X,I3)
 1002 FORMAT(I3)
      DO 6 K=1,N
      READ (4,1003) X1(K),X2(K),DATA(K)
 1003 FORMAT (2X,2F5.0,1X,F5.1)
      WRITE(2,1103) X1(K),X2(K),DATA(K)
 1103 FORMAT(1X   ,1X,F6.1,1X,F6.1,1X,F6.1)
    6 CONTINUE

C     CALCULATE MAP VALUES
C
      XX2=X2MAX
      DO 100 I=1,60
      XX1=X1MIN
      DO 101 J=1,IW
C
C     CALCULATE SQUARES OF DISTANCES BETWEEN
C     CURRENT GRID POINT AND ALL DATA POINTS
C
      DO 102 K=1,N
      DIST(K)=(XX1-X1(K))**2+(XX2-X2(K))**2
  102 CONTINUE
```

```
C
C     FIND THE SIX NEAREST DATA POINTS AND CALCULATE SUMS
C
      S1=0.0
      S2=0.0
      DO 103 K=1,6
      IC=1
      DO 104 L=2,N
      IF(DIST(L).LT.DIST(IC)) IC=L
  104 CONTINUE
      IF(DIST(IC).LT.SMALL) GO TO 10
      D=SQRT(DIST(IC))
      S1=S1+DATA(IC)/D
      S2=S2+1.0/D
      DIST(IC)=+9.0E+35
  103 CONTINUE
C
C     CALCULATE GRID POINTS AND STORE IN MATRIX
C
      AMAP(I,J)=S1/S2
      GO TO 11
   10 AMAP(I,J)=DATA(IC)
   11 XX1=XX1+DX1
      IF(J.LT.100) GO TO 101
  101 CONTINUE
      WRITE (3'I)(AMAP(I,J),J=1,IW)
      XX2=XX2-DX2
  100 CONTINUE
      WRITE (2,598)XX2
  598 FORMAT(///////,2X,'YX2= ',F10.5)
      STOP
      END
```

```
      MASTER PLOT
C   SPECIAL PLOT FOR WIDE RANGE OF CONTOUR VALUES
      DIMENSION AMAP(60,100),PR(140),CONTOUR(30),CH(30)
      DEFINE FILE  3(100,100,U,I)
      DATA CH    /1H-,1H1,1H+,1H2,1H.,1H3,1H*,1H4,1H-,1H5,1H+,1H6,1H.,1H7
     1,1H*,1H8,1H-,1H9,1H+,1HS,1H.,1HA,1H*,1HB,1H-,1HC,1H+,1HD,1H.,1HE/
      DATA BLANK/1H#/
  999 CONTINUE
      I=1
      DO 100 II=1,60
      READ(3'I)(AMAP(II,J),J=1,100)
  100 CONTINUE
      READ(1,200)BASE,CINT
  200 FORMAT(2F5.1)
      DO 135 K=1,29
      CONTOUR(K)=BASE+(CINT*K)
      WRITE(2,115)CONTOUR(K),CH(K)
  115 FORMAT(F6.0,5X,A1)
  135 CONTINUE
      WRITE(2,122)
  122 FORMAT(1H1,15X,102(1H*))
      DO 101 I=1,60
      DO 102 J=1,100

      PR(J)=BLANK
      IF(AMAP(I,J).LT.BASE) GO TO 102
      DO 103 K=1,29
      IF(AMAP(I,J).LE.CONTOUR(K)) GO TO 13
  103 CONTINUE
      K=30
   13 PR(J)=CH(K)
  102 CONTINUE
      WRITE(2,500)(PR(J),J=1,100)
  500 FORMAT(16X,1H*,100A1,1H*)
  101 CONTINUE
      WRITE (2,112)
  112 FORMAT(16X,102(1H*))
      IF (CINT.EQ.5) GO TO 999
      STOP
      END
```

APPENDIX V

```
SYMAP, VERSION 5.17

LABORATORY FOR COMPUTER GRAPHICS AND SPATIAL ANALYSIS
GRADUATE SCHOOL OF DESIGN
HARVARD UNIVERSITY
CAMBRIDGE, MASSACHUSETTS 02138
UNITED STATES OF AMERICA
ELAPSED TIME(SECS)=      .03
```

A-OUTLINE

```
VERTEX           DOWN     ACROSS

                 ISLAND   1

(   1)           2.00      2.00
(   2)           2.00     12.00
(   3)          12.00     12.00
(   4)          12.00      2.00
AREA=    100.00           CENTER=(       7.00,        7.00)
```

B-DATA POINTS

POINT	DOWN	ACROSS
(1)	6.10	.80
(2)	7.20	1.20
(3)	1.30	1.90
(4)	3.00	2.00
(5)	7.20	2.40
(6)	5.90	3.10
(7)	11.60	3.40
(8)	11.50	3.40
(9)	6.40	3.40
(10)	12.10	3.50
(11)	12.10	3.70
(12)	11.50	3.70
(13)	12.10	3.80
(14)	11.90	3.80
(15)	7.30	3.80
(16)	6.70	3.80
(17)	14.30	3.90
(18)	12.00	3.90
(19)	11.50	4.00
(20)	10.90	4.00
(21)	13.90	4.10
(22)	.50	4.10
(23)	14.10	4.20
(24)	13.10	4.20
(25)	12.80	4.20
(26)	9.70	4.20
(27)	14.00	4.30
(28)	12.10	4.30
(29)	12.10	4.40
(30)	11.50	4.40
(31)	11.10	4.40
(32)	11.00	4.40
(33)	6.80	4.40
(34)	10.40	4.50
(35)	8.20	4.50
(36)	12.70	4.60
(37)	12.10	4.70
(38)	11.50	4.70
(39)	13.60	4.80
(40)	12.90	4.90
(41)	11.80	5.00
(42)	11.30	5.10
(43)	4.90	5.10
(44)	12.50	5.20
(45)	11.30	5.40
(46)	4.30	5.40
(47)	12.00	5.60
(48)	2.90	5.80
(49)	1.70	5.90
(50)	11.40	6.10
(51)	10.70	6.20
(52)	10.40	6.50
(53)	2.60	6.50
(54)	.80	6.50
(55)	10.80	6.60
(56)	7.80	6.60
(57)	7.30	6.60
(58)	8.10	6.80
(59)	2.10	6.80

(60)	7.90	7.00
(61)	.30	7.60
(62)	1.90	8.00
(63)	3.10	8.10
(64)	8.40	8.70
(65)	8.20	9.70
(66)	7.10	10.00
(67)	6.20	10.10
(68)	5.70	10.40
(69)	7.40	10.60
(70)	6.30	10.60
(71)	6.60	10.70
(72)	7.60	11.00
(73)	7.00	11.00
(74)	8.40	11.20
(75)	6.30	11.50
(76)	5.80	11.50
(77)	8.40	11.70
(78)	9.60	12.10
(79)	10.20	12.20
(80)	10.40	12.50
(81)	9.60	12.50
(82)	2.70	12.70
(83)	10.20	12.90
(84)	5.20	13.20
(85)	11.60	13.40
(86)	10.80	13.40
(87)	10.10	13.40
(88)	10.60	13.70
(89)	9.60	13.80
(90)	5.40	14.00

E-VALUES

DATUM	VALUE
(1)	35.00
(2)	35.00
(3)	25.00
(4)	25.00
(5)	35.00
(6)	35.00
(7)	95.00
(8)	95.00
(9)	25.00
(10)	85.00
(11)	95.00
(12)	95.00
(13)	85.00
(14)	85.00
(15)	35.00
(16)	35.00
(17)	65.00
(18)	85.00
(19)	75.00
(20)	95.00
(21)	55.00
(22)	35.00
(23)	75.00
(24)	65.00
(25)	75.00
(26)	45.00
(27)	75.00
(28)	85.00
(29)	75.00
(30)	85.00
(31)	75.00
(32)	75.00
(33)	35.00
(34)	75.00
(35)	25.00
(36)	55.00
(37)	65.00
(38)	75.00
(39)	65.00
(40)	45.00
(41)	65.00
(42)	65.00
(43)	25.00
(44)	45.00
(45)	45.00
(46)	35.00
(47)	45.00
(48)	45.00
(49)	35.00
(50)	65.00
(51)	55.00
(52)	45.00
(53)	25.00
(54)	35.00
(55)	65.00
(56)	35.00
(57)	35.00
(58)	25.00
(59)	15.00

(60)	25.00
(61)	25.00
(62)	25.00
(63)	25.00
(64)	15.00
(65)	25.00
(66)	15.00
(67)	15.00
(68)	15.00
(69)	25.00
(70)	15.00
(71)	25.00
(72)	25.00
(73)	25.00
(74)	35.00
(75)	15.00
(76)	15.00
(77)	25.00
(78)	35.00
(79)	25.00
(80)	5.00
(81)	35.00
(82)	15.00
(83)	15.00
(84)	25.00
(85)	5.00
(86)	5.00
(87)	35.00
(88)	25.00
(89)	25.00
(90)	15.00

```
F-MAP
-----

C TOPOGRAPHY OF BEDROCK RELATIVE TO ODL  WITHIN THE NATIONAL GRID SQUARE   SP 0720  0820  8710  8810

ELECTIVE

1 MAP SIZE IS             10.00 INCHES LONG BY           10.00 INCHES WIDE
2 EXTREME POINTS ARE (       2.00,        2.00) AND (       12.00,       12.00)
3 NUMBER OF LEVELS IS 10
4 LOWER DATA LIMIT IS       0.00
5 UPPER DATA LIMIT IS     100.00
6 LEVEL SIZES ARE PROPORTIONED TO   1)    10.00   2)    10.00   3)    10.00   4)    10.00   5)    10.00
                                    6)    10.00   7)    10.00   8)    10.00   9)    10.00  10)    10.00
7 NEW SYMBOLS ARE

10 MAP TEXT
                  C        ISOPLETH  MAP
                  C        SHOWING  CONTOURING  OF  BEDROCK  SURFACE
                  C        IN  AREA  NGR SP 0720  0820  8710  8810

                     SCALE  1:100

                     DATA POINTS REPRESENT BOREHOLE LOCATIONS

                     LEVELS REPRESENT ORDINANCE DATUM LEVELS OF BEDROCK

                       LEVELS          ODL M
                         1             95-97
                         2             98-100
                         3            101-103
                         4            104-106
                         5            107-109
                         6            110-112
                         7            113-115
                         8            116-119
                         9            120-122
                        10            123-126
11 ACTUAL VALUE  PRINTED AT EACH POINT
13 MAP SCALE IS       1.00
21 MAP VALUES STORED ON TAPE 8
22 CONTOURS CONTINUOUS
27 CONTOUR OR PROXIMAL MAP
32 EXTRAPOLATION MINIMUM IS         0.00
33 EXTRAPOLATION MAXIMUM IS       100.00

 .11 SECONDS FOR INPUT
ELAPSED TIME(SECS)=      .13
```

MAP 1

C TOPOGRAPHY OF BEDROCK RELATIVE TO ODL
C WITHIN THE NATIONAL GRID SQUARE
C SP 0720 0820 8710 8810

MAP SCALE = 1.0000 INCHES ON OUTPUT MAP/UNITS ON SOURCE MAP

MAP SHOULD BE PRINTED AT 6.0 ROWS PER INCH AND 10.0 COLUMNS PER INCH

ROW = (DOWN COORDINATE - 2.00) * 6.0000
COLUMN = (ACROSS COORDINATE - 2.00) * 10.0000

DATA POINTS FOR MAP

POINT	ROW	COLUMN	DATUM	VALUE	LEVEL
1)	25	-11	1	35.00	4
2)	31	-7	2	35.00	4
3)	-3	-0	3	25.00	3
4)	6	0	4	25.00	3
5)	31	4	5	35.00	4
6)	23	11	6	35.00	4
7)	58	14	7	95.00	10
8)	57	14	8	95.00	10
9)	26	14	9	25.00	3
10)	61	15	10	85.00	9
11)	61	17	11	95.00	10
12)	57	17	12	95.00	10
13)	61	18	13	85.00	9
14)	59	18	14	85.00	9
15)	32	18	15	35.00	4
16)	28	18	16	35.00	4
17)	74	19	17	65.00	7
18)	60	19	18	85.00	9
19)	57	20	19	75.00	8
20)	53	20	20	95.00	10
21)	71	21	21	55.00	6
22)	-8	21	22	35.00	4
23)	73	22	23	75.00	8
24)	67	22	24	65.00	7
25)	65	22	25	75.00	8
26)	46	22	26	45.00	5
27)	72	23	27	75.00	8
28)	61	23	28	85.00	9
29)	61	24	29	75.00	8
30)	57	24	30	85.00	9
31)	55	24	31	75.00	8
32)	54	24	32	75.00	8
33)	29	24	33	35.00	4
34)	56	25	34	75.00	8
35)	37	25	35	25.00	3
36)	64	26	36	55.00	6
37)	61	27	37	65.00	7
38)	57	27	38	75.00	8
39)	70	28	39	65.00	7
40)	65	29	40	45.00	5
41)	59	30	41	65.00	7
42)	56	31	42	65.00	7
43)	17	31	43	25.00	3
44)	63	32	44	45.00	5
45)	56	34	45	45.00	5

46)	14	34	46	35.00	4
47)	60	36	47	45.00	5
48)	5	38	48	45.00	5
49)	-1	39	49	35.00	4
50)	56	41	50	65.00	7
51)	52	42	51	55.00	6
52)	50	45	52	45.00	5
53)	4	45	53	25.00	3
54)	-6	45	54	35.00	4
55)	53	46	55	65.00	7
56)	35	46	56	35.00	4
57)	32	46	57	35.00	4
58)	37	48	58	25.00	3
59)	1	48	59	15.00	2
60)	35	50	60	25.00	3
61)	-9	56	61	25.00	3
62)	-0	60	62	25.00	3
63)	7	61	63	25.00	3
64)	38	67	64	15.00	2
65)	37	77	65	25.00	3
66)	31	80	66	15.00	2
67)	25	81	67	15.00	2
68)	22	84	68	15.00	2
69)	32	86	69	25.00	3
70)	26	86	70	15.00	2
71)	29	87	71	25.00	3
72)	34	90	72	25.00	3
73)	30	90	73	25.00	3
74)	38	92	74	35.00	4
75)	26	95	75	15.00	2
76)	23	95	76	15.00	2
77)	38	97	77	25.00	3
78)	46	101	78	35.00	4
79)	49	102	79	25.00	3
80)	50	105	80	5.00	1
81)	46	105	81	35.00	4
82)	4	107	82	15.00	2
83)	49	109	83	15.00	2
84)	19	112	84	25.00	3
85)	58	114	85	5.00	1
86)	53	114	86	5.00	1
87)	49	114	87	35.00	4
88)	52	117	88	25.00	3
89)	46	118	89	25.00	3
90)	20	120	90	15.00	2

STANDARD SEARCH RADIUS IS 2.3392

.05 SECONDS FOR INITIAL CALCULATIONS
ELAPSED TIME(SECS)= .10

C TOPOGRAPHY OF BEDROCK RELATIVE TO ODL

C WITHIN THE NATIONAL GRID SQUARE

C SP 0720 0820 8710 8810

C ISOPLETH MAP
C SHOWING CONTOURING OF BEDROCK SURFACE
C IN AREA NGR SP 0720 0820 8710 8810

SCALE 1:100

DATA POINTS REPRESENT BOREHOLE LOCATIONS

LEVELS REPRESENT ORDINANCE DATUM LEVELS OF BEDROCK

LEVELS	ODL M
1	95-97
2	98-100
3	101-103
4	104-106
5	107-109
6	110-112
7	113-115
8	116-119
9	120-122
10	123-126

DATA VALUE EXTREMES ARE 5.00 95.00

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	0.00	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00
MAXIMUM	10.00	20.00	30.00	40.00	50.00	60.00	70.00	80.00	90.00	100.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

```
FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
  LEVEL        1       2       3       4       5       6       7       8       9      10
          ===========================================================================

  SYMBOLS

          ===========================================================================
  FREQ.        3      11      21      17       7       3       8       9       6       5
       1   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I
       2   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I
       3   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I   I
       4           I   I   I   I   I   I   I   I           I   I   I   I   I   I   I   I
       5           I   I   I   I   I   I   I   I           I   I   I   I   I   I   I   I
       6           I   I   I   I   I   I   I   I           I   I   I   I   I   I
       7           I   I   I   I   I   I   I   I           I   I   I   I
       8           I   I   I   I   I   I                   I   I   I   I
       9           I   I   I   I   I   I                           I   I
      10           I   I   I   I   I   I
      11           I   I   I   I   I   I
      12                   I   I   I   I
      13                   I   I   I   I
      14                   I   I   I   I
      15                   I   I   I   I
      16                   I   I   I   I
      17                   I   I   I   I
      18                   I   I
      19                   I   I
      20                   I   I
      21                   I   I

   .06 SECONDS FOR HISTOGRAM
ELAPSED TIME(SECS)=     1.54

   1 MAPS HAVE BEEN PRODUCED
END OF JOB
```

DATE - 04/11/75

DATA ON INPUT CONTROL CARDS -
BEDROCK TOPOGRAPHL ODL OF NGR SP 0720 0820 8710 8810 VIEWED FROM SOUTH

THE DATA MATRIX HAS 59 ROWS AND 99 COLUMNS

2- 3 TYPE OF DRAWING PROJECTION	2	2-15 ROWS PER INCH IN DATA MATRIX	6
2- 4 DIRECTION OF LINES	4	2-16 CONTROL INFORMATION	-0
2- 5 NO. OF BINOMIAL SMOOTHINGS	-0	2-17 SCALE LEGEND	1
2- 6 PLOTTING WAYS	-0	2-18 FLOATING PLANE	-0
2- 7 REPEAT DATA	-0	2-19 BASE	3
2- 8 LINE INTERVAL	-0	2-20 NO. OF SYMBOLS	-0
2- 9 NON-STUDY AREA SYMBOL	-0	2-21 FILE NO. OR USER SUBROUTINE	1
2-10 NON-STUDY AREA	-0	2-22 SET MINIMUM	-0
2-11 NON-STUDY BELOW AMIN	-0	2-23 SET MAXIMUM	-0
2-12 SQUARE ROOT	-0	2-24 IFORM	-0
2-13 SAME VERTICAL SCALE	-0	2-25 NO. OF LEGENDS	-0
2-14 ENDLINES	-0		

3- 1 ALTITUDE	45.00	3- 6 MAXIMUM	-0.00
3- 2 AZIMUTH	0.00	3- 7 VIEWING DISTANCE	-0.00
3- 3 WIDTH	5.00	3- 8 STEP SIZE	-0.000
3- 4 HEIGHT	1.00	3- 9 SYMBOL SIZE	-0.000
3- 5 MINIMUM	-0.00	3-10 BLOCK THICKNESS	-0.00

THE PLOTTER IS INITIALIZED

THE CONTROL INFORMATION HAS BEEN PLOTTED

THE MAIN DRAWING HAS BEEN COMPLETED
END OF PLOT FOR BEDROCK TOPOGRAPHL ODL OF NGR SP 0720 0820 8710 8810 VIEWED FROM SOUTH