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ENVIRONMENTAL GEOLOGY STUDY
Parts of west Wiltshire and south-east Avon

by

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Front cover

The cover illustration is an approximately ½-scale reduction of "A map of the country five miles around Bath on a scale of one and one half inches to the mile. Coloured geologically in 1799 by William Smith".

The map shows the Great Oolite (yellow), the Lias (blue) and the Trias (red). It is considered to be the first map ever produced showing accurately the outcrop of strata according to an ordered stratigraphic sequence.

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NOTE TO USER

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

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

The possible occurrence of undetected anomalous site conditions and of uncharted shallow workings and mineshafts should always be anticipated. The accuracy of shaft locations and mined limits, as depicted on the thematic maps, cannot be guaranteed; nor does the indicated occurrence of mineral deposits necessarily imply an economic resource. The possible presence of unmapped and variable thicknesses of superficial deposits and made ground, and of landslipped strata on valley slopes, particularly within the urban area of Bath, should also be taken into account in any planning procedures.

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

ACKNOWLEDGEMENTS

We wish to record our thanks to all data sources for making available the additional information acquired during the course of this study. A summary of these sources and the types of data supplied are given in section 1.3. Acknowledgement of most of the individual suppliers of data is made in the Schedule of Records.

We are particulary grateful to the following for their ready co-operation and helpful advice during our researches: Sir Alexander Gibb and Partners; C.J. Associates; Foundation Engineering; Geotechnical Engineering; Mander, Raikes and Marshall. Avon County Council, Bath City Engineer's Department; Wessex Water Authority; Wiltshire County Council; Kingston Minerals; Mr. D. Pollard, Dr. K. Privett and Mr R. J. Tucker.

SUMMARY

The objective of this study has been to collect and interpret the available environmental geology data and to use it to compile a set of thematic maps and this report. The maps and report are intended for use by those not trained in geology as well as specialists, and to help assess the land-use planning implications of surface and subsurface development.

A data base was established using existing British Geological Survey holdings and also additional information acquired from a variety of public and private sector data sources. The information was collated in a form which enables it to be transferred to an appropriate archive. An annotated key map showing the location of site investigations and boreholes accompanies the set of thematic maps. The data were evaluated in terms of their format, level of detail, availability, reliability and status (confidentiality and copyright restrictions). Deficiencies in the data base and the likely costs of investigations which would be required to provide fuller information or parity of coverage throughout the study area were identified. A comprehensive schedule of records detailing the nature, source and confidentiality of the data, and a full bibliography of published and unpublished literature are presented.

A general summary of the geology and geological structure of the study area is given. Lithological descriptions are provided for solid rock formations and for superficial drift deposits. Significant variations of lithology and thickness are noted. Thematic maps of solid lithostratigraphy and drift deposits (Maps 1 and 2 respectively) were compiled from updated 1:10 000 geological maps. Areas shown as 'foundered strata' on existing geological maps have been re-surveyed in order to achieve parity of interpretation throughout the study area (thematic Map 15).

Areas of made ground and infilled land are identified (thematic Map 3). Their relationship to the local geology is indicated and details of waste type and thickness are given, where known.

The mineral resources of the area are outlined. The source rocks of the building freestones (Bath Stone) are identified and described, and their physical properties tabulated. Their occurrence is defined within the limitations of the available data (thematic Map 4) and the stability and structural restraints upon their exploitation are summarized. The characteristics of the commercial fuller's earth, including its mineralogy, are given. The occurrence of the earth is indicated (thematic Map 5) although its limits are locally speculative because of the sparsity of borehole data.

An account is presented of the hydrogeology, identifying the principal aquifers and describing the well yields of all rock formations and superficial deposits (thematic Map 6). Zones of groundwater travel times are proposed and their relationship to the susceptibility of aquifers to contamination reviewed.

The extensive areas of disturbed ground on valley slopes have been delineated by reference to geological maps and aerial photos (thematic Map 10). The mechanics, structural effects and influence upon surface development of landslipped and cambered strata are described.

The distribution of slope angles (thematic Map 11) is shown by a number of slope categories, each with a specified range of values. Characteristic slope angles for particular lithologies have been determined.

Bedrock types are grouped into a number of units (thematic Map 8), by the geotechnical properties and engineering behaviour of which are fully described. A range of site investigation test data are presented and assessed. Similarly, the geotechnical properties of superficial deposits are discussed and they are divided into units of engineering significance (thematic Maps 9a - d). Most geotechnical data relate to the City of Bath and its environs. Comparisons are made with geotechnical data from outside the study area.

The relationship between groundwater and groundsurface conditions is reviewed. Bedrock types are classified as either permeable or impermeable and are divided into five hydrostratigraphic units according to their stratigraphic position. The location of actual or potential spring lines is indicated (thematic Map 7). The groundwater regime of alluvial deposits in relation to groundsurface conditions is described and the limits of areas which have been subject to flooding defined.

The location and extent of areas undermined by the working of coal, limestone and fuller's earth are defined (thematic Map 13) and a brief historical revue of their working is presented. The relationship between ground instability and methods of mineral extraction is discussed. Particular attention is given to the factors which govern roof collapse in abandoned Bath Stone mines. Selected details of the principal freestone mines are given. The locations of vertical mine shafts are shown (thematic Map 12) and those of mine adits and slope shafts are tabulated in the text.

Several recommendations for further investigations to achieve parity of coverage throughout the study area and to provide fuller information are presented.

1. INTRODUCTION

1.1. Objectives of the Study

The objectives of this study, as defined in the contract for the work, have been to collect, collate, evaluate and interpret the existing stratigraphical, geotechnical, hydrogeological, mining and mineral resource data for the study area, and to use it to compile a set of thematic geological maps and this report. The maps and report are intended to be of use to the non-specialist as well as those trained in geology, mining or civil engineering and related disciplines. It is hoped that they will provide a valuable aid to land-use planning for surface development, mineral and water resources, the suitability of mined areas for sub-surface development and other matters. The report also identifies weaknesses in the data base which might warrant further investigations or specialist advice.

The main work has been a desk study of existing archival information, augmented by additional data acquired during the course of the study. In particular, a limited field examination of "foundered strata" was undertaken at an early stage. This was later amplified by a re-survey of these areas, which is the subject of a supplementary report.

1.2 Topographical setting: Historical and Geological background

The topography of the study area is illustrated in Figure 1. Most of the eastern half is characterised by a gently undulating landscape which constitutes the dip slope of the Cotswolds escarpment. Several minor streams, which occupy shallow valleys, drain eastwards into the upper part of the River Avon.

The remainder of the area consists of plateau-like tracts mainly capped by limestones, cut by the deeply incised valleys of the River Avon and its tributaries. There is a maximum relief of the order of 160 m.

Throughout history the local geology has had a significant impact on land use. A Roman spa was established on the thermal springs at Aquae Sulis. The town of Bath spread rapidly from the 18th century onwards and there are records of numerous foundation failures as building covered the landslips on the slopes of the Avon valley. In more recent times, industrial development has been largely confined to the relatively stable lower slopes and the alluvial floodplain of the River Avon.

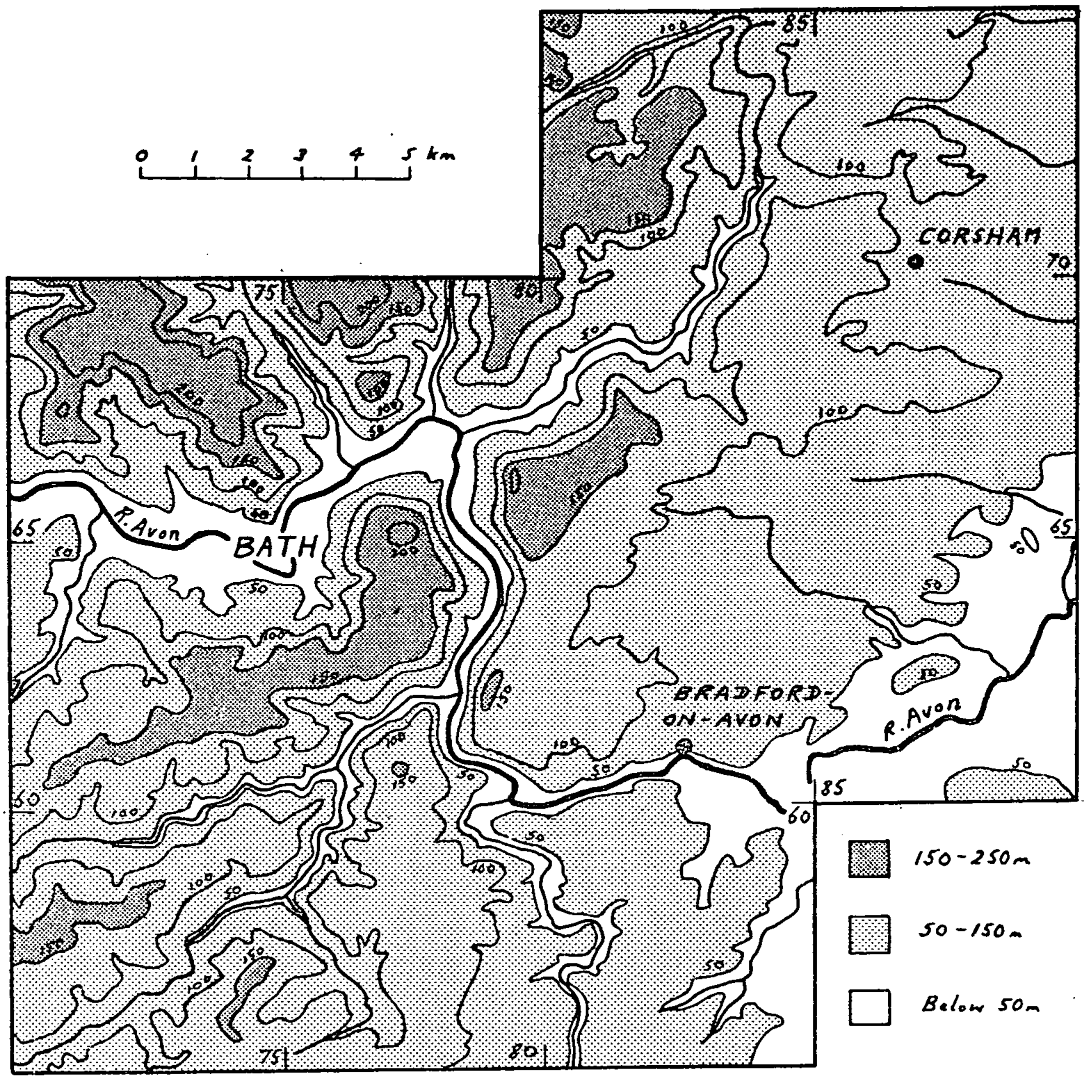


FIG. 1 RELIEF AND DRAINAGE OF THE STUDY AREA.

The construction of local canals along the lower slopes of the valleys in the late 18th and 19th centuries was bedevilled by disturbed ground conditions, necessitating extensive remedial measures. Major roads have similarly been affected by movement on disturbed valley slopes and by the encroachment of mud-flows. Both the A36 and the A46 have suffered such problems and they have been the subject of several slope stability studies. Railways are confined to the floors of the valleys below the main landslips and have been less prone to failure.

Local rock formations provide an abundant source of raw materials. The massive freestones of the Great Oolite have been quarried and mined since Roman times, leaving a legacy of extensive underground chambers some of which are used for storage. The local occurrence of a bed of commercial fuller's earth towards the top of the Fuller's Earth formation has led to its exploitation in mines to the south of Bath. Coal Measures at depth in the Radstock Basin have been mined to the west and south-west of Bath. Areas beneath which minerals have been extracted may still retain a potential for surface subsidence and the precise location of abandoned mine shafts is essential where surface development is under consideration. The terraces of the River Avon are a potential source of aggregate.

The Inferior Oolite, Great Oolite and Midford Sands formations constitute the principal aquifers of the study area, from which the bulk of the local water supply is obtained. Thus, local developments need to take into account the possible contamination or sterilisation of groundwater resources.

1.3 Establishment of the Data Base

A data base was established using the existing B.G.S. holdings, supplemented by other information obtained by negotiation with likely holders of additional data. The 1:10560 geological maps in the B.G.S. archive provided the basis for the compilation of the 1:25000 Solid Lithostratigraphical and Drift thematic maps. Site investigation data, acquired before the commencement of the study, are housed in the B.G.S. Records Office at Keyworth; they comprise trial pit, borehole and geotechnical data. The information is registered on a National Grid basis and sites are located on 1:10560 maps. Incoming data from other sources have been registered and sited on the same basis to give uniformity of presentation. The archive also includes hydrogeological data. Collections of representative rock and fossil specimens from a number of fully cored boreholes within the study area are at present held in the B.G.S. core store at Acton, in London, and are available for reference.

B.G.S. holds a set of abandoned Bath Stone mine plans, mostly at a scale of 1:10560. Confidential internal reports provide additional information about underground cavity assessments.

Partial cover of the study area by rather poor quality aerial photographs taken in 1946 are held by B.G.S. These have been augmented by more recent, better quality photos to give complete coverage of the district.

Other data relevant to the objectives of the study were obtained from the following sources:

	Source	Data
a)	Consulting and Contracting Engineers	Trial pit descriptions; borehole logs; measurements of geotechnical properties.
b)	Private Consultants	Engineering geology information.
c)	Local Authorities	Site investigation reports; Bath Stone mine plans; landfill sites; groundwater information.
d)	Record Offices	Bath Stone mine plans.
e)	Mineral Operators	Trial borehole data; mine plans.
f)	Academic Bodies	Engineering geology and general geological data.
g)	Caving Clubs	Club publications and mine plans for Bath Stone workings.
h)	Ordnance Survey	Location of mine shafts and backfilled quarries.
i)	Literature	Geology; hydrogeology; mineral resources; mining; mining subsidence; superficial disturbances; ground stability; geotechnical techniques and parameters.

1.4 Evaluation of the Data Base

1.4.1 General Comment

All the collected and collated data were evaluated in terms of the objectives of the study. In this report the reliability, deficiences and format of the data are discussed under appropriate headings in sections 2-7; confidentiality and copyright are considered in section 1.5; and recommendations for additional investigations to achieve parity of coverage are presented in section 8.

In general, however, it may be noted here that the thematic maps are to be regarded as being the best interpretation of the information available at the time of compilation and should be used for preliminary studies only. They are not intended as a substitute for on-site investigations or detailed local searches.

1.4.2 Aerial photographs as a data source.

Aerial photographs offer a quick, low-cost technique for investigating a wide variety of topographic features including landslip*, camber*, landfill, mineshaft location and land subsidence. The method is particularly effective when used in conjunction with a field survey.

Aerial photographs are of two types, oblique and vertical. The former show views similar to those obtained from elevated terrestrial viewpoints; the latter are taken vertically downwards. Oblique views are often used for illustration, being more visually informative to the untrained eye. However, vertical photographs are more widely available and can be used to derive accurate planimetrically correct information with regard to land form and use. Vertical air photographs were therefore used as a data source in this project.

Photographic cover at scales of 1:25 000 (approx.) and 1:10 000 (approx.) was available from several sources (see Appendix I). Some cover at a scale of 1:25 000, which was flown in 1946 by the RAF, is held in B.G.S. files. In addition, air photos at 1:10 000, flown partly in 1975 and partly in 1981, were obtained from J.A. Storey and Partners and from Cartographic Services. These give up-to-date cover of the entire study area at the same scale as the working base maps, enabling easy transfer of data.

*Please refer to Glossary (p.163) for definitions of technical terms.

No attempt was made to study changes in landslip development over the timescale covered by the air photographs but this could be a useful approach in a site specific study.

The more recent air photgraphic cover is of high quality with regard to the accuracy of flying, the resolution of detail on the print and the weather conditions, the last being characterised by an absence of cloud or mist, thus ensuring clarity of detail. The sorties, like most modern aerial photos, were flown with high sun angles for the purposes of land survey, which requires minimum shadow. For the interpretation of topographic features, as necessary for the present study, a lower sun angle is to be preferred. Nevertheless, the photos proved to be very informative. The RAF cover was flown under good visibility conditions but the prints suffer from darkening round the edges.

The aerial photo cover was used for:

a) detection of landslipped and cambered ground where it had not been indicated on the 1:10 000 Geological Survey maps.

b) confirmation of the boundaries of landslipped and cambered ground indicated on the 1:10 000 Geological Survey maps.

c) definition of the limits of fill on landfill sites where the boundaries were not known.

1.5 Confidentiality and Copyright of the data

Information from commercial organisations was sought on the basis that it would be treated as the confidential property of their clients. It was considered that if this undertaking had not been given, far less data would have been received, an outcome that would have been prejudicial to the effectiveness of the study. Many site investigation reports were thus obtained on the understanding that site-specific data would not be published, but would be generalised for the purpose of compiling thematic maps. Thus, a substantial proportion of the total site investigation data acquired during our searches is filed under confidential cover and individual reports can only be made available for reference by negotiation with the owner.

All B.G.S. published maps are Crown Copyright and permission to reproduce them requires the appropriate authorisation.

1.6 Location of Geotechnical Data Sources

Thematic Map 14 shows the approximate location of site investigation reports and borehole logs which were obtained for the project or were already held in the B.G.S. borehole records archive.

The number of boreholes and pits described in a single site investigation may vary from a single exploration to over one hundred. More than 1,100 individual pits and boreholes obtained from site investigation reports were recorded in the geotechnical database (Geotech 1 and Geotech 2).

The high density of data points within the boundary of a site investigation makes it impracticable to register the individual locations at a map scale of 1:25 000. Furthermore, the disclosure of the precise location of a borehole may, in some cases, be a breach of confidentiality. Thus, only the boundaries of site investigations have been shown.

On the map, the location of a site investigation is depicted by a dot accompanied by a letter/number code which refers to the report listed in the schedule of geotechnical data sources and to the geotechnical database files. Very large investigations are shown by a large dot and their boundaries are indicated by solid, dashed or dotted lines.

Map 14 also shows, on an individual basis, water wells and boreholes which are recorded in the B.G.S. borehole records archive; these are indicated by a numbered open circle. The borehole is uniquely identified by the National Grid 1:10 000 scale map on which it is located together with an accession number, thus - "ST75NW/7". All such wells and boreholes are accurately located on the 1:10 560 reference maps in the B.G.S. Records Department at Keyworth, together with many of the individual site investigation boreholes.

Some borehole and well records are currently held by the B.G.S. on the understanding that they are confidential and are not to be released without the consent of the owner of the information. Some of the site investigation and other data collected during this project were obtained under similar conditions; therefore site specific borehole data have not been referred to individually in this report.

2. GEOLOGY AND DISTRIBUTION OF MADE GROUND

2.1 Summary of the Geology and Geological Survey of the study area

The geology of the study area was first systematically surveyed on the 1 inch to 1 mile scale and published on the Old Series Geological Survey maps between 1857 and 1873. Prior to that, several geological pioneers had been concerned with the rocks of the district, beginning with William Smith's work on the construction of the local canals in the late 18th century. It is surprising in these circumstances that the area was not mapped by the Geological Survey on the 6-inch scale until 1944-58. The results of that survey were included on the 1-inch New Series sheets 265 (Bath) and 281 (Frome) published in 1965. Thematic Map 1 (Solid Lithostratigraphy) shows the outcrop geology of the the study area at a scale of 1:25 000; Figure 2 gives a simplified version.

The oldest rocks exposed in the study area are the Coal Measures which crop out only at Corston [c 701 654]*, west of Bath. Carboniferous rocks extend eastwards beneath the sub-Trias unconformity and are extensively folded, faulted and locally overthrust. The less competent mudstones of the Coal Measures are commonly crushed and overturned.

Above the unconformity, rocks of the Mercia Mudstone and Penarth groups crop out in the valleys west of Bath and near Radstock. The undulating countryside characteristic of much of the study area is underlain mainly by Middle and Upper Jurassic clays, with subordinate limestones and sands. In addition, the massive limestones of the Great Oolite commonly form plateau-like tracts, whilst those of the Inferior Oolite give rise to bench-like outcrops on valley slopes. The area is dissected by the incised valleys of the River Avon and its tributaries which cut down through the Liassic clays of the Lower Jurassic.

The valley slopes have, in the past, been affected by shallow mass movements which make ground conditions potentially unstable. The landslips mostly date from late-glacial times and are commonly degraded. Some slips and mud-flows are more recent in origin, however, and show fresh morphological features; a few are still active at the present day. Cambering of the massive limestone outcrops is widespread and is accompanied by dip-and-fault structures, with open fractures or gulls and with solution cavities. In the valley floors, there is evidence of valley bulging in the incompetent clays.

* National Grid References relate to 100 km square ST throughout this report.

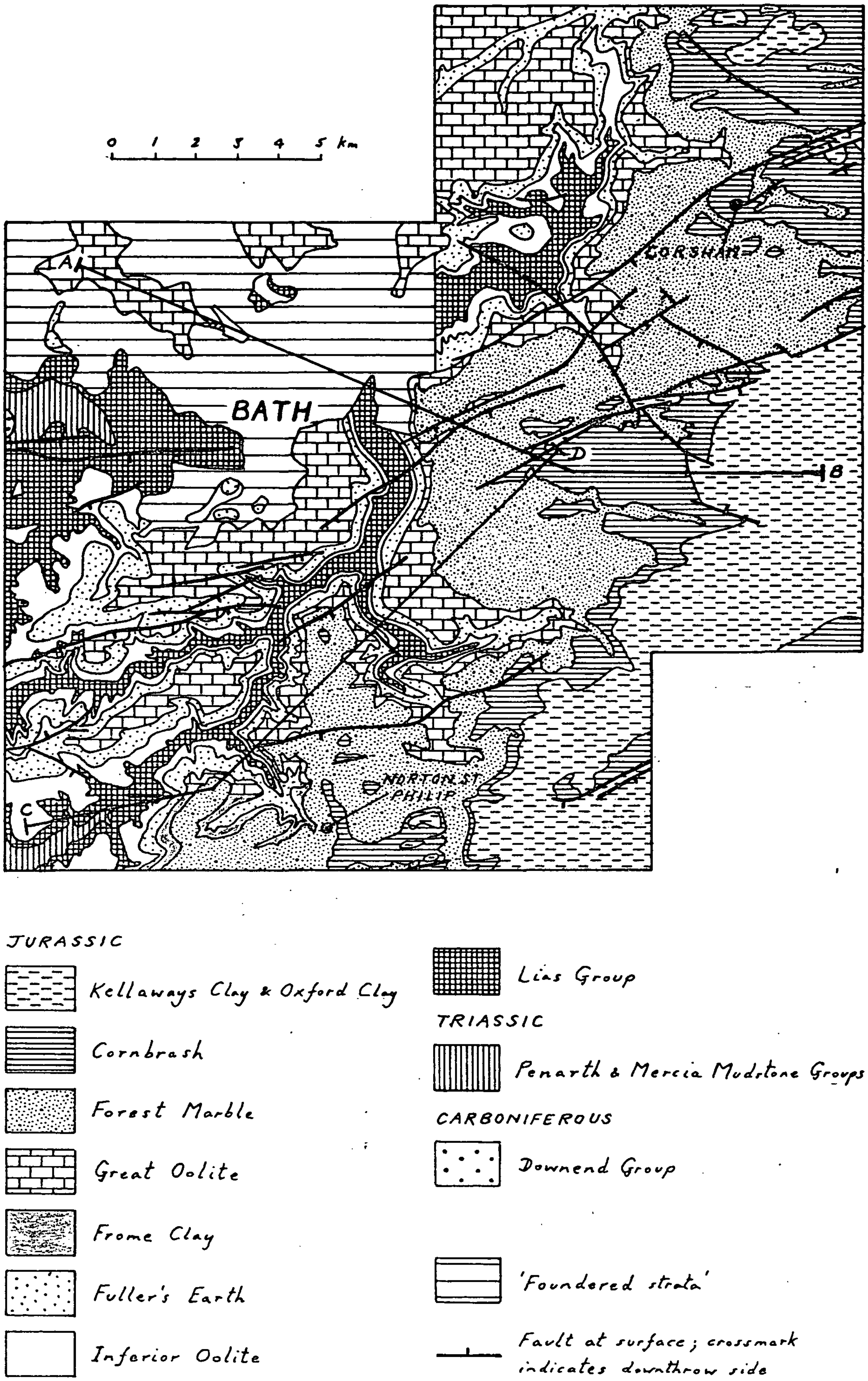


FIG. 2 SIMPLIFIED SOLID GEOLOGY OF THE STUDY AREA
(See figs. 4 & 5 for sections along the lines A-B & C-D respectively)

Veneers of solifluction deposits locally mask the disturbed slopes and can themselves be an engineering hazard since they may include and be underlain by shear planes.

Structurally, the Triassic and Jurassic rocks dip gently to the east-south-east and are cut by several west-south-west trending normal faults. Where the outcrops have slipped or cambered, they commonly display considerable dips at variance with the regional trend.

The most prominent drift deposits are those of the three terraces of the River Avon, mainly comprising gravels. The terraces are well developed near Melksham, and small tracts occur at Bath. The deposits of the lowest terrace also infill a buried valley below the alluvium of the Avon floodplain. The remaining drift deposits are mainly restricted to scattered patches of solifluction Head and high level gravels of uncertain age and origin, the lithology of the former varying widely in response to their source materials. More extensive spreads of Head, largely derived from the Oxford Clay outcrop, occur south of Melksham.

A helpful and more detailed guide to the geology of the study area is given in "Bristol and Gloucester District" (British Regional Geology series), third edition (G.W. Green, in press).

2.2 Geological Sequence

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

Superficial Deposits (Drift)

Quaternary

- Alluvium
- Alluvial Fan Deposits
- River Terrace Deposits
- Head
- Deposits of Unknown Age

Solid Formations	Thickness (metres)
Jurassic	
Oxford Clay	up to 25
Kellaways Clay	21

	Thickness (metres)
Great Oolite Group	
Cornbrash	1.5 - 6.0
Forest Marble	16 - 30
Great Oolite/Frome Clay	22 - 39
Fuller's Earth	28 - 44
Inferior Oolite Group	
Inferior Oolite	12 - 18
Lias Group	
Midford Sands	0 - 31
Dyrham Silts	0 - 12
Lower Lias Clay	12 - 110
Blue Lias	2 - 19
Triassic	
Penarth Group	
Lilstock Formation	6
Westbury Formation	3
Mercia Mudstone Group	
Blue Anchor Formation	3
Mercia Mudstone Group (undifferentiated)	0 - 77
Dolomitic Conglomerate	0 - 60
Carboniferous	
Upper Coal Measures (Supra-Pennant Group)	
Radstock Formation	340
Barren Red Formation	140
Farrington Formation	340
Upper Coal Measures (Pennant Group)	
Mangotsfield Formation	240
Downend formation	175
Middle Coal Measures	250
Carboniferous Limestone (undivided)	93 proved

2.3 Solid Lithostratigraphy

2.3.1 Source Data

The map of Solid Lithostratigraphy (Map 1) is compiled from reductions of 6 inch to 1 mile geological sheets based on field surveys between 1944 and 1958. Borehole and trial pit data acquired since the completion of these surveys indicate that the mapped outcrops of solid formations are reliable within the recognised limits of accuracy. Where boundaries are shown as broken lines, an unspecified degree of uncertainty in their position is indicated. Continuous lines may be regarded as accurate to within about 20 m either way, though the degree of accuracy varies between different surveyors.

Boundaries extrapolated below areas of landslip and drift deposits, where borehole data are sparse or lacking, are generally to be regarded as conjectural. Those on cambered valley slopes are also uncertain because cambered strata commonly trail downslope into a thick hillwash, which may extend some distance and mask the true limits of solid formations. Again, more general spreads of hillwash or solifluction deposits (Head) can give rise to similar uncertainties.

Published literature and unpublished research provide a reliable and detailed understanding of the regional stratigraphy of the Jurassic rocks, which crop out over all but a small portion of the project area. The uncertainties concerning the relationships between the Great Oolite Formation (mainly limestones) of the Bath area and corresponding mudstone strata (Frome Clay) to the south of the City have now been largely resolved (Penn and Wyatt, 1979); the revised 1:10 000 geological sheets in the data archive incorporate these revisions. The upper part of the Triassic succession, which crops out in valleys on the western margin of the area, is well known from both outcrop and borehole data. However, the lower part of the sequence, which is not exposed, is poorly known because of the sparsity of deep boreholes. Those parts of the Upper Coal Measures which were once worked for coal in the Radstock-Dunkerton area are well known from records of colliery shafts, boreholes and underground workings. However, there is much less information for the older workings around Newton St Loe [c 708 653] and Twerton [c 715 645], where only the coal-bearing sequence in the Downend Formation is satisfactorily recorded. Over the greater part of the project area the Carboniferous rocks at depth are little known. These include the Carboniferous Limestone which has been penetrated in only five boreholes, three of which are in Bath.

Two particular deficiences in the mapped outcrops of the Jurassic formations call for comment. The first concerns the failure to distinguish between the Bath Oolite and Upper Rags members of the Great Oolite Formation, which are mapped as one unit. Thus the outcrop of the Bath Oolite, a valuable local limestone resource, cannot be separately defined on existing maps. Another, lesser implication is that the Upper Rags, which is regarded by some as being the basal member of the Forest Marble (corresponding to the Acton Turville Beds, mapped in the north of the project area; Penn and Wyatt, 1979), cannot thus be assigned on the 1:25 000 lithostratigraphic map. Therefore, on this map it has, together with the Acton Turville Beds, been retained as the uppermost member of the Great Oolite.

There is also a failure to separate the Kellaways Clay and Oxford Clay in part of the study area. Though the lithologies have been separated in borehole logs, the lack of surface indications make this difficult in the field. Thus, the base of the Oxford Clay to the NNW of Melksham has had to be amended on the basis of borehole data. The distinction between the two formations is of relevance because sand and sandy clay lithologies in the Kellaways Clay have different geotechnical properties from the clays which form the bulk of the Oxford Clay/Kellaways Clay sequence.

2.3.2 Description of Solid Formations

The following describes the Solid Formations in ascending order of succession. The sequence is shown as a generalised vertical section in the margin of thematic Map 1.

Carboniferous Limestone

The Carboniferous Limestone is entirely concealed beneath younger strata. It has been proved in only five boreholes, of which three are in Bath.

A maximum of 93 m was penetrated in Lucknam Borehole [8338 7071] where it consisted of hard limestones with some dark grey and purple shales. In the shaft at Batheaston [c7814 6776] the bulk of the 78 m penetrated was composed of hard, grey and red 'stone', which was recognised as Carboniferous Limestone in correspondence dating from the time of the drilling.

At Bath, Triassic strata are known to rest unconformably on the Carboniferous Limestone. In the Kingsmead Borehole [7478 6480] the latter comprised 34.5 m of grey and pink crinoidal limestones containing some cherty shale; overlying 27.5 m of hard, grey, fine-grained limestones which were in part oolitic.

MIDDLE COAL MEASURES

The Middle Coal Measures are best known from south of the study area, near Mells [c700 490], where they consist mainly of grey shales and mudstones with workable coal seams and associated fireclays. There are some beds of sandstone, mainly near the top of the sequence.

Within the study area these measures were worked only at Twerton Colliery [c715 645]; few lithological details are recorded. However, it is thought that the succession is not dissimilar from that near Mells.

UPPER COAL MEASURES (PENNANT GROUP)

Downend Formation

Massive, grey, coarse-grained and current-bedded sandstones and grits dominate the succession, which also includes several workable coal seams. The latter were worked during the early 1800's in the Newton St Loe area [c708 653].

Mangotsfield Formation

Beds of this formation, like the underlying strata, are mainly coarse-grained sandstones and grits, but there are no coal seams. Towards the top, shales and mudstones also occur.

UPPER COAL MEASURES (SUPRA-PENNANT GROUP)

Farrington Formation

The base of this formation is drawn at the first workable coal above the dominantly sandstone succession described above. The sequence consists of grey shales and mudstones containing workable coal seams, together with their associated fireclays. There are some coarse-grained sandstone beds, which commonly rest directly on coal seams, and a few bands of ironstone nodules. The coal seams contributed a significant proportion of the deep-mined coal of the Somerset Coalfield.

Barron Red Formation

This group of beds was named after the occurrence of red shales and mudstones, which are common in the middle of the sequence. The remainder consists of the more normal grey measures, which include intermittent sandstones, sandy shales and bands of ironstone nodules. There are no workable coals, but a few coaly partings with associated fireclays are present.

Radstock Formation.

Grey shales and mudstones with several workable coals represent the Radstock Formation. Fireclays and some sandstone beds also occur.

MERCIA MUDSTONE GROUP

Mercia Mudstone Group (undifferentiated)

Within the study area the Mercia Mudstone (formerly Keuper Marl) is represented mainly by red silty and sandy mudstones, commonly with greenish patches and streaks, and with intermittent persistent greenish bands. There are also sporadic beds of greenish grey calcareous sandstone or siltstone known as 'skerries'. The mudstones are typically massive and fairly uniform, and have a sub-conchoidal fracture. At the surface they weather into heavy red clays.

The Mercia Mudstone rests unconformably upon a pre-Triassic landscape which locally has considerable relief. Because of this, thickness variations are thought to be considerable and rapid, though there are few deep boreholes to give proven values. A maximum thickness of 77 m has been recorded within the study area, but locally the thickness may be greater. Elsewhere, however, the Mercia Mudstone is quite thin or even absent, as beneath parts of Bath.

In the vicinity of buried hills there is commonly a marginal variation of the Mercia Mudstone known as the Dolomitic Conglomerate, which originated as screes of coarse rock debris eroded from contemporary uplands. These screes, which may be quite extensive, consist of coarse angular rock debris or even boulder beds, for the most part composed of Carboniferous Limestone. The matrix of these beds is usually a red sandy mudstone. They are normally buff-coloured and dolomitic, but red ferruginous beds also occur. These breccio-conglomerates thin and pass laterally into the normal Mercia Mudstone lithologies away from the source rocks. Thicknesses vary greatly, the recorded maximum being at Batheaston [c7814 6776] where 60.3 m was penetrated in the abortive coal shaft/borehole.

Blue Anchor Formation (formerly Tea Green Marl)

This formation consists of silty and sandy mudstones which differ from those of the Mercia Mudstone only in their greenish grey colour. Locally, there are hard sandy calcareous bands.

PENARTH GROUP

The Penarth Group, which is shown undivided on Map 1, comprises the Westbury Formation and the overlying Lilstock Formation. The constituent Members of the latter and the former names of all these strata (in brackets) are as follows:

		(Langport Member	(= White Lias)
	(Lilstock Formation(		
Penarth Group(		(Cotham Member	(= Cotham Beds)
	(Westbury Formation		(= Westbury Beds)

Westbury Formation

The Westbury Formation consists mainly of dark grey to black, thinly bedded, very fossiliferous shales, with some dark grey limestone bands and also thin beds or lenticles of calcareous sandstone. At the base there is commonly a thin, sandy, conglomeratic and phosphatic limestone containing abundant teeth, scales and bones of fish and other marine vertebrates, as well as quartz pebbles and fragments of the underlying rocks. These beds rest with a sharp, erosive base upon the Blue Anchor Formation.

Lilstock Formation - Cotham Member

Greenish grey marls, shelly in part, with some pale limestone beds are typical of the Cotham Member. They rest with a sharp junction on the underlying black shales and range from 3 to 4 m in thickness. A hard, splintery calcite mudstone at the top, with a mammilated upper surface and a flat smooth base may be found locally; this is the well-known Cotham Marble. It has attractive arborescent markings in the vertical plane which gives rise to its alternative name of Landscape Marble.

Lilstock Formation - Langport Member

The Langport Member consists of pale grey and cream limestones with subordinate marls and clays. The old name (White Lias) reflects the characteristic whitish hue of the rocks when weathered. The thickness of the member ranges from 3.0 - 3.7 m in most districts, but is over 5 m near Radstock and probably also elsewhere towards the southern margin of the study area.

Where the Langport Member is thickest it can be divided into two parts, the lower of which consists of thin rubbly limestones with clay partings. The upper part comprises harder, more regularly bedded, uniform porcellanous limestones with a conchoidal fracture. The top bed ('Sun Bed') is recognised by the presence of U-shaped burrowfills.

LIAS GROUP

Blue Lias

The Blue Lias comprises up to 19 m of interbedded limestones and shales or mudstones, in which the ratio of the former to the latter ranges from 1:1 to 1:4 or more. Most of the limestones are hard, bluish grey, muddy and fine-grained. At the base, however, there are flaggy shelly limestones, sometimes referred to as the 'Ostrea Beds'. Beds of porcellanous, laminated limestone also occur. The mudstones range from mid grey, calcareous and blocky to dark grey, weakly calcareous, laminated and bituminous, the latter weathering to 'paper' shales.

In the Avon valley around Bath, the Blue Lias is divided into four units. The following sequence recorded at Weston is typical:

Unit D Persistent beds of hard limestone (0.15-0.30 m thick) interbedded with similar thicknesses of mudstone. The tops and bases of the limestones may be level or wavy - 5.4m

Unit C Thinly bedded, nodular, impersistent limestone beds, interbedded with thin mudstones - 4.8m

Unit B 'Saltford shales'. Mudstones and shales with widely-spaced thin bands of limestone and septarian nodules - 3.4m

Unit A Thin-bedded clays/shales and limestones, commonly in irregular beds. Laminated limestones and 'paper' shales in the upper part - 3.6m

To the south of Bath the Blue Lias thins considerably, and at the south-west corner of the study area is as little as 1.5 m in thickness. Here it consists of thin-bedded, muddy limestones with shale partings; the sequence recorded at Weston is no longer recognisable.

Lower Lias Clay

Mudstones and shales dominate the Lower Lias Clay sequence, in which there are only sporadic bands of muddy limestone. Broadly, the succession can be divided into three parts, the lowest of which comprises dark grey mudstones and shales with very few limestone beds or layers of calcareous nodules. The middle part is characterised by paler calcareous mudstones with a greater number of limestone beds. The upper part consists of pyritous, silty, micaceous mudstones with scattered clay-ironstone nodules.

A maximum thickness of about 110 m is present in the Bath area. However, south of grid northing 60 the Lower Lias Clay thins rapidly towards Radstock where only about 10 m of beds are present. Here, 2-4m of mainly ironshot shelly limestones at the base are overlain by silty mudstones. The thinning of the sequence results partly from periods of non-deposition during Liassic times and partly from pre-Inferior Oolite erosion.

Dyrham silts

The Dyrham Silts comprise grey and bluish grey, laminated, micaceous silts and clayey silts which pass down into the Lower Lias Clay below. They have been mapped only in the north-west corner of the study area, near North Stoke [c701 696], but have also been recorded in boreholes near Swainswick [c760 685], north-east of Bath.

At the top of the Dyrham Silts there is the so-called Junction Bed which has a sharp erosive base. It consists of up to 3.0 m of hard, shelly, ironshot and oolitic limestone with conglomeratic bands. The bed is variable in thickness and locally absent. Because of its thinness, it has been mapped in only a few places; the outcrops are too small to be shown on the 1:25 000 map (Map 1).

Midford Sands

This formation is characterised by uniform, yellowish brown, fine-grained silty sands. Locally, the sand is weakly cemented to form a soft, friable sandstone and, commonly, there are intermittent bands of hard calcareous sandstone concretions ('doggers' or 'sand burrs'). The Midford Sands thin to the south of Bath and wedge out in the Cam valley at Dunkerton [703 590] and in the valley of Wellow Brook, 1.5 km east-north-east of Wellow [755 588].

INFERIOR OOLITE GROUP

Inferior Oolite

Over much of the study area the Inferior Oolite rests upon the Midford Sands. In the southern margin, where the latter is absent, it overlies the Lower Lias Clay. Only the Upper Inferior Oolite is represented, the middle and lower units being absent in the present district. It was mapped undivided, but three divisions can usually be recognised.

At the base there is the Upper Trigonia Grit, from 1.5 to 3.0 m in thickness. This consists of hard, sandy, very shelly limestones, which are in part ironshot or oolitic. The basal bed is conglomeratic, with pebbles of quartz and sandstone, the latter derived from the Midford Sands. The top bed is commonly bored and oyster encrusted. Thick-shelled bivalves coated with encrusting worm tubes are the most common fossils.

These beds are overlain by the Upper Coral Bed, 2.5 to 4.5 m in thickness. It comprises masses of compound coral in a matrix of whitish chalky limestone irregularly interbedded with bands of marl. Its top surface is hardened, bored and covered with encrusting oyster shells. The Upper Coral Bed is less well developed north of the River Avon where it is locally absent.

The Doulting Beds are next in sequence; they are largely creamy white oolites, massive and thick-bedded in the lower part but flaggy in the upper part. Scattered bivalve shell moulds and small solitary corals are characteristic. Overlying the oolites there are rubbly, shelly, fine-grained limestones with a hardened and bored top. These so-called Rubbly Beds have commonly been included in the Inferior Oolite (e.g. Richardson, 1907) but they are, in fact, best regarded as the basal beds of the Fuller's Earth Formation.

GREAT OOLITE GROUP

The Great Oolite Group comprises the strata between the top of the Inferior Oolite and the base of the Kellaways Clay. Within this sequence there are significant changes in the thickness and lithology of certain formations, which are shown in Figure 3.

Lower Fuller's Earth

Grey silty calcareous mudstones dominate the Lower Fuller's Earth succession, but there are also thin muddy limestone bands. A persistent bed of very shelly mudstone containing an abundance of small oyster shells (Acuminata Bed) occurs 3-5 m below the top. Another very shelly band 1-2 m above it, is known as the Echinata Bed. Both beds are useful in correlation. The Lower Fuller's Earth is fairly consistently between 13 and 14 m in thickness, but is locally as little as 10 m and, at the north-east margin of the study area, increases to 16 m or more.

Fuller's Earth Rock

The Fuller's Earth Rock is represented mainly by rubbly, shelly, marly limestones with bands of shell-fragmental calcareous mudstone. It is commonly conglomeratic at the base, with phosphatised and bored limestone pebbles. At and to the south of Bath the Fuller's Earth Rock is generally from 3 - 5 m thick, but to the north-east of the city it thins to 1 - 2 m as a result of lateral passage of the upper beds into mudstones.

Upper Fuller's Earth

As with the Lower Fuller's Earth, grey silty mudstones dominate; but intermittent thin muddy limestone beds and dark grey shaly mudstones also occur. From just south of Bath to the northern margin of the study area the formation is between 22 m and 29 m thick. Elsewhere, it thins southwards to a minimum of about 12 m at the southern margin of the area.

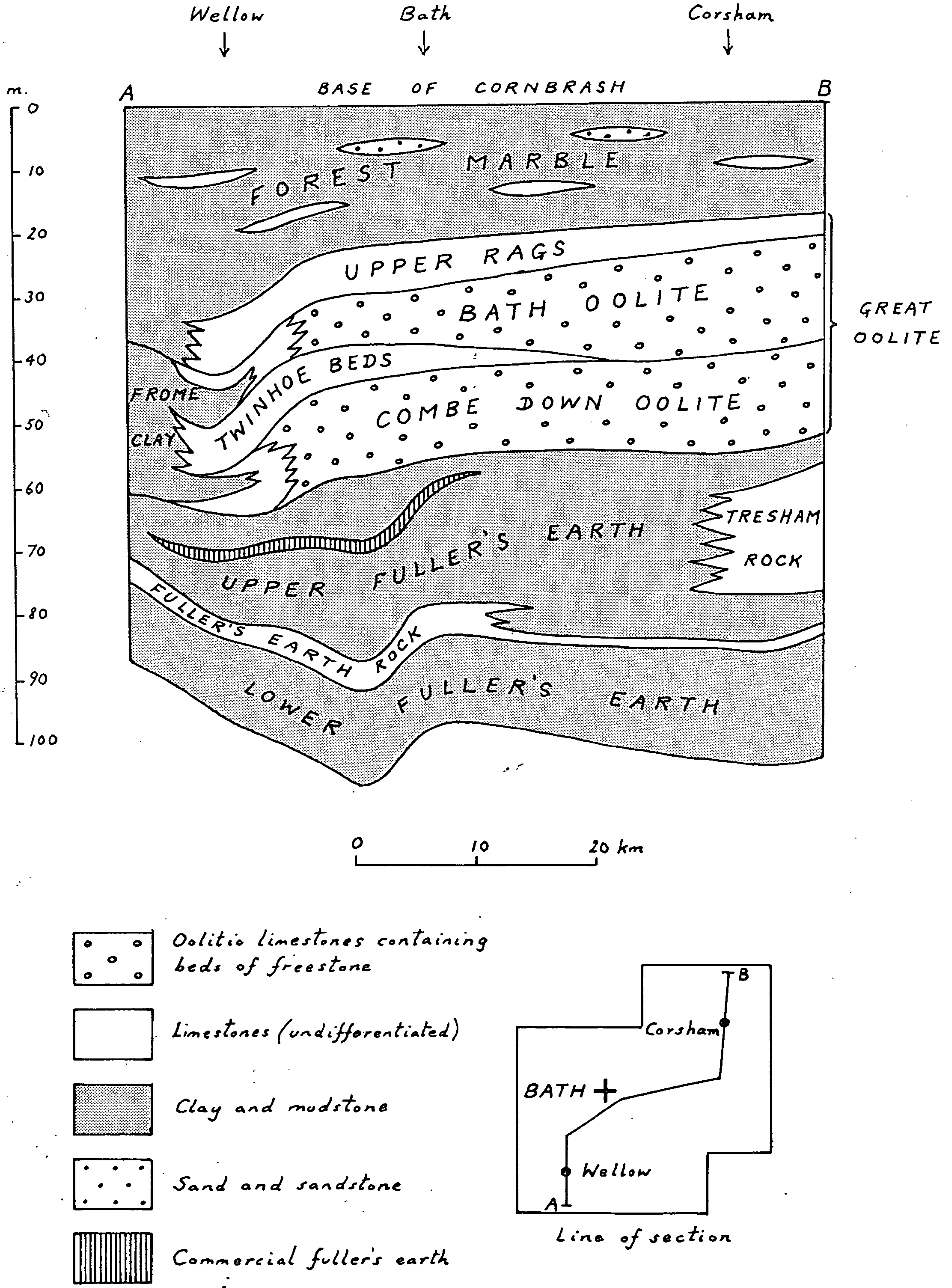


FIG. 3 DIAGRAMMATIC SECTION SHOWING THE VARIATIONS IN THICKNESS AND LITHOLOGY OF FORMATIONS COMPRISING THE GREAT OOLITE GROUP

From 3 m to 10 m below the top of the Upper Fuller's Earth there is a bed of commercial fuller's earth (Fuller's Earth Bed) up to 3.3 m in thickness (see section 3.2). At outcrop, this bed is confined to Bath and to an area south of the city, extending almost to the southern margin of the study area. Its eastward limit below superincumbent strata is unknown.

In the north-east corner of the district, beneath a cover of younger rocks, much of the Upper Fuller's Earth passes laterally into fine-grained muddy limestones (Tresham Rock - see Figure 3).

Great Oolite

The Great Oolite is composed almost wholly of limestones, with only a few thin marl beds, and includes the well-known commercial freestones which are collectively known as Bath Stone (see section 3.1). Where present, it ranges from 32 to 35 m in thickness, but about 6 km south of Bath and near Trowbridge it passes southwards into a succession of mudstones, the Frome Clay (Figure 3).

For the purposes of this report, Green and Donovan's (1969) definition and classification of the formation is adopted. This recognises four members, in ascending sequence as follows: Combe Down Oolite, Twinhoe Beds, Bath Oolite and Upper Rags.

Combe Down Oolite

This member rests with slight unconformity upon the underlying Fuller's Earth; its base is sharp, commonly erosive and locally conglomeratic, with pebbles of Fuller's Earth limestones. It is fairly uniform in lithology throughout the district and consists mainly of massive, cross-bedded, shell-fragmental oolites and oolitic limestones in which marl-filled burrows are locally numerous in the lower part. There is often a plane, bored top surface.

There are local variations in lithology; thus, in the Great Chalfield - Holt district [c865 625], 4km east-north-east of Bradford-on-Avon, there are 3-4m of interbedded mudstones, detrital limestones and oolitic limestones at the base. At Corsham [c.855 693), there is a 3.5 m bed of shell-fragmental marl in the lower part.

North of Box and Corsham the Combe Down Oolite is generally 13 to 15 m thick, with a local maximum of 18 m at Box Hill [c835 687]. Up to 18 m is also present at Combe Down, Bath [c750 625]. South and south-east of Bath and Corsham the oolites thin towards their southern limit, where they are from 2.5 - 7.5 m in thickness.

The Combe Down Oolite is the source of certain of the local building freestones and has been worked extensively at Combe Down, Bath, and in the Box area. The workable freestone comes from the upper beds which are free from marl-filled burrows.

Twinhoe Beds

The Twinhoe Beds, which are up to 13 m thick, consist typically of three lithologies. At the base there are marly, ironshot, pisolitic limestones. These are overlain by marly, pisolitic, shelly limestones which, in turn, are succeeded by fine-grained, compact, detrital limestones. The Twinhoe Beds gradually thin to the north and finally wedge out at outcrop in the vicinity of Box [833 688], and at depth near Atworth [c850 660].

Bath Oolite

Massive oolites and oolitic limestones are characteristic of the Bath Oolite. They are commonly even-grained and well-sorted, with a sparse matrix and little shell debris. A coralline bed has been proved locally at the base.

The Bath Oolite is in the order of 17 m thick at and to the north of Corsham, but thins steadily to the south mainly as a result of the lateral passage of the lower strata into the Twinhoe Beds. Thus, near its southern limit it is less than 5 m thick and consists of fine-grained detrital limestone with few or no ooliths.

Like the Combe Down Oolite, the Bath Oolite provides good quality oolite freestones which have been worked in a number of districts.

Upper Rags

The Upper Rags are mainly composed of cross-bedded, streaky, shell-fragmental oolites and oolitic limestones with bands of whitish, recrystallised, coarsely shell-fragmental limestone. Intermittent beds of marly, non-oolitic, shell-detrital limestone also occur. Coralline limestone is commonly present at the base and also locally at the top in the south.

Forest Marble

This formation is composed largely of grey or greenish-grey, calcareous mudstones and clays which contain varying proportions of interbedded calcareous sandstone or sandy limestone in the form of wisps, lenses and thin bands.

Sand-filled burrows are plentiful at some levels, and carbonaceous plant debris also occurs. Thicker bodies of sand/sandstone and of coarse-grained, shell-fragmental, sandy and oolitic limestone, both commonly containing muddy partings and strings of mudstone pebbles, are present throughout the sequence. They are generally impersistent and lenticular in form, thus precluding correlation even over short distances. Lenticular masses of sand up to 10 m thick, which contain large sandrock concretions, are particularly well-developed south-south-east of Bath, near Hinton Charterhouse (Hinton Sands) [c770 580].

The Forest Marble south of Bath and Bradford-on-Avon is from 25 to 30 m in thickness. To the north, however, the thickness is less, ranging from 16 to 25 m, the smallest values being towards the north-eastern corner of the study area.

Cornbrash

Fine-grained, shell-detrital limestones containing a few marl partings are characteristic of the Cornbrash. They are massive, hard and bluish grey where unweathered, but become rubbly, flaggy and rich brown in colour at outcrop. The thickness of the formation is variable, ranging from 1.5 to 6.0 m.

KELLAWAYS CLAY AND OXFORD CLAY

Kellaways Clay

The Kellaways Clay is represented mainly by darkish grey silty shelly clays and shaly mudstones. There are also intermittent beds of sandy clay, silt, sand and sandstone which are more numerous in the top few metres. Locally, the topmost bed is a hard, calcareous, quartzose sandstone, which is the local representative of the Kellaways Sand. The thickness of this bed was 0.15 to 1.37 m in boreholes drilled just east of Whitley [c897 662]. The impersistence and thinness of this bed accounts for its having not been recognised at outcrop.

Oxford Clay

Only the basal 25 m of Oxford Clay are estimated to be present within the study area. A borehole at Melksham [9088 6466], just outside the study area, proved these beds to consist almost wholly of dark grey clayey shales with many fossil-packed partings.

2.4 Drift Deposits

2.4.1 Source Data

It has not been possible to produce an isopachyte map showing variations in thickness of the Drift deposits because of the sparsity of borehole data, particularly outside the Bath district. Thus it was concluded that on thematic Map 2 notes were more appropriate than speculative isopachytes. Even within the city of Bath, where borehole logs are more numerous, their distribution is such that an effective isopachyte map is not feasible. Information about Drift thicknesses on Map 2 is deduced from an inspection of field survey notes and such borehole data as are available.

The source geological maps themselves impose limitations, in that Head deposits (excluding those associated with landslipped ground) in and adjacent to Bath, which are proved in many boreholes, are not indicated. The largely built-over valley slopes in Bath no doubt made recognition of such deposits difficult, quite apart from the fact that many of the slopes are encompassed within the areas of 'foundered strata'. Because of these limitations, a general note is added to Map 2 to indicate the widespread occurrence of a veneer of Head up to, and locally exceeding 3 m on valley slopes and in valley floors in and around Bath.

2.4.2 Description of Drift Deposits

Much of the mapped Drift comprises narrow linear tracts of alluvium and very small spreads of other superficial deposits. Only Head deposits between Staverton and Semington, and the alluvium and river gravels of the Avon valley near Melksham and at Bath, are of any great extent.

The following is a brief description of the Drift deposits in order of their presumed ages, commencing with the most ancient:

Deposits of Unknown Age

Small patches of problematical drift deposits occur locally on the tops of interfluves, at various heights. Those at Claverton Down [c770 635] consist of brown silty loam containing some oolite fragments and flints. The remainder, at Limpley Stoke [c775 609] and Tellisford [c805 558], comprise clayey sand and gravel, containing many flint and chert fragments.

The age and source of these deposits is unknown, although the occurrence of flint and chert suggests the possibility of a glacial origin.

Head

Head includes a heterogeneous group of superficial deposits which have accumulated by downslope solifluction, mainly under periglacial cold-climate conditions. Soil creep continues to add its contribution at the present day. The deposits incorporate weathered surface debris, the character of which reflects the variety of source materials upslope. They are usually poorly sorted and unbedded, though weak stratification may occur locally. Included rock fragments are usually angular or sub-angular. Not uncommonly, Head deposits are underlain by a shear surface, particularly where they overlie clayey strata. Relic shear surfaces may be present within the body of the sediment.

In the eastern part of the study area, between Staverton [860 600] and Corsham [885 716], the patches of Head are largely composed of silts and sandy loams, up to 1.5 m in thickness. All the occurrences are associated with outcrops of Kellaways Clay and it is probable that much of the Head is derived from the intermittent silty and sandy beds which diversify the Kellaways Clay succession.

The patch of Head at Trowbridge [843 579] contains much gravel in which chert, flint and chalk pebbles occur. These lithologies are foreign to the area and thus the deposit may represent redistributed glacial sediments. About 3 km to the west, at Wingfield [c815 575], a large spread of gravelly loam represents solifluction debris originating from the gravels of the Third Terrace.

Small patches of Head in the valley floor 1 km south-west of Dunkerton [c702 583] consist dominantly of limestone gravel, which is probably derived from the outcrop of the Inferior Oolite upslope. The sandy, stony loams at the foot of the valley slope, 1 km south-south-west of Bathford [784 656], are presumably a mixture of redistributed landslip debris, which includes material originating from the Inferior Oolite limestone, the Midford Sands and the Fuller's Earth and Lias clays.

Just south-west of Newbridge [714 656], there is a spread of stony clay, the gravel content of which almost certainly derives from the extensive outcrop of the Blue Lias higher up the valley slope. A small patch of stony clay 1 km to the west [702 656] lies at the margin of the river alluvium below a valley slope in Coal Measures sandstone.

River Terrace Deposits

River Terrace deposits are associated with three terrace features in the river valleys, the elevation of each falling steadily downstream. The sediments of the Third Terrace are at the highest level, whilst those of the First Terrace not only occur on the lowest bench just above the river alluvium but also fill a buried channel beneath it.

The terrace sediments mainly comprise fine to coarse-grained bedded sands and gravels in which there is a mixture of locally derived Jurassic lithologies and far-travelled constituents such as flint and chert. Locally, there is a surface veneer of sandy loam.

The sandy gravels which fill the sub-alluvial buried channel in the Avon valley are commonly very coarse-grained and include many large cobbles and boulders of the local Blue and 'White' Lias limestones, as well as smaller and less abundant pebbles and cobbles of Carboniferous Limestone, Old Red Sandstone, flint and chert. Thicknesses exceeding 5 m have been recorded in boreholes.

Alluvial Fan Deposits

These deposits occur as fan-shaped accumulations of angular loamy gravel at the mouths of small tributary steams. Their content indicates derivation from very local source rocks. The two occurrences shown on Map 2 are near Norton St Philip [764 563] and at Freshford [792 605].

Alluvium

Narrow ribbons of alluvial deposits occur in the floors of the river valleys. They constitute a diverse range of sediments which commonly include soft clays, silts and silty and sandy loams. Locally, they are stony and contain either scattered rock fragments or gravelly lenses and interbeds. In some places, bands or lenses of dark organic clay or peat are present. A basal gravel lag deposit is not unusual. The sequence of sediments may vary rapidly over short distances.

2.5 "Foundered Strata"

A considerable part of the deeply disected landscape close to Bath, mainly to the north of the city, is shown on the published 1-inch geological sheet 265 (Bath) as 'foundered strata'. Within the area thus depicted no distinction is made between landslipped and cambered ground (see Glossary for definitions); nor are any solid formational boundaries within the Lower and Middle Jurassic sequence indicated. Thus the value to the user is greatly reduced.

The significance of the term 'foundered strata' has been explained (Hawkins and Kellaway, 1971) as originally being a response to the cartographical requirement of showing solid formational boundaries below landslip. The apparent impracticability of showing such boundaries with any confidence beneath those highly disturbed valley slopes which could not be certainly identified as individual landslips, led to their representation as 'foundered strata', symbolised by horizontal lines. It has been emphasised (ibid) that the intensity of superficial disturbances on the valley slopes around Bath precludes a distinction between landlipped and cambered ground, and that the 'mèlange' of deposits from the various rock formations could not be resolved into distinct units.

A brief field examination of areas shown as 'foundered strata' demonstrated that landslipped ground, ground disturbed by cambering and areas of undisturbed strata can generally be distinguished. This conclusion was supported by the fact that parts of the 'foundered strata' area were originally mapped in traditional style, showing these distinctions. Consequently, it was decided to re-survey all areas of 'foundered strata' in order to achieve parity of interpretation and to provide a more meaningful geological map output. The resulting revisions are the subject of a supplementary report. Thus, thematic Map 1 retains the areas of 'foundered strata' as shown on existing geological maps; and Map 10 shows the inferred limits of landslip within these areas, based on an analysis of aerial photos.

2.6 Geological Structure

All but a small tract of the study area west of Bath is underlain by Triassic or Jurassic strata which dip gently (5°) and fairly uniformly to the east-south-east, such that younger beds crop out progressively eastwards (Figure 4). This simple structure is locally modified by shallow flexures, most of which have approximately E-W axes. Additionally, there are several WSW-trending faults and a few faults at right angles to them. As a result of these structural complications the outcrop pattern of the rock formations shows some degree of complexity.

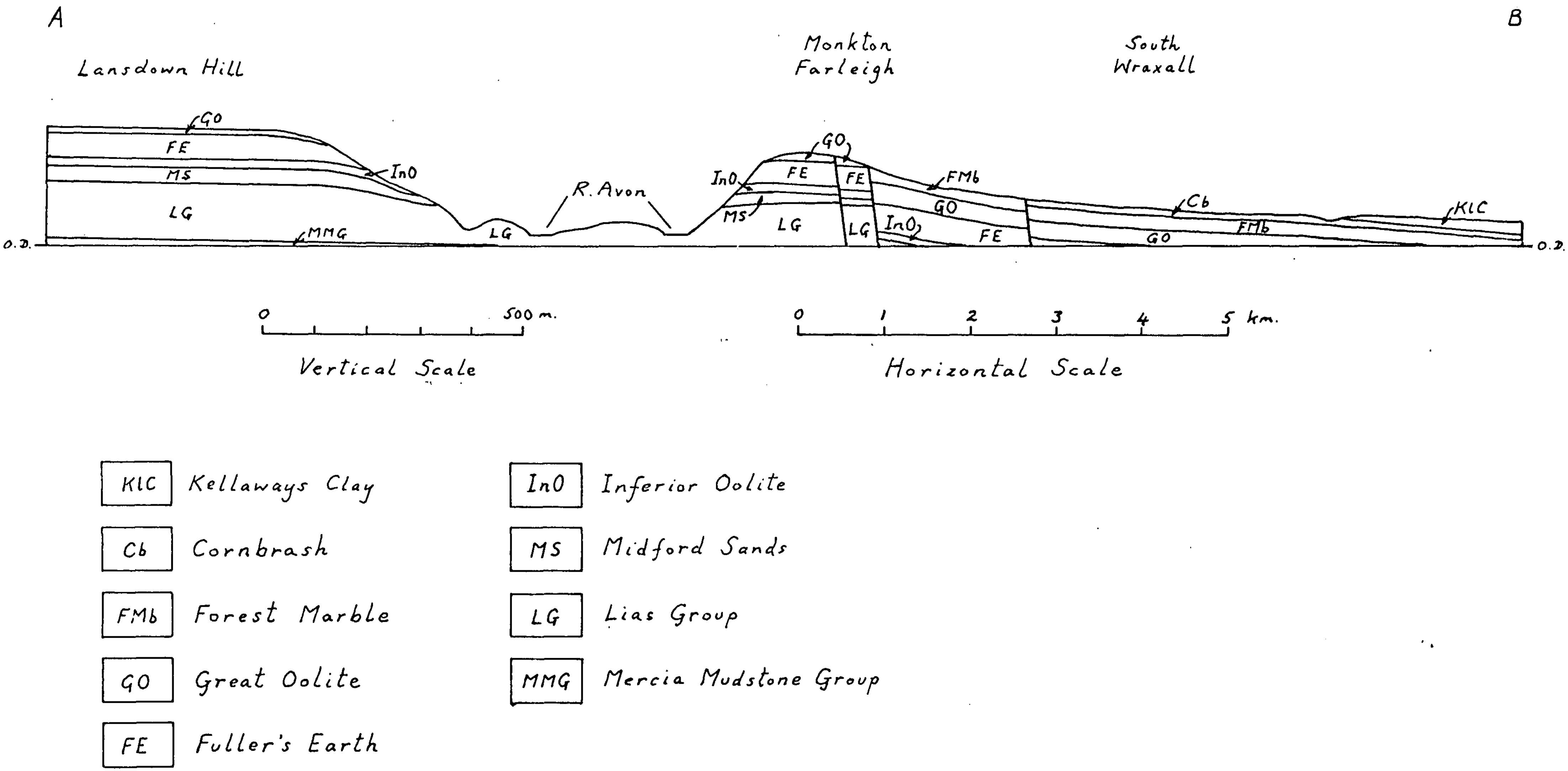


FIG. 4 SECTION TO SHOW THE GEOLOGICAL STRUCTURE ALONG THE LINE A-B
(for line of section see fig. 2)

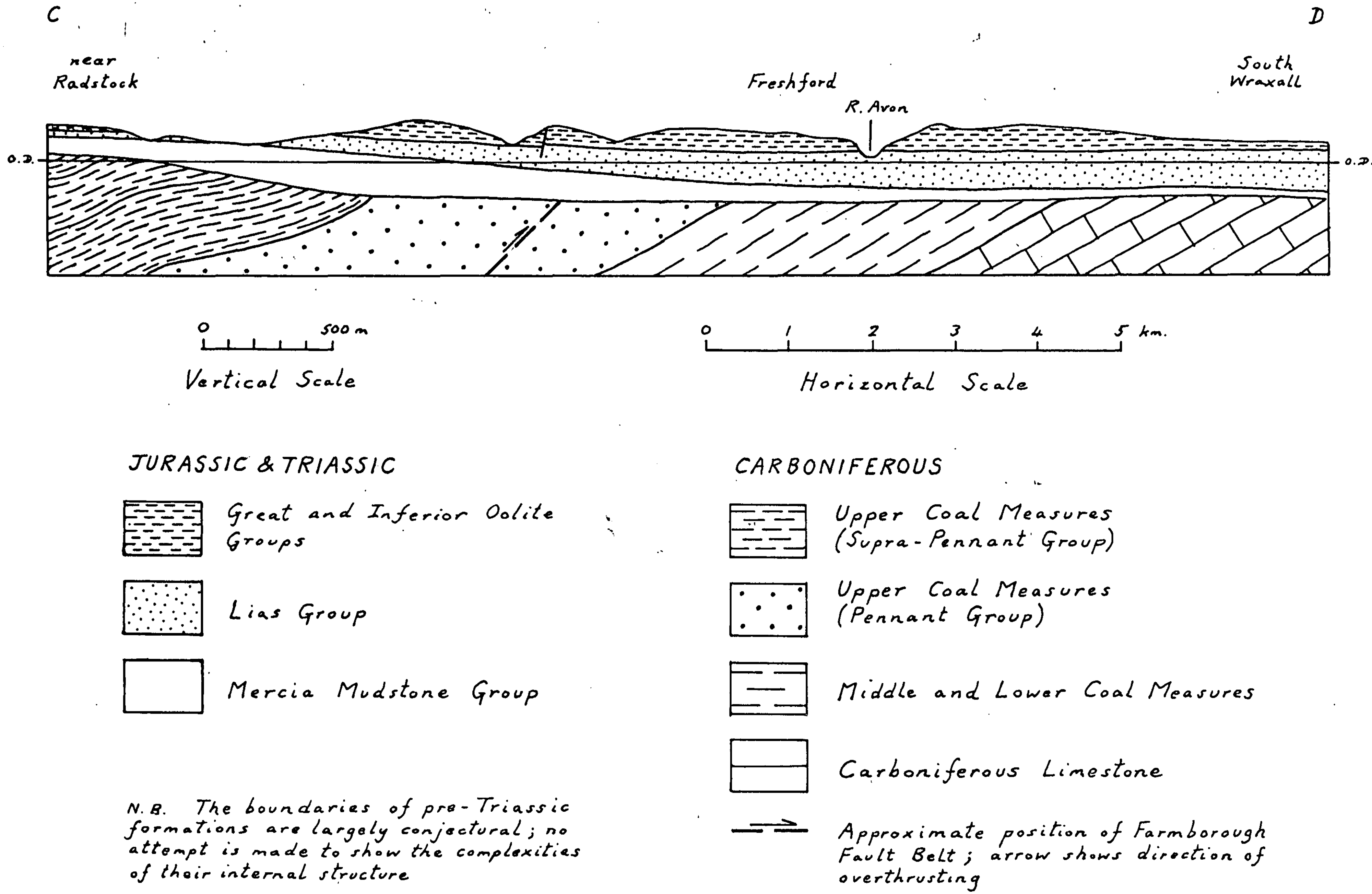


FIG. 5 SIMPLIFIED SECTION TO SHOW THE STRUCTURAL RELATIONSHIP BETWEEN CARBONIFEROUS AND YOUNGER STRATA (Drift deposits omitted: see fig. 2 for line of section)

Beneath the cover of Triassic and Jurassic strata are concealed rocks of Carboniferous age, including the Coal Measures and Carboniferous Limestone which are extensively folded, faulted and overthrust. Apart from the Somerset Coalfield area, the structure of which is reasonably well understood as a result of coal mining, the disposition of the Carboniferous strata beneath the Triassic is little known because of the sparsity of deep borehole data. Thus the inferred structure shown in Figure 5 is conjectural.

The concealed Coal Measures of the Somerset coalfield are disposed in a large elongate basin with a west-north-west trending axis (Moore, 1939; Kellaway, in press). Only the south-east portion of this structure lies within the study area. It is broken into two discrete parts by the Farmborough Fault Belt which separates the Pensford Basin to the north-north-west from the Radstock Basin to the south-south-east. This fault belt is a west-south-west trending structure which enters the study area north of Dunkerton and continues to the south of Bath. It is one of several overthrust faults of similar trend which displace the strata, locally in excess of 100 m. There are also a number of approximately north-south normal faults which intersect these almost at right angles. This complexity of structure is responsible for the difficulties with which some of the coals were formerly worked.

2.7 Made Ground and Infilled Land

2.7.1 Introduction

The occurrence of made ground or infilled land is significant in terms of foundation conditions. In particular, ground composed predominantly of domestic refuse offers an unsatisfactory foundation of low strength for large surface structures. Buildings at such sites require special foundations, such as piles driven through the fill to an underlying firm base.

Again, artificial deposits of waste materials are generally heterogeneous and may give rise to ground conditions which exhibit a range of geotechnical properties. Thus differential compaction under loading is always a possibility.

The contrast in ground conditions between infilled land and the surrounding natural strata can be considerable. Therefore, structures built over the boundary between the two are likely to suffer damage if the disparity between them has not been recognised.

The possible occurrence of corrosive chemicals in made ground/infilled land should be acknowledged when buildings are erected on these sites. Consequently, site investigations should include a chemical analysis and reference to the records of previous waste disposal operators. Where necessary, sulphate-resisting or other special cements for piles and concrete rafts could be used in construction, possibly in conjunction with protective coatings, such as polythene, hard bitumen, epoxypitch or polyurethene bitumen [Carter, 1983]. The site investigation should also include a methane survey so that, where appropriate, methods of preventing methane accumulation in basements, service ducts, etc., can be incorporated in the structural design.

Where there is a risk of contamination of aquifers, the relationship between landfill and the underlying and adjacent strata is of some importance. A tabulation of landfill sites indicating this relationship is given in Appendix II. However, no evidence for the occurrence of toxic wastes has been found during the study. Moreover, since 1976 landfill operators have been obliged to obtain waste disposal licences from the relevant County Councils; and issue of licences is subject to the approval of Wessex Water Authority. Thus, sites located on potential aquifers, where there is no substantial risk of contamination, have been authorised by the local authority. There is, nevertheless, the possible risk of methane diffusion from domestic refuse, through permeable country rock to ground close by a landfill site.

2.7.2 Source Data

Thematic Map 3 shows the location of artificial deposits in two categories: (i) Made Ground, which constitutes those deposits dumped upon the existing ground surface and (ii) Infilled Land, where artificial materials have been used as backfill in former quarries and railway cuttings.

The locations of most current and recently completed landfill sites have been determined from data supplied by local authorities. However, the distribution of sites shown on Map 3 cannot be assumed to be exhaustive, since older (pre-1976) backfilled and restored sites may not have been identified. Furthermore, on some of the original 'County Series' geological maps there are areas, such as waste tips adjacent to collieries, which are not specifically shown as made ground (although evidently so). This implies the possibility that other tracts of made ground may not have been shown on these maps. A number of landfill sites have been identified by a National Grid reference only, and site plans are not available. The location of these sites must be regarded as approximate, except where old quarries or cuttings have been backfilled.

For some of these sites the limits of tipping have been determined from aerial photos.

For most tracts of made ground/infilled land the type of waste material is known (see Appendix III). The bulk of them have either domestic refuse or industrial waste, or a combination of both. The latter consists of excavation, demolition and construction wastes. Other wastes include boiler ashes, riverbed dredgings and spoil from railway cuttings.

Other categories of information have been supplied by the local authorities. They include the status of sites in terms of licensing and commissioning, ownership, present use, dates of tipping and volume/tonnage of waste. These data are incomplete and each item applies to only a proportion of the known sites.

It should be stressed that, though Map 3 indicates known landfill sites and made ground where site specific data are available or where recognisable land surface features are present, a variable thickness of fill can be expected throughout most of the urban area of Bath, as confirmed by borehole data.

The tabulated information concerning types and thicknesses of waste should be regarded as a general description only. Any surface development on tracts of made ground/infilled land should be accompanied by a site investigation to establish fuller details of these parameters.

3. MINERAL RESOURCES

3.1 Great Oolite Freestones

3.1.1 Introduction

'Bath Stone' is the name given collectively to building stones derived from more than one level in the Middle Jurassic limestone sequence in the Bath area. They are freestones i.e. limestones which can be sawn or trimmed in any direction, and which are suitable for carving and moulding. They have been used extensively in the buildings of Bath itself and, historically, have been in demand for public buildings elsewhere. Although demand is now less because of competition from artificial building materials, the stone is still a valuable commodity.

Bath Stone has been worked since Roman times. In early days the freestones were much quarried at outcrop, but since the 18th Century they have been won mainly from underground workings, where they are of much better quality. They have been worked under a variety of local names (see thematic Map 4; Green and Donovan, 1969) although they derive principally from just three levels in the Great Oolite limestone sequence.

3.1.2 Lithologies of the Great Oolite

The Great Oolite formation is divided into four members, in ascending sequence as follows: Combe Down Oolite, Twinhoe Beds, Bath Oolite and Upper Rags (see section 2.3.2 and thematic Map 4).

The oolites and oolitic limestones of the Combe Down Oolite contain ooliths of various sizes and are characterised by much variation in the proportion of shell debris, both of which may give rise to a corresponding lack of uniformity in the quality of stone. The matrix of the rock is mainly of clear calcite. Commonly, the lower part of the Combe Down Oolite contains many clay-filled burrows which make the stone unsuitable for building purposes. Thus, the freestones are worked mainly from the upper part of the member.

The Twinhoe Beds do not contain any rocks suitable for building purposes. The succeeding Bath Oolite consists of more uniform oolites and oolitic limestones than those of the Combe Down Oolite, and they contain less shell debris. They are also finer-grained and have a matrix of very fine-grained calcium carbonate. The oolites are rather impure at Bradford-on-Avon where they have never been worked.

Within the Upper Rags freestones of commercial quality are developed only around Bradford-on-Avon [c825 610], where they were formerly worked as Bradford Ground Stone. Elsewhere, the shell-fragmental oolites of this unit are too variable and otherwise unsuitable to be regarded as a potential freestone resource.

3.1.3 Properties of the Freestones

The durability of freestones is substantially a function of their physical structure. Thus, for example, coarser grain size and a greater content of shell debris render a rock more durable. The saturation coefficient (extent to which pore spaces are filled when allowed to absorb water for a specified period) and the microporosity (proportion of micropores to total pore space; micropores 5 micrometres diameter) are useful indicators of durability; and the crystallisation test (percentage weight loss after immersion in sodium sulphate solution, followed by drying) gives a direct measure of the same parameter. Table 3.1 summarizes values obtained from tests on Bath Stone from one working quarry in Combe Down Oolite and three mines exploiting the Bath Oolite (Leary, 1984).

The low saturation coefficient, microporosity and crystallisation test values of the Combe Down Oolite, reflecting in part its coarser grain size, indicate that it provides a stone with better weathering qualities than the Bath Oolite. However, the value of a freestone rests not only in its durability but also in the acceptability of its texture and colour.

Values of specific gravity, water absorption and porosity taken from manuscript notes by G.F. Harris (1893) are given in Table 3.2; and additional data from other sources are presented in Table 3.3.

The high natural moisture content of the Bath Oolite demands that it be stored underground during the winter months to avoid deterioration by frosting. For this reason, primarily, the Bath Oolite is mined rather than quarried at outcrop. By contrast, the Combe Down Oolite can be stored in the open throughout the year and thus be quarried satisfactorily in surface workings.

3.1.4 Occurrence of the Freestones.

Any attempt at assessing the potential distribution of commercially acceptable freestones in the study area is hindered by the paucity of available data for areas other than those already mined. No trial boreholes appear to have been sunk in modern times primarily for the purpose of proving the

Table 3.1 : Physical Properties of Bath Stone.

Values obtained from tests on Bath Stone (Leary, 1984)

	Saturation coefficient	Microporosity (% saturation)	Crystallisation Test (% weight loss)
Bath Oolite	0.73-0.99	57-85	16.75
Combe Down Oolite	0.54-0.55	22-34	13-16

Table 3.2 : Physical Properties of Bath Stone

Values obtained from tests on Bath Stone (G.F. Harris, 1893)

Rock Type	Specific gravity (dry)	% Water absorbed	Porosity % in 1 week
Odd Down (CDO)	2.27	9.5	21.2
Combe Down (CDO)	1.77-2.40	6.3-16.4	13.4-24.7
Box Ground Stone (CDO)	1.89-2.25	8.7-13.0	18.2-28.4
Hartham Park Ground Stone (BO)	2.06-2.31	11.3-11.5	23.4-26.9
Winsley Ground Stone (BO)	2.17	10.2	22.3
Westwood Ground Stone (BO)	2.03-2.17	6.5-11.4	20.3-23.2
Stoke Ground Stone (BO)	1.90-2.33	9.2-14.1	20.6-26.7
Corsham Down Stone (BO)	1.91-2.31	10.4-14.0	21.0-28.3
Monks Park/Ridge/Park Lane Stone (BO)	1.99-2.39	8.6-13.5	20.4-30.5
Farleigh Down Stone (BO)	1.90-2.19	10.2-14.9	20.9-32.6

CDO = Combe Down Oolite BO = Bath Oolite

Table 3.3: Physical Properties of Bath Stone

Values obtained from tests on Bath Stone (various sources)

	Dry Bulk Density (tonne/m^3)	Compressive Strength (MN/m^2)	Compression Wave Velocity (km/sec)	Young's Modulus (GN/m^2)
[1]Combe Down 'Fresh'	2.1	19.3	3.77	23.5
[1]Combe Down 'Used'	1.9	13.3	3.54	11.9
[2]Box Ground	2.0	11.6		
[3]St Aldhelm Box Ground	2.1	11.5		
[3]Corsham Down	2.1	13.7		
[3]Hartham Park	2.0			
[3]Farleigh Down	1.9	6.7		
[3]Corsham Stone (Blue)	2.1			
[3]Stoke Ground	2.0	11.5		
[3]Combe Down	2.1	16.2		
[3]Monks Park	2.2	24.0		
[2]Monks Park	2.2	24.3		

1. B.G.S. Engineering Geology Unit Report 76/3
2. 'Quarries in Britain and Ireland' Quarry Managers Gazette
3. 'British and Foreign Building Stones'. Watson, J., 1911

occurrence and quality of suitable building stone; thus, proved resources of freestone cannot specifically be determined. A number of trial shafts were sunk near the abandoned mines at Box [c840 694] and south of Corsham [c875 675] but there are no logs for most of these; logs for the remainder do little more than indicate the presence of freestone at depth. Cored boreholes drilled more recently for water supply purposes have demonstrated the widespread occurrence of oolites, which might include commercial freestones. However, it is not possible to specify precisely their stratigraphical position, thickness and quality. Nor is the available borehole data sufficient to enable an isopachyte map of overburden on Great Oolite to be drawn. As with the Fuller's Earth Bed (see 3.2), only an expensive programme of drilling would suffice to accurately delimit the resources of Bath Stone.

Comparative vertical sections of selected Great Oolite sequences (excluding Upper Rags) in the study area are shown on Map 4. These indicate the relationships between freestones which have been worked, under a variety of local names, and the overall distribution of oolites in both worked areas and elsewhere. The occurrence of oolites is, however, no guarantee that a freestone is present. It is evident that the Combe Down Oolite is fairly uniform in thickness throughout the study area, ranging from 12-18 m. The Bath Oolite, by contrast, increases northwards from c 6m-8 m at Bath to about 18 m at Biddestone [865 735]. The increase partly results from the thinning out of the Twinhoe Beds by lateral passage into the Bath Oolite.

The outcrop of the Great Oolite (undivided) is shown on Map 4, and on Map 1 the individual members of the formation are separately indicated, except for the Bath Oolite and Upper Rags which were not differentiated during the geological survey of the area. Although this results in a prime source rock, the Bath Oolite, not being separately shown, this is no great disadvantage since freestone from this source would almost certainly be mined rather than quarried at outcrop. North of Box and Corsham, where the Twinhoe Beds are absent, the Great Oolite is necessarily shown undivided.

The inferred overall distribution of freestones, as shown in Map 4, is not the sole basis for determining the extent of potential exploitable Bath Stone. As noted above, the quality of stone will have to be acceptable in terms of colour, texture, hardness, strength and durability. In addition, the minimum thickness of workable freestone, where mined, would need to be 3 m in the context of present working methods and economics. A sound roof bed is required, and a minimum thickness of overburden to the mined stone is necessary to prevent surface subsidence. At present a minimum of 17 m is considered appropriate at Westwood Mine, near Bradford-on-Avon.

Combe Down Oolite can be satisfactorily worked at outcrop and, indeed, is still exploited at Mount Pleasant and Upper Lawns quarries, Combe Down, Bath. However, much of the outcrop is on valley slopes where structural disturbances (see below) may place restraints on the dimension of stone capable of being produced.

Because of the paucity of reliable borehole data, the thickness of overburden upon the Bath Oolite is indicated on Map 4 in a generalized way rather than by isopachytes. Thus the extent of the Forest Marble cover (clays and limestones) indicates the area in which overburden on the Bath Oolite ranges from nil to c 30 m. The area in which the Cornbrash and younger rocks overlie the Forest Marble is that in which overburden is invariably greater than 25 m.

A further constraint upon the extent of potential freestone resources is the structural condition of the source rocks. Where they are very broken and disturbed by various types of fracture, mining is difficult and hazardous, and the ratio of good quality stone to waste is greatly reduced. Therefore, as a broad generalisation, it can be said that exploitation of freestones is neither practicable nor economic (a) in ground adjacent to faults or fault zones and (b) in ground close to or beneath valley slopes where 'superficial' disturbances, such as cambering (see section 5.1), are commonplace.

The groundwater regime is a further crucial factor. Water will inevitably gain ready access to workings in the kind of ground noted above and create drainage problems. It may also soften and wash out clay infill in open fractures, resulting in roof instability. An assessment of abandoned mines has shown that workings below the outcrop of the freestones, or where they have no clay cover, are likely to be more affected by the entry of circulating groundwater than where they have a substantial cover of impervious Forest Marble clays. In the latter case, mines are, for the most part, stable and dry. Thus, the area in which the Great oolite is overlain by Forest Marble clays and younger rocks is shown on Map 4. The working of commercially acceptable freestones within this area would be a more attractive proposition than elsewhere.

Within this area it is reasonable to assume that Bath Stone of satisfactory quality is to be found in the Corsham and Monkton Farleigh districts, where it has been worked so extensively in the past. In particular, the Bath Oolite in the general vicinity of Monks Park is likely to provide a good building stone, for it is hereabouts that the hardest and most close-grained of the various freestones is exploited, in workings with a good, sound roof bed. It has to be emphasized, however, that suitable stone has been obtained from slightly different levels within the Bath Oolite from different localities, and that the lithological characteristics of the source rock can vary significantly within short distances.

3.2 Fuller's Earth

3.2.1 Introduction

Fuller's Earth has probably been worked in the Bath area since Roman times. The name derives from its ability to adsorb oil, grease and colouring matter and to be used, therefore, as a medium for cleansing or 'fulling' woollen cloth. This was its principal use until the 19th century when a greater range of applications was developed. Today, for example, fuller's earth is used in oil refining, as a bonding agent in foundry moulding sands, as a suspension agent for drilling muds and agricultural sprays, for grouts in civil engineering applications and for pharmaceutical preparations.

In the United Kingdom the term 'fuller's earth' is restricted to clays consisting almost entirely of the clay mineral montmorillonite, with calcium as the main cation. Deposits within the study area fall within this definition.

The mineral may be processed to give three main products; the natural earth, the sodium-exchanged earth and the acid-activated earth. Natural earth is processed by crushing, drying and milling without additives. Before cessation of mining in 1980, only natural fuller's earth was produced in the study area.

At present, working of fuller's earth in the United Kingdom is concentrated elsewhere, in a raw material of higher quality. However, reserves within the study area constitute a potential long term resource, the protection of which was considered imperative by the South West England Regional Fuller's Earth Conference of 1952. Nevertheless, reserves which were known to lie within the pre-1951 Bath City boundary (i.e. north of Wansdyke) were then written off because of either actual or potential sterilization by surface developments (see Map 5).

The Conference concluded that, as far as could be foreseen, there was little likelihood of conflict between the mining and treatment of fuller's earth and other users or interests in the land. However, a proposed extension to the Cotswolds Area of Outstanding Natural Beauty includes areas with potential fuller's earth resources and it may well be that new mineral workings in these areas would not be favoured.

*

3.2.2 Characteristics of the Fuller's Earth Bed

The commercial fuller's earth is confined to a single stratum (Fuller's Earth Bed) near the top of the Fuller's Earth formation. The clays of this formation, despite its name, are composed predominantly of the clay mineral illite, montmorillonite being restricted mainly to the Fuller's Earth Bed. To the north of the study area, montmorillonite has been confirmed from several levels in both the Upper and Lower Fuller's Earth, but amounts are small and there is much contamination by calcite and illite.

The Fuller's Earth Bed ranges up to a maximum of about 3.3 m in thickness. It lies between 3 m and 10 m below the top of the Fuller's Earth formation and generally rests on a bed of argillaceous limestone or very calcareous mudstone. The commercial earth consists of bluish-grey clay which weathers to a yellowish colour. It has a smooth, soapy texture in its natural state. When dry it becomes hard and brittle, with a sub-conchoidal fracture. Distinctively, it disintegrates rapidly into a clay slurry when immersed in water.

The highest quality earth, containing between 60% and 85% of montmorillonite, with alkali feldspar (5%-10%) and calcite (up to 20%) as the main impurities, occurs in the lower part of the Fuller's Earth Bed. It passes up gradually into earth of poorer quality with as little as 40% montmorillonite, mainly because of an increased proportion of calcite (20% or more) and illite. Very small amounts of other impurities occur throughout the bed, such as pyrite, ankerite and quartz. Locally, in the Combe Hay area, calcareous nodules up to 0.3 m across occur in the lower part of the bed, and similar nodules up to 1.5 m across are present in the upper part.

3.2.3 Occurrence of Fuller's Earth

The known occurrences of the Fuller's Earth Bed are confined to Bath and to an area south of the city, extending almost to the southern margin of the study area. This area is shown on Map 5 as "fuller's earth present". Its southern limit, at and near the outcrop, is reasonably well authenticated and lies between Baggridge No. 2 Borehole [7407 5602], in which 1.0 m of fuller's earth was proved, and Faulkland Borehole [7439 5395] in which the earth was absent. The extrapolation of the limit eastwards is conjectural because of the lack of borehole data.

Exploratory drilling in the Combe Hay [c735 607] and Wellow area [720 578 - 755 598], south of Bath, has provided adequate proof of probable economic reserves of fuller's earth. However, the borehole and laboratory data are confidential; thus details of thickness and quality of the mineral are not available for publication.

The occurrence of commercial grade earth near Baggridge [c743 565], south of Wellow, has been proved in B.G.S. boreholes. Accordingly, resources of the mineral are confidently predicted here, although the borehole data suggest that the Fuller's Earth Bed is unlikely to exceed 1 m in thickness over much of the area. Further exploratory drilling would be needed to ascertain the potential mineral reserves hereabouts.

The northern limit of the Fuller's Earth Bed is approximate. Its most northerly proved occurrence is in boreholes drilled at the university site at Bathampton Down [c774 646]. It is not recorded, however, in the outcrop of the Fuller's Earth formation immediately north of the River Avon at Bath. Nor is it present in the Fuller's Earth succession in Swainswick No. 15 Borehole [7576 6907], 4 km north of the city. The mineral is also absent in Atworth Borehole [8589 6635], 10 km east of Bath, although faulting at the appropriate stratigraphical level could possibly have cut it out. Thus, the northern limit of the Fuller's Earth Bed is shown on Map 5 as an arbitrary and approximate E-W line drawn between Bathampton Down to the south and Lansdown Park and Batheaston to the north.

The eastern limit of the Bed is not known. It has not been recorded at outcrop in the Avon valley between Claverton and Freshford, and drillers' logs of boreholes to the east of this are not sufficiently informative to enable its presence or absence to be proved conclusively. Should the Fuller's Earth Bed persist to the eastern margin of the study area, it would lie in excess of 90 m below ground level.

In the area labelled on Map 5 as "fuller's earth probably present" there are very few boreholes, located either within the area or immediately to the west of it, which have established the occurrence of fuller's earth. The inference that the mineral is probably present throughout the whole of this tract is made in the light of the relationship between the known limits of the Fuller's Earth Bed north and south of Bath and the regional stratigraphical framework.

Areas labelled on Map 5 as "fuller's earth possibly present" are those where there is no certain proof of the occurrence of mineral, but where the same considerations of regional stratigraphy apply.

Known resources of fuller's earth which are not at present sterilised by existing and planned surface developments are as follows:

Combe Hay (north) and Southstoke

Until abandonment in 1980, mining of fuller's earth was concentrated on either side of the Fosse Way close to Combe Hay Works [729 612]. Worked out ground is shown on Map 5. The remaining area of unexploited mineral is likely to be of similar quality (up to 85% montmorillonite). The thickness of the Fuller's Earth Bed probably ranges up to 3 m or so. An E-W fault with a downthrow of between 3 m and 8 m transects the unexploited ground; the maximum thickness of overburden is in the order of 25 m

Combe Hay (south)

A faulted area of fuller's earth [c 735 606] occurs 1 km south-east of the formerly worked area referred to above. A single borehole has proved the Fuller's Earth Bed but details are confidential. The overburden reaches a maximum of c 40 m adjacent to the faulted northern margin of the block.

Midford

Fuller's earth was formerly mined to the north-west of Midford, near Pack Horse Farm [c 756 613]. No abandonment plan has come to light and thus the extent of worked out mineral is unknown. The thickness of the Fuller's Earth Bed is less than at Southstoke, probably between 1.5 and 2.5 m. The overburden ranges from c 4.3 m to c 7.0 m in thickness except south of an E-W trending fault where it probably reaches a maximum of c 40 m.

Dunkerton

Faulted outliers of fuller's earth occur 1½ km north-east [c722 603] and 1 km north of Dunkerton [c 711 600]. Mineral has been proved in the former, where overburden adjacent to the northern boundary fault reaches c 35 m. It is likely that the Fuller's Earth Bed in these two blocks is no greater than 2 m in thickness.

Duncorn Hill

A small outlier at Duncorn Hill was once worked in a small way from an adit at [7113 6056]. Trial holes nearby are said to have proved only 1.2 m of earth. The overburden here does not exceed 15 m.

Twinhoe Ridge

Drilling has proved the Fuller's Earth Bed throughout the 'Twinhoe Ridge' between White Ox Mead [c 720 578] and Twinhoe village [c 755 598], near Wellow; its thickness ranges from c 1.3 m to c 3.3 m. Details of mineral quality are confidential. Thickness of overburden is between 10 and 20 m in the western part of the ridge, but increases north-eastwards to a maximum of about 40 m near Twinhoe [c749 591].

Baggridge

Boreholes drilled to the south of Wellow, near Baggridge [c 743 565], proved between 0.7 m and 1.05 m of fuller's earth containing 60-75%

montmorillonite, with 5-20% of calcite impurity. The mineral lies at depths of up to 55 m below ground level. The relatively low percentage of montmorillonite as compared with the earth at Combe Hay, and the thinness of the bed, suggest that the deposit hereabouts is hardly of commercial grade.

4. HYDROGEOLOGY

4.1 Introduction

The water resources of the area are administered by the Wessex Water Authority (Bristol Avon Division). In the report on Groundwater Resources of the United Kingdom (published by the European Economic Community), the district lies mainly in areal unit 7, with a small part in unit 2.

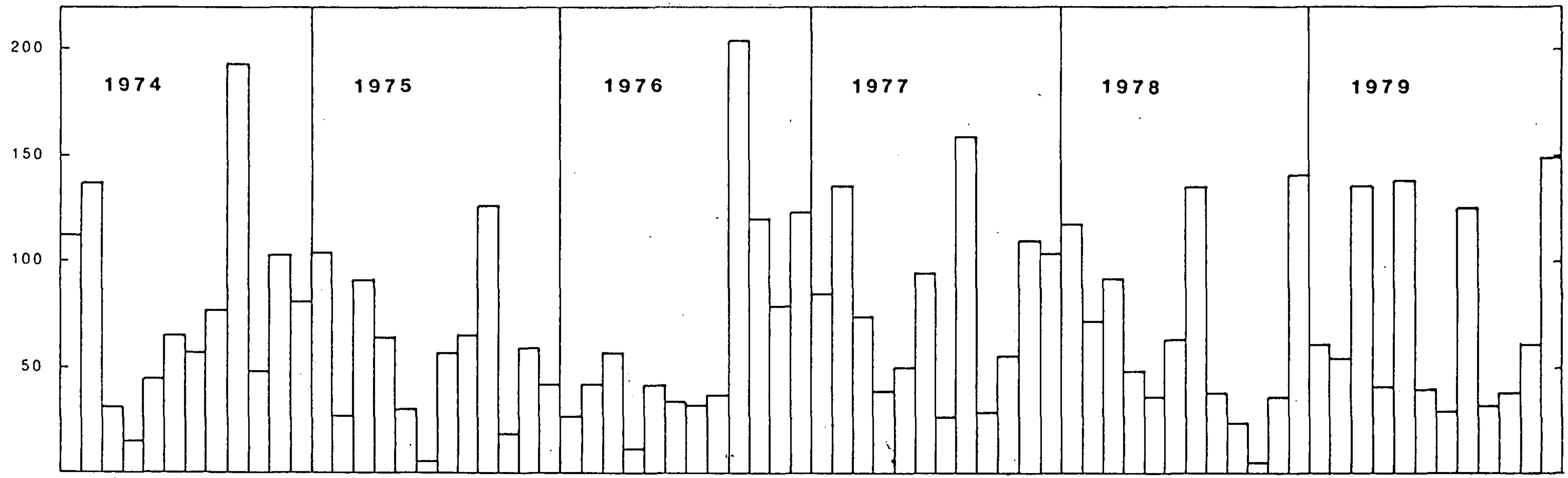
The surface drainage is dominated by the River Avon (the Bristol Avon) and its tributaries, the Frome and the Midford Brook. There is a small surface reservoir at Monkswood [757 711], just outside the northern boundary.

The mean annual rainfall over the area is approximately 830 mm. Figure 6 shows the monthly rainfall figures for Batheaston Reservoir [769 685], which is reasonably representative of the district, for the years 1974-1979. This includes the period of the 1976 drought where the hydrogeologically significant factor was the low rainfall from October 1975 to March 1976. Annual evaporation/transpiration is of the order of 450 mm. The Wessex Water Authority has noted (personal communication) an apparent 15-year cycle in rainfall intensity in this district. The period shown in Figure 6 is broadly within the low part of this cycle.

The main aquifers in the area are the Great Oolite limestones above and the Inferior Oolite limestones and the Midford Sands below (Map 6). Small local supplies can be obtained from the Forest Marble and the Fuller's Earth. Thermal springs issue from the Lias in the Bath area.

The water well and borehole logs housed in the B.G.S. Hydrogeology Unit's archive are of variable quality. A number of those ascribed to drillers give little lithological detail and are sometimes difficult to interpret, despite the fact that the Jurassic succession of the area is well known. On the other hand, logs of observation wells drilled in the last 15 years by Wessex Water Authority are very reliable because most of the wells were fully cored and were logged by geologists.

The figures received for abstraction rates and rainfall amounts are considered satisfactory. Those for groundwater levels would be improved by a denser network of observation wells, the drilling of which, however, would be far too costly. The amount of data relating to water chemistry has been found to be rather limited.



Monthly rainfall in millimetres measured at Batheaston Reservoir (ST 769 685)

Monthly long-term average (1941-1970)

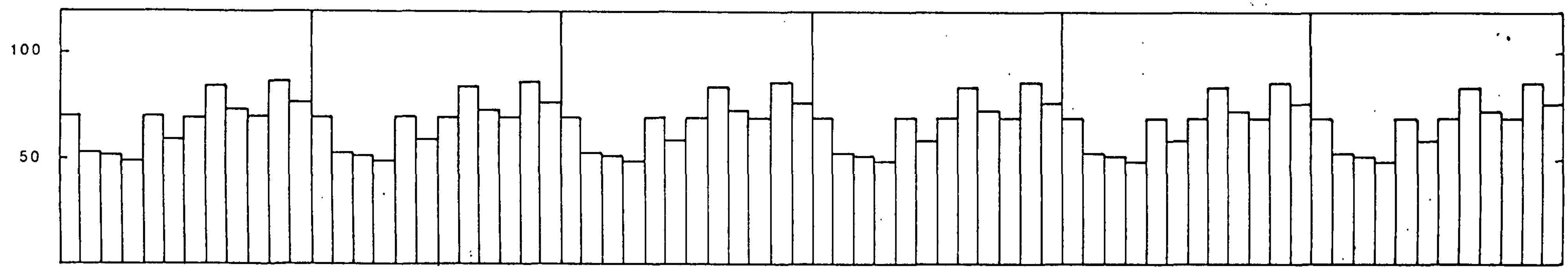


FIG. 6

4.2 Groundwater Resources and Well Yields

Mercia Mudstone and Penarth Groups

The outcrops of the Mercia Mudstone and Penarth Groups are limited to small areas in the west and south-west of the district. The outcrops are too small to have any hydrogeological significance.

Lias Group (beneath the Midford Sands)

Being dominantly clay, the Liassic strata are hydrogeologically important only in that they support groundwater in the overlying Midford Sands and Inferior Oolite. A few small yields have been obtained for domestic purposes, but this formation has little potential for groundwater supply.

Midford Sands and Inferior Oolite

The Midford Sands thin out to the south, and are of importance only in the central and north-central parts of the district. The sands are in hydraulic continuity with the Inferior Oolite limestones.

The resources of these strata are difficult to estimate. However, the outcrops are narrow, permitting only limited recharge directly to the sands and to the limestones. Some replenishment is probably gained from seepage from the Fuller's Earth. The stream valleys in the west dissect this aquifer into discrete blocks which tend to drain rapidly and are too small to support substantial yields from wells. Where the Great Oolite outcrop is deeply dissected, spring discharge often passes over the Fullers's Earth outcrop and infiltrates into the Inferior Oolite.

All the current use of groundwater from this aquifer is of spring discharge. From Tucking Mill [763 617] and Midford [762 608], the annual licensed take is 2.3 million cubic metres (m^3), and in 1980 the actual take was 2.1 million m^3. At Midford, the natural spring flow is augmented by shallow shafts with headings. A number of springs in the neighbourhood of Monkswood Reservoir [757 711] are licensed for a further 2.7 million m^3 annually.

Yields of boreholes in the Inferior Oolite have generally been small, rarely exceeding 400 cubic metres per day (m^3/d) in this district. Failure to intersect suitable water-bearing fissures results in little or no yield, and this is not unusual. The Midford Sands require the installation of sand screens and filter packs, but problems are often caused by fine-grained and running sands. Yields of more than 2000 m3/d have been recorded but are unusual.

Seasonal fluctuation of groundwater level in the Inferior Oolite where it is confined appear to be small. An observation borehole [Atworth No. 1: 8589 6635] showed an overall range of only 1.5m during the years 1974-1979.

At outcrop, the groundwater of both the Midford Sands and the Inferior Oolite is generally of the calcium-bicarbonate type. Total dissolved solids are usually of the order of 300 to 500 milligrammes per litre (mg/l), while the total hardness (as $CaCO_3$) is normally between 200 and 300 mg/l. The mean concentration of nitrate (as NO_3) is less than 40 mg/l, but may locally exceed 50 mg/l. Iron is usually less than 0.2 mg/l. Fluoride is often present although the normal concentration is less than 0.5 mg/l.

To the south-east, where it is confined beneath younger strata, the groundwater of the Inferior Oolite tends towards the sodium-chloride type. Although there is only limited information available, it is considered that a chloride ion concentration greater than 250 mg/l is unlikely in this district. With increasing thickness of cover, there may also be an increase in sulphate (as SO_4) to more than 100 mg/l.

Fuller's Earth

The Fuller's Earth and the Fuller's Earth Rock do not form a good aquifer. Small quantities of groundwater can be obtained from the limestone horizons, rarely exceeding a few cubic metres per day; the intervening beds of clay and marl restrict groundwater flow. Some interchange of groundwater probably takes place with the underlying Inferior Oolite and the overlying Great Oolite limestones.

Great Oolite

Potentially, the Great Oolite limestones form the major aquifer in the district. In the west, the outcrop is dissected and the consequent rapid drainage results in little potential for supply. Towards the southern margin of the district, the aquifer terminates by passage of the limestones into impervious mudstones. In the east, three groundwater sources were operational although at present only one is still in use.

The Great Oolite within this district forms only a small part of an aquifer unit which extends to the east and the north. Much of the infiltration replenishes the aquifer outside the district boundaries, and it is not meaningful to assess the groundwater resources of only part of the overall unit. The Holt source [870 621], the only operative public supply from the Great Oolite in the district, is licensed for 4.56 million m3/d which, in the view of the Wessex Water Authority, represents the maximum that may be pumped in view of the licensed sources elsewhere.

The yield of boreholes in the Great Oolite is rather variable, which would be expected in a fissured aquifer of this type. Assuming a borehole diameter of 300 mm and a penetration of 10m of saturated aquifer, the mean yield is of the order of $600m^3/d$.

Seasonal fluctuations in groundwater level are considerable. The well hydrograph for Chalfield [8286 6382] shows an overall fluctuation of more than 20m beneath a cover of Forest Marble (Figure 7). At Allington [8970 7479], the well hydrograph shows a similar range (Figure 8). In both hydrographs, the low groundwater levels resulting from the low rainfall of the winter of 1975-1976 is well shown. Map 2 shows the countours on the potentiometric surface in September 1976 before recharge commenced, and these may be regarded as minimum known levels.

The groundwater in the Great Oolite is generally of the calcium-bicarbonate type, tending in the eastern part of the district to the sodium-chloride type beneath a thickening cover of Kellaways Beds and Oxford Clay. Total dissolved solids may exceed 500 mg/l, and the total hardness is generally between 250 and 350 mg/l (as $CaCO_3$). The chloride ion concentration is usually less than 40 mg/l, but rises to the east with values of about 200 mg/l on the district margin. Iron concentrations are generally low, less than 0.3 mg/l. Fluoride is often present and may exceed 1.0 mg/l. Sulphate (as SO_4) is generally less than 100 mg/l, but may exceed this value beneath thick cover.

Forest Marble and Cornbrash

The Cornbrash and the limestones within the Forest Marble form restricted aquifers capable of supporting small demands of a few cubic metres per day. However, supplies are sometimes unreliable, and wells tend to dry out during prolonged droughts.

Some interchange of groundwater may take place with the underlying Great Oolite, but the amounts involved are likely to be small.

Kellaways Beds and Oxford Clay

Small supplies of groundwater have been taken from the sandier beds of the Kellaways Clay, but more than 5 m^3/d would be unusual. Shallow, dug wells in the weathered zone of the clays, rarely constructed to more than 15m depth, yield a little water; however, such sources are vulnerable to pollution from surface drainage.

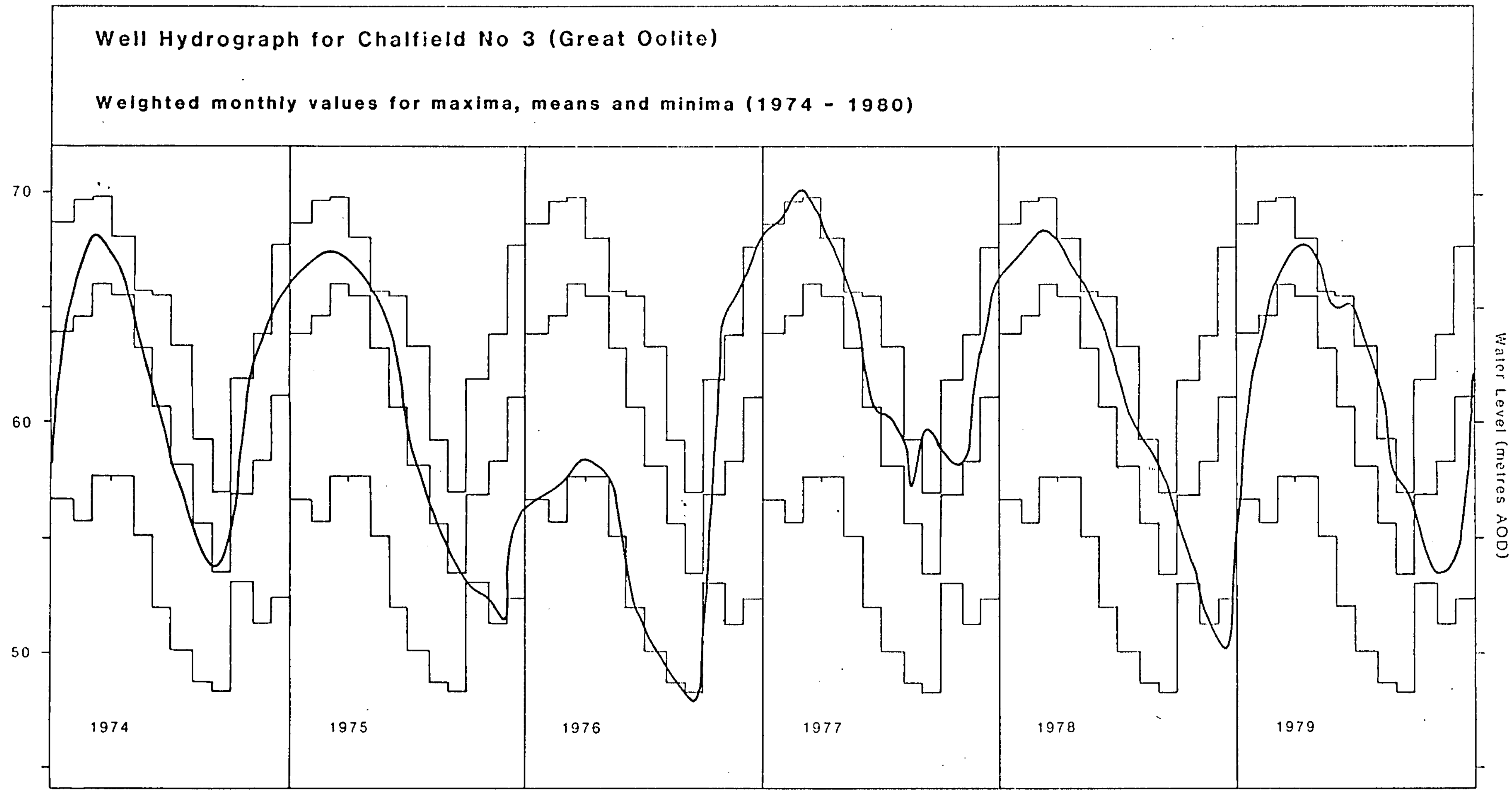

Well Hydrograph for Chalfield No 3 (Great Oolite)
Weighted monthly values for maxima, means and minima (1974 - 1980)
70
60
50
1974
1975
1976
1977
1978
1979
Water Level (metres AOD)

FIG. 7

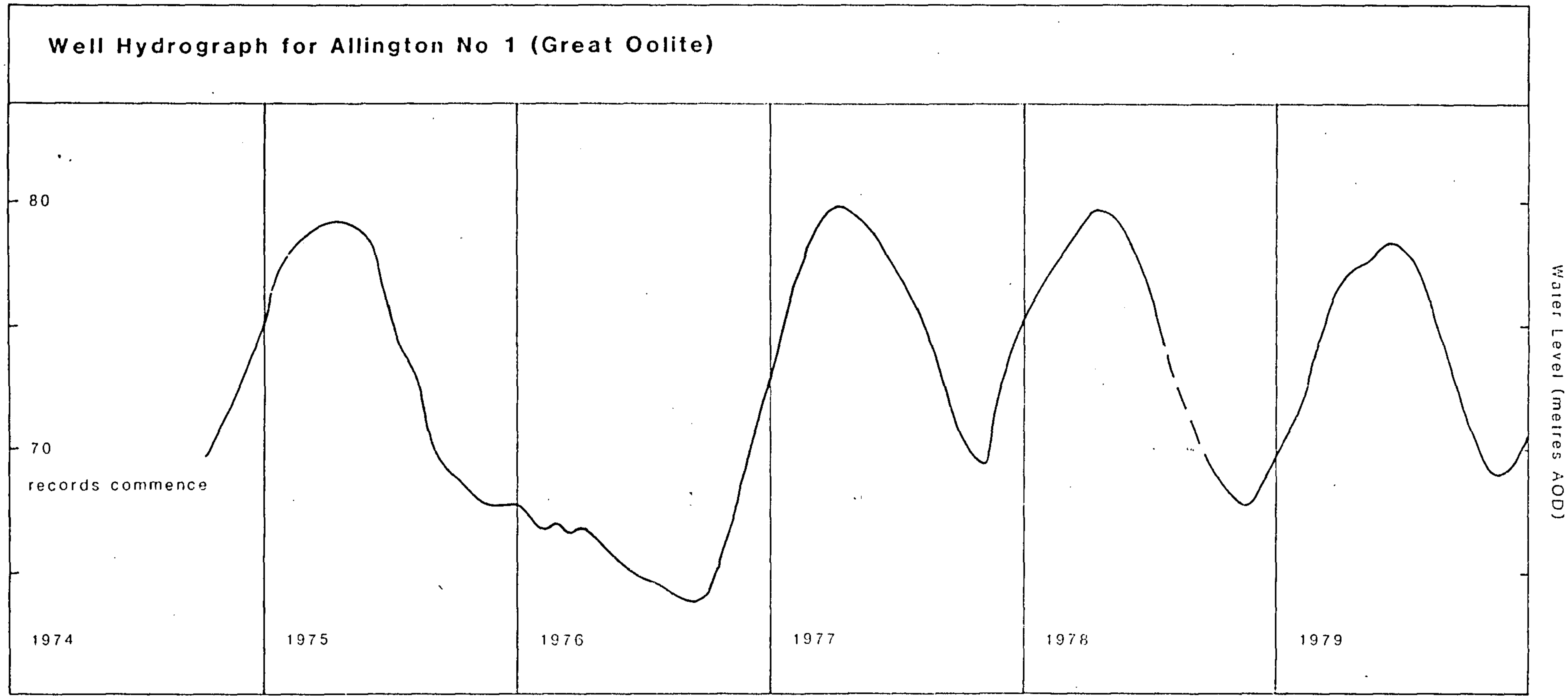

Well Hydrograph for Allington No 1 (Great Oolite)
80
70
records commence
1974
1975
1976
1977
1978
1979
Water Level (metres AOD)

FIG. 8

Superficial deposits

Where sands and gravels overlie the Oxford Clay and the Kellaways Beds, small supplies of groundwater could be obtained. However, these deposits tend to drain rapidly and often cannot support a continuous demand. Pollution from surface sources is a continuous threat, and high concentrations of nitrate in particular are commonly present. Where the sands and gravels underlie a river or stream, induced recharge may permit a more continuous supply, albeit at the expense of stream flow.

Superficial deposits overlying permeable strata are often dry. Even when saturated, more reliable sources can generally be developed from the underlying strata for a relatively small increase in depth.

4.3 Protection of aquifers

4.3.1 Introduction

The Control of Pollution Act (1974) and the E.E.C. Directive of 17th December 1979, both require that aquifers be protected from pollution.

When effluents and similar polluting substances are either discharged on to the land surface or issue as leachates from, for example, landfill waste disposal sites, they may infiltrate into underlying strata where the latter are sufficiently permeable. Where generally recognised aquifers underlie a potential pollution source, the degree of vulnerability of the aquifer can be related to the time taken for materials to pass in solution or suspension from the ground/surface to the saturated zone (travel time). For those strata which are not generally recognised as aquifers, but from which small supplies of groundwater may be obtained, vulnerability cannot be so clearly established, and a different approach should be used.

4.3.2 Generally recognized aquifers

In this study a generalised four-fold classification of travel times is adopted.

Zone 1	travel time more than 20 years
Zone 2	travel time 1 year to 20 years
Zone 3	travel time 1 week to 1 year
Zone 4	travel time less than 1 week

A lithostratigraphical unit may exhibit variable travel times depending on the exact circumstances. The saturated zone in the Midford Sands, for example, is usually close to the ground surface and is, therefore, assigned to Zone 4. Under cover, however, the travel time is significantly reduced to values similar to the Inferior Oolite.

Because of the fissured nature of the aquifer, the travel time of pollutants through the Inferior Oolite limestones is likely to be small. The outcrop is, therefore, assigned to Zone 4. Beneath the Fuller's Earth, the Inferior Oolite is assigned to Zone 3, passing into Zone 2 with thickening cover. When the overburden includes the Great Oolite, the groundwater head would probably be such that little downward flow would occur, and Zone 1 would apply.

Similarly, the Great Oolite can be placed in Zone 4 at outcrop, and in Zones 2 and 3 beneath Forest Marble cover. Where the Oxford Clay is present at the surface, the aquifer may be assigned to Zone 1.

Once a pollutant has entered an aquifer, the time it may take to travel laterally to a given point (such as a groundwater source) and the effect upon groundwater quality will depend upon the local characteristics of the aquifer and upon the nature of the pollutant. To attempt general comments applicable to the whole district would be misleading.

4.3.3 Formations not generally recognised as aquifers

Although small supplies of groundwater may be obtained from formations other than the Great and Inferior Oolite and the Midford Sands, the water-bearing horizons tend to be discontinuous and of limited extent, and may be interbedded with clays and marls. Pollution from surface sources is likely to take place only locally, while its subsurface extent would also be limited.

5. SUPERFICIAL DISTURBANCES AND SLOPE ANGLES

5.1 Distribution of Landslipped and Cambered Strata

5.1.1 Introduction.

The valley slopes around the City of Bath have been extensively affected by superficial disturbances. Evidence of movements dating from Pleistocene times to the present day have been recognised. As noted in section 2.5, much of the disturbed ground around Bath has, in the past, been described as 'foundered strata'. However, as a result of the recent re-survey (see Supplementary Report) landslipped and cambered strata have been differentiated and distinguished from in situ bedrock.

The complexity of the intermingled slips and their commonly highly degraded topographic expression have made it difficult to map them in detail. However, the data collection phase of the study did produce some mapped and described individual landslips relevant to thematic Map 10 ("Landlippped and Cambered Ground") but not in sufficient numbers to warrant inclusion; some, indeed, are too small to show at the scale of 1:25 000. Where data are available on individual slips a brief description is included in Appendix IV.

5.1.2 Cambering

Cambering is the slow downward movement of strata due to the removal or plastic deformation of the underlying beds by relatively deep seated processes under glacial or periglacial conditions. It commonly occurs on a large scale and typically manifests itself by the fracturing and tilting downslope of strong competent rocks on valley slopes (Figure 9). Competent rocks, such as sandstone and limestone, are those which behave in a rigid, brittle manner when subjected to stress, rather than deform plastically. In the Bath area the major competent strata are the Great Oolite limestones which cap the valley slopes and the Inferior Oolite limestones which outcrop out on valley sides. Cambered outcrops of these beds exhibit overall dips of anything up to 10°.

Map 10 shows the direction of tilt and approximate outcrop of these competent strata where affected by camber, but it must be realised that disruption of strata above and below the indicated horizon will also have been caused by cambering.

Neither the mechanism by which cambering is brought about nor the detailed morphology of cambered ground is thoroughly understood. In the Swainswick area [c760 675] borehole logs have been interpreted as indicating the cambered Inferior Oolite to comprise large fault-bounded blocks of limestone in mutual contact and tilted towards the valley floor i.e. dip-and-fault structure (Chandler et al, 1976). In a more recent study the movement of the blocks is regarded as much more extensional in nature, resulting in many isolated limestone blocks tilted valleywards but without the interblock faulting (Gibb, 1984).

It is probable that, in general, movement of the limestone blocks becomes increasingly extensional downslope, commencing with a dip-and-fault structure and passing downslope into isolated blocks. At the downward limit of the cambered formation, the beds commonly degenerate into a mass of smaller blocks and finally into a trail of limestone rubble.

Fissures between limestone blocks brought about by differential rates of downslope movement during cambering or landslipping are called gulls. They may be up to 5m deep, 1.5m wide and several metres long (Privett, 1980) and are often air-filled, although they may also be filled with a heterogeneous mixture of sand, clay and limestone debris. The position of a debris-filled gull may sometimes be detected on the surface as a linear depression. Air-filled gulls in massive, fissured limestones are frequently bridged at the surface by weathered flaggy limestone beds which form a natural arch, making it impossible to distinguish them from completely rubble-filled gulls. In many cases there is no surface expression of either type of fissure.

Cambering of the incompetent beds in the Bath district is commonly expressed in the Midford Sands by a marked thinning of the sequence valleywards, from the normal 25-30m to 10m or less near Swainswick [760 675]; and in the Fuller's Earth and Lower Lias clays by zones of disturbance (layers with high dips or contortions) to considerable depths beneath valley slopes e.g. to at least 35m near Swainswick.

The relationship of cambered Lower Lias Clay to the terrace deposits of the River Avon at Twerton indicates that cambering took place during the Wolstonian (or possibly the preceeding Anglian) Glaciation (Chandler et al, 1976). Evidence in the Swainswick valley, at Limpley Stoke and at Bathampton Down, also indicates that cambering took place at a relatively remote time (Hawkins and Kellaway, 1971). It is therefore reasonable to suppose that cambering is no longer actively affecting the hillsides under the current climatic conditions.

The potential problems of cambered strata which should be anticipated when development is planned, are the presence of gulls and solution cavities in the competent limestone strata and relic shear surfaces in the deformed incompetent clays. The difficulty of predicting ground conditions in disturbed strata below a mantle of Head deposits should also be recognised.

Building foundations which cross debris-filled gulls may suffer from differential settlement, and where air-filled gulls are encountered parts of foundations may be without support. Where bridged gulls are present, excavations may not penetrate the bridge and the gull will only be detected at a later date when the foundations start to fail.

In areas where gulling is suspected site investigation should include the stripping of topsoil and thorough probing of all fissures. The foundations should also be designed to take into account the possible presence of undetected bridged gulls. Re-inforced ground beams, rafts and mushroom footings have been used successfully in these circumstances.

The possible presence of relic shears within clay units in cambered ground must be considered in any engineering design, as they will reduce the strength of the material below that determined by testing undisturbed material. Site investigation should therefore include methods of drilling or pitting by which relic shear surfaces may be detected in the core samples. Building design should avoid high loadings where shear surfaces are suspected, and the disposal of storm water into such areas should be avoided in case old shears are lubricated and reactivated.

The detection of changes in ground conditions below a blanket of Head is not cheaply or routinely possible, as yet. Intensive drilling, pitting and trenching can achieve the objective but is costly, disruptive of the surface, and the results may be ambiguous. Geophysical methods such as resistivity and ground probing radar show promise when used by experienced operators in suitable circumstances, but are not yet universally or routinely applicable.

5.1.3 Landslip

The areas on Map 10 shown with vertical lines are those which by field survey and/or aerial photographic interpretation are considered to have undergone perceptible downslope movement of earth or rock by falling, sliding or flowing under the influence of gravity as a result of relatively shallow processes (i.e. shallow compared to the process of camber formation).

Three basic modes of movement are found, namely flows, rock falls and slides (Figure 10), of which flows and slides are most common. A further distinction may be made between slides on a planar surface and slides on a curved surface which are termed 'translational' and 'rotational' slides respectively.

In the Bath area the oldest known examples of landslipping are the large rotational failures associated with the oversteepening of valley sides at the outside of river bends during the last major down-cutting by the River Avon in late Devensian times. Landslips thought to have taken place at this time include those at Bailbrook [773 673], Beacon Hill [751 659], Beechen Cliff [751 641], Twerton [726 644] and North Stoke [700 687] (Kellaway and Taylor, 1968; Hawkins and Privett, 1979). These major slips are thought to be rotational failures but have been degraded by subsequent minor landslipping, agriculture and development to the point where identification of their precise structure is only possible by careful mapping in conjunction with an extensive programme of cored boreholes.

The majority of the slips in the Bath area are smaller and shallower, and are most frequently translational planar slides or flows. Most of them were probably formed in the periglacial conditions of the late Devensian Stage when the climate was much wetter and when intense and repeated freeze/thaw action caused deep weathering and disruption of the rocks, together with their downslope mass movement by solifluction, commonly over a basal shear plane. Minor activity has continued periodically to the present day.

Two factors have been the cause of much of the more recent mass movement, namely the removal of support at the foot of slopes and the action of groundwater.

The removal of support at the foot of slopes by river erosion to produce oversteepening was more common in prehistoric times and was the cause of major rotational failures e.g. that of Beechen Cliff [751 641]. More recently, human activity has instigated slips in this manner when the construction of roads, railways, canals, etc. involved the imprudent removal of material from a hillside.

The action of ground water is primarily that of reducing the shear strength of the overconsolidated clays of the hillslope bedrock and of the mantle of Head overlying it, causing failure of the hillslope, often by circular rotational sliding. Continued input of water into the slip mass saturates the disrupted clays further and lubricates the slip planes below and within the slipped ground, thus promoting additional movement of a translational type. Ultimately, the highly disrupted and saturated slip mass may continue down the slope as a debris slide/mud flow. At the same time the hillside above the slip will have been left oversteepened by the removal of material below, and a second failure may occur which proceeds downhill in the same manner as the first. The sequence may be repeated to form a multiple retrogressive failure which will continue until the hillside is reduced to an angle of repose such that the gravitational forces promoting downslope movement are in equilibrium with the strength of the material of which the slope is composed.

Two main aquifers supply water to the hillsides in the study area, namely the Great Oolite and Inferior Oolite/Midford Sands. Both are underlain by overconsolidated clays, the Fuller's Earth Clay and Lower Lias Clay respectively. In both clay formations thin limestone bands act as minor aquifers which inject further water into the system. Repeated failures in the clays ultimately remove or weaken the beds supporting the aquifer itself, causing it to fail at its outcrop by rotational or translational sliding, and sometimes causing free rockfall or toppling of the Great Oolite limestones.

Landslips are often composed of multiple movements differing in type and time of occurrence. In this area they are concentrated on the outcrops of the Fuller's Earth and the Lower Lias clays below the major aquifers. The Upper Fuller's Earth is particularly prone to landslipping because of its inherently high plasticity and mineralogy, and the high recharge and storage capacity of the overlying aquifer which tends to give rise to permanent springs, relatively unaffected by seasonal variation.

The problem presented to land use by slope instability is mainly that of slip reactivation by the removal of material from the slip toe, the surcharging of the slip mass by tipping and the increase of the water content of the slip mass by interference with the natural water regime. Development of slipped ground, if unavoidable, should be preceded by a rigorous site investigation to define the areal extent, geotechnical properties of, and thickness of the slip mass; the position of slip planes under and within it; and the piezometric surface or surfaces within the affected area. Development may be modified to avoid problems or remedial measures may be designed to solve them.

5.2 Distribution of Slope Angles

5.2.1 Introduction

The aim of thematic Map 11 (Distribution of Slope Angles) is to show the typical land forms present in the study area by dividing the slopes into categories related to the characteristic slope angles developed by the various lithologies. The map may be used in conjunction with other maps in the report to pick out those slopes which might be susceptible to landslip activity.

TABLE 5.1 Average Slope Angles for the Major Lithologies of the Bath Area

Author	Locality	Great Oolite Plateau	Great Oolite Edge	Great Oolite Camber	Fuller's Earth	Inferior Oolite Edge	Inferior Oolite Camber	Midford Sands	Lower Lias
Cook 1973	Lansdown				9 - 13				
	Swainswick 1				9		6½	11	
	Swainswick 2				12		11		
Chandler 1976	Swainswick 3				15½	25		13 - 19	9 - 10½
	Swainswick 4				11½				
	Horsecombe Vale		31		12				
Privett 1980	Bath area	3	15-30	5-10	8 - 17	30	6 - 9	6 - 18	6 - 20
	Brass Knocker				11		11 - 13	7 - 17	
Hobbs 1980	Claverton		15		11 - 13		9 - 10	5 - 6	5 - 16
	Hengrove Wood		21 - 24		18 - 23	35		17 - 20	10 - 13
	Sheep House		17		12		11	11	11
	Browns Folly		21		13		10	6	8
Average		3	22	7	13	30	9.6	12	10.8

5.2.2 Characteristic Slope Angles

Characteristic slope angles are those which occur most frequently either on all slopes, under particular conditions of lithology or climate, or in a particular area (Young 1961). They are identified by plotting the frequency of occurrence of slope angles found on particular lithologies or in particular areas and identifying peaks in slope angle distribution.

Characteristic angles have been interpreted as limiting angles for various processes of mass movement (Carson and Petley, 1970; Hutchinson, 1967; Rouse 1967, 1975) with upper (maximum) and lower (minimum) limiting angle values between which a particular process operates.

In engineering terms stable slopes are those in which the slope angle falls below the lower limiting angle for rapid mass movement; those slopes with angles above this value may be considered unstable. The latter are regarded as being in a state of limiting equilibrium, where the shear stress is equal to the shear strength, and they will therefore have a factor of safety of 1 (where the factor of safety is defined as the ratio of the shear strength to the shear stress).

The slope angles which have developed in the Bath area are largely the result of the climatic conditions which have prevailed since the end of the Devensian Glaciation. Slope development was most active in the wetter conditions of early post glacial times. The generally drier climatic conditions which now prevail have brought about the end of the widespread mass movement which must have been active then, but has left the slopes only marginally stable. Chandler has shown (Chandler et al, 1976) that many clay slopes in the Swainswick area are at, or close to, their angle of limiting stability, with factors of safety close to unity i.e. very small adverse changes in the factors which promote mass movement will change the slope from a state of stability to one of instability.

Similar results were obtained for slopes in the Avon valley between Bath and Limpley Stoke (Hobbs 1980), and the relative frequency of landslip activity in historic times tends to confirm this conclusion. Where local increases in the height of the subsurface water levels return to or exceed previous maximum values, active mass movement resumes.

Characteristic slope angles are usually determined by examining slope frequency data from a representative number of slope profiles measured in the field. In the study area a large number of profiles would be required to take into account the gradual changes in the lithology within formations across the study area and also the effects of microclimatic variation. Such a program was beyond the brief of this study and reference was therefore restricted to

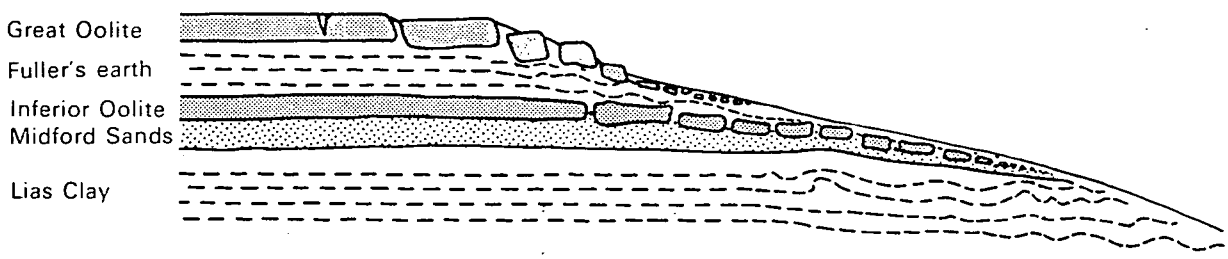


Fig. 9 Diagramatic Representation of Cambering in the Bath Area

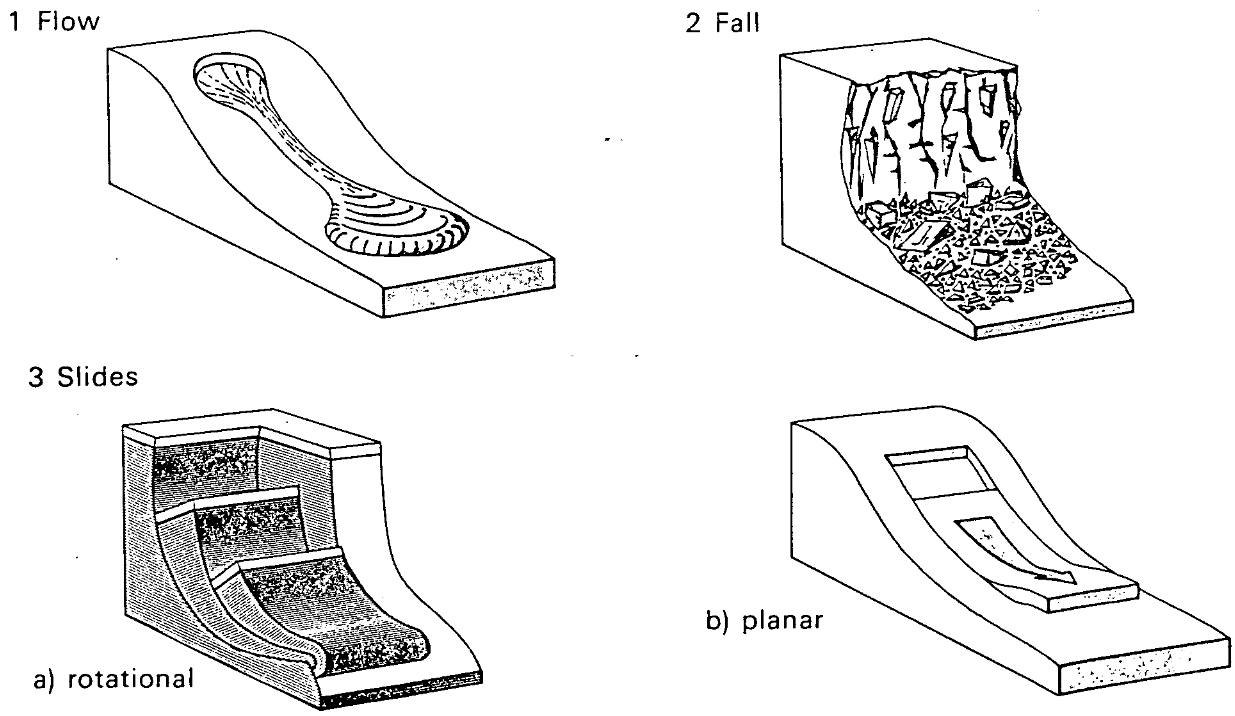


Fig. 10 Types of landslip movement which occur in the Bath area.

published and other literature sources (table 1) and to general observation of the landforms present.

Characteristic slope angles of the main lithologies.

a) Oxford Clay, Kellaways Clay, Cornbrash, Forest Marble.
These formations form ground of very subdued relief to the east of the Great Oolite outcrop with slope angles of a few degrees; only in a few minor valleys do slope angles exceed 5 degrees. No characteristic slope angle data were found relating to these formations.

b) Great Oolite.
The Great Oolite forms three main land forms; the east-facing dipslope plateau, the west-facing scarp slope, and the cambered margins of the plateau.
The dipslope and plateau areas have very low slope angles of about three degrees, controlled by the regional dip of the formation. The scarp slope shows angles of between 15 and 30 degrees. The cambered Great Oolite outcrops show slopes of about 5 to 10 degrees.

c) Fuller's Earth
Fuller's Earth slopes show slope angles in the range 8 to 17 degrees, with most slopes falling between 9 and 15 degrees. The fairly wide range of slope angles is due to variations in lithology and also because slopes did not reach a state of maturity with regard to the development of characteristic slope angles before their development was arrested by the onset of drier climatic conditions. The formation had been the focus of much mass movement in the wet post-glacial period and therefore exhibits a number of more or less degraded landslip forms including backscarps, debris slides and flows, each with its own range of slope angles. Some sections of outcrop are, however, at the characteristic angle of a mature slope.

d) Inferior Oolite
The Inferior Oolite forms flat hilltops and benches of low slope angle on the mid valley sides, but is widely and severely cambered to give slope angles of up to 11 degrees. The scarp slope of the Inferior Oolite outcrop shows slope angles of 25 to 30 degrees but is of limited extent.

e) Midford Sands

The Midford Sands are capable of standing at quite steep slope angles but are strongly influenced by the level of the local water table. They therefore form a wide range of slope angles, ranging from 6 to 19 degrees. Slopes at the upper limits are exhibited by outcrops well above the water table, and slopes at the lower limits are formed at areas of high water table where springs issuing from the base of the formation promote flow failure. The Lower Lias shows slopes in the range 6 to 20 degrees but its characteristic slope angle is in the range 9 to 11 degrees. The higher slope values may be attributed to the backscarps of landslips caused by river erosion at the foot of valley slopes.

f) Blue Lias, Penarth Group, Mercia Mudstone.

These formations do not form major land forms in the study area and no information regarding characteristic slope angles has been found.

5.2.3 Slope Categories

The available slope information was considered in the light of the accuracy of slope angle measurement using maps at the scale of 1:10 000, and the following slope categories were chosen:

0-5, 5-10, 10-15, 15-20, 20-25 and + 25 degrees.

Slope angles were determined manually by direct measurement of contour separation on base maps at a scale of 1:10 000, and isoclines were drawn at the slope category limits i.e. 5, 10, 15, 20 and 25 degrees. Areas of ground falling between the isoclines thus defined the fields of occurrence of the chosen slope categories. The complexity of some areas of the slope map made its reduction and reproduction at a scale of 1:25 000 impracticable within the time and money available. However, by limiting the slope categories to 0-5, 5-10, 10-15 and +15 degrees and smoothing the outlines of the resulting slope fields, reproduction at 1:10 000 was achieved with a minimal loss of content.

5.2.4 Stability interpretation of Slope Categories

1. 0-5 degrees.

Generally stable ground formed by alluvium/terrace deposits on valley floors, Great Oolite limestone plateaux and the subdued topography of the Forest Marble, Cornbrash, Kellaways Clay and Oxford Clay.

2. 5-10 degrees.

Generally stable ground composed of minor valley slopes, the cambered margins of Great Oolite limestone plateaux, the cambered outcrops of Inferior Oolite limestone, and part of the outcrop of the Lower Fuller's Earth and Lower Lias Clay, including degraded landslipped material.

3. 10-15 degrees.

Generally stable ground under the present climatic regime. Bedrock lithologies include Lower Fuller's Earth clay, Inferior Oolite limestone, Midford Sands and Lower Lias Clay. Large areas of landslipped material are included in this category. The potential for mass movement is influenced by the thickness and nature of the superficial material which covers the slope, the depth of the water table below the slope surface and the nature of the bedrock. Instability may be instigated accidentally by overloading or undercutting the slope or increasing the height of the water table in the superficial material.

The Fuller's Earth, Lias Clay and landslip debris are particularly susceptible to mass movement.

4. +15 degrees.

The ground within this category includes upper valley slopes, free rock faces and landslip backscarps. It is composed mainly of the Great and Inferior Oolite limestones, Upper Fuller's Earth clay and the Midford Sands. Large areas of landslipped material are included in this category. Some of the slope forming material is likely to be at or very close to its residual shear strength, and the slope itself at its angle of limiting stability with a factor of safety at or close to unity.

Many areas within this category are susceptible to the initiation of slope instability by quite small changes in circumstances e.g. increased water input to the slope. The Upper Fuller's Earth is especially sensitive in this respect.

6. GROUND CONDITIONS AND GEOTECHNICAL PROPERTIES

6.1 Ground Conditions in Relation to Groundwater

6.1.1 Introduction

If the geotechnical behaviour of the superficial material (including weathered bedrock) of an area is known, then consideration of the subsurface water regime would enable the area to be zoned in terms of ground surface conditions relevant to land use.

The limited geotechnical data relating to the superficial materials of the study area and the lack of information on their distribution and thickness has made it necessary to adapt a more general approach.

Three main divisions have been recognised: (1) areas which are or have been subject to flooding, (2) areas of alluvium and terrace deposits and (3) areas of bedrock covered by a variable and largely unknown thickness of superficial material. This division has been subdivided into permeable and impermeable bedrock units to give five hydrostratigraphic subdivisions.

6.1.2 Ground Condition Categories

1) Areas Susceptible to Flooding.

The area on the map shown in heavy stipple represents the maximum area which has been subjected to flooding and has been derived from the records held by the Wessex Water Authority. Site specific information may be obtained from the W.W.A. who hold plans at 1:25 000 for the river Avon from Newbridge to Bathford and at 1:10 000 for the rest of the area. It should be noted that even where areas previously subject to flooding have now been protected, the ground may still be subjected to high ground water conditions due to their low lying nature.

2) Areas of Alluvium and Terrace Deposits

The alluvium occurs in the valley bottoms and is largely coincident with or adjacent to the areas liable to flooding. It is reasonable to assume, therefore, that the water table is generally close to the ground surface and that it maintains the alluvium in a saturated condition.

Terrace deposits of sand and gravel occur at three levels on the valley floor and lower valley sides. They are free draining and probably offer stable ground conditions for a wide variety of land use. However, the regional water table may be quite close to the surface of the lower terraces and deep excavations may have very high rates of inflow of water.

3) Bedrock with variable cover of superficial deposits.

(a) HYDROSTRATIGRAPHIC UNIT 1

This unit forms an extensive area of subdued relief on the dipslope of the Cotswold Escarpment in the eastern part of the study area. The bedrock is composed predominantly of impermeable clays and mudstones of the Oxford Clay, Kellaways Clay and Forest Marble formations. Some lenticular bodies of sand and limestone occur within the outcrop of the Forest Marble, and the thin rubbly limestone of the Cornbrash forms extensive outcrops between the Kellaways Clay and the Forest Marble.

In general the impermeable nature of the strata results in a surface drainage regime and maintains high water table conditions in superficial materials. This is particularly true of the Oxford Clay vale on the eastern margin of the area which forms a low-lying, poorly drained area between the dip slope of the Cotswolds to the west and the Corallian escarpment to the east.

(b) HYDROSTRATIGRAPHIC UNIT 2

Unit two is a highly permeable unit and is composed of the limestones of the Great Oolite and those of the overlying basal Forest Marble which are in hydraulic continuity. These beds cap the flat-topped hills and dissected plateaux which surround the City of Bath. They are very free draining due to the large numbers of discontinuities within them and their outcrop is almost totally devoid of surface water.

The exceptions are springs which discharge on the dip slope to the east where its surface elevation drops below that of the water table.

Superficial material lying on the limestones of this unit tends to be thin and is subject to very efficient under-drainage. The water table is far below the ground surface over much of this unit.

c) HYDROSTRATIGRAPHIC UNIT 3

Unit three is formed by the outcrop of the Fuller's Earth which consists of overconsolidated mudstones with occasional thin limestones bands. A three to five metre thick shelly limestone, the Fuller's Earth Rock, divides the Fuller's Earth into upper and lower units 12-29m and 10-16m thick respectively. The Fuller's Earth acts essentially as an impermeable unit which causes a line of springs to be generated at the base of the Great Oolite. The overall performance as an aquiclude is, however, not perfect and some leakage of water from the Great Oolite into the thin limestones and Fuller's Earth Rock takes place, which results in minor springs discharging at outcrop within the Fuller's Earth formation.

Superficial material lying on the Fuller's Earth outcrop is composed of Fuller's Earth Head with some limestone rubble derived from the Great Oolite; it is maintained in a saturated condition by the springs at the base of the Great Oolite and from within the Fuller's Earth. The springs issuing from the Fuller's Earth sequence are particularly important with regard to ground conditions because of the discharge at the interface with the Head, which is often the location of a basal shear plane of a low residual shearing strength, and which also forms an impermeable barrier to the flow of groundwater. Thus a high confined piezometric head is applied at the most sensitive level in the sequence and mass movement may be initiated.

d) HYDROSTRATIGRAPHIC UNIT 4

Unit 4 is highly permeable and comprises the Inferior Oolite limestone (15m) and the underlying Midford Sand, (up to 25m). The two formations are in hydraulic continuity and together form a major aquifer. The Inferior Oolite is frequently cambered and broken, which significantly enhances its permeability. This unit underdrains any superficial material present, which is usually composed of Fuller's Earth Head and which becomes more sandy and rubbly downslope as Inferior Oolite limestone rubble and Midford Sands are incorporated. The Head is maintained in a drained, relatively stable state and mobile material originating from upslope on the Fuller's Earth may be stabilised by the underdrainage when it moves onto the permeable strata of Unit 4.

c) HYDROSTRATIGRAPHIC UNIT 5

Unit 5 is of limited extent in the valley floors and low lying areas of the western part of the study area and is formed by the strata below the Midford Sands. Several formations are represented in this unit but the most important are the mudstones of the Lower Lias Clay and the interbedded muddy limestones and shales of the Blue Lias. The Penarth Group and the Mercia Mudstone Group are also present.

The lithologies of unit 5 are varied, but within the study area and for the production of map 7 they may generally be regarded as impermeable. The Lower Lias Clay is especially so and acts as an aquiclude, which causes a spring line to occur at the base of the Midford Sands. The presence of a spring line and the fact that this unit forms valley floors which are clearly close to the regional water table help to maintain a high water content in the superficial materials present.

6.2 Geotechnical Properties of Bedrock

6.2.1 Bedrock Units

The objective of thematic Map 8 is to group the bedrock types into a small number of Units, the members of which possess broadly similar geotechnical properties and engineering behaviour. The map is based on thematic Map 1 (Solid Lithostratigraphy). The key gives a general description of the Units, a detailed table of geotechnical properties abstracted from the Data Base and also a brief assessment of the likely engineering behaviour of the Units. Stratigraphic divisions have been omitted from the map itself for clarity. Geotechnical properties are, however, entered in the key under both Unit and stratigraphic headings due to the risk of overgeneralizing large bodies of data specific to stratigraphic units. It is hoped that the map will provide a simple presentation for non-geologists of the broad range of bedrock types in the area.

Five Bedrock Units are distinguished by conventional ornament and 8 sub-Units distinguished by lettering, as follows:

1) Unit "L": limestones of the Great Oolite, Inferior Oolite, Cornbrash, and Forest Marble. This unit is not subdivided.

2) Unit "S": sandstones and sands incorporating Midford Sands and Hinton Sands (Forest Marble) in sub-Unit Ss/Sh, and the Downend Formation in sub-Unit Sh.

3) Unit "C": clays, mudstones and marls incorporating Oxford Clay in sub-Unit C/M and Mercia Mudstone in sub-Unit M/C.

4) Unit "C,M,L": clays, mudstones and limestones incorporating Blue Lias and Fuller's Earth Rock in sub-Unit L/CM and Forest Marble, Frome Clay, Lower Lias Clay, Fuller's Earth (Upper and Lower) and Penarth Group in sub-Unit CM/L.

5) Unit "C/Ss": clays and sands of the Kellaways Beds. This Unit is not subdivided.

Those sub-Units consisting predominantly of interbedded layers of different lithologies (i.e. sub-Units Ss/Sh, C/M, M/C, L/CM, CM/L, and C/Ss) are described in Key A in terms of the average proportion of each lithological component present in the area. The first letter of the sub-Unit indicates the predominant component, the slash indicates interbedding, and the second letter the subordinate component. Two or more letters not separated by a slash indicates a mixture of the components rather than interbedding. (In the database, subscripts s and h are applied to clays, sands and limestones wherever a distinction between 'soft' and 'hard' can be made. The terms 'soft' and 'hard' are arbitrary in this context except where used for clays, in which case 'soft' indicates an undrained shear strength, Su, of <100kPa and 'hard' indicates an Su of >150kPa. Clays with intermediate values of Su are indicated by Csh or CsCh.).

6.2.2. Geotechnical Data

The great majority of data comes from the area in and around the City of Bath, the Avon valley between Bath and Batheaston, and the eastern flank of the Swainswick valley. Throughout the remainder of the study area data are very sparse due to the lack of engineering activity in a dominantly agricultural environment. Consequently, a spatial imbalance exists in the Database. In addition, imbalances are to be found in the distribution of data for lithological units and across the range of geotechnical tests.

The clays are, by far, the most widely sampled and tested group as a result of their widespread involvement in slope instability. The Lower Lias Clay is particularly well tested with over 700 test specimens recorded. In contrast, the limestones have remained virtually untested. There is an abundance of Atterberg Limit, Triaxial Test and Density/Moisture Content data but a paucity of particle-size, chemical (organic and carbonate) and compressibility test data. There is a very limited incidence of either geophysical or in-situ and down-hole test data. Standard Penetration Test data, though abundant, are frequently inconsistent. A wide variety in the units of measurement for most tests was found, a large percentage of the units having to be converted as part of the data logging process. Few site investigations quoted values for either Rock Quality Designation (R.Q.D.) or Fracture Spacing Index (If or F.I.). No geotechnical data whatsoever were found for the Frome Clay and Downend formations, and very little for the Penarth Group, Hinton Sands and the Forest Marble.

A very small number of site investigations included some of the following tests: Specific Gravity, Compaction (C.B.R. & Modified Proctor), Permeability (field) Cone Penetration (C.P.T.), Rock Penetration (R.P.T.) Swelling, Vane Shear (Lab. & Field), Unconfined Compressive Strength (U.C.S.) and Shear Box (peak & remoulded).

The Database is divided, at present, into 2 volumes: GEOTECH 1 comprising all geotechnical data and GEOTECH 2 comprising borehole logs with lithological descriptions. Both volumes utilise a simple coding system by means of which any sample from the study area may be placed in a broad geotechnical group identified by one or more letters (Table 6.1). This system is not a standard one but is virtually self-explanatory. Examples of the data sheets used for GEOTECH 1 & 2 are given in Appendix VIII. GEOTECH 1 also includes a 'reliability code' applied to each data point as follows: A (=good quality test data), B (=moderate) and C (=poor).

The two Database volumes feature both a B.G.S. borehole reference number (based on 1:10 560 scale map registration numbers) wherever applicable, and a confidential coded reference number which refers to the whole site investigation. Where possible, each sample point is located by National Grid reference.

6.2.3 Geotechnical Properties of Bedrock

a) Limestones

Limestones in the study area include oolitic, pisolitic, shell-fragmental and coralline types. Bedding ranges from massive to flaggy. A surface 'brash', consisting of rubbly limestone fragments in a matrix of totally weathered rock and soil, is often encountered in the uppermost metre.

The Uniaxial Compressive Strength of unweathered limestone is moderately high but very little test information is available on fresh rock in the study area. For most engineering purposes the behaviour of the rock mass is largely determined by the discontinuities within it. The strength and deformability of weathered limestone range from those of fresh rock to those of a loose silty, sandy gravel soil. The behaviour under load of the latter is, however, different from that of an alluvial deposit of comparable particle size because of the differing strengths, shapes and packing of the gravel grade material. The strength of intact, fresh limestones ranges from weak to very strong depending on degree of cementation and recrystallisation, mineralogy and grain size. Oolitic freestones tend to be moderately weak when freshly quarried but harden on exposure to air, thus creating a 'crust' which is resistant to weathering.

S.P.T. values for fresh limestone range from N=50 to 1500 and, for weathered limestone, from N=5 to 15. This test is, however, unsuited to intact rocks; many results are R.P.T's (the penetration in mm. for 50 blows) converted to S.P.T.'s and as such may be unrepresentative.

Uniaxial Compressive Strength values for unweathered limestones are: Great Oolite 7.6 $\rightarrow$ 19MPa ($\bar{x}$=12.8, SD=3.3,n=9); Cornbrash 0.7 $\rightarrow$ 15.9 MPa ($\bar{x}$=5.2, SD=5.4, n=7); Blue Lias limestone 9 $\rightarrow$ 76 MPa (n=5).

No additional test information is available for limestones. Surprisingly, no rock index (e.g. Point Load) data have emerged. Reports on the building stones of the Great Oolite (Forster & McCann, 1976; Watson, 1911) give Uniaxial Compressive Strength values of between 6 and 24 MPa. and Young's Moduli (Ei) of 12,000 to 24,000 MPa.

TABLE 6.1

GEOTECHNICAL CODE USED IN DATABASE

(VOLS "GEOTECH 1 & 2")

Symbol	Description
$C^*, C_s, C_h, C_s/C_h$	Clay or silt (C_h has Su >150 KPa and C_s has Su$<$ 100KPa; C_sC_h has $100<$Su<150 KPa)
F	Fill (all made ground and landfill)
G	Gravel or cobbles
H	Head (undifferentiated)
L^* Ls, Lh	Limestone (L_h is hard competent rock, Ls is soft, weak or incompetent rock)
M^*, Ms, Mh	Mudstone, siltstone, claystone or shale.
O	Soils rich in organics.
P	Peat
S^*, Ss, Sh	Sand, sandstone (Particle size range $0.06 \rightarrow 2.0$mm) (Ss = uncemented sand S_h = cemented sand/sandstones)
T	Topsoil
V	Void, cavity, very cavernous deposit.

Database volumes (currently held at B.G.S.):
"GEOTECH 1" contains numerical geotechnical data
"GEOTECH 2" contains borehole log summaries and descriptions.

Use of Code (Vol. GEOTECH 1 & 2):
Two or more letters together indicates a 'Mixture', the letters being in order of abundance (e.g. Cs Ss G = soft gravelly sandy CLAY or SILT). Two or more letters separated by a slash indicates interbedding (e.g. L/M = LIMESTONE with bands of mudstone). A letter in brackets indicates a component of lesser abundance or importance (e.g. C (Ss) = slightly sandy CLAY or SILT; M/(L) = MUDSTONE with thin bands of limestone).

Data quality (Vol. GEOTECH 1)
Quality of data is estimated in terms of three categories:
A) = Good B) = Fair and C) = Poor.

Uncertainty (Vols. GEOTECH 1 & 2)
Uncertainty on the part of the data source is indicated by "?" and uncertainty on the part of the present authors by "??".

Sample Type (Vol. GEOTECH 1 & 2)
U = undisturbed (e.g. block sample, rotary-drilled core, or U4).
D = disturbed (e.g. bag sample)
(S & A = shell and auger drill).

* No subscript indicates lack of test data or adequate description to specify.

b) Sandstones

In the study area these include 'hard' coarse-grained sandstones, calcareous sandstones (Sh) and 'soft' silty sands (Ss) with calcareous sandstone concretions (Sh). The principal outcrops are those of the Midford Sands (Ss/Sh) and the sand beds in the Kellaways Clay (C/Ss). Few data are available for either, and most are for the Midford Sands.

The 'soft' Midford Sands is, apparently, either a silty, clayey uniform fine sand (Claverton area) or a sandy uniform coarse silt (Swainswick area). In both cases the D60 values lie in the range of 0.05 to 0.1mm but on opposite sides of the silt/sand division (see Figure 11). Plasticity and moisture content are typically low. A single residual strength test gave a value of 32° for Ø'r with C'r=0. S.P.T. values for Midford Sands give Relative Densities in the range medium dense to dense. Reworked material and lenses of cemented sand may be expected to deviate below and above this range respectively.

The sand component of the Kellaways Clay has low to intermediate plasticity with a Øu of between 30° & 40°. The sand probably contains variable proportions of clay and silt, making the properties rather unpredictable. No further geotechnical information was obtained for the 'SAND' unit.

c) Clays and Mudstones

These are widespread in the study area and form a major component of many formations. They are also the subject of the great majority of geotechnical test data. The bulk of this data deals with the Lower Lias Clay and the Fuller's Earth in the Bath city and Swainswick areas respectively.

The Lias clays (LLi) are overconsolidated, silty and occasionally sandy clays of low to very high plasticity. Geotechnical properties are dependent on the degree of weathering (Russell, 1976). Typically, weathering grades I to IV are encountered (Chandler, 1976) with consistencies ranging from 'hard' at a depth of 5m to 'firm' near surface. Variations of Undrained Shear Strength with depth from different boreholes are shown in Figure 12.

Plasticity and undrained shear strength data have been collated separately for the four 1:10 000 scale maps ST76NE, SE, SW & NW in an attempt to distinguish regional variations. (Examples are given in Figs. 13 & 14). Mean values for Liquid Limit are 47.7% (SD=8.8, n=232), 46.5% (n=23), 57.1% (n=52) and 53.8% (n=59). These results suggest an increase in Liquid Limit from east to west, possibly reflecting a decrease in clay fraction. Populations of Liquid Limit are normally distributed. The corresponding Plasticity Indices are: 25.9% (SD=6.8), 21.4% (n=23), 31.5% (n=53), and 31.3% (n=59).

PARTICLE SIZE DISTRIBUTION
ENVELOPES

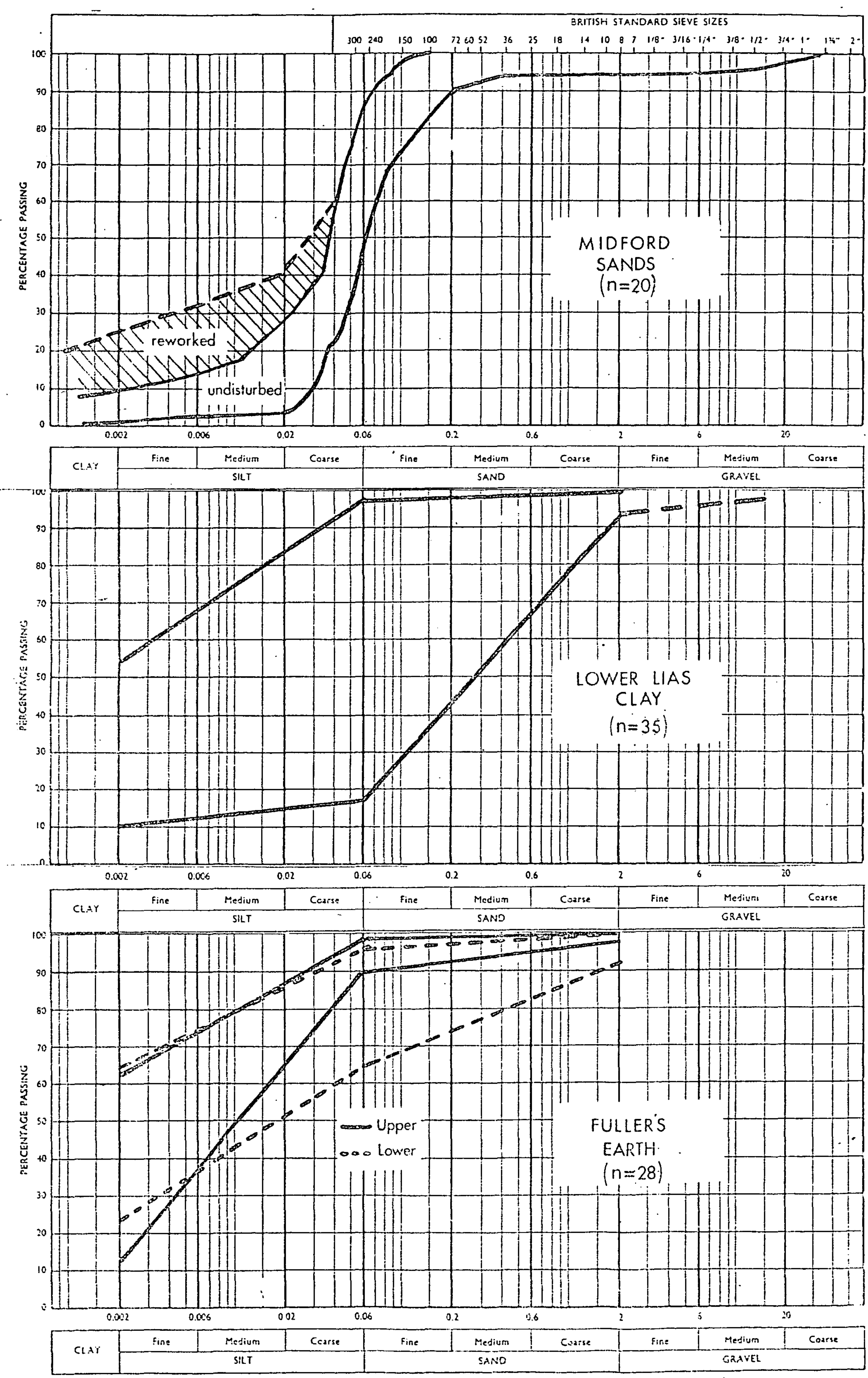


Fig 11

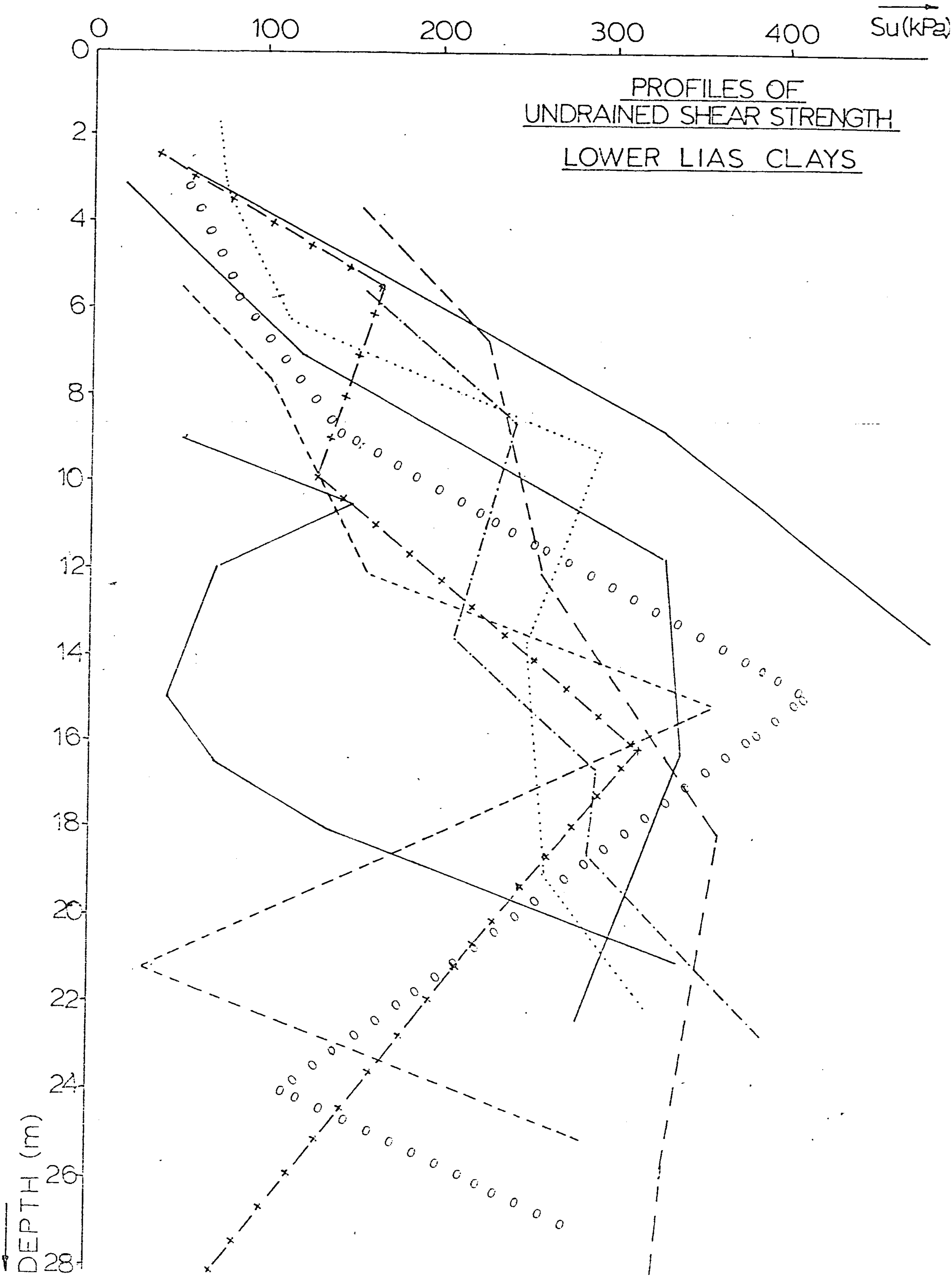
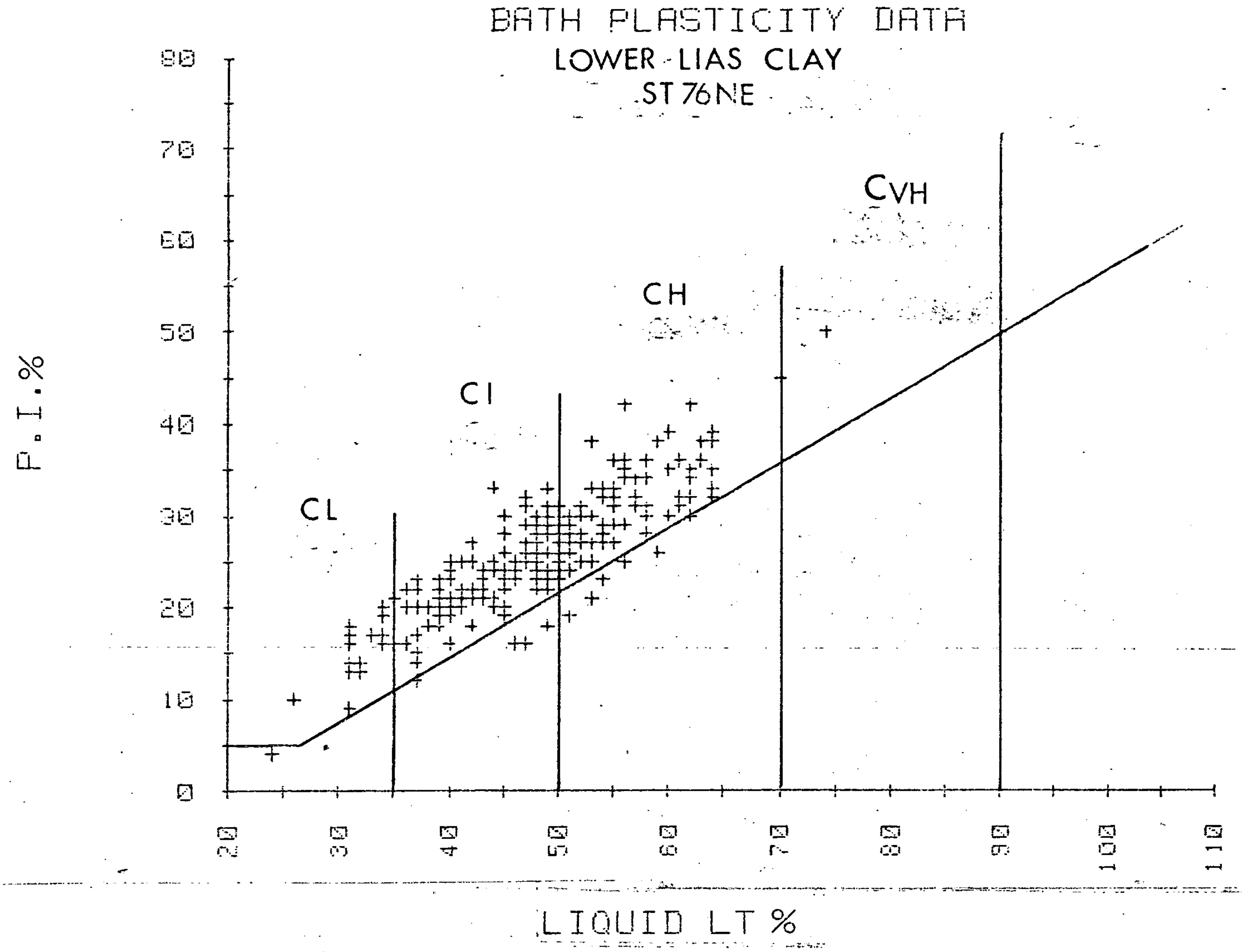

PROFILES OF
UNDRAINED SHEAR STRENGTH
LOWER LIAS CLAYS
Su(kPa)
0
100
200
300
400
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
DEPTH (m)

Fig 12


BATH PLASTICITY DATA
LOWER LIAS CLAY
ST 76NE
P.I.%
CL
CI
CH
CVH
0
10
20
30
40
50
60
70
80
20
30
40
50
60
70
80
90
100
110
LIQUID LT %

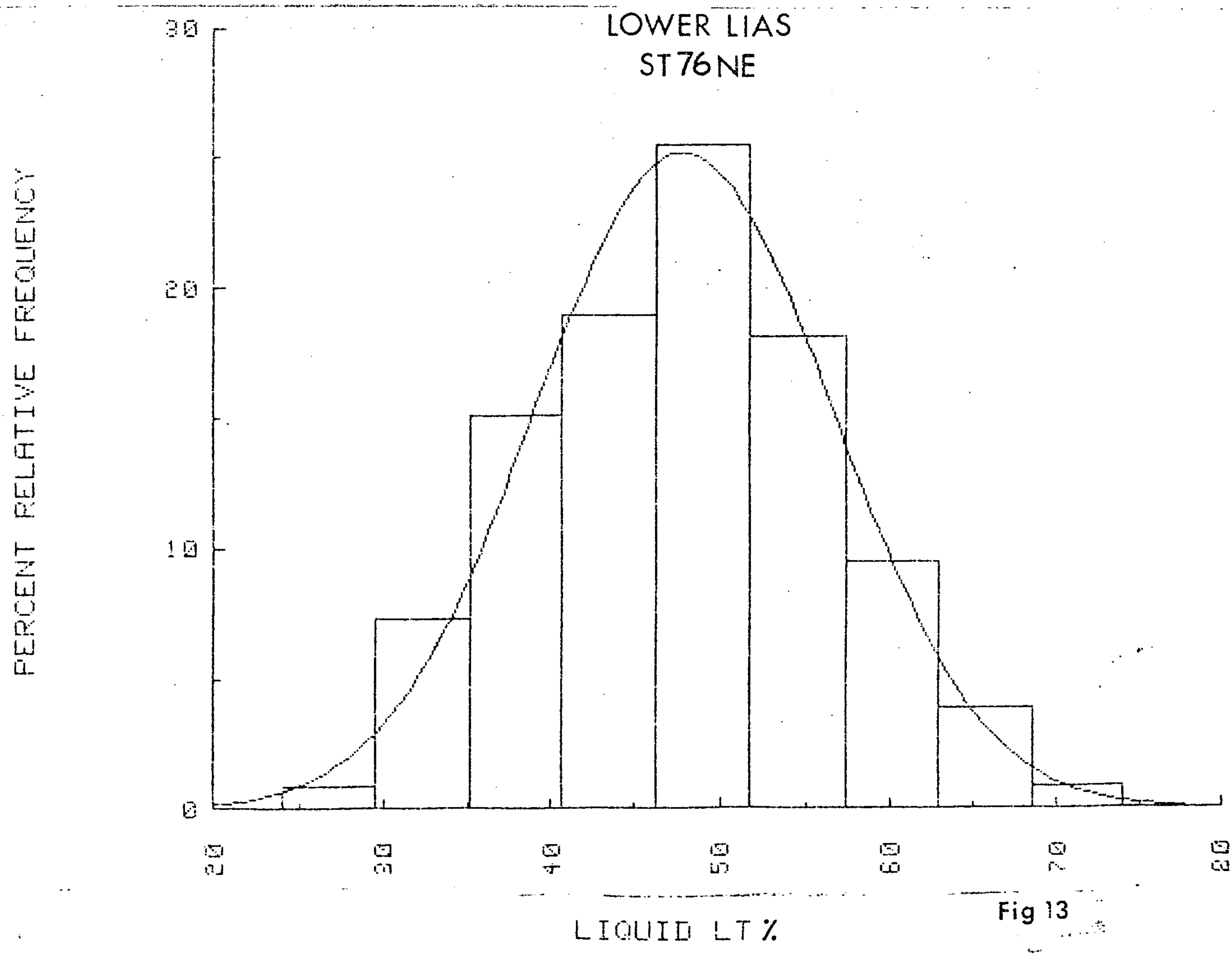

LOWER LIAS
ST 76NE
PERCENT RELATIVE FREQUENCY
0
10
20
30
20
30
40
50
60
70
80
LIQUID LT %

Fig 13

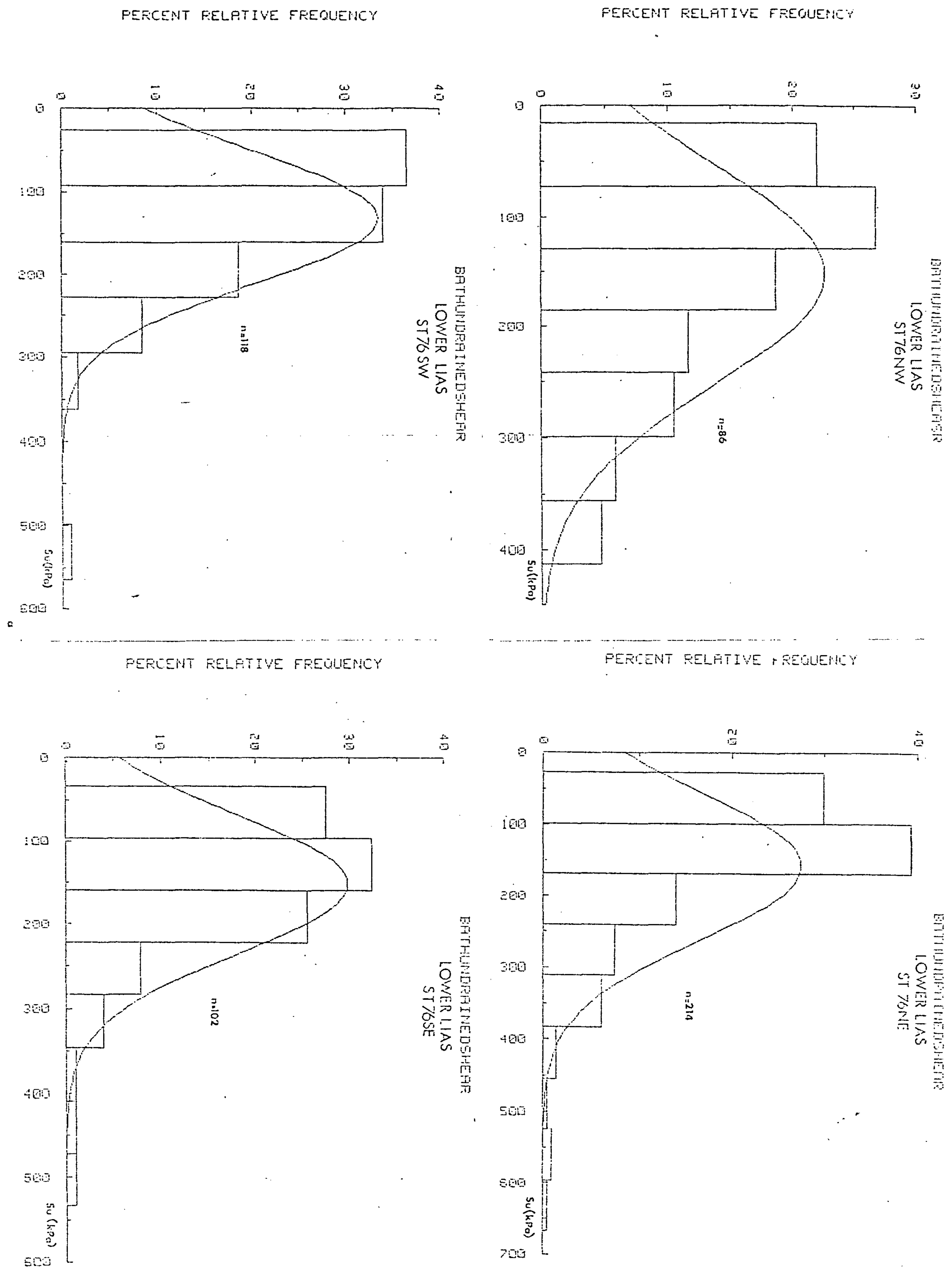

PERCENT RELATIVE FREQUENCY
BATHUNDRAINEDSHEAR
LOWER LIAS
ST76 SW
n=118
Su(kPa)
PERCENT RELATIVE FREQUENCY
LOWER LIAS
ST76NW
n=86
Su(kPa)
PERCENT RELATIVE FREQUENCY
BATHUNDRAINEDSHEAR
LOWER LIAS
ST76SE
n=102
Su (kPa)
PERCENT RELATIVE FREQUENCY
LOWER LIAS
ST 76NE
n=214
Su(kPa)

Fig 14

'Casagrande' charts (L.L.v P.I.) show the Lower Lias clays to be largely inorganic silty clays of 'low' to 'very high' plasticity with some clayey, micaceous silts of intermediate to high plasticity, (see Figure 13).

The Activity (=P.I./%clay size) of the Lower Lias clay ranges from 0.4 to 1.4 (x=0.69, SD=2.6, n=34) thus placing the LLi clay in the 'inactive' to 'active' group (Skempton, 1953).

A plot of Liquidity Index [=(m-P.L.)/P.I.] with depth for all Lower Lias clay samples tested is shown in Figure 15. Points are scattered either side of L.I. =0. A decrease in L.I. with depth can be seen. These results are in keeping with those of a moderately overconsolidated clay (Simons & Menzies, 1975).

The mean value of Bulk Density is 2.02gm/cc (SD=0.1, n=615) and the mean value of Dry Density is 1.64 (SD=0.11, n=160); the populations of both are normally distributed (see Figure 16).

Mean values for the undrained shear strength (Su) of Lower Lias clays from 1:10 000 maps ST76NE, SE, SW & NW are: 158kPa (SD=104, n=214), 152kPa (SD=84, n=102, 131kPa (SD=81, n=118) and 153kPa (SD=100, n=86), respectively. These results show a remarkable similarity considering the wide variety of sources. The data are not normally distributed; the populations for maps ST76NE, SE and SW have very similar coefficients of skewness. The histograms are skewed toward their upper ends due to a transition from clay to soft mudrock. There may in fact be a bimodal distribution, dividing clays from mudrocks but there are too few samples of the latter to make this clear.

Residual Strengths have a mean of Ø'r = 22 (n=16) with a wide scatter of results. Values of C'r are also very variable (0 to 98kPa). Both Ø'r and C'r appear to be unusually high (Cripps & Taylor, 1981). The spread of results is due, in part, to differences in test method, but also to differences in plasticity. The lowest values for Residual Strength should be taken for design purposes (Chandler, 1976).

Compressibility (Mv) ranges from very low to high. Few samples of highly weathered Lias clay were represented in the data but values of Mv for such material may be expected to be high.

The Fuller's Earth clays (FE) are frequently, but not always subdivided into 'Upper' and 'Lower' as far as site investigation data are concerned. The subdivision has been made here in an attempt to elucidate differences in geotechnical properties between the 'Upper' and 'Lower' units. The 'Upper' Fuller's Earth (UFE) contains the so-called 'commercial' Fuller's Earth Bed which is a thin bed of clay rich in calcium montmorillonite. Limited data for this bed show Liquid Limits of 70 to 100% and Plastic Limits of 45 to 65%, though locally these are likely to be higher. Weathered FE appears to be softer and slightly more plastic than fresh FE and has been classified (Gibbs, 1983) at Swainswick as a separate unit 'Softened FE'. The UFE has a mean Liquid Limit of 55% (N=76) and mean Plasticity Index of 30% (n=76) for map ST76NE; and L.L. =55% (SD=16.5, n=38) and P.I.=35% (SD=13, n=38) for map ST76SE. Few data are available for the rest of the area.

The Activity of the Fuller's Earth as a whole ranges from 0.5 to 1.1 (x=0.78, SD=0.33, n=25), placing the FE in the 'inactive' to 'normal' groups (Skempton, 1953).

The Liquidity Index v.depthplot (Fig.15) shows a scatter of values around L.I. =0, as for L. Lias but having no discernable trend with depth, possibly due to the small artesian water source in the underlying Inferior Oolite. Moderate overconsolidation is indicated (Simons and Menzies, 1975).

The Bulk Density has a mean value of 2.03gm/cc (n=77).

The mean Undrained Shear Strength (Su) for all U.F.E. samples tested is 83kPa (SD=73, n=38).

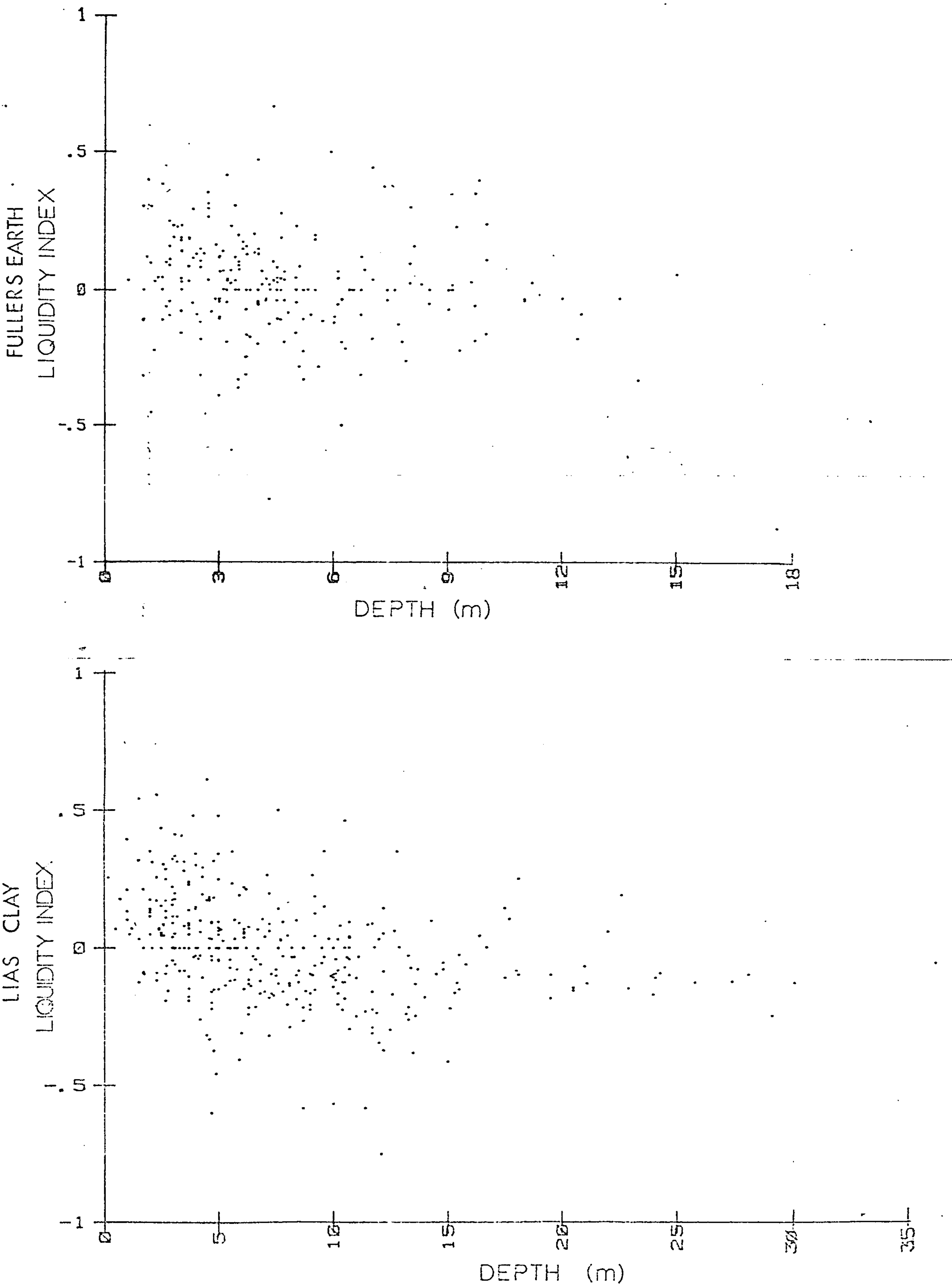
The Lower Fuller's Earth (LFE) clay has the following plastic properties: mean L.L.=44.5% (n=85), mean P.I.=27.4% (n=85) for map ST76NE; and mean L.L.=47.6% (SD=1.35, n=15), mean P.I. =27.7% (SD=11, n=15) for the remainder of the study area. Values of Su for all L.F.E. samples tested have a mean of 97.6kPa (SD=94, n=21); some of these samples are weathered.

Residual Shear Strengths for the Fuller's Earth as a whole are: mean C'r =8.9 (n=13) and mean Ø'r = 19.6 (n=16). Compressibility (Mv) of the Fuller's Earth clay as a whole is 'low' to 'medium'.

Data concerning the remaining clay/mudstone groups are limited, and may be summarised as follows:

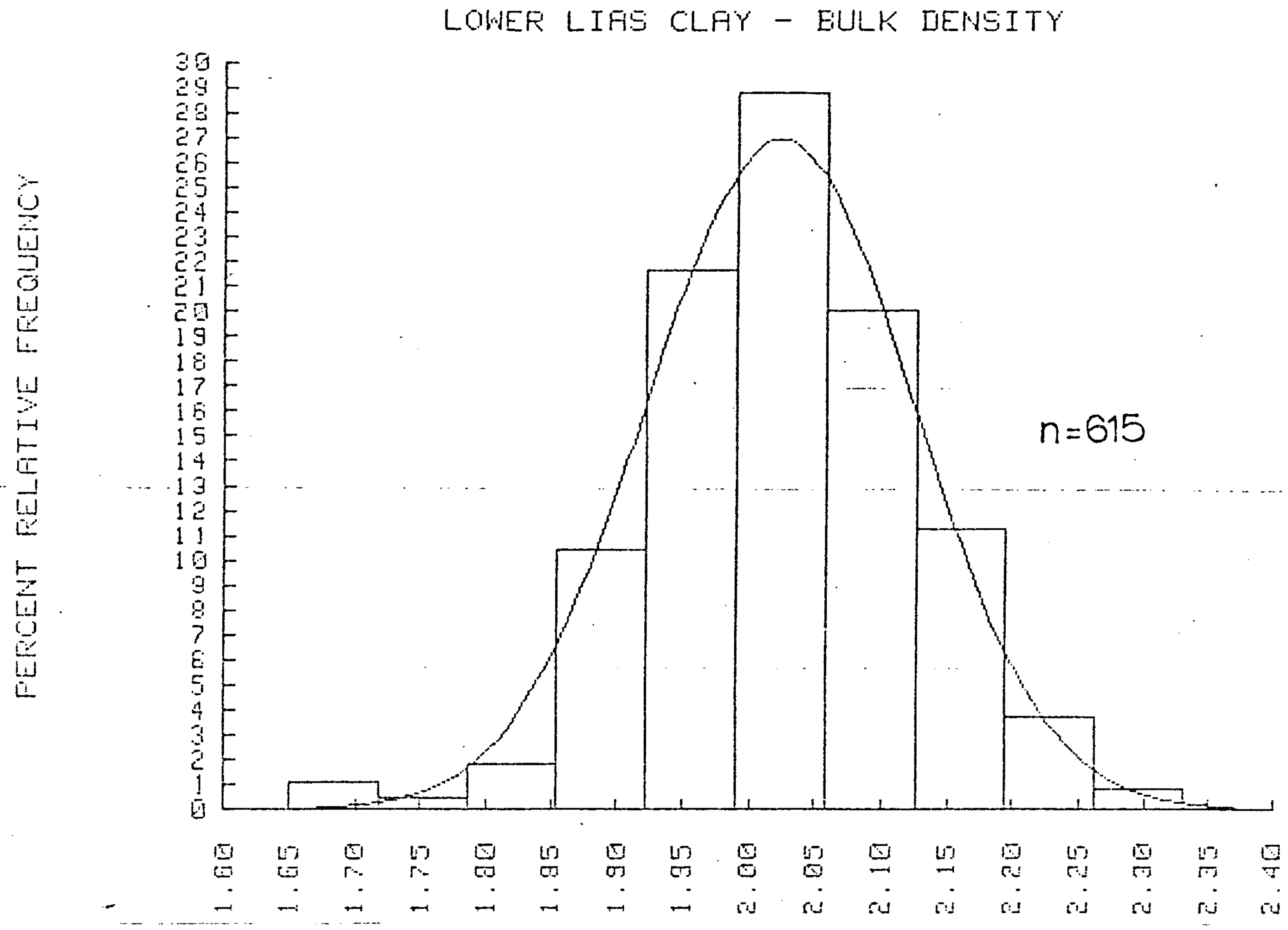
Forest Marble (clay): Liquid Limit, mean = 60.8% (n=13); Plasticity Index, mean = 39.5% (n=13); Undrained Shear Strength - no data. The clays at outcrop are very variable and surprisingly little is known about their geotechnical properties either in or out of the study area.

Blue Lias (clay): Liquid Limit - no data; Undrained Shear Strength, mean =141kPa (n=11); Unconfined Compressive Strength, (mudstones): four results give a wide scatter of values (70,0.7, 1.4 & 1.4 MPa) reflecting the transition from 'hard' clay to 'strong' mudstone. Compressibility (Mv) is given as 'low' to 'very high' (n=4); in fact the Mv is more likely to be 'low' throughout with the exception of highly weathered material. Three values for Young's Modulus (Eu), obtained from cyclic Triaxial tests, were 17.8, 59.2 and 69.3 MPa.



FULLERS EARTH
LIQUIDITY INDEX
1
.5
0
-.5
-1
0
3
6
9
12
15
18
DEPTH (m)
LOWER
LIAS CLAY
LIQUIDITY INDEX
1
.5
0
-.5
-1
0
5
10
15
20
25
30
35
DEPTH (m)

Fig 15


LOWER LIAS CLAY - BULK DENSITY
PERCENT RELATIVE FREQUENCY
n=615
1.60
1.65
1.70
1.75
1.80
1.85
1.90
1.95
2.00
2.05
2.10
2.15
2.20
2.25
2.30
2.35
2.40

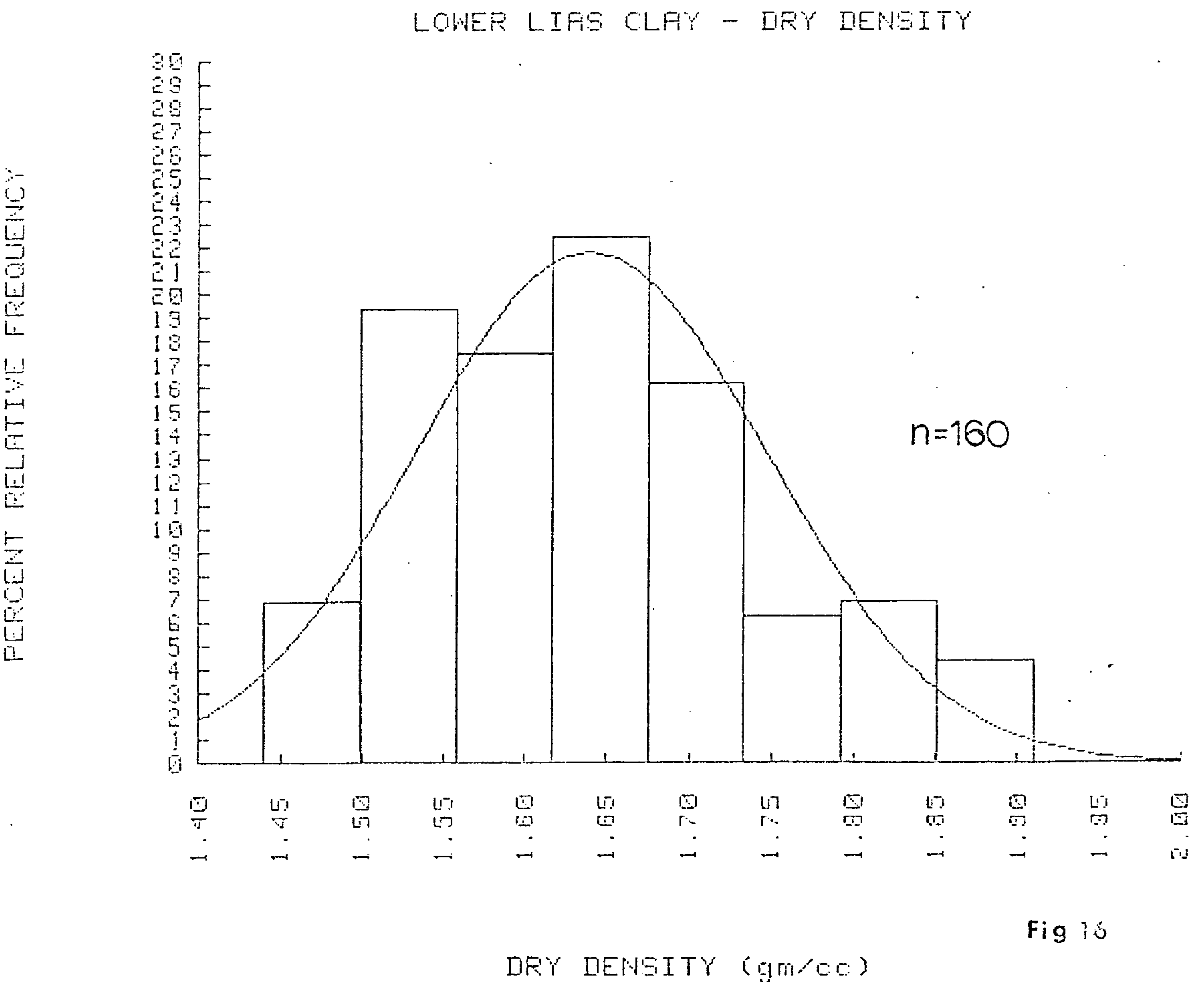
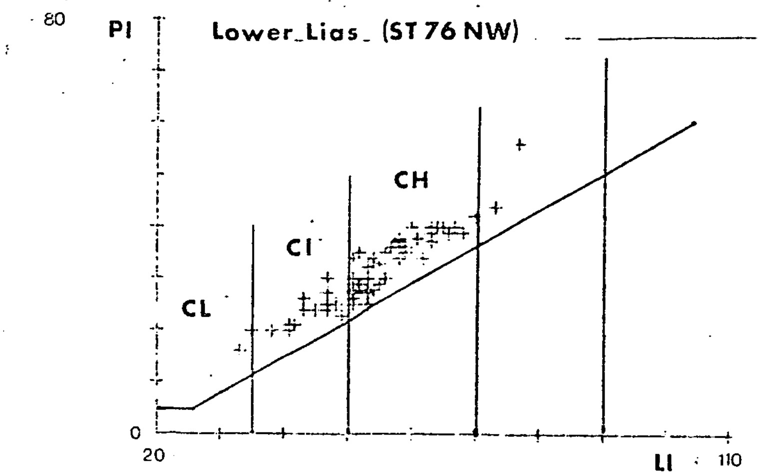
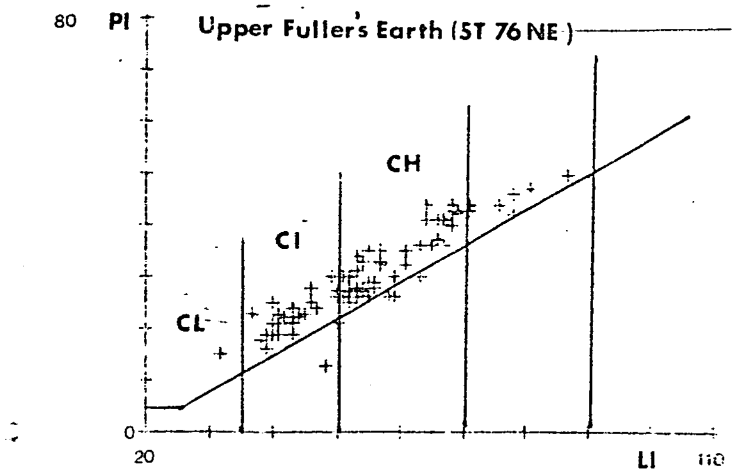
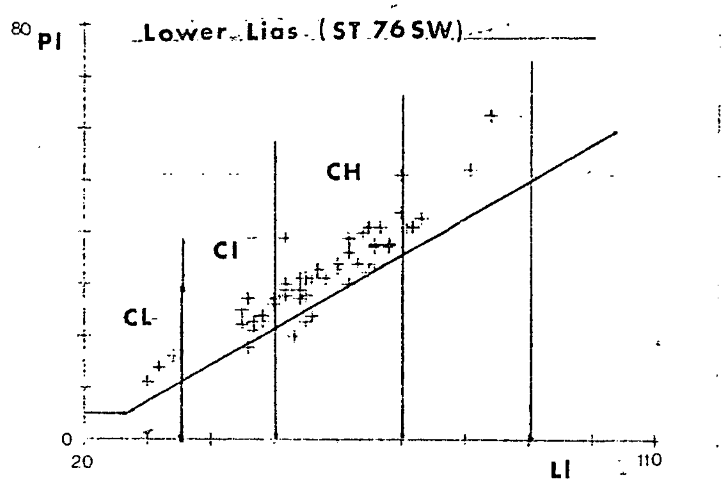
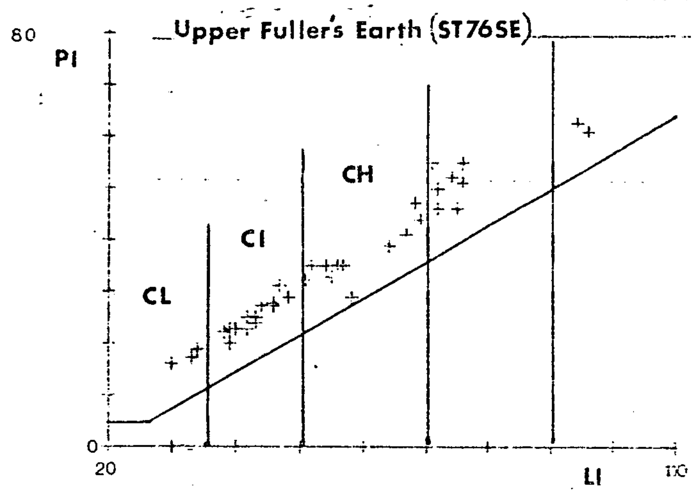

LOWER LIAS CLAY - DRY DENSITY
PERCENT RELATIVE FREQUENCY
n=160
1.40
1.45
1.50
1.55
1.60
1.65
1.70
1.75
1.80
1.85
1.90
1.95
2.00
DRY DENSITY (gm/cc)

Fig 16

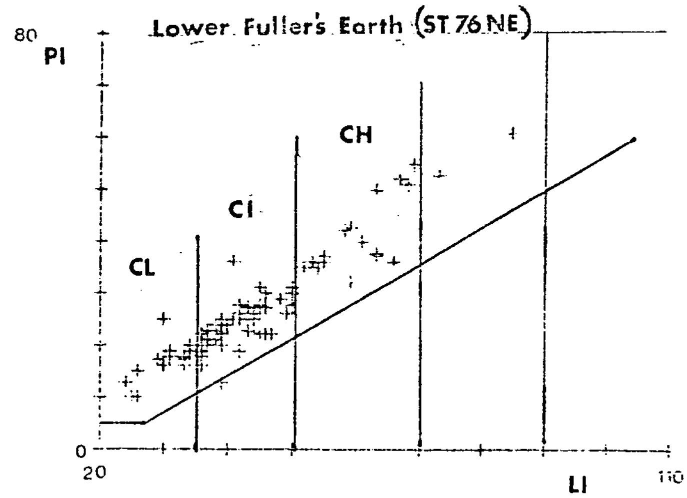








6



CL = low plasticity clay
CI = intermediate "
CH = high "

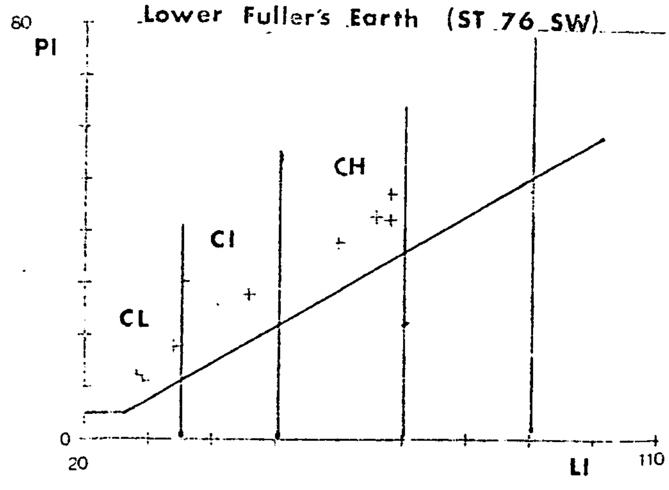
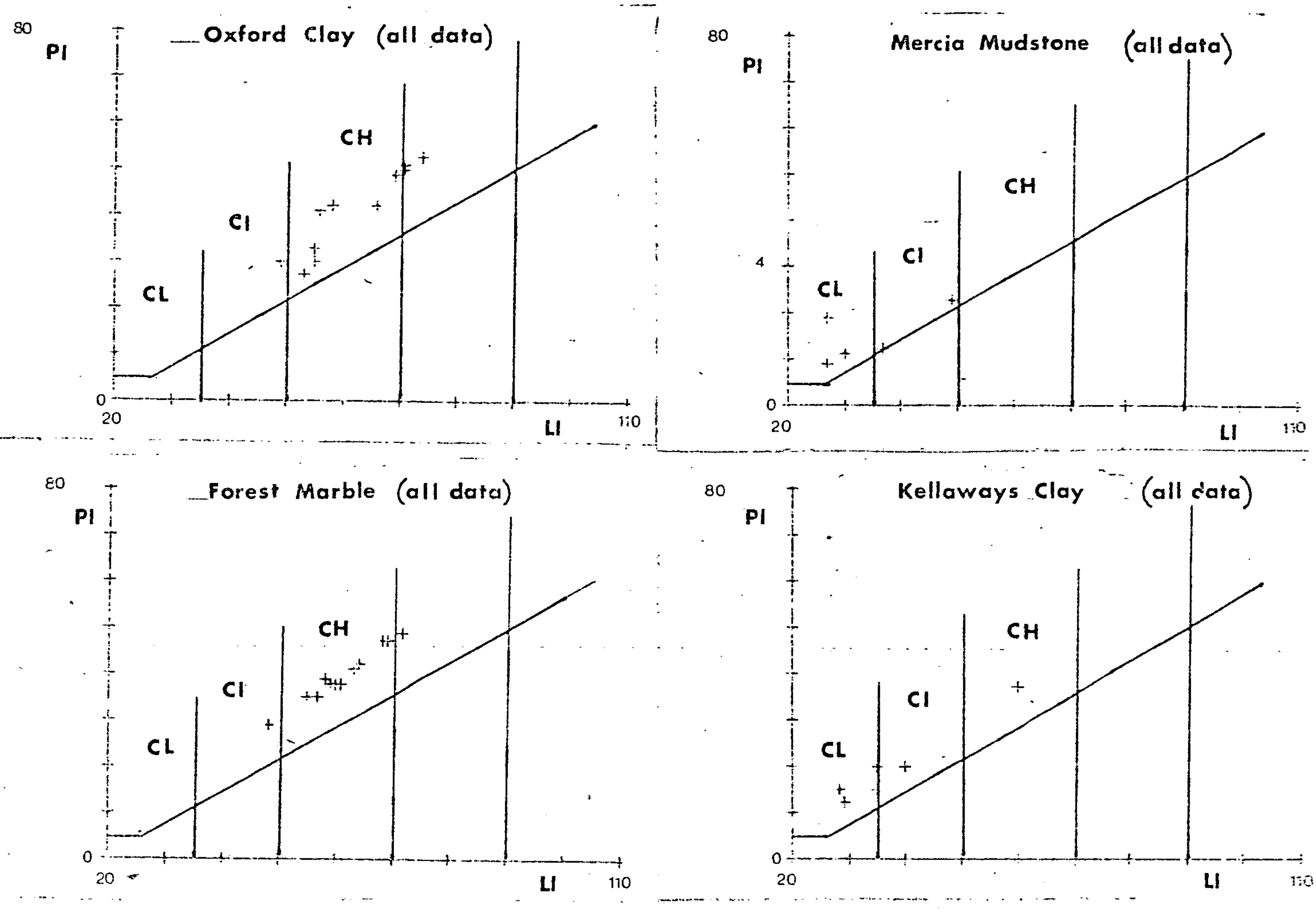
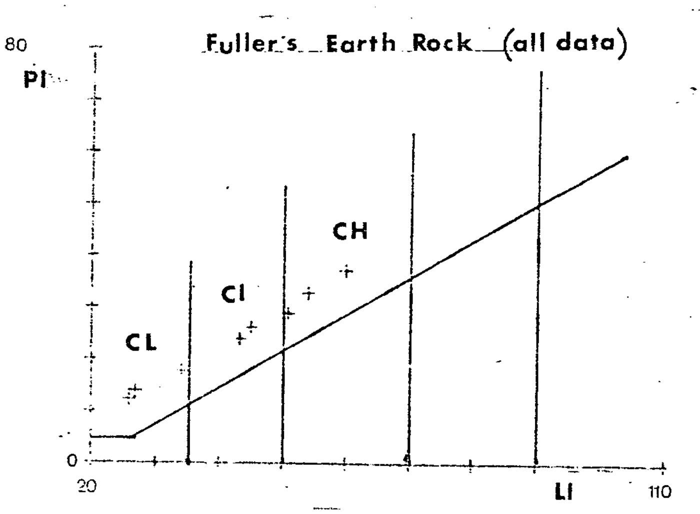


Fig.17
CASAGRANDE
PLASTICITY CHARTS
[LIQUID LIMIT = L.L.
PLASTICITY INDEX = P.I.]





L.L.= LIQUID LIMIT
P.I.= PLASTICITY INDEX

CL = low plasticity clay
CI = intermediate "
CH = high "

Fig.18
CASAGRANDE PLASTICITY
CHARTS

Fuller's Earth Rock (FER)- clay

Liquid Limit, mean =42.5% (n=8); Plasticity Index, mean =24.1% (n=8); with a 'Casagrande' rating of 'low' to 'high'. The plasticity appears to be lower than that of either the Upper or the Lower Fuller's Earth, but this may be due to the small amount of data for the FER. A single Triaxial test gave an Su of 222 kPa. The FER is variable in both content and extent, and only becomes significant in extent to the SW of the area.

Oxford Clay:

Liquid Limit, mean =61.5% (n=11); Plasticity Index = 40.7% (n=11), giving a 'Casagrande' rating of 'high'. Unconfined Compressive Strength lies in the range 41 to 290 kPa (n=4). Compressibility (Mv) is given as 'low' to 'high' (n=6). In general, these results agree with those quoted for Oxford Clay elsewhere (Cripps & Taylor, 1981; Russel, 1976; Horseman et al, 1982) with the exception of the compressibilities which seem to be high, even for weathered Oxford Clay.

Mercia Mudstone (formerly Keuper Marl)

Liquid Limit, mean =34% (n=5); Plasticity Index, mean =15% (n=5), giving a 'Casagrande' rating of 'low' to 'intermediate'. Undrained shear Strength, Su, mean =200kPa (n=19). A single value for Su of 550kPa was obtained for the Blue Anchor formation (formerly the 'Tea Green Marl'), a thin bed found at the top of the Mercia Mudstone. Compressibility (Mv) is 'very low' to 'medium'. It is reported elsewhere (Davis, 1971; Chandler, 1969) that structural modifications due to weathering have a significant effect on the stress-strain properties of the Mercia Mudstone; effective strength and deformation moduli are reduced; Meigh (1976) gives values of E in the range 100 to 1200 MPa for 'fresh' MM from the Midlands and 10 to 100 MPa for weathered MM. Also a decrease in the Overconsolidation Ratio (O.C.R.) reduces the load beyond which significant deformation takes place. The Mercia Mudstone, though described formerly as a 'marl', in fact has a carbonate content of between 5 and 20% placing it rather in the class of carbonate-rich clay/mudstone.

Kellaways Clay

Liquid Limit: a single 'high' value was obtained (but see under "sands" above). No further data are available for the study area. Horseman et al (1982) give a 'Casagrande' range of 'low' to 'high' for the "Kellaways Beds" in Oxfordshire but this includes part of the "sand" member. In fact it is probably impossible to completely separate the "sand" and "clay" members as far as engineering behaviour is concerned.

Frome Clay

No geotechnical data, whatsoever, is available in the study area and nothing has come to light elsewhere.

Penarth Group

This is an amalgamation of the Westbury Formation with the former 'White Lias' and 'Cotham Beds'. No plasticity data are available. Undrained shear strength Su, =139, 150 & 324kPa (Cotham Member); Su =204 & 367kPa (Westbury Formation). Hawkins and Privett (1981) describe shear plane clays within the Cotham Beds as being high in montmorillonite with consequent high plasticity (L.L. = 96%, P.I. =36%); residual shear strength is given as $\phi'r=5 \rightarrow 11^{\circ}$ and $C'r = 4 \rightarrow 14$kPa.

Casagrande diagrams for the various sub-units are shown in Figures 17 & 18.

Laboratory data for which few results are available include the following: Specific Gravity, Chemical (pH, sulphate content, organic content and carbonate content) and Particle-size. Standard Penetration Test results are also discussed.

Specific Gravity: (BS1377, test 6B). Data exist for the Upper Fuller's Earth in the Swainswick area and for the Lower Lias Clay in the Bathampton area.
S.G. for Upper Fuller's Earth: mean = 2.64 (SD = 0.03, n = 11) and S.G. for the Lower Lias Clay: mean = 2.66 (SD = 0.028, n = 7).

pH: Values of pH (BS1377 test 11A) lie between 6.5 and 9.5 for all bedrock tested. Mercia Mudstone, Blue Lias and Lower Lias Clay have some values below 7.0, the remainder of those tested all being about 7.0. The mean value for the Lower Lias Clay is 7.53 (SD = 0.44, n = 56); for the Upper Fuller's Earth the mean value is 7.18 (n = 4); and for the Lower Fuller's Earth it is 7.90 (n = 6). The Oxford Clay gives a mean pH of 7.5 (n = 9). The only result exceeding 8.5 was from weathered Forest Marble (9.5).

SO3: The total sulphate content of the soil (see B.S. 1377, test 9) was found to be generally low. Most of the bedrock types tested gave values below 0.5% (i.e. classes 1 and 2, CP 2004). However, the Blue Lias, the Lower Lias Clay and the Upper Fuller's Earth did exceed 0.5%. One sample of Lower Lias Clay gave an SO3 content of 1.4% (Class 4). Only three out of a total of 51 samples of Lower Lias Clay tested exceeded 0.5%.

Organic: (BS1377, test 8). Although several borehole logs use the adjective organic or describe the presence of organic matter, only five laboratory determinations of organic content were located. These ranged from 0.8 to 3.5% ($\bar{x}$ =1.7%) for the Lower Lias Clay. The Oxford Clay is likely to have high organic contents (Horseman et al, 1982). The Fuller's Earth is also likely to have moderately high organic contents in parts (Penn et al, 1979).

Carbonate: Only six determinations were available from site investigation sources, all of which were for Upper Fuller's Earth: mean = 43% (n = 6). The test method is described in Molina (1974). Clearly the range of carbonate contents is very wide for most of the clay/mudstone group considering their close proximity to carbonate-rich horizons in the study area. Penn et al (1979) give $CaCO_3$ % in the range 25% to 70% for all FE except the 'commercial' bed for which the content is 5%. The variation reflects the cyclic nature of the carbonate-rich and carbonate-poor/organic-rich zones. Similar gradations are found in the Lias and the Oxford Clay (Gallois & Horton, 1981; Horseman et al, 1982).

S.P.T.: The Standard Penetration Test is widely used (Sanglerat, 1972). The test was originally designed to measure the relative density of sands but its use in cohesive soils and hard rocks may be misleading. Quoted values for "N" (number of blows per 300 mm penetration) are in some cases derived from either the C.P.T. (Cone Penetration test) or the R.P.T. (Rock Penetration test) and are not strictly S.P.T. results. C.P.T.'s are converted to S.P.T's using the empirical formula ($N = Nc/1.5$), where Nc is the cone penetrometer test value. This is not, however, universally applicable (Carter, 1983). Geotechnical Engineering Ltd. makes use of the R.P.T. test which measures the penetration in mm for 50 blows with an S.P.T. apparatus. This value is then extrapolated to obtain an 'equivalent' N value. This results in N values of 1000 or more for rock compared with a maximum of N = 50 initially conceived from the S.P.T. test (Terzaghi & Peck, 1967). It seems unlikely that a test penetrating only a few millimetres (as in some cases) can be considered representative of a rockmass. Gibbs & Holtz (1957) recommend a correction factor for overburden. Also it seems likely that pore pressure build-up in clays may lead to error.

Taking into account the above, it is not surprising that the N values obtained are very variable. Fresh limestone gives values between 300 and 1500 and weathered limestone as low as 8. On the other hand, over-consolidated clays are reported with N values as high as 600 (Blue Lias) and 400 (Fuller's Earth). Also some sources define an arbitrary upper boundary (e.g. 60, 400) beyond which they do not quote an N value. Results of Standard Penetration tests should be treated with caution.

P.S.A.: Particle size analyses are available only for the Lower Lias clays, the Fuller's Earth and the Midford Sands. Grading curve envelopes for the above are shown in Figure 11. The narrow envelope of the Midford Sands is notable;

the reworked zone shows that finer material is being mixed in with the coarse silts and fine sands. The Lower Lias clays have a broad envelope from clay to sandy silt size. The difference between Upper and Lower Fuller's Earth envelopes is not thought to have any statistical significance.

6.2.4 Engineering Behaviour

Limestones (Unit L) Some members of this Unit have provided high quality building freestone, mainly from the 'Combe Down Oolite' and 'Bath Oolite' members of the Great Oolite. These are ideal building materials as they are easily worked and dressed. The freestones are characteristically homogeneous and free from marly bands, borings, and major discontinuities. Other members of the Unit, however, are less suitable as John Rennie discovered when building the Dundas aqueduct (Clew, 1970b); poor quality limestone was taken from close by but proved unstable, necessitating demolition of part of the structure.

The Compressive Strength of the intact limestone may be very high and, in the case of crystalline limestone, extremely high and may in fact be comparable with those of some granites (Attewell & Farmer, 1976). However, the phenomena of weathering, solution and slope instability may, in certain circumstances, serve to reduce dramatically the bearing capacity of these otherwise competent materials (Hunt, 1984; Ingold, 1975). The jointed nature of limestone allows water, possibly of an aggressive nature, to enter the rockmass and dissolve the limestone adjacent to the joint faces. Voids ranging in size from millimetres to tens of metres may result with time. These voids may be completely undetectable at the surface, but for specialist techniques. Some near-surface solution voids of one metre width have been found. Voids have also been recorded where slope instability and solution have combined forces.

The phenomenon of cambering (see section 5.1.2), found in both the Great Oolite and the Inferior Oolite, results in 'gulls' (tension cracks) often some distance from the surface expression of instability. 'Gulls' may be open, infilled with either overlying or underlying sediment, or bridged i.e. the uppermost bed is unaffected. Gulls remote from the outcrop may be encountered in tunneling. Various geophysical techniques have been moderately successful in detecting gulls and open joints in the study area (Claverton Down - Soil Mechanics Ltd, HS1; Odd Down-Wimpey, GE33; Hobbs, 1980). Large solitary slipped blocks of Great Oolite and to a lesser extent of Inferior Oolite are occasionaly found. These may be unstable, and ultimately require destruction and removal (Cording, 1971; Schuster, 1978).

Foundations on the Great Oolite plateaux are generally executed without major problem. Ground beams, spread footings or rafts may be employed to 'bridge' potential cavities associated with open joints, or to prevent the risk of 'punch-through' where the limestone is thin and underlain by a material of markedly lower stiffness e.g. Fuller's Earth (Peck et al, 1974; Davis, 1971.)

Foundations on the mid slope limestones, e.g. Inferior Oolite, are however more difficult due to the problems associated with cambering. Unexpected variations in sub surface conditions have been noted at several sites on cambered Inferior Oolite. A cambered limestone block possibly more than 100 metres wide and 10 metres thick may be bounded on all sides by, for example, reworked Midford Sands with little or no surface expression of this very sharp boundary. This phenomenon presents obvious difficulties for both foundations and excavations.

Weathering of limestones generally results in the formation of a thin surface 'brash' of perhaps 1 or 2 metres thickness. This consists of partly weathered limestone blocks and rubble in a matrix of soft gravel-sized rock fragments and residual silt and clay, sometimes with a detritus of individual oolite grains.

Bedding has an important influence on rockmass competence (Hoek & Brown, 1980). A range from massive freestone to very flaggy or 'brashy' rock is found. Blocky and flaggy rock may perform satisfactorily under vertical loading (perpendicular to bedding plane) but be unpredictable with oblique loading or in cut slopes where relative movement or hinging between blocks may occur. Discontinuities between blocks may be filled with clayey or residual granular (oolite) material, both of which reduce the friction between blocks. Resistance of oolite to crushing at localized stress concentrations is not high. Compacted weathered limestone makes a good fill material. The mass permeability of the limestone Unit is high due to joints and solution cavities. It has been shown that very large quantities of water, and presumably lean concrete, can be 'lost' through the narrowest of surface openings. Modest artesian pressures have been noted in the Inferior Oolite at outcrop (Clew, 1970b) as well as in boreholes.

Crushed Jurassic limestones make stable aggregates in concrete if no marly bands are present. Spalling due to freezing, and dust formation during mixing are, however, likely problems (Collins, 1983).

<u>Sands and Sandstones</u> (Unit S) The greater part of this Unit in the study area is represented by the Midford Sands. As described earlier, these 'Sands' are in

fact silty fine-grained sands and sandy coarse silts, generally in a loose or partially cemented state, with irregular bands or lenses of hard sandstone (or siltstone). The 'Sand' in its undisturbed state is markedly uniform (see figure 11). Permeability is unexpectedly low but higher than the underlying clays, resulting in a prominent spring-line. Much of the 'Sand' is partially cemented, enabling steep slopes (70°+) to stand unassisted. Disturbance of the cement bond by either landslip or water movement causes the sand to return to a loose state and, ultimately, to behave as a slurry when fully saturated. Reworked 'sands' are contaminated with fine silts and clays, further reducing the stability. Midford Sands initiate cambering of the Inferior Oolite by lateral spreading following loss of lateral support and pore pressure build up. Large parts of the lower valley slopes are covered by a thin hillwash of Midford Sands, making identification of the bedrock difficult. Undisturbed Midford Sands have S.P.T. values in the 'medium dense' to 'dense' range. Peak strength values achieved in shear box tests are considered unreliable and conservative values for Ø and Ør are normally taken with cohesion assumed to be zero despite 'low' to 'intermediate' plasticity ratings.

It is difficult to quantify the percentage of 'sandstone' to 'sand' because the former often occurs as large lenticular bodies of unknown extent. Permeability and strength will be strongly influenced by the grain size. Stability will be a function of disturbance, degree of cementation and the position of the watertable. From the Swainswick area the Midford Sands is reported (Gibbs, 1983) as having no bedding fabric and large numbers of sub-vertical fissures, probably associated with cambering. A bed of siltstone at the base of the Midford Sands (the Junction Bed) is discontinuous but may reach 3m in thickness. The Sandstones/Siltstones have a lower modulus ratio than limestone (Attewell & Farmer, 1976) and deform non-elastically or semi-elastically.

The use of the 'sands' as a resource is hampered by the variability of cementation and the presence of the sandstone 'doggers' (lenses). The sandstones make moderately good aggregate. The Downend Formation contains coal seams but is otherwise a massive sandstone/grit sequence. The Hinton Sands are probably not dissimilar to the Midford Sands as far as engineering behaviour is concerned.

There are indications from the Bunter Sandstone (Meigh, 1976; Bell, 1975) that undermining, as well as causing fractures in the rockmass, may actually affect the rock fabric by increasing the deformability.

c) Clays and Mudstones

(Units C, M & C,M,L.) The geotechnical properties of these two groups overlap considerably and laboratory and field descriptions are often seen to be inconsistent with the test results if a rigorous classification is used (such as that of the Engineering Group Working Party (Anon, 1977). Nomenclature is recognized as a problem (Cripps & Taylor, 1981) and despite the overlap in properties between a so-called 'hard' over-consolidated clay and a 'weak' mudstone there is clearly a real difference between the two.

This can be seen in the mudstone and clay inter-bedding of many members of this Unit. The mudstone and the clay can exist under the same stress conditions, be of similar age, and have been deposited in similar environments and yet behave differently; one as a 'rock' and the other as a 'soil'. The controlling factor is clearly induration or cementation. Weathering of the over-consolidated clays destroys the effects of the over-consolidation and they become softer and less brittle, with the behaviour of a normally consolidated clay. Weathering of the mudstone causes mechanical breakdown and destruction of cementation bonding, producing drastic reductions in shear strength and deformation modulus (Bjerrum, 1967). Fissuring and the effects of water are two important factors in weathering of clays and mudstones and in their engineering behaviour. The clays are particularly susceptible to stress relief fissuring near surface (Skempton, 1970; Chandler & Skempton, 1974). Comparison of laboratory samples with down-hole tests has shown that in the case of the Oxford Clay most of the fissuring seen in the core is produced directly by stress relief on extraction (Horseman et al, 1980; Cripps & Taylor, 1981).

Two results of destressing and addition of water, of importance to engineering, are slaking and swelling. Both mudstones and over-consolidated clays may swell as a result of stress relief and disruption of the electro-osmotic forces present between particles of clay mineral; in particular the smectite (montmorillonite) and 'mixed-layer' groups (Barton, 1972). The 'active' clay minerals may be detected in the index properties of the clay and a guide to the swelling potential is given by the Plasticity Index. Of all the members of the C, M, L Unit the most potentially swelling is the Upper Fuller's Earth, but the Lower Fuller's Earth, Lower Lias Clay and Oxford Clay are all potentially swelling clays. The swelling behaviour of Oxford Clay is described in detail in Hobbs et al, (1982). Swelling becomes important where engineering works induce a change in the water regime either by successive drying and wetting (e.g. in an excavation open for a considerable time) or by changing the hydraulic gradient (e.g. by boring a tunnel). Clays which are confined and prevented from swelling may develop very large swelling pressures causing damage to foundations, tunnel lining, etc.

Shrinkage is a problem which produces deformation of foundations. Those clays with a high swelling potential are also likely to have a high shrinkage potential.

Heave in clays and mudstones may also be caused by the oxidation of pyrite. The pyrite content need only be small to cause considerable heave (c.0.5% Taylor & Spears, 1981).

An important factor in the analysis of foundations on clays is the strength profile: strength plotted against depth shows that over-consolidated and normally consolidated clays undergo an increase in strength with depth, but the increase is more rapid for the over-consolidated clay. Cripps & Taylor (1981) give the following rates of increase of undrained shear strength (Su) with depth (all are from data outside the study area):

Oxford Clay	28 - 30 kPa/m
Lias Clay	37 kPa/m
Mercia Mudstone (Keuper Marl)	37.5 kPa/m

The figure for Lias Clay may be compared with the profiles in Figure 12 where a somewhat smaller gain in strength with depth is seen. Increases in shear strength are recorded to depths of between 5 and 10 metres in Fuller's Earth Clay and Oxford Clay in the study area. The drop in shear strength near the surface is due to weathering and to stress relief, and the associated increase in water content. Effective cohesion and friction angle are progressively reduced to the so-called "fully-softened" condition (Skempton, 1970). Slipping may further reduce this to a 'residual' value as a result of preferential alignment of clay particles. The strength and deformational characteristics of clays are also affected by disturbance. The Mercia Mudstone (Keuper Marl) is particulary 'sensitive' to disturbance. The Lower Lias clays in the Bath area are reported as exhibiting considerable microfolding and disturbance at depth. This feature may locally be associated with faulting but is more commonly the result of valley bulging and cambering (Horswill & Horton, 1976; Vaughan, 1976). Disturbance resulting in localised softening may adversely affect deep excavations and tunnels in the Bath area.

Most members of Units C, M and C, M, L (see Map 8) feature interbedding (or rhythmic bedding), involving clay and mudstone in the case of Unit C, M and clay, mudstone and limestone in the case of Unit C, M, L. These components or elements are present in varying proportions but all present a similar problem in foundation analysis. Most conventional foundation analyses assume a homogeneous medium.

Poulos & Davis (1974) describe an elasto-plastic 'two-layer' analysis in which the two layers possess contrasting deformation moduli (E). Stress beneath a foundation tends to be concentrated in the layer of highest modulus. So, in the case of a thin mudstone overlying a clay, the stress will be concentrated in the mudstone (i.e. the bearing pressure contours will not penetrate as deeply as for a homogeneous mudstone or clay). Conversely, if a thin layer of clay overlies mudstone then the stress will be concentrated in the mudstone (i.e. the pressure bulb will penetrate more deeply). This is a highly simplified concept, of course. However, if one introduces a third thin layer (i.e. limestone) with, again a different deformation modulus, the picture becomes very complex: particularly if one considers the jointing within the limestone, and the deformations consequent upon a 'punching through' action into softer material beneath.

As a general guide, the proportions of the three components will, in part, determine the foundation behaviour (see Map 8, Key A). For example, a sub-unit with thick bands of limestone and thin bands of clay (e.g. Blue Lias) will probably have a better bearing capacity than a sub-unit having the reverse (e.g. Fuller's Earth). This will, however, depend on the foundation type and the local rock conditions.

Localised weathering and consequent softening may occur in clays or mudstones adjacent to limestone bands (Privett, 1980). Solution of limestone by lateral ground water movement in the limestone may also result in disturbance of an overlying or underlying clay bed. Particular problems can be expected where soft limestones and highly pyritized clays are interbedded. In this case both heave of the clay and chemical attack of the limestone may take place. In some cases the chemical reaction between sulphides and carbonates produces carbon dioxide; this may be a problem in unvented excavations and tunnels.

Choice of excavation and tunnelling methods will be influenced by the relative proportions and frequency of the C, M and L components. Depending on the rise and orientation of the excavation, rapid changes in hardness will be experienced. Combinations of methods will be required in many cases. Deflection of tunnelling machines by limestone bands may be experienced. Also the cutting face may be half in hard limestone and half in soft clay, presenting problems of uneven wear and instability.

Small scale 'cambering' may be experienced in large excavations open for long periods, where the limestone bands are strongly jointed.

Note should be taken of the possibility of methane gas build-up within unvented deep excavations and tunnels in the vicinity of Coal Measures strata. Methane may dissolve in ground water and be carried some distance through porous media.

6.3 Geotechnical Properties of Superficial Deposits

6.3.1 Introduction

Thematic Maps 9a-d consist of the four 1:10 000 scale maps ST 76 NE, SE, SW and NW which cover the Bath city, Batheaston and Swainswick areas. The decision not to present one map at the 1:25 000 scale covering this area was based on the acute shortage of site investigation data in the other largely rural districts.

The maps show superficial 'Units' of geotechnical significance, and depths to bedrock where known. The 'Units' consist of the superficial deposit category with the underlying bedrock in the form of annotation. The major superficial categories, which are distinguished by ornament, are: Head (♿), Alluvial Deposits (~), Landslip (LS) and Fill (F). Thus a 'Unit' will be made up of one or more superficial categories and a bedrock lithology e.g. Unit "LS/FE" signifies slip overlying Fuller's Earth.

A summary of the geotechnical properties and engineering behaviour are then given in the key. Areas where data is too sparse to justify allocation of a Unit, are clearly indicated on the map.

6.3.2 Geotechnical Units

Landslip

Landslipping for the whole area is described in detail in section 5.1.3 and indicated on thematic Map 10. Landslips cover a large proportion of the area included in Maps 9(a-d). These slips mostly have Fuller's Earth as their active component, with the exception of some slips on the western side which are in Lower Lias Clay. Slips are usually of a shallow translational/flow type, but some deep rotational slips are recorded. Map ST76SW (9c) shows the fewest landslips of the four. The landslipped mass may be highly variable in composition and may contain material from several horizons intimately intermixed. Alternatively, the slip mass may consist entirely of one lithology in a totally or partially disrupted state. Large blocks of competent material, such as limestone or mudstone, may retain their integrity within a matrix of totally disturbed material.

Landslips are invariably underlain by a shear plane or a shear zone containing several shear planes. These are usually at their residual (minimum) strength due to large scale strain, and are bounded by softened material, often of clayey nature, with an elevated moisture content. Many instances of re-activation of ancient slip planes are recorded in engineering practice.

It is difficult to predict the engineering behaviour of slip masses other than to say that they are problematic and should be avoided for all but the most minor of structures. Excavation in, or placement of fill on landslips can upset the equilibrium of the slip mass and trigger renewed slip activity of either part or whole of the slip. Underlying bedrock may be disturbed or partially involved in the slip. Adequate drainage is essential both on and close to slip masses to prevent re-activation. The landslip itself upsets the local hydrological regime. Shallow landslips may receive special piled foundations or may be bridged, but the most widely used methods are those of large-scale drainage, stabilisation with surcharge at the toe, removal of part of the slip mass, retaining structures, or vegetation stabilisation. Drainage, vegetation and retaining structures have been used with partial success on the A36, A363 and A46. Remedial measures to stabilise landslips date back to William Smith, who drained Fuller's Earth slopes during construction of the Somersetshire Coal Canal (Philips, 1844). If engineering works are planned for an area of suspected landslipping it is imperative that the site investigation should adequately define the nature and extent of the landslip. A stability analysis should also be carried out.

Geotechnical properties of slip material are not quoted here but are contained in the main data file. They do not differ significantly from those of the parent material (Gibbs, 1983). Care must, however, be taken in the selection of shear strength parameters for design purposes. Test method is a crucial factor in determining 'residual' values (Lupini et al, 1974) for stability analysis.

Head

Head deposits are derived from bedrock by the action of periglacial freeze-thaw processes and have subsequently been modified by solifluction and multiple sliding. Head deposits are characterised by numerous slip surfaces which are the relic features of periglacial mass movements. Head is a prime source material for shallow landslipping and the two categories 'Head' and 'Landslip' may be easily confused.

Head is very extensive in the area (particularly to the North of Bath) and may be up to 6m in depth. It contains a wide variety of material in different proportions, including the lithology of the source material and the lithologies of bedrock subsequently traversed by the Head during its downslope movement. For example, the Head overlying the Fuller's Earth is dominantly a silty clay with occasional gravel cobbles and boulders of limestone originating from the

Great Oolite as well as the Fuller's Earth Rock. The structure of the Head is generally random, but more than one layer with its own shear plane may be found within the deposit (Chandler, 1970; Conway, 1979). Rock fragments (or clasts) tend to be angular rather than rounded.

Head overlying Midford Sands consists of Inferior Oolite rubble in a matrix of disturbed fine sandy silt. Towards the lower part of the slopes and often on Lower Lias Clay bedrock, a thin hillwash-type of Head is found, possibly without discrete shear planes (Privett, 1980). A so-called "Solifluction Gravel" has also been identified (Gibbs, 1983) at the bottom of valley slopes. Construction on Head is problematic due more to the presence of relic shear surfaces than to the content of the Head. Where removal of Head is not possible, site investigation should include techniques capable of identifying instability. Removal of Head may, in itself, re-activate slope movement. Thickness of Head can vary rapidly; thus hollows in the original ground surface can be filled to considerable depth locally. Head tends to be thicker on shallower slopes. Where Head overlies cambered bedrock (e.g. Inferior Oolite or Blue Lias) the Head may infill open gulls or solution cavities and be in a loose state (Hawkins & Privett, 1981).

The geotechnical properties of Head have been found to vary considerably, depending on the parent material. Plasticity values tend to be lower than those of the parent material with perhaps the exception of Head derived from the Midford Sands. There are insufficient data to draw any conclusions about the undrained shear strength of the Head in view of the variability of the deposits and the fact that laboratory samples may not be representative. Seasonal variations in undrained strength are to be expected within one or two metres of the ground surface. Residual strength parameters of $\phi'r = 30^\circ$ & $C'r = 0$ have been used for Head deposits with clay fraction $< 15\%$ (Gibbs, 1983). These values for residual strength may need to be reduced where 'commercial' fuller's earth is present. Plasticity and undrained shear strength data are shown in Figures 19 & 20.

S.P.T. values for Head range from N = 10 to 51 with a mean of 24 (n = 29).

Bearing in mind the variability and potential engineering problems presented by Head material, it is recommended that site investigations make maximum use of trial pits and trial trenches. These will enable direct examination of shear surfaces to be made and undisturbed samples to be taken.

Alluvial Deposits

The alluvial deposits in the area fall into two groups; namely Alluvium and Terrace Gravels.

a) Terrace Gravels

The Gravels occur in beds up to 3m in thickness directly overlying benches cut in the Lias Clay or underlying the clays and peats in valley floors. Borehole records from a number of localities reveal the presence of a buried channel close to the present course of the Avon, the lower part of which is filled with gravel.

Particle size data for the Terrace Gravels show it to be slightly sandy gravel with occasional gravelly sand and lenses of sand only.

Geotechnical data is limited in the case of the Terrace Gravels. S.P.T. values range from N = 8 to 42 with a few values exceeding 100.

b) Alluvium (clays and peats).

The clays, organic clays and peats of the Alluvium are lightly over-consolidated and have a desiccated crust near the surface. Geotechnical data for the clayey Alluvium are as follows: S.P.T. range is N = 2 to 74 with a mean of approximately 20 (n = 67). Chemical determinations show pH values in the range of 6.9 to 8.3 with a mean of 7.5; and total sulphate content in the range of 0.001% to 0.150%, (i.e. Class 1, CP 2004). The clayey Alluvium normally has an intermediate or high plasticity. Plasticity and undrained shear strength data are shown in Figures 20 and 21.

The selection of shear strength and compressibility parameters must be determined from local conditions. The presence of peat in the form of impersistent lenses or thin laminations may lead to high compressibilities locally. Peat does not seem to be present in sufficient quantity to influence the pH test values.

The depth of the alluvial deposits is typically in the range of 3 to 6 metres but depths of up to 15 metres are recorded in the Bath city area. Insufficient sub-surface data are available to map the different lithologies of the alluvium.

Fill

The term 'fill' covers a wide range of materials which may be either re-arranged natural deposits or synthetic matter derived from man's activities. These include: refuse tips, quarry fill, building rubble, mining spoil, etc. The age of the fill ranges from pre-Roman to modern and must include the several 'plague-pits' in Bath city.

Geotechnical data for Fill are usually supplied by site investigations. It has, however, proved impossible to make a generalised assessment of the deposit due to its almost infinite variety. Compacted quarry or building waste may provide satisfactory shallow foundations, whereas domestic or industrial refuse may not support load and, furthermore, may act as a source of combustible or poisonous gases. Methane may be produced within colliery tips. Thematic Map 3 shows the distribution of registered landfill sites, whilst Maps 9(a-d) show, in addition, those areas of unregistered Fill where known.

7. MINED AREAS AND LOCATION OF SHAFTS

7.1 Mined Areas

7.1.1 Introduction

The occurrence of underground workings has possible implications for surface developments, in that subsidence effects resulting from the removal of material at depth could produce ground instability at the surface. Thus a knowledge of the location, extent and overburden thickness of the mines, together with an appraisal of likely subsidence effects, is of some importance in the planning of future developments. It should be recognised, nevertheless, that rigorous site investigation will normally ensure the recognition of any surface subsidence, and that modern methods of construction can overcome its effects.

The underground cavities left after the extraction of Bath Stone also have a potential utility for storage and other adaptations. Consequently, some assessment of their stability and groundwater regime is of value.

The location and extent of mined ground within the study area is shown on Map 13, in three categories according to the mineral which was exploited. The following account therefore describes mining activities under the same heads.

7.1.2 Coal Mines

The working of coal probably dates back to Roman times but was sporadic and small-scale until the mid-1600's. The earliest workings were mainly shallow excavations at outcrop, which later gave way to shallow pits and levels exploiting coal at depth.

In the 1700's, improved machinery enabled deeper mining to be undertaken, and an increasing shortage of wood for fuel gave an impetus to the demand for coal. Thus mines proliferated, reaching a peak of activity during the first quarter of the twentieth century. Thereafter, there was a steady decline in the number of working collieries and the output of coal as it became increasingly uneconomic to work. Finally, the last surviving pit closed in 1973 and there is no likelihood of coal-mining ever being resumed.

There were two distinct areas of mining within the study area. The first was in the Pensford Basin north of the Farmborough Fault Belt, near Newton St Loe [c 708 653] and Twerton [c 715 645], where coal seams near the base of the Upper Coal Measures and in the Middle Coal Measures respectively were worked at depths of 60 m to 170 m below the surface. The second was in the Radstock

Basin south of the fault zone, where coals at higher levels in the Upper Coal Measures were mined at depths ranging from 60 m to 570 m below ground level (see also 6.1.4).

The earliest major workings were near Newton St Loe, which were active from about 1730 until closure in 1845. There are no extant mine plans, but a geological cross-section in the possession of the N.C.B., together with the locations of known abandoned mine shafts, indicate that underground workings extend eastwards from the Globe Pit at Newton St Loe to near Twerton. Their actual limits are not known. The mines exploited coal seams within the dominantly sandstone succession of the Downend Formation (Upper Coal Measures), in beds dipping in the order of 15° to the west.

Later in the 1800's, coal was deep-mined near Twerton, just west of Bath. A plan of the workings at Twerton Colliery is available but its degree of accuracy and registration with surface topography is uncertain. It shows the pattern of headings in the Top Vein of the Middle Coal Measures, dating from 1867 to 1875, but not apparently the full extent of the workings. In Twerton No. 1 Shaft the Top Vein was encountered at about 110 m below the surface.

The most productive deep-mined area was in the Radstock Basin, between Dunkerton [700 585] and Radstock [710 550], where ten coal seams were exploited; five in the Radstock Formation and five in the Farrington Formation. The earliest workings were in the former which are at a lesser depth; but at a later date the shafts were deepened to intersect coals in the Farrington Formation. Coal seams were worked at depths ranging from c 60 m to c 570 m below the surface.

The following collieries were operative within the study area between the specified dates: Dunkerton (1906-1927) [698 585], Lower Writhlington (1829-1973) [705 553], Woodborough (early 1800's) [703 555], Shoscombe (1828-1860) [709 555], Braysdown (1840-1959) [704 560] and Foxcote (1853-1931) [711 552].

Coal was mined mostly by longwall methods, in which all workable coal was extracted along a single working face supported by props. Locally, the pillar and stall method was adopted but only on a limited scale.

A comprehensive archive of abandoned coal mine data for the Radstock-Dunkerton area is held by the N.C.B. It includes abandonment plans for each mined coal seam at scales of 1:2500 and 1:10560, and also geological sections and other miscellaneous information. Selected information of the same type is housed in B.G.S. files, which now includes photocopies of the N.C.B. 1:10560 abandonment plans.

7.1.3 Fuller's Earth Mines

Like coal, fuller's earth has probably been worked in the Bath area since Roman times. For most of this period the mineral bed was exploited on a relatively small scale at outcrop only. This occurred at or near such places as Wellow, Dunkerton, Duncorn Hill, Englishcombe, Southstoke, Odd Down, Monkton Combe, Lyncombe and Widcombe (Woodward, 1894). The location of several of these old workings is now uncertain.

More recently, the Fuller's Earth Bed has been extensively worked away from the outcrop by driving adits into hillsides at the level of the bed. The largest of these underground workings was at Combe Hay [c729 612], where production was mainly concentrated. However, mines just north-west of Midford [c755 614] were also of some importance at one time.

At Combe Hay, the mineral was worked 18-25 m below the surface. The main haulage adits were supported by steel arches which were strengthened with concrete where the adits passed beneath roads. From these, subsidiary roadways supported by timbers served the working faces. A 23 m-wide strip was left unworked on either side of the Bath-Radstock road (A367) as a safety precaution. The fuller's earth was worked largely by the pillar and stall method but, in the last few years before closure in 1980, a shortwall retreat method was employed which enabled a greater proportion of mineral to be extracted. A detailed abandonment plan of the Combe Hay Mine at a scale of 1:2500 is contained in the project archive and gives a reliable indication of the extent of underground workings and of the location of shafts and adits, all of which have been sealed.

At Midford the fuller's earth was mined up to c 15 m below the surface. Neither an abandonment plan nor any other plan showing the limits of the workings has been traced. Thus the extent of worked out mineral here remains speculative. However, it may be possible to determine the approximate limits by an inspection of the ground surface, because fuller's earth mining is usually accompanied by some surface subsidence. It is thought that mining ceased at Midford soon after the Second World War (Powell, 1978).

Collapse of mine workings invariably followed after they were worked out and, unlike the Bath Stone mines, they offer no scope for underground development.

7.1.4 Bath Stone Mines

Bath Stone was probably first worked for local use in Roman times, and intermittently thereafter until the early 1700's. With the completion of the

River Avon navigation in 1725, greater ease of transport and the accessibility of new markets promoted a great expansion of stone quarrying. It was at this time that exploitation of stone from underground workings first became significant, mainly in the Combe Down area of Bath [c760 625]. The opening of the Kennet and Avon canal in 1810 further enhanced the output of Bath Stone.

The next major stimulus to stone mining came when the Box railway tunnel was completed in 1841. The tunnel penetrated substantial reserves of good quality stone in the Box Hill-Corsham area [c845 693]. Thus, from a second tunnel dug parallel to the original one, an elaborate system of mine galleries gradually developed, served by a network of mineral lines which fed into the main line at Corsham. Ultimately, the complex of workings constituted one of the largest stone mines in the world with, it is said, over 60 miles of mine galleries. Other mines in the Neston-Gastard area [c875 680] were connected to the railway at Corsham by surface tramways.

Large scale mining of stone at Combe Down probably came to an end by 1880, but continued elsewhere until the Second World War, after which fall in demand, lack of skilled labour and the cost of mechanisation reduced the number of working mines considerably. Today, only three are in production, namely Monk's Park [879 683] and Westwood [808 579] (Bath and Portland Group), and Hayes Wood [775 608] (The Bath Stone Co. Ltd.).

Access to earlier mines was generally by level or gently sloping adits from hillsides or existing open quarries. At a later date, when freestones were worked some distance from valley slopes and below a substantial overburden, sloping shafts were cut from the surface to the freestone level. The adits and slope shafts served both for access and the haulage of mined freestone. In addition, vertical mine shafts were sunk locally as a means of bringing stone to the surface. Other shafts were dug to provide ventilation and/or light for the workings.

Bath Stone has always been mined by the pillar and stall method, in which sub-parallel rooms were excavated and inter-connected, leaving residual pillars of unmined stone to support the roof. In some mines the pillars were cut with sides sloping inwards towards towards the base; this allowed blocks of greater size to be excavated from the lower part of the working face.

Abandoned freestone mines, particularly those at shallow depth or beneath valley slopes, may locally be susceptible to some degree of instability and might possibly affect existing or proposed surface developments. Thus they need to be carefully assessed when future new constructions are planned. This situation is especially applicable to the Combe Down/Odd Down districts of Bath where, in addition, unsuspected old mines may be present.

Some mines, on the other hand, represent an asset in that they have potential for underground development. Up to the present, certain mines which are stable and dry have been cleared of debris and adapted for various uses e.g. mushroom farming, storage of national treasures during the last war, secure accommodation for valuables, and for underground engineering works. Other possible uses might be recreation (caving), education (industrial archaeology), conservation of wildlife habitats (notably bats) and disposal of inert wastes.

It is thought that all the major mines in the study area have been identified, but it must be understood that there may be other, as yet undetected smaller mines, particularly in the vicinity of Bath where the earliest major workings were located. Elsewhere, the occurrence of air shafts suggests the presence of underground workings, although no other evidence of their existence has been obtained.

The limits of most of the mines are shown on 1:2500 plans held in the data archive. These are generally reductions from large survey plans at scales in the order of 1:500, and are thought to be reasonably accurate. They do not show the individual supporting pillars within the worked areas, for which information the original large scale plans should be consulted. These plans are held by the data sources. The indicated limits of older mines at Combe Down and Odd Down, Bath, are approximations only because there appear to be no accurately surveyed mine plans for them. It should be noted that a statutory requirement to lodge abandonment plans has only been in force since 1872. A number of very small workings are shown on Map 13 by a generalised symbol; as far as is known, there are no accurate mine surveys, although caving clubs have published generalised plans for some of them, with emphasis on accessible passages.

There may not always be true registration between mine plans and surface topography. The possibility of small survey errors at the foot of a mine shaft or slope, where mine surveys originated, should be borne in mind. Any errors made at the outset will have been compounded as mine workings extended.

There is no certainty that all mine adits and slope shafts have been identified from available sources, but those known to occur are shown on 1:2500 plans in the archive. Their National Grid references are tabulated in Appendix V. Brief details of the principal Bath Stone mines are given in Appendix VI.

7.2 Ground Instability related to Mining

Because of the small number of verifiable instances of ground instability which could be related to mining subsidence, it is unnecessary to produce a 1:25,000 map to illustrate this theme. However, the following remarks give an outline of subsidence processes and summarize the ground movements which are considered to have resulted from coal, fuller's earth and freestone mining within the study area.

7.2.1 Subsidence due to Mineral Extraction

When material is removed from below the ground surface the roof above the resulting void will collapse into the empty space which has been created, unless the void is sufficiently small in relation to the strength of the roof material for a stable roof span to be maintained. When collapse occurs, a void is formed above the original excavation which is itself then filled by further collapse. In this way the void migrates upwards.

If the workings are at shallow depth the progressive upward collapse may reach the surface to form a depression in the ground termed a 'crown hole' or 'post hole'. Where workings are at greater depth, the increased bulk of the disrupted rock which fills the void will in time be sufficient to compensate for the volume of material originally removed and to give some support to the overlying strata, thus preventing further collapse. The weight of the overlying strata will, however, cause the broken rock to be compressed and, if the initial excavation was over a sufficiently wide area in relation to its depth from the surface, sagging of the strata will reach the surface as a general lowering, which is called surface subsidence (Figure 22). The subsidence will be greatest over the centre of the workings and decrease outwards, reaching zero at a point some way beyond the vertical projection of the edge of the worked out area. The distance is dependent upon the lithology, structure and thickness of the overburden. In British coal fields, for workings in a level seam, this limit has been found to be described approximately by a line drawn outwards at an angle of 35° to the vertical projection of the edge of the extracted zone. The maximum amount of lowering will never be equal to the thickness of extracted mineral due to the bulking effect of the collapsed strata; and the lowering will decrease as the depth of the mineral seam below ground surface increases and as a greater volume of strata is affected.

Subsidence will start to affect a point on the surface as soon as material is extracted from below and the roof is allowed to collapse, if the point falls within the zone of influence defined by the 35° limit angle. The subsidence will continue while material is being extracted but will stop almost completely as soon as the working ceases, or the point falls outside of the zone of influence of the extraction operations. However, residual subsidence of approximately 5% of the total may continue for a number of weeks, depending upon the depth below surface of the extraction zone and the presence or absence of old workings, the collapse of which may be reactivated (Shadbolt 1977).

The prediction and calculation of subsidence due to mineral extraction has been brought to its current state of knowledge as a result of the efforts of Continental and British mining engineers, based on their observations of the effects of coal extraction. The current state of the art in the United Kingdom is described in 'The Subsidence Engineers Handbook' published by the National Coal Board. Although current subsidence engineering practice is largely based on the effects of coal mining, the principles will, in general, apply to the underground extraction of other minerals. Variations between actual and predicted subsidence behaviour are likely to be the result of differences between the lithology of the overburden and that of the Coal Measures.

The prediction of subsidence behaviour assumes the collapse of the roof into the void left by the extracted mineral. In practice two methods of mining have been used, namely pillar and stall (also called room and pillar) and long or short wall total extraction. The two methods produce different types of collapse and, consequently, the subsidence which they cause.

In the case of pillar and stall mining, pillars of mineral are left in place to support the roof. The amount of mineral extracted may vary between 50% and 90% depending upon the strength of the mineral and the strength and integrity of the roof. The calculation of the subsidence behaviour of this type of working is not easily achieved using established formulae because the collapse of the workings is complicated by the behaviour of the pillars. These may not fail or crush for many years but, when they do, they are likely to fail as isolated instances or groups rather than as a uniform collapse. More often the roof collapses into the rooms around the pillars, also in an unpredictable sequence.

With long or short wall total extraction mining, an area of mineral is removed in its entirety by means of a working face which moves through the mineral seam. The roof is supported only in the immediate vicinity of the working face, the unsupported area behind it being allowed to collapse into the void. Some stowage of waste material in the void may be employed to minimise subsidence and to dispose of waste rock. Long/short wall mining is the current modern coal mining practice in Europe and it is upon experience of this method that subsidence prediction is based.

In the study area three minerals have been extracted by underground mining i.e. coal, fuller's earth and Bath Stone.

7.2.2. Ground Movements due to Coal Mining

The coal seams in the Somerset Coalfield are thin, steeply dipping and much faulted. Consequently, local techniques of working were developed from very early times which were generally similar to the longwall or shortwall total extraction method. Where pillar and stall methods had to be used the pillars were usually removed before abandonment, allowing the collapse of the roof to take place. It is reasonable to assume that subsidence resulting from long wall or short wall mining would have started when mining commenced, and stopped completely within two years of abandonment. In the few cases of pillar and stall mining, subsidence would have taken place at the time of pillar removal and be finished completely two years after that date. In all cases the amount of subsidence will have depended on the number of seams worked, their total thickness and their depth below the surface.

There are two areas of coal mining within the study area, separated by the E-W Farmborough Fault. North of the fault, mining took place around Newton St Loe [c708 653] up to 1845 and also at Twerton [c715 645], which was abandoned by the end of the nineteenth century. No evidence was found to indicate that shallow pillar and stall workings exist in this area and it is reasonable to assume that subsidence due to coal mining is likely to have finished many years ago.

South of the Farmborough Fault, in the south west corner of the study area, coal was worked in various mines from the end of the eighteenth century to the abandonment of Lower Writhington Colliery in 1973. The workings in these mines were much deeper than those at Newton St Loe and Twerton, extending from 60 m to 570 m below ground surface. Subsidence at the surface would therefore have been less for a given seam thickness. Total extraction was the common practice from the time of the earliest workings, and thus all subsidence effects would have been completed over 50 years ago, except for the most recently abandoned pits at Braysdown (1959) and Lower Writhington (1973). The modern practice of longwall caving was used at these two pits prior to closure and thus all subsidence effects should have been completed by two years after abandonment.

In view of the methods of working in the Somerset Coalfield and the long abandonment of most mines within the study area it is concluded that mining subsidence due to coal extraction is no longer likely to be active. Also that there is only a small chance of there being unknown shallow pillar and stall workings dating from very early times (pre 1800), which could cause ground instability in the future.

7.2.3 Ground Instability due to Fuller's Earth Mining

Very little information was found in published sources describing the manner in which fuller's earth was mined in the Bath area. An abandonment mine plan of the Combe Hay Mine [c729 612] shows that the most recent working there was by a shortwall retreat caving technique which appeared to have been used since at least 1974. The older workings were all exploited by a form of the pillar and stall method which, from the mine plan, appeared to be a series of cross cuts between gate roads driven at right angle to the main drivages. Initial extraction was at a ratio of 75% which left 15 m square pillars of unworked material to support the roof. When a section of mine was due to be abandoned the extraction ratio was increased by pillar robbing, the weakened pillars then collapsing within a few weeks (Avon CC.1975). The prime reference to the subsidence effects of fuller's earth mining is a single paragraph in the South West Regional Fuller's Earth Conference of 1952, which was paraphrased by Highley (1972) as follows:

'The nature of the underground working does however cause subsidence usually within 3 months, the land generally falling in a regular plane but remaining suitable for agricultural purposes providing the surface of the affected area is suitably treated. After initial subsidence there is a risk of further subsidence usually for a period of 5 to 7 years, owing to the collapse of the underground supports in former workings. Reinstatement of the surface is undertaken by the mineral operator. Extraction of fuller's earth therefore has very little practical effect on agricultural production, either here or elsewhere. In order to enable the land to consolidate for the purpose of surface building it should be left for a further period of about 12 years after the secondary subsidence'.

It may be possible to reduce the 22 years delay between mining and development in areas undermined by fuller's earth extraction by using improved building techniques, such as the C.L.A.S.P.* system and the flexible service connections now used in areas subjected to coal mining subsidence. Development would, however, have to be viewed in the light of the possible presence of old

*Consortium of Local Authorities Special Programme.

pillar and stall workings at relatively shallow depth whose potential for collapse would be unknown. In such circumstances any increase in ground water flow due to the installation of stormwater soakaways, increased loading by building, or vibration due to road traffic could initiate roof falls or pillar collapse, resulting in surface subsidence.

7.2.4 Ground Instability due to the Mining of Bath Stone.

The extraction of Bath Stone by mining has been carried out on a large scale within the study area for some 250 years, and extensive areas have been mined. However, surprisingly few references to ground instability due to stone mining were found in published sources. Possibly a search of newspaper or other records would reveal more examples. Ground collapse in the form of post or crown hole formation has occasionally taken place, sometimes unexpectedly, and is therefore an occurrence which should be foreseen as a possibility where unstable mines are at shallow depth.

Factors which Govern Roof Collapse

The potential for the roof of a room in a limestone mine to collapse is governed by a number of factors, many of which are inter-dependent. Among these factors are:

1. The spacing, dilation and infill of joints
2. Pillar spacing and room size
3. Overburden stress
4. Use and condition of mining supports
5. Roof bed thickness
6. Hydrogeological regime of the mine

The frequency and nature of the jointing in a mine will have controlled, to some extent, the way in which the mine was developed and the stone exploited. Where possible, natural joints would have been used to assist in the removal of stone. The spacing of pillars would be such as to avoid leaving joint bounded blocks unsupported in the roof bed which would otherwise have been likely to drop out. Thus, widely spaced joints enabled large roof spans and wide pillar spacings to be used, with the creation of large rooms. Wide pillar spacing could also be employed where joints were tightly closed, for roof blocks were effectively held in lateral compression or 'in pinch'. If joints were closely spaced and dilated, the mining of stone became less viable because closer pillar spacing was necessary to support the fractured roof, and the dimensions of extracted blocks decreased.

Where small areas of close-spaced and/or dilated joints were encountered, more frequent use of timber, stone and sometimes steel supports was necessary to support the roof until better ground was encountered. Where open joints in the roof were a problem, oak or elm wedges were driven in to maintain the roof 'in a state of pinch'. The thicker the roof bed the greater was the possibility of joint blocks interlocking to form stable arches. Where roof beds were thin, separation on the upper bedding plane resulted in slabbing from the roof even where joints were widely spaced.

The hydrogeological regime has an important bearing on the stability of old mine workings and acts in a number of ways. In damp humid conditions wooden props and wedges used to support unstable roof blocks will in time rot; the rate of rotting will depend upon humidity, temperature, the composition of the mine air and the type of timber used. Iron or steel will be similarly affected by rust but will take longer to lose its strength totally. Stone is less likely to be affected but frost shattering may occur near the entrances to mines in very hard winters.

When water percolates down through the overburden and enters the mine through the roof, it may remove material filling dilated joints and gulls, causing the roof to become unstable and to collapse. In time, solution of the limestone itself may result in a similar failure but, in the human timescale, this is unlikely to be a major problem. The presence of water will, however, act as a lubricant between roof blocks, thereby assisting collapse.

The problem of mine collapse in room and pillar workings is complex and its magnitude or time of occurrence cannot be predicted with any certainty because of the large number of factors involved. The wide range of possible mine conditions was demonstrated in the few mines visited, and it was also apparent that conditions can vary considerably within the workings of a single mine. Ideally each mine requires a thorough examination to provide an accurate assessment of its stability state. Nevertheless, it is possible to make some general observations about the stability of mines in the area as a whole.

Where mining has been undertaken close to the outcrop there is a great potential for joint-bounded block failure aided by the virtually unimpeded entry of ground water. This is because the Great Oolite is commonly cambered on valley slopes and is affected by much minor faulting and jointing which may have undergone considerable dilation to produce gulls. The overburden may also be very thin, as little as 3 metres. Once a failure has taken place, progressive upward collapse will almost certainly take place, ultimately reaching the surface.

Where mining has moved further into the hillside the strata are much less likely to have suffered from cambering. Joints are more widely spaced and are tightly closed, and the overburden is much thicker and likely to be, in part, of impermeable Forest Marble clay which seals the roof from the adverse effects of water. If roof failure does occur, there is much more likelihood of a stable natural arch being formed before the void migrates to the surface. In practice there is a continuous range of conditions between the two extremes and a single mine may pass from the former to the latter condition as it extends deeper into the hillside. Westwood mine shows this transition very clearly.

The general assessment of mine stability was achieved by visiting 12 mines in the area, which included the two working mines at Monk's Park [879 683] and Westwood [808 597], and the following abandoned mines: Lodge Hill [769 634], Wallington [779 608], Mount Pleasant [768 633], Murhill (Winsley) [794 607], Pickwick [855 708], Kingham [765 622] and also several small un-named mines. The mines were chosen to give as wide a representation of mine conditions as possible, commensurate with safety and the time available.

Three modes of mine instability were observed, the most common being collapse of the roof into the rooms and galleries formed by the removal of the stone. Failures range in magnitude from individual block dropouts to total progressive upward collapses of the overlying strata to the surface. Much less common is pillar failure by compressive crushing; the only area in which this failure type has affected a large number of pillars is in the abandoned Westwood mine. Although the pillars had fractured in 1929 and show a classical failure mode of two conjugate shears with spalling of the pillar sides, total collapse had not subsequently taken place. In another mine in Bradford-on-Avon, movement along an inclined (cross bedded) bedding plane within a pillar was observed; some remedial and monitoring work had been carried out. An isolated case of the inflow of softened Forest Marble clay down an abandoned slope shaft into a mine was observed in the disused part of Westwood mine.

Roof collapse is considered to be the only type of failure which is likely to be important in Bath Stone mines. Some examples of groundsurface instability which are referred to in various reports are given in Table 7.1.

Table 7.1

Examples of Groundsurface Instability referred to in various reports

Combe Down	
Firs Mine[760 625]	'few total collapses of Galleries but many wedges robbed and in places roof precariously wedged' (Price, 1984).
Combe Down (=Byfield) Mine[757 624]	Subsidence in back garden of 8 North Road, during investigation a crown hole in the grounds of Fairfox House was seen. Further small subsidences expected (Mehew, 1976). Combe Road collapsed near the Jupiter Public House in the late 1970s during road works (Price, 1984). Infilled shaft collapsed at Rock Lane exposing the underside of a building at [7586 6234]. (P.Wooster, 1978.)
Lodge Hill (=Shaft) Mine[769 634]	Crown hole occurred adjacent to Shaft Road in 1984 and a similar hole was observed in an adjacent field.
Hampton Down [c777 651]	Mine roof dangerous when abandoned in 1845 the land above the mine being described as 'gruffy ground'. (Price, 1984).

7.3 Location of Shafts

The location of abandoned shafts is of importance in the planning of surface developments in areas which have been mined. It is thought that within the present study area most mine shafts have been identified from the various data sources. However, it is possible that others may exist, especially in areas where mines were abandoned before publication of the first Ordnance survey maps. Thus Map 12 should not be considered wholly definitive.

Of the 156 sites shown, 100 are indicated on one or other of the three editions of the 1:10560 'County' Series Ordnance Survey maps dating from the First Edition published between 1887 and 1891. It is assumed that the location of these is reasonably accurate. The positions of the remaining shafts are derived from other sources, mainly mine plans. It is estimated that there are errors of up to 30 m in the sites of a small number of these. Therefore, it should be emphasized that no shaft location can be assumed to be precisely accurate, and that its position should be positively confirmed by an appropriate method of detection.

There is some uncertainty as to the exact position of the abortive coal trial shaft sunk in the early 1800's at Batheaston (Richardson 1928, p.49). However, the position shown on Map 12 [c7814 6776] is thought to be a good approximation. There is documentary evidence to show that originally there were two trial shafts at this location, probably close together.

The status of the vast majority of shafts is unknown, although a few are undoubtedly still open at the surface and others are definitely known to be capped or backfilled. Of the latter, those associated with Combe Down Mine (=Byfield Mine) at Bath [757 624], and with the Box/Clift Mines at Box [c840 695], are said to have been backfilled (Price, 1984). Those at the abandoned fuller's earth mine at Combe Hay [c729 612] have all been capped or backfilled. It is important that in any proposed development the status of each known mine shaft should be determined by on-site inspection during the course of site investigations.

The National Grid references for the shafts shown on Map 12 are given in Appendix VII.

8. RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

The following are selected recommendations to achieve parity of coverage and to give fuller information within the study area.

8.1 Re-survey of areas shown as 'foundered strata'

Ground currently shown as 'foundered strata' within the study area (see section 2.5) has been re-surveyed in order to achieve parity of interpretation with other areas covered in this report (see Supplementary Report). There remain c12 sq.km of so-called 'foundered strata' outside the study area, mainly on National Grid sheets ST77SW and SE and adjoining the re-surveyed areas of sheets ST76NW and NE (Figure 23)

The unrevised ground is within 5-8km of the centre of Bath and is arbitrarily separated from the re-surveyed areas by National Grid northing 70. It would be unfortunate for local users of currently available geological maps, and indeed of this report, if the geology of the area in question continued to be represented by an outdated and unhelpful interpretation. Nor can it be satisfactory for ground having essentially the same characteristics to be depicted quite differently on either side of such an abitrary dividing line. Furthermore, the special problems that cambered and landslipped ground pose for surface development (see sections 5.1, 5.2) offer a persuasive argument for the limits of such disturbed ground to be satisfactorily defined.

Thus, we recommend that the remaining areas of 'foundered strata' be re-surveyed with the aim of distinguishing between landslipped ground, cambered strata and in-situ bedrock.

8.2 Location, limits and conditions of abandoned Bath Stone Mines and Shafts

The present study has shown that there are considerable differences in conditions and stability both between the several freestone mines within the study area and within the boundaries of individual workings. Thus it is recommended that, in order to fully appraise their potential for creating ground instability and their suitability for underground development, a further study be initiated with the following objectives.:

a) To amplify the existing catalogue of mines which contains their location, a plan of the workings, details of access, and an assessment of their stability, groundwater regime, extraction ratio and suitability for development.

Such a study might well incorporate additional data searches, including the consultation of solicitors, family archives, caving groups, industrial archaelogists, etc. The field work would require an engineering geologist or mining engineer to examine all known accessible mines in order to determine their stability and to assess their potential. Where suitable mine plans are not available, accurate surveys of mine limits would be necessary.

The rigorous examination of all known mines, as described above, represents an ideal approach to the problem of abandoned mine workings in the Bath area. However, it is recognised that an initial pilot study may be desirable, which could be extended to the rest of the area if required. The pilot study would look at a small number of mines of medium size, say one in each of the main mining areas at Bradford-on-Avon, Neston-Garstard, Box Hill, Westwood and Bath. The mines would be visited and a detailed description of their structural discontinuities, groundwater regime, extraction ratio and overall stability made. Hopefully, the factors found to control the stability of these mines will enable an approximate assessment of the stability of other mines in their immediate vicinity to be made.

b) To determine which geophysical method or combination of methods will provide information as to the existence and extent of underground cavities (including mine shafts) where abandoned mines are known or suspected, and for which there are no mine plans or there is no known access. This could be accomplished initially by a pilot study at a known mine for which there is good access and a detailed mine plan.

To detect a cavity by geophysical method requires that there is a good contrast in properties between the cavity and the surrounding medium, and that the effect of the cavity is sufficient to be detected above the background noise of the method. At Bath, many mines are at shallow depth and are substantially air filled; there is therefore reason to believe that geophysical methods would be successful in many cases.

A helpful guide to geophysical methods is contained in B.G.S. Engineering Geology Unit Report No. 82/5 "The Use of Geophysical Methods in the detection of Natural Cavities, Mineshafts, and Anomalous Underground Conditions".

c) To monitor selected mines below crucial surface developments, where mine infilling is considered inappropriate or too costly. The methods used will determine the frequency of roof falls and pillar collapse, and give an early warning if activity becomes dangerously high.

Visual inspection does not give a reliable record of changes. Periodic photography from fixed points is possible but sight lines are normally restricted. The use of catch nets, as currently in use at Castle Fields Mine in the West Midlands, has proved very successful; it has shown activity to be greater than expected and has identified areas within the mine where rock falls are particularly frequent. Also under development in the West Midlands is a microseismic or acoustic emission network for the detection of rock falls on a continuous monitoring basis. This system is intended for use in mines where access is not possible.

8.3 Determination of landslip distribution and thickness by geophysical methods

Although the overall extent of landslipping within the study area is broadly recognised, the numerous constituent landslips largely coalesce to produce a potentially unstable complex of flows, slides and rotational masses. Thus individual landslips can rarely be mapped separately, particularly as degradation and agricultural land use have subdued the original surface morphology. In many localities the landslipped ground can be outlined only approximately by conventional mapping techniques, and little idea of the character and depth of unstable material, or the style of movement can be obtained. Again, because of degradation, the distinction between landslipped material and soliflucted Head deposits often cannot easily be made from surface indications. Locally, it is difficult to clearly distinguish between areas of cambered limestone beds and bodies of slipped material carrying rafts of limestone.

Consequently, a reliable, rapid and inexpensive method of determining the limits of landslipped ground and Head deposits, and particularly of estimating the thickness of mobilised deposits would be invaluable.

Rotary or percussive borehole drilling is a standard method of investigation but is expensive and time-consuming. Samples obtained by this method are commonly of insufficient quality to show subtle features such as shear planes, and the information retrieved is from discrete points in a highly variable medium.

Trial pitting is a much quicker method and provides greater information at lower cost. Again, however, it is relatively discontinuous and causes greater disturbance of the ground surface. Pitting is only effective to depths of 5-6m and cannot therefore be wholly satisfactory for areas mantled by thicker spreads of superficial deposits.

Geophysical methods offer relatively good continuity of information with minimal disturbance of the ground surface. However, surveys must be carried out by experienced operators with sufficient geological background and borehole or trial pit control to establish a meaningful interpretation. Previous work in the Bath area (Hobbs 1980) indicates that geophysical methods show some promise of defining landslipped areas and of distinguishing basic lithological variations in disturbed ground, which were not otherwise apparent.

It is therefore recommended that a study be considered to evaluate the effectiveness of geophysical methods of examining the nature and extent of superficial material in an area where previous detailed site investigations have been carried out, and where there is high quality borehole, trial pit and geotechnical control. The valley slope in the vicinity of Swainswick would provide an ideal location for such a study. The aim would be to identify a geophysical method or combination of methods which could be applied to other valley slopes in the Bath area where the same stratigraphical sequence is present, but for which there is limited site investigation data. The application of such methods would enable future site investigations to be planned more effectively and economically. Their use in a number of key localities might also enable a more satisfactory map of superficial deposits to be produced.

8.4 Amplification of the Geotechnical Data Base

There is an imbalance in the distribution of geotechnical data in the study area in terms of both areal distribution and geotechnical sub-units. The great majority of the data are concentrated in and around the City of Bath and deal particularly with the Lower Lias and Fuller's Earth clay formations. Also, most of the data relate to samples recovered from depths of less than 10 metres.

Some major geotechnical sub-units, for example Oxford Clay and Mercia Mudstone, are very poorly represented in the data base; others, such as the Frome Clay, are not represented at all. The geotechnical properties of the hard rock formations, particularly the limestones, are very poorly represented. The superficial deposits are well covered so far as the number of data are concerned but, in site investigation reports, there commonly exists confusion between Landslip, Head and Alluvial deposits.

In order to redress the imbalance of geotechnical data it is recommended that a limited number of high quality, moderately deep, cored boreholes be drilled at selected sites in the outcrops of the Oxford Clay, Kellaways Clay, Mercia Mudstone and Midford Sands. The drilling programme should be accompanied by a wide-ranging geotechnical test programme. The results would fill a gap in the nationwide geotechnical database for these formations as well as serving the engineering requirements of the study area. It is true that such a programme of drilling and testing would not be sufficient to redress the geographical imbalance of data which is, however, considered to be of secondary importance.

8.5 Computerisation of the Data Base

The information collected in the course of the study is in the form of site investigation reports, logs for water wells and mineral exploration boreholes, literature in the form of books, published scientific papers and unpublished Ph. D theses, and the maps and notebooks of the British Geological Survey.

The contract required that the data should be assembled in a form suitable for incorporation into a database at the completion of the contract. To this end pit and borehole locations have been registered in the borehole records archive and geotechnical data have been abstracted from site investigation reports and entered onto pro forma data sheets which form the two volumes Geotech I and Geotech II.

This section describes the recommended approach to computerisation of the project data and suggests the most suitable means whereby this may be achieved.

a) Aim

The aim is to computerise the descriptive rock and soil properties and geotechnical data collected during the project. Bibliographic references should also be included in the resulting database.

The end product will be a condensed and readily accessible guide to the geotechnical properties and engineering behaviour of the bedrock and superficial materials of the area.

The database is intended to be used in answering routine enquiries from private and public sector individuals and organisations. To this end it will be aimed specifically to meet the preliminary data requirements of the civil or mining engineer, architects and government planners.

b) Data Format

The data base will comprise a brief descriptive text with physical and geotechnical data in tabular format. No arithmetic processing facility is envisaged.

c) Database Structure

The database will be organised on the basis of a framework related to the stratigraphical subdivision of the rocks of the study area. Sophisticated search facilities will be needed. Search keywords might take the following forms: "FULLER'S EARTH" or "FULLER'S EARTH + LIMESTONE + STRENGTH" or simply "LIMESTONE". Stratigraphical codes may be incorporated as keywords, and a location code based on National Grid co-ordinates will be necessary.

d) Input, Editing, Output Facilities

Input of the data will be direct from keyboard and the task may be undertaken by staff of varying levels of expertise in computer usage. It is therefore essential that the software be designed with such people in mind (i.e.'user friendly'). The software should include on-screen editing facilities, which will also enable confidential data to be removed from outputs when necessary.

The form and quality of the output is important. Annual reports could be prepared on a routine basis if information is updated throughout the year and/or reports in response to specific enquiries could be produced. Flexibility of format is therefore desirable in the form of a modern word processing package which will enable a standard text to be added to the database extract. The printed output would be obtained by using a high quality dot matrix printer.

e) BGS Available Hardware

The Engineering Geology Research Group IBM-PCXT computer was chosen because of its suitability as a geotechnical database machine. It has been widely adopted as a standard business machine and has an enormous range of software available. [The 640 K Byte microcomputer is linked to a 10 M Byte hard disc unit, twin 320 k Byte floppy disc drives, and has parallel and serial interfaces. A wide carriage, near letter quality, dot matrix printer (the Epson FX-100) is used for the printing output].

f) BGS Available Software

The Engineering Geology Research Group has chosen the database programme "dBASE III" written by Ashton-Tate for the IBM-PC (or similar machine) as the most suitable database for the requirements of a geotechnical database at a reasonable cost. The programme is fast, 'user friendly' and fulfills the requirements described above.

g) Manpower Requirements

The length of time required to computerise the project information will depend to some extent on the limits decided upon for the type of data entered and the output requirements of the potential customers. It is suggested that an initial 2 man months may be required to finalise the database format and consult with prospective customers (local authorities, central government). The input of the data would follow and may take 6 man months of effort although a more precise estimate would be available after the 2 month lead into the exercise.

APPENDIX I
AVAILABILITY OF PHOTOGRAPHIC COVER

Cover flown by:	Scale	Date	Remarks
Ministry of Defence	1/10000	4.11.46	Sortie CDE/UK/1821)All 3 Sorties
F6t2 (Air)	1/10000	4.1.46	Sortie 3G/TUD/UK/25)Required to
St. Georges Road	1/9900	12.7.46	Sortie 106G/UK/1661)give full cover
Harrogate			
N. Yorkshire			
*Ordnance Survey	Approx.	1965	
Air Photo Cover Group	1/25,000	1972	
Romsey Road		1975	Complete cover from several sorties
Maybush		1980	
Southampton SO9 4DH		1981	
Clyde Surveys Ltd.	1/12,000	1973/4	Western area for Wilts. C.C.
Reform Road			
Maidenhead	1/10,000	1964	Bath for City of Bath
Berkshire SL6 8BU			
BKS Surveys Ltd.			
47 Ballycairn Road			
Coleraine	No Cover		
Co.Londonderry			
N. Ireland BT51 3H2			
J.A. Storey & Partners			
92-94 Church Road	1/10,000	1981	Full cover except west edge. For
Mitcham			Wilts C.C.
Surrey			
Cartographical Services	1/10,000	1975	Bath and north west for Avon C.C.
(Southampton) Ltd.			
Landford Manor			
Salisbury	1/12,000	1980	South west for Somerset C.C.
Wiltshire			

APPENDIX II
RELATIONSHIP OF MADE GROUND/INFILLED LAND TO GEOLOGY

1:10 000 Sheet	N.G.R.	Geology of Site
ST75NW	717 595	Infill of cutting partly in Inferior Oolite, partly in Midford Sands
	700 586	Made ground on Alluvium overlying Blue Lias
	706 579	Infill of quarry in Inferior Oolite
	734 576	Infill of cutting in Lower Lias, capped by Inferior Oolite.
	737 578	Infill of cutting partly in Inferior Oolite, partly in Lower Lias
	703 560	Made ground on Inferior Oolite
	704 557	Made ground mainly on Lower Lias, partly on Inferior Oolite
	703 552	Made ground on Alluvium overlying Mercia Mudstone
	711 552	Made ground partly on Lower Lias, partly on Inferior Oolite
ST75NE	769 586	Infill of quarry in Great Oolite
ST76NW	736 686	Made ground on landslipped Upper Fuller's Earth
	719 656	Made ground on Alluvium overlying Mercia Mudstone
	722 652	Made ground on Alluvium overlying Mercia Mudstone
	764 664	Made ground on Alluvium overlying Lower Lias
	760 656	Made ground on Alluvium overlying Lower Lias
ST76SW	703 673	Made ground on Midford Sands
	708 643	Made ground on Lower Lias
	716 646	Infill of quarry in Blue Lias; also partly made ground on Blue Lias
	714 644	Made ground on Blue Lias
	732 643	Infill of pit in Lower Lias
	733 649	Made ground on Alluvium overlying Blue Lias
	743 649	Made ground on Alluvium overlying Lower Lias
	745 647	Made ground on Alluvium overlying Lower Lias
	731 634	Made ground on landslipped Lower Lias

1:10 000 Sheet	N.G.R.	Geology of Site
	726 628	Made ground mainly on Inferior Oolite, partly on Lower Fuller's Earth
	742 628	Made ground on Great Oolite
	745 626	Made ground on landslipped Fuller's Earth, Inferior Oolite and Midford Sands
	736 624	Infill of quarry in Great Oolite
	738 618	Infill of quarry in Great Oolite
	747 623	Infill of quarry in Great Oolite
	748 623	Infill of quarry in Great Oolite
	732 614	Made ground on Great Oolite
	737 602	Partly infill of cutting in Inferior Oolite, partly made ground on Lower Fuller's Earth
ST76SE	757 626	Infill of quarry in Great Oolite
	756 623	Infill of quarry in Great Oolite
ST76SE	759 621	Infill of quarry in Great Oolite
	768 623	Infill of quarry in Great Oolite
	767 623	Made ground on Great Oolite
	788 640	Made ground on Midford Sands
	752 605	Partly infill of cutting in Midford Sands, partly made ground on cambered Inferior Oolite
ST85NW	809 599	Infill of quarry in Great Oolite
	849 590	Made ground on Oxford Clay
	841 556	Infill of pit in Oxford Clay
ST86NW	832 688	Infill of quarry in Great Oolite
	802 677	Made ground on Alluvium overlying Lower Lias
	879 697	Made ground on Forest Marble clays
ST86SW	862 621	Made ground on Forest Marble clay and limestone
	834 604	Made ground on Alluvium overlying Forest Marble clay

APPENDIX III

SELECTED DATA FOR MADE GROUND/INFILLED LAND SITES

1:10 000 Sheet	N.G.R.	Category	Waste Type	Completion Date	Thickness (m)
ST75NW	713 596	IF	Industrial	Tipping	?
	700 575	NF	Colliery spoil	?	?
	706 579	IF	Industrial	?	?
	737 578	IF	Industrial	?	?
	734 576	IF	Industrial		?
	703 560	MG	Colliery spoil	?	?
	704 557	MG	Colliery spoil	?	?
	703 552	MG	Colliery spoil	?	?
	711 552	MG	Colliery spoil	?	?
ST75NE	769 586	IF	Industrial	Tipping	?
ST76NW	736 686	MG	Industrial	Tipping	?
	719 656	MG	Industrial	?	av. 1.7
	722 652	MG	Domestic/ Industrial	?	3.8-6.0
ST76NE	793 685	IF	Domestic/ Industrial	Tipping	?
	764 664	MG	Industrial	?	?
	760 659	MG	Domestic/ Industrial	1955	av. 2.1
ST76SW	708 643	MG	Industrial (inc. asbestos)	1980	?
	716 646	IF	Industrial	?	?
	714 644	MG	Domestic/ Industrial	?	?
	732 643	IF	Domestic	?	av. 6.0
	743 649	MG	Industrial	?	av. 1.2
	745 647	MG	River dredgings	?	av. 1.5
	731 634	MG	Domestic	?	?
	726 628	MG	Domestic/Boiler ashes	?	av. 2.6
	742 628	MG	Domestic	?	av. 1.5
	745 626	MG	Domestic	?	?
	736 624	IF	?	?	?
	738 618	IF	Domestic	1948	av. 2/1

1:10 000 Sheet	N.G.R.	Category	Waste Type	Completion Date	Thickness (m)
	747 623	IF	?	?	?
	748 623	IF	?	?	?
	732 614	MG	Industrial	Tipping	?
	737 602	MG/IF	Industrial	?	?
	757 626	IF	Industrial	?	av. 4.6
ST76SE	756 623	IF	Industrial	?	av. 3.7
	759 621	IF	Industrial	1979	?
	768 623	IF	Industrial	?	?
	767 623	MG	Industrial	?	up to 4.5
	788 640	MG	Industrial	?	?
	752 605	MG/IF	?	1984	?
ST85NW	809 599	IF	Domestic/ Industrial	1972	?
	849 590	MG	Industrial	Tipping	?
	841 556	IF	Domestic	1925	?
ST86NW	832 688	IF	Industrial	1979	?
	802 677	MG	Industrial	?	?
ST86NE	879 697	MG	Railway cutting spoil	?	?
ST86SW	862 621	MG	?	?	?
	834 604	MG	Mainly domestic	1978	?

N.B. IF = Infilled land MG = Made ground

APPENDIX IV

LANDSLIPS NAMED AND DESCRIBED IN PAPERS AND REPORTS

1. NORTH STOKE [700 687]

Ref. Hawkins and Privett (1980)

This landslip is situated 3 km north-west of Bath and extends from the western edge of the village of North Stoke westwards onto the alluvial flats of the River Avon and is therefore largely outside the study area.

The slip has taken place in cambered Inferior Oolite, Midford Sands and Head and is complex and degraded. Hummocky slip debris extends from the Inferior Oolite/Midford Sands backscarp to the margin of the River Avon. Erosion by the river has caused minor slips to take place in the toe of the slip which have affected the road at [696 684] for many years.

2. HEATHER FARM [723 682]

Ref. Hawkins and Privett (1979, 1980)

This slip is situated 1km north west of Bath on the south facing slope of Lansdown Hill. The semicircular backscarp is formed by the Upper Fuller's Earth clays and the Great Oolite limestones which cap them.

The main slip mass is composed of Fuller's Earth and Head, and is the result of numerous individual flows and slides. It extends some 400m downslope from the base of the backscarp.

A steep sided gully has been cut within the slip by water discharging from the springs at the base of the Great Oolite and from thin limestone bands within the Fuller's Earth. It is thought that much of the landslipped material has been removed down this gully thus accounting for the small amount of debris present below a large backscarp.

3. BAILBROOK [773 673]

Ref. Hawkins & Privett (1979, 1980), Gibb (1984)

The Bailbrook slip has been recognised as such on the grounds of its morphology which is dominated by a 1km long slightly curved backscarp 25m high at an angle of slope of 30-40 degrees. Hawkins and Privett compare the Bailbrook slip to the North Stoke slip in terms of mode of origin and style of movement i.e. oversteepening of the slope by river erosion caused a deep rotational failure to take place. The subdued topography within the Bailbrook slip is considered to be the result of many years of agricultural use. The site investigation carried out in 1983 for the proposed A4/A36 Batheaston/Swainswick bypass included several boreholes through the Bailbrook slip which provided the first subsurface data of the area. The evidence of the boreholes does not wholly support the existence of a major landslip at this location. The top of the Lias clay encountered by the boreholes within the boundary of the slip does not appear to have suffered vertical displacement, although there is an unusually large number of slickensided joints and bedding planes.

The backscarp could have originated by spring sapping at the base of the Midford Sands, an origin favoured by the straightness of the scarp. The report by Sir Alexander Gibb and Partners concludes that in any engineering design both possible origins of the morphology must be taken into account.

4. SALLY-IN-THE-WOODS [791 652 - 795 647]
Ref. GKN Rep.SM 361 1959
GKN Rep.SM 475 1960
Foundation Ungineering F69/977 1969 GKN Rep.S 1575 1969
Nott Brodie 1979

The section of the A363 which passes through Sally-in-the-Woods has been subject to minor slipping for many years. The ground movements are shallow, 4m deep rotational slides in Head and landslip debris. The section of road investigated in the listed reports is cut by the ENE/WSW trending Monkton Farleigh Fault. North of the fault the slips appear to be associated with the junction of the Inferior Oolite and Midford Sands, and south of the fault with the base of the Lower Fuller's Earth. The local geology is not well established despite a number of site investigations.

6. BEACON HILL [751 659]
Ref. Kellaway & Taylor 1968
Hawkins & Privett 1979
Strata Surveys Rep. B20907 1973

The extensive area of landslipping which forms the south-east slope of Beacon Hill is considered by both Kellaway and Hawkins to be a deep rotational slide caused by the oversteepening of the hillside by the erosive action of the River Avon, probably in the latter part of the late Devensian glaciation. The failure took place in Lower Lias shales overlain by cambered Inferior Oolite and Midford Sands. The backscarp behind the body of the slip cuts the base of the Lower Fuller's Earth which caps Beacon Hill.

The report by Strata Surveys For M.P. Kent, however, appears to indicate, on the evidence of a borehole into the slip mass, that the slip may be relatively shallow and more translational in character.

The area on and around the slip has been extensively built upon, making accurate mapping of the landslip very difficult except for the backscarp. It is, however, reasonable to assume that the landslip debris extends downslope to the present course of the River Avon. Several areas within the assumed limits of the Beacon Hill slip have been active since the late eighteenth century when the development of the area commenced. Since that time at least six instances of earth movement have been recorded and it is probable that many other cases before and after that date have not been recorded.

Recorded movements include:

a) Camden Crescent [749 657]

The construction of Camden Crescent in 1794 was delayed by a series of shallow landslips which destroyed some houses and caused the abandonment of others. Camden Crescent remains uncompleted, a crescent in name alone, although no further movements have taken place since that time.

b) Hedgemead slip [750 656]

The Hedgemead area which lies downslope and to the south-east of Camden Crescent was developed between 1860 and 1875. The first signs of slipping probably occurred in the early 1870's and continued periodically until the late 1800s. In total 2.5 hectares of land were affected and at least 135 houses destroyed or demolished due to the direct or indirect effects of the movement.

The landslips were shallow translational movements in Head composed of Fuller's Earth, Midford Sands and Inferior Oolite which had been barely stable prior to development. The slips were largely triggered by increased water input into superficial material as a result of the service works associated with the housing i.e. infiltration from leaking sewers, water supply pipes and storm water soakaways.

The improved water flow in the Midford Sands caused by natural piping induced by water abstraction from wells may also have proved detrimental to stability because, when wells were abandoned, water continued to be brought into a critical area but was no longer removed.

The presence of confined aquifers in the limestones of the Lower Lias, which could have supplied water under pressure to the Head/bedrock interface, may also have played a part in the failure. No remedial measures proved effective, with the result that the area was turned over to recreation purposes, as Hedgemead Park.

c) Beacon Common Slip [751 662]

In 1958 a small rotational slip 10m across occurred in the outcrop of the Fuller's Earth clay where the backscarp of the Beacon Hill slide cuts Beacon

Common. The failure had undergone 5m of vertical displacement by 1961 and had generated a mud flow which extended down slope for 120m. The movement was finally stabilised by the installation of herring bone drains in the hillside.

d) Perfect View Slip. [752 662]

On the 5th of December 1972 during a period of wet weather, a 50m long crack appeared in the roadway of Perfect View, and the downslope side dropped 75mm. The movement ruptured a water main which supplied copious amounts of water to the area. On the 6th December the downslope side had dropped a total of 0.75m, but no further movement took place. Piezometric measurements showed porewater pressure had dropped in the main body of the slip by the 10th December. No reference to further movement has been found.

e) St Stephen's Hill [750 659]
Ref. BA69 S.W.I.R.L. Rep 1495

During January 1979, in St Stephen's Road, a masonry retaining wall 0.5m thick and 3-5m high underwent a 5 degree rotation accompanied by cracking of the upper road level pavement. The conclusion of the site investigation was that the wall failed due to inadequate design and that it was only effective in the past because of the use of good quality back fill. The site investigation also pointed out that the area around the site was in a state of marginal stability. Boreholes and trial pits showed the area to be underlain by coarse to fine granular hillwash on weathered, disturbed and fissured Lias clay.

f) Mount Road [750 659]
BA 49 Somerset C.C. Lab Rep. 48/77(ACC)

During the autumn of 1975 a failure occurred in the masonry retaining wall supporting the east side of Mount Road. The wall was founded on 4m of Lower Fuller's Earth lying on Inferior Oolite limestone. Water percolating from behind the wall had caused leaching and erosion of the Fuller's Earth to the detriment of the structural integrity of the wall. Remedial measures suggested included grouting and various configurations of ground anchors which were designed to tie the wall back into solid stable ground.

7. BEECHEN CLIFF [751 641]
Ref. Hawkins, A.B. 1976
Kellaway, G.A., Taylor, J.H. 1968
Soil Mechanics (1967) SM 4734
Hawkins (1980) Rep. to Bath City

The Beechen Cliff slip is considered to be a deep-seated rotational slide of late Devensian age which has affected strata from the Inferior Oolite limestone capping the hill, through the Midford Sands into the Lower Lias clays and silts which outcrop at its foot. A backscarp at a slope angle of 38-52 degrees is present above the debris apron.

A series of boreholes through the slip mass proved the debris to be 18m thick. Another borehole nearby showed fissuring in the Lias clay to a depth of 24m, indicating that a slip plane in the Lias clay may also be present.

Beechen Cliff is situated on the outside of a curve of the River Avon and it is thought by Kellaway and Hawkins that the slip occurred in late Devensian times as a result of oversteepening of the hillslope by river erosion.

The effect of tree and vegetation cover on the face of Beechen Cliff is considered by Hawkins in his report to the Bath City Engineer in 1980. The steep cliff area appears to be currently stable and no movements during the last hundred years are recorded. However, movements did take place in the slip mass below the cliff at Calton Gardens in 1973 and at Calton Road in 1974.

8. CALTON GARDENS [750 641]
Ref. M.P. Kent 1972
Soil Mechanics 1973 Rep.6173

In December 1972 a landslip took place south of Calton Gardens, opposite house numbers 45 to 50. The movement had been initiated by the excavation of the foot of the slope in order to construct a layby next to the road; the slope was to be supported by a retaining wall. Heavy rainfall occurred before the wall could be completed and movement of the hillside took place.

An investigation of the slip showed it to be approximately 50m wide across the toe by 30m up the slope, and relatively shallow in depth. It was confirmed that the slip had taken place by the partial reactivation of an ancient slip due to removal of support at the bottom of a 22 degree slope. The situation was aggravated by the existance of a confined aquifer in the Lias Clay below the slip which supplied water under pressure to the slip plane at the slip/bedrock interface.

Remedial measures recommended were drainage of the confined aquifer and an improved retaining wall founded well into the Lias Clay.

9. CALTON ROAD [752 642]
Ref. Geotechnical Engineering SM/S/1974

An investigation into the failure of a retaining wall in Calton Road showed that the wall had failed due to deterioration of its structure. However, the investigation looked at the stability of the retained slope itself and found that the slope angle of 70 degrees and cutting height of 2.5-3.5m in slip debris composed of silty, sandy, limestone rubble, was only marginally stable. The recommendation was made that the slope either be regraded to one of 35 degrees or that a more effective retaining wall be designed and built to replace the old one, preferably in sections to minimise the risk of failure during construction.

10. HENGROVE WOOD [780 650]
Ref. Gibb 1984
Somerset C.C. Rep.4068
Hobbs 1980

The Hengrove Wood slip was described by Sir Alexander Gibb and Partners in their report as having a length of at least 700m, and maximum depth of 20m and as having taken place in Lias clay.

B.G.S. records show Hengrove Wood to be only part of a belt of landslipped ground which runs the entire length of the valley side, affecting strata from the limestones of the Great Oolite at the top, to the Lias clays at the base. The area was described in detail by Hobbs (1980) who considered the Great Oolite to be uncambered but to have given rise to a number of minor rotational and translational failures which had slid and toppled onto the Fuller's Earth outcrop below. The Fuller's Earth outcrop is heavily wooded and the severity and style of movement was not clear. The main failure on this section of the valley side appeared to be on the lower valley slope below a 10m scarp of Inferior Oolite limestone and Midford Sands. The movement is a shallow translational slip in cambered Inferior Oolite and Midford Sands with a slip plane possibly extending into the Lias Clay. Alternatively the slip may have simply overridden an original ground surface of Lias Clay.

The marginal stability conditions which are present in some parts of this slip are demonstrated by the movements which took place within it in 1966 near Dry Arch [781 655].

11. DRY ARCH BATHAMPTON [781 655]
Ref. AV20 Structural Soils Rep. 4068

In 1966 a site investigation into the cause of cracking of the tarmac of the A36 near Dry Arch, Bathampton, was carried out by Structural Soils. The cause was found to be a slip 90m long by 50m wide which had started as a small rotational failure of the road embankment and developed into a translational slide in the Fuller's Earth/Inferior Oolite/Midford Sands Head. The bedrock below the site is Lower Lias clay and the junction with the Midford Sands is a short distance upslope, above the road.

The area had been subject to earth movements in the past and the latest slip was considered to have been triggered by heavy rain causing an increase in water flow from the Midford Sands/Lias spring line, possibly aggravated by earth moving operations which had been carried out below the slipped part of the hillside.

12 TWERTON [726 644]
Ref. Chandler 1976

Chandler refers to this slip as being 700m wide and extending more than 300m upslope from the No.1 terrace. The slip is important because of its relationship to the terraces of the River Avon which enable the time of its movement to be established. Field evidence shows that it pre-dates the aggradation of the No.1 terrace and post-dates the deposition of the No.3 terrace which indicates that the slip took place in late Devensian times.

The slip is in Head and Lower Lias clay below a backscarp of Midford Sands and was probably caused by oversteepening of the hillside by river erosion on the outside of a river bend.

13 SWAINSWICK LANDSLIP BELT [c760 765]
Ref. Gibb 1984

The Sir Alexander Gibb report on the proposed A46 bypass refers to the east side of the Swainswick valley as "the Swainswick Landslip Belt". This valley side is only one example of landslipped valley sides in the Bath area and is not unique in any respect, other than its significance to the construction of the A46 Bypass.

14 OLD HOUSE SLIP [763 674]
Ref. Gibb 1984

The Sir Alexander Gibb report describes this slip as being "200m wide and 11m deep in Lias clays". B.G.S. records show the backscarp to be of Inferior Oolite and Midford Sands, and coincident with a NW/SE fault with a downthrow to the SW.

15 A46 [7563 6896]
Ref. Foundation Engineering Rep. F69/977/2

This slide occurred on the downhill side of a newly constructed three lane section of the A46 north of the intersection with the A4. Surplus material, mainly clay, had been dumped into a gully on the downslope side of the road.

Heavy rain in July 1968 caused the tipped material to become saturated and flow downhill for a distance of 300m. Investigation of the event showed that previous movements of this type had taken place through natural causes, the last occurrence having been some 60 years previously.

The bedrock below the site is Fuller's Earth clay. Water is fed into the area by the spring line at the base of the Great Oolite limestone which outcrops upslope of the road.

16 A46 ABOVE SWAINSWICK [754 694 - 752 700]
Ref. AV93 Exploration Associates 1977

This investigation concerns a 500m section of the A46 which had been subject to subsidence prior to 1977.

The road had been built on Upper Fuller's Earth clay below the junction with the Great Oolite limestone which is often the site of an active spring line. The report concludes that the Great Oolite is not cambered at this locality and that the movements are shallow flows and translational slides.

Stabilisation of the road embankment by drainage, and the interception and diversion of water inflow into the area was recommended.

17 MEADOW LANE [770 662]
Ref. Gibb 1984

"A series of landslips in Lias clays covering an area of approximately 250m wide and having a depth in excess of 10m"

This is part of the general occurrence of slipping on the valley sides around Bathampton Down.

18 A36 LIMPLEY STOKE [780 611]
AV 92 Exploration Associates 1977

This investigation looked at a 100m section of the A36 downslope from Limpley Stoke village, which had suffered disturbance by minor landslip movements.

Boreholes in the slipped material indicate a thickness of 7 to 15 metres of slip debris lying on cambered Inferior Oolite in the north and on downfaulted Great Oolite in the south. The landslipping is considered to be typical of the stability state of the valley side as a whole.

19 HINTON HILL [756 582]
Ref. AV73 Somerset C.C. Rep 67/78ACC

Cracking of the road surface at the top of Hinton Hill required an investigation to be carried out in 1978 by Somerset County Council. The investigation showed the road to be constructed on the edge of the outcrop of the Great Oolite limestone above a landslip covered slope of Fuller's Earth. The angle of slope of the hillside was 12 degrees and the slip was between 6 and 7.5 metres thick. The report concluded that the subsidence of the road was being caused by ground water seeping through the permeable Great Oolite limestone and creating a mudflow condition in the Fuller's Earth clay downslope of the road. Drainage measures alone were considered insufficient to ensure the long term stability of the site and some form of retaining structure was recommended, the most economical being piles.

Further subsidence and cracking was expected to occur to the west of the existing unstable section.

20 A4 RUDLOE - BOX [836 696]
Ref. Wilts. C.C. Rep SM/L/1298/KWV

This report concerns the section of the A4 between the villages of Rudloe and Box which had suffered from subsidence problems since 1930, the most recent movement having been opposite the Cliff Works.

The road had been constructed along the edge of the Great Oolite outcrop partly on virgin ground and partly (the downslope side) on Great Oolite limestone fill which had been excavated during the building of the Box Hill railway tunnel.

The road movements appear to have been the result of a number of small slips in the Upper Fuller's Earth clay which had been softened by water from the spring line at the base of the Great oolite, the situation being aggravated by the poor compaction of the fill.

Recommended remedial measures were drainage and grouting of the fill.

21 COMBE HAY [731 611]
Ref. AV124

In March 1980 and again in March 1981 a 200m section of the A367, 1km north of the village of Combe Hay, subsided. A subsequent investigation showed the movement to be due to a shallow, 1.6m thick translational landslip in old landslip debris. The debris was between 2 and 5 metres thick in total and rested on the Upper Fuller's Earth just below the junction with the overlying Great Oolite limestone. Previous landslipping was demonstrated by several generations of tarmac repairs exposed in the trial pits which had been dug in the roadway.

Remedial measures considered were drainage and the retention of the slope by structural means; drainage was recommended on the grounds of lower cost.

22 BANNER DOWN [794 687]
Ref. AV68 C.J. Associates 51001

A section of the unclassified road (Fosse Way) on the eastern side of Banner Down had suffered slipping and required an investigation to be carried out in November 1975. The road had been built on 2-3 metres of previously slipped material lying on the Upper Fuller's Earth clay downslope of the junction with the overlying Great oolite limestone. No details of the cause of the failure or recommendations for remedial measures were included in the report.

23 MAGDALEN AVENUE [746 642]
Ref. Wilcox Cooper Associates Rep. S4687

Structural cracks in No. 28 Magdalen Avenue, Bath were investigated in November 1981. The building had been constructed on fill and landslip debris lying on Lower Lias clay. Natural landslipping was therefore suspected as the cause of the problem. However, the investigation found that structural inadequacies of the building and disturbance of the foundations by excavations nearby were the cause of the failure.

24 BLOOMFIELD ROAD [739 630]
Ref. Larnach 1963 Rep. to Bath City
Underwood 1963 Rep. to Bath City

In 1963 a slip took place in a field north of Bloomfield Road after the field had been used as a waste disposal site. An inspection of the site showed the tipped material to be Fuller's Earth clay and the ground on which it had been dumped to be Fuller's Earth Head lying on Fuller's Earth bedrock. The loading of the slope, which stood at an angle of between 25 and 30 degrees, had caused a circular rotational failure to take place in both the tipped material and the Head below. The initial failure developed into a translational slide and ultimately a mudflow as it progressed downslope. The mudflow was particularly wet, probably due to the water issuing from the base of the Great Oolite limestone which capped the hill.

Remedial measures recommended were the drainage of the slip mass and the careful regrading of the slope with the removal from the site of all excavated material.

25 LANDSOWN [727 679]
Ref. Cook 1973

A shallow, 3m thick landslip 210m long, affecting 12 acres of ground on the south facing slope below the Great Oolite plateau at Lansdown, took place between October 1969 and January 1971. The slip developed in three main phases which were mainly movements of mudflow type but with some degree of translational sliding.

The slip was started by the dumping of rubbish into an old abandoned quarry at the base of the Great Oolite limestone. Springs had been observed issuing at this level of the hillside, and the blocking of these drainage paths resulted in the saturation of the fill and underlying Head deposits causing failure. Once slippage had started, minor aquifers in the Fuller's Earth under the slip mass may have aided further movement.

APPENDIX V

BATH STONE MINES: LOCATION OF MINE ADITS AND SLOPE SHAFTS

1:10 000 Sheets	Mine	N.G.R. Adits	N.G.R. Slope Shafts
ST76NE	Monkton Farleigh	7963 6613	
		7970 6606	
		7978 6612	
	Single Way	7700 6517	
ST76SE	Murhill (Winsley)	7945 6076	
		7952 6072	
		7942 6093	
	Hayes Wood	7757 6073	
	Freshford	7785 6062	
	Stoke Hill	7786 6077	
	Wallington	7791 6082	
	St Winifred's	c7701 6253	
	Lodge Hill	7695 6250	
		7684 6243	
	Mount Pleasant	c7675 6232	
	Kingham	7644 6215	
	Coxe's	7560 6223	
	Greendown Place	7555 6231 (3 close together)	
	Beechwood Road	7598 6203	
ST85NW	Westwood	8074 5984	8093 5961
		8057 5968	
ST86NW	Box/Clift	8377 6967	
		8365 6930	
		8356 6918	
		8366 6917	
		8367 6918	
		8331 6895	
		8334 6884	
		8366 6917	
		8332 6876	
		8328 6863	

1:10 000 Sheets	Mine	N.G.R. Adits	N.G.R. Slope Shafts
	Kingsdown	8104 6702	
	Longsplatt		8257 6729
	Monkton Farleigh	8084 6585	8025 6620
	Dapstone	8018 6524	
		8027 6515	
ST86NE	Westwells		8550 6880
	Corsham Side		8614 6858
	Brockleaze		8650 6818
	Hollybush		8568 6790
	Monks Park		8770 6832
	Ridge		8745 6803
	Eastlays		8800 6775
	Goode's		8864 6727
	Park Lane		8715 6722
ST86SW	Poultons	8267 6026	
	Jones Hill	8234 6030	
	Bethell	8243 6007	
	Bradford-on-Avon	8311 6056	
		8312 6082	
		8312 6112	
		8285 6123	
		8235 6108	
		8233 6106	
ST87SW	Brewer's Yard	8461 7038	
ST87SE	Pickwick		8551 7028

APPENDIX VI

DETAILS OF PRINCIPAL BATH STONE MINES, BY NATIONAL GRID SHEETS

Abbreviations:

BO = Bath Oolite

CDO = Combe Down Oolite

UR = Upper Rags

ST76SE

Firs Mine

N.G.R. 760 625

Owner: ?

Mining ceased: by 1860 probably

Present use: disused

Mines stone: Combe Down Stone (CDO)

Depth of working face: up to 15m

Overburden: as little as 2m possibly

Condition: ?

Combe Down or Byfield Mine

N.G.R. 757 624

Owner: ?

Mining ceased: by 1860 largely; minor working up to 1920

Present use: disused

Mined stone: Combe Down Stone (CDO)

Depth of working face: ?

Overburden: as little as 2m possibly

Condition: two crown hole subsidences known, at [7567 6240] and [7581 6228]

Coxe's Mine

N.G.R. 757 623

Owner: ?

Mining ceased: by 1900

Present use: disused

Mined stone: Combe Down Stone (CDO)

Depth of working face: ?

Overburden: ?

Condition: ?

Lodge Hill or Shaft Mine

N.G.R. 769 634

Owner: ?

Mining ceased: mid 1930's

Present use: disused

Mined stone: Combe Down Stone (CDO)

Depth of working face: 5-10m

Overburden thickness: as little as 2m

Condition: Variable; roof falls locally; three surface crown hole subsidences known at [7688 6244], [7691 6233] and [c7700 6240].

St Winifred's Mine

N.G.R 770 634

Owner: ?

Mining ceased: by 1940

Present use: disused

Mined stone: Combe Down Stone (CDO)

Depth of working face: 5m-10m

Overburden thickness: ?

Conditions: ?

Mount Pleasant Mine

N.G.R. 768 633

Owner: ?

Mining ceased: ?

Present use: disused

Mined stone: Combe Down Stone (CDO)

Depth of working face: 5m-10m

Overburden thickness: ?

Condition: Variable; some large roof falls and open joints.

Hayes Wood Mine

N.G.R. 775 608

Owner: The Bath Stone Co. Ltd.

Mining ceased: 1940; reopened 1982

Present use: in production

Mined stone: Stoke Ground Stone (BO)

Depth of working face: originally 2.4m

Overburden thickness: 15m-30m

Condition: believed stable and dry

Stoke Hill Mine

N.G.R. 778 608

Owner: ?

Mining ceased: ?

Present use: disused

Mined stone: Stoke Ground Stone (BO)

Depth of working face: 2.4m

Overburden thickness: 15-30m

Condition: unknown, but the portion on the east side of the A36 road (known as Wallington Mine) is poor, with failed pillars, roof falls and wide open fissures.

Freshford Mine

N.G.R. 777 606

Owner: ?

Mining ceased: ?

Present use: disused

Mined stone: Stoke Ground Stone (BO)

Depth of working face: 1.9m

Overburden thickness: 15-30m

Condition: unknown.

ST85NW

Westwood Mine

N.G.R. 808 597

Owner: Bath and Portland Group

Mining ceased: by 1900; reopened 1970

Present use: partly in production; partly an engineering works; partly disused.

Mined stone: Westwood Ground Stone (BO)

Depth of working face: c3m

Overburden thickness: 15-20m

Condition: Generally good; open fractures near valley slope; some failed pillars in disused workings.

ST86NW

Clift/Box Mine

N.G.R. 840 694

Owner: ?

Mining ceased: 1968 (final closure of Clift Mine)

Present use: disused

Mined stone: Box Corngrit and Box Ground Stone (CDO); locally also Corsham Down Stone (BO)

Depth of working face: 4-6m (Clift Mine)

Overburden thickness: 30-40m

Condition: Poor; open joints common; roof falls; pillar collapses; much water through joints and fissures.

ST86NE

Westwells (=Moor Park) Mine

N.G.R. 855 689

Owner: Bath and Portland Group

Mining ceased: 1949 (Tucker, 1968); 1952 (Perkins 1979).

Present use: disused

Mined stone: Moor Park Stone (BO)

Depth of working face: 2.4-2.7m

Overburden thickness: 10-20m

Condition: good, but subject to periodic flooding.

Brooklease Mine

N.G.R. 847 681

Owner: Wansdyke Securities

Mining ceased: ?

Present use: storage

Mined stone: Bath Oolite

Depth of working face: ?

Overburden thickness: c21m

Condition: probably good

Monks Park Mine

N.G.R. 980 793

Owner: Bath and Portland Group

Present use: still in production

Mined stone: Monks Park Stone (BO)

Depth of working face: 6-7m

Overburden thickness: 10-25m

Condition: Good; few closed joints; sound roof and pillars; dry

Ridge Mine

N.G.R. 875 681

Owner: ?

Mining ceased: 1914

Present use: disused

Mined stone: Bath Oolite

Depth of working face: c25m

Condition: ?

Eastlays Mine

N.G.R. 881 676

Owner: Magic Builders Ltd.

Mining ceased: 1930's

Present use: ?

Mined stone: Bath Oolite

Depth of working face: 4m

Overburden thickness: c20m

Condition: ?

Park Lane Mine

N.G.R. 872 671

Owner: ?

Mining ceased: 1958

Present use: disused

Mined stone: Bath Oolite

Depth of working face: 4.3m at entrance

Condition: probably not good; NE-SW open joints; calcite deposits common (?much water).

Elm Park Mine

N.G.R. 885 682

Owner: ?

Present use: ?

Mined stone: disused

Depth of working face: ?

Overburden thickness: 15-20m

Condition: good

Kingsdown (=Swan) Mine

N.G.R. 811 669

Owner: ?

Mining ceased: ?

Present use: disused

Mined stone: Bath Oolite

Depth of working face: ?

Overburden thickness: c5-15m

Condition: probably not good; several roof collapses are recorded.

Longsplatt Mine

N.G.R. 925 782

Owner: ?

Mining ceased: ?

Present use: disused

Mined stone: Bath Oolite

Depth of working face: ?

Overburden thickness: ?

Condition: ?

Monkton Farleigh Mine

N.G.R. 809 659

Owner: N. McCamley & D. Edwards Ltd.

Mining ceased: 1930's

Present use: Mine Museum in part

Mined stone: Farleigh Down Stone (BO)

Depth of working face: 4-7m

Overburden thickness:

Condition: ?

Dapstone Mine

N.G.R. 801 652

Owner: ?

Present use: disused

Mined stone: Farleigh Down Stone (BO)

Depth of working face: ?

Overburden thickness: 8-15m

Condition: ?

Norbin Barton

N.G.R. 822 611

Owner: ?

Mining ceased: ?

Present use: disused

Mined stone: Bath Oolite

Depth of working face: ?

Overburden thickness: ?

Condition: flooded in winter.

ST86SW

Bethell Mine

N.G.R. 822 601

Owner: Darlington Mushrooms

Mining ceased: ?

Present use: mushroom cultivation

Mined stone: Bradford Ground Stone (UR)

Depth of working face: 5m

Overburden thickness: 15-20m

Condition: believed good.

Jones Hill Mine

N.G.R. 823 603

Owner: ?

Mining ceased: ?

Present use: disused

Mined stone: Bradford Ground Stone (UR)

Depth of working face: ?

Overburden thickness: ?

Condition: ?

Poultons Mine

N.G.R. 828 603

Owner: Darlington Mushrooms Ltd.

Mining ceased: by 1900

Present use: mushroom cultivation

Mined stone: Bradford Ground Stone (UR)

Depth of working face: ?

Overburden thickness: ?

Condition: believed good.

ST87SW

Brewer's Yard Mine

N.G.R. 846 704

Owner: ?

Mining ceased: ?

Present use: disused

Mined stone: Hartham Park Stone (BO)

Depth of working face: ?

Overburden thickness: ?

Condition: ?

Pickwick Mine

N.G.R. 855 708

Owner: Simon Verity

Mining ceased: 1958

Present use: in preparation as "The Bath Stone Quarry Museum"

Mined stone: Hartham Park Stone (BO)

Depth of working face: ?; partly worked at upper and lower levels, but mainly at lower level only.

Overburden thickness: ?

Condition: good; sound roof and pillars, few open joints, dry; cleared of debris.

APPENDIX VII

BATH STONE MINES: LOCATION OF VERTICAL SHAFTS

1:10 000 Sheets	Locality	N.G.R. Air/Light Shafts	N.G.R. Vertical Mine Shafts/Trial Shafts
ST76NE	Monkton Farleigh Mine	7948 6578	
		7991 6565	
		7975 6555	
		7973 6550	
		7972 6544	
		7971 6539	
		7973 6539	
		7987 6543	
ST76SE	Freshford Mine	7779 6059	
	Firs Mine	7598 6254	7600 6257
		7593 6250	
	Combe Down Mine	7568 6240	7586 6234
		7570 6236	
		7572 6232	
		7580 6233	
	Coxe's Vertical Shaft Mine		7545 6240
	Vinegar Down Mine	7601 6208	
ST85NW	Westwood Mine		8093 5961
ST86NW	Clift Mine	8423 6963	
	Box Mine	8421 6937 (2 close together)	
		8385 6927	
		8376 6883	
	Box-Corsham area	8476 6988	
		8489 6954	
		8458 6939	
		8473 6937	
		8435 6906	
		8484 6893	
		8465 6890	
		8419 6874	

1:10 000 Sheets	Locality	N.G.R. Air/Light Shafts	N.G.R. Vertical Mine Shafts/Trial Shafts
		8432 6869	
		8450 6873	
		8398 6856	
ST86NW	Norbin Barton Mine	8222 6621	8217 6613
	Monkton Farleigh Mine	8002 6592	
		8033 6611	
		8035 6605	
		8040 6602	
		8045 6597	
		8049 6593	
		8050 6591	
		8045 6615	
		8030 6585	
		8007 6545	
ST86NE	Box-Corsham area	8500 6931	8634 6984
		8516 6982	
		8549 6979	
		8522 6970	
		8514 6881	
		8516 6869	
		8647 6931	
		8616 6919	
		8689 6878	
	Westwells Mine	8546 6884	
	Corsham Side Mine	8608 6855	
	Brockleaze Mine		8651 6826
	Hollybush Mine	8373 6788	
	Monk's Park Mine	8773 6859	
		8780 6838	
		8782 6832	
	Ridge Mine		8730 6806
			8744 6802
			8754 6805
			8755 6794

1:10 000 Sheets	Locality	N.G.R. Air/Light Shafts	N.G.R. Vertical Mine Shafts/Trial
			8765 6798
			8708 6801
	Elm Mine	8856 6828	
		8856 6819	
		8849 6809	
ST86NE	Eastlays Mine	8800 6759	8770 6774
		8795 6747	8792 6776
		8802 6750	8819 6774
		8815 6759	8794 6753
		8822 6763	
		8848 6775	
		8861 6783	
	Goode's Mine	8870 6746	
	Gastard area	8914 6795	
		8923 6789	
	Park Lane Mine		8698 6741
			8736 6746
			8690 6717
			8711 6712
			8728 6716
			8744 6715
			8718 6772
ST86SW	Poultons Mine	8272 6033	
	Bethell Mine	8237 6006	
ST87SW	Brewer's Yard Mine		8458 7036
			8462 7037
ST87SE	Biddestone area	8510 7277	
	Pickwick Mine area	8542 7073	8531 7072
		8557 7074	8561 7041
		8564 7053	8532 7044
	Corsham area	8575 7011	
		8591 7004	

1:10 000 Sheets	Locality	N.G.R. Air/Light Shafts	N.G.R. Vertical Mine Shafts/Trial
			8765 6798
			8708 6801
	Elm Mine	8856 6828	
		8856 6819	
		8849 6809	
ST86NE	Eastlays Mine	8800 6759	8770 6774
		8795 6747	8792 6776
		8802 6750	8819 6774
		8815 6759	8794 6753
		8822 6763	
		8848 6775	
		8861 6783	
	Good's Mine	8870 6746	
	Gastard area	8914 6795	
		8923 6789	
	Park Lane Mine		8698 6741
			8736 6746
			8690 6717
			8711 6712
			8728 6716
			8744 6715
			8718 6772
ST86SW	Poultons Mine	8272 6033	
	Bethell Mine	8237 6006	
ST87SW	Brewer's Yard Mine		8458 7036
			8462 7037
ST87SE	Biddestone area	8510 7277	
	Pickwick Mine area	8542 7073	8531 7072
		8557 7074	8561 7041
		8564 7053	8532 7044
	Corsham area	8575 7011	
		8591 7004	

APPENDIX VIII

SAMPLE DATA SHEETS USED FOR DATABASE VOLUMES GEOTECH 1 and 2.

LIST OF ABBREVIATIONS

A	Activity (P.I./% clay size)
C	Clay and silt (35% silt & clay size)
CARB	Carbonate content (total calcium carbonate) ref. Molnia, 1974
C.P.T	Cone Penetration Test
C.R.	Core Recovery (%)
c'r	Residual cohesive strength (effective) (KPa)
cu	Undrained cohesive strength (total) (KPa)
Cv	Coefficient of consolidation. (m^2/year)
Ei	Initial tangent, Youngs Modulus of Elasticity (KPa)
Eu	Undrained Youngs Modulus of Elasticity (KPa)
F.I.(or If)	Fracture Spacing Index (unit length/no. of fractures) (mm)
k	Permeability (m/s)
k_1	Primary permeability (m/s)
k_2	Secondary permeability (m/s)
KPa	Kilopascal (=kN/m^2)
MPa	Megapascal (=1000 KN/m^2)
L	Limestone
L.I.	Liquidity Index
L.L.	Liquid Limit
m/c	Moisture content (% of dry weight)
Mv	Modulus of volume change or modulus of compressibility (m^2/MN)
M	Mudstone, shale
n	Number of data points
N	Standard Penetration Test value (No. of blows/300mm)
Nc	Cone Penetration Test value (N_c =1.5N)
O.C.R.	Overconsolidation Ratio (maximum previous overburden pressure÷present overburden pressure)
ORG.	Organic content (ref. B.S.1377 Test 8)
P.I.	Plasticity Index (Liquid Limit - Plastic Limit)
P.L.	Plastic Limit
P.S.A.	Particle size analysis
R.Q.D.	Rock Quality Designation
R.P.T.	Rock Penetration Test (penetration in mm for 50 blows using SPT apparatus)
S.D.	Standard Deviation

S.P.T.	Standard Penetration Test. No of blows for 300mm penetration.
su	Undrained shear strength (total) (KPa)
S	Sand, sandstone
x	Mean
ϕr	Residual angle of internal friction (degrees)
ϕu	Undrained angle of internal friction (degrees)
γb	Bulk Density or Bulk Unit weight (gm/cc)
γd	Dry Density or Dry Unit Weight (gm/cc)

SCHEDULE OF RECORDS

Schedule of geological maps.

All geological maps are located in the B.G.S. archive.

'County' Series 1:10560 sheets (hand-coloured) and field slips

Gloucs.	77NW
Somerset	7NE/SW; 8 NW, SW, SE; 13 NE, SE; 14 NW, NE, SW, SE; 20 NE, SE; 21 NW, NE, SW, SE
Wilts	25 NW, NE, SW, SE; 26 NW, SW; 32 NW, NE, SW, SE; 33 NW, SW; 38 NW, NE, SW, SE; 39NW

National Grid 1:10560 sheets (available as uncoloured dyeline copies)

ST 75 NW (published) NE; 76 SW, SE; 85 NW; 86 NW, NE, SW, SE; 87 SW, SE

National Grid 1:10560 field slips

St 87 SW, SE

Published 1:63360 sheets 265 (Bath) and 281 (Frome)

Schedule of Infilled Land and Made Ground Data

A. Site Plans	Scale of Plan	Source
ST75NW		
Dunkerton (railway/canal cutting)	1:1000	Private
ST76NW		
Round Hill Farm, Kelston	1:1000	Bath Waste Disposal Services
Newbridge/Brassmill Lane, Bath	1:1250	(8 individual plans) - Bath City Engineer.
" " "	1:500	Bath City Engineer
ST76NE		
Lambridge, Bath	1:500	Bath City Engineer
Lambridge, Bath	1:1250	Bath City Engineer
Lambridge, Bath	1:10000	South-West Electricity Board
Kensington Meadows	1:1250	(3 individual plans) - Bath City Engineer
" (ground & tip levels)	1:1250	Bath City Engineer
" (cross sections)	------	Bath City Engineer
Banner Down Quarry	1:10000	Private

A. Site Plans	Scale of Plan	Source
<u>ST76SW</u>		
Claysend Farm, Newton St Loe	1:10000	Private
Pennyquick Bottom (north)	1:2500	Bath City Engineer
Pennyquick Bottom (north)	1:10560	Bath City Engineer
Pennyquick Bottom (south)	1:1250	Bath City Engineer
Locksbrook, Bath	?	Bath City Engineer
Green Park, Bath	1:1250	Bath City Engineer
Norfolk Crescent	1:1250	Bath City Engineer
Victoria Brick & Tile Works Bath.	1:2500	Bath City Engineer
Southdown, Bath	1:2500	Bath City Engineer
Rush Hill, Bath	1:2500	Bath City Engineer
The Tumps, Odd Down, Bath	1:1250	Bath City Engineer
Barrack Farm, Odd Down, Bath	1:1250	Bath City Engineer
Combe Hay Mine	1:2500	Bath Plant Hire Services Ltd
Woodland Farm, Combe Hay	1:500	Private
South Stoke	1:2500	Avon County Council
<u>ST76SE</u>		
North Road Quarry, Bath	1:1250	Bath City Engineer
Combe Down Quarry, Bath	1:1250	Bath City Engineer
Combe Down Quarry, Bath	1:10000	Bath Waste Disposal Services
Quarry, Shaft Road, Bath	1:10000	D.W. Frayling, Construction
Shaft Road Playing Fields, Bath.	1:1250	Bath Plant Hire Services Ltd
<u>ST86NW</u>		
Box Bridge, Shockerwick	1:10000	W. Reed (Plant Hire), Bath

B. Other Data

List of Local Authority and Private landfill sites	Avon County Council	
List of Local Authority and Private landfill sites	Wiltshire County Council	

Schedule of Coal Mine plans

	Scale	Source
A. Abandonment Plan		
Coals of the Farrington Formation - No. 1, No. 5, No. 6, No. 7 and No. 9 seams	1:10560	N.C.B
Coals of the Radstock Formation - Great, Top Little, Slyven, Under Little and Bull Seams	1:10569	N.C.B.
Great Vein workings in the Radstock Basin	1:10560	N.C.B.
B. Other Plans		
Twerton Colliery mine plan	2 chains to 1 inch.	N.C.B.
Mine plans, cross-section, logs, etc. for Braysdown, Dunkerton, Foxcote and Writhlington mines	1:10560	B.G.S. archive

Schedule of Fuller's Earth Mine mine plans

Combe Hay Mine (abandonmnent plan)	1:2500	Laporte Industries Limited
" " " (1946 mine plan)	1:2500	B.G.S. archive
" " " "	1:10560	" "
" " " (section in the mine)	-------	" "

Schedule of Bath Stone Mine Plans*

ST76SW

Mines in Odd Down District	1:10560	Bath City Engineer 'Combe Down Freestone Mines, Bath' (Butcher & Mehew).

*Some information held in BGS archives may not be available to the general public.

Mine	Scale	Source
ST76SE		
Mines in Combe Down district	1:10560	Bath City Engineer
Combe Down Mine (=Byfield Mine)	1:1250	"Combe Down Stone Mine" (Mehew)
Mines near Greendown Cottages	?1:500	Bath City Engineer
Coxe's Mine	1:500	Bath City Engineer
Lodge Hill (=Shaft), Mount Pleasant and St. Winifred's Mines	1:2500	B.G.S. archive
Ditto + Combe Down Mine	1:10560	B.G.S. archive
Lodge Hill and Mount Pleasant Mines	1:2500	Avon County Council
Hayes Wood, Stoke Hill and Freshford Mines	1:2500	B.G.S. archive
- ditto -	1:2500	Mr. R.J. Tucker
- ditto -	1:10560	B.G.S. archive
Stoke Hill (part) & Wallington Mines	1:2500	W. Wilts.District Council
ST85NW		
Westwood Mine (2 plans)	1:2500	Kingston Minerals Ltd
Westwood Mine	1:2500	W. Wilts.District Council
ST86NW & NE		
Box Mine	100' to 1 inch	Mr. R.J. Tucker
- ditto - (part of)	3 chains to 1 inch	Wilts Record Office
- ditto - (part of)	3 chains to 1 inch	Wilts Record Office
Box, Clift, Sands, Spring, Hudswell and Moor Park Mines	1:2500	Kingston Minerals Ltd
- ditto -	1:10560	B.G.S.archive
Brockleaze Mine	1:2500	Wansdyke Securities Ltd
Monks Park, Ridge, Park Lane and Eastlays Mines	1:2500	Kingston Minerals Ltd
- ditto -	1:10560	B.G.S. archive
Eastlays & Park Lane Mines	1:2500	Kingston Minerals Ltd
Monks Park, Ridge & Elm Mines	1:2500	Kingston Minerals Ltd
Monks Park, Ridge, Park Lane and Elm Mines	1:2500	B.G.S. archive

Mine	Scale	Source
Elm Mine	1:2500	Kingston Minerals Ltd
Elm, Eastlays & Goode's Mines	1:10560	B.G.S. archive
Kingsdown Mine	1:2500	Mr. R.J. Tucker
Kingsdown Mine	1 chain to 1 inch	"Bath Freestone Workings" (Price): Wilts Record Office
Kingsdown and Longsplatt Mines	1:10560	B.G.S. archive
Monkton Farleigh, Dapstone and Norbin Barton Mines	1:10560	B.G.S. archive
Monkton Farleigh Mine	1:2500	W.Wilts District Council
Norbin Barton Mine	1:2500	W.Wilts District Council
<u>ST86SW</u>		
Kingsfield Mine	1:2500	W.Wilts District Council
Jone's & Budbury Mines	1:2500	W.Wilts District Council
Jones Hill & Bethell Mines	1:2500	W.Wilts District Council
Poultons Mine	1:2500	W.Wilts District Council
Bethell Mine	1:2500	B.G.S. archive
Bethell Mine	40' to 1 inch	Darlington Mushrooms
Poultons Mine	40' to 1 inch	Darlington Mushrooms
Jones Hill, Poultons, Bethell & Westwood Mines	1:10560	B.G.S. archive
<u>ST87SW & SE</u>		
Pickwick, Brewer's Yard and Copenacre Mines	1:2500	Kingston Minerals Ltd
- ditto -	1:10560	B.G.S. archive

Schedule of Hydrogeological Well Data

The following data sheets, abstracted from the Hydrogeological archive, give an outline of the geological sequence and information about water levels, yields and chemistry:

ST75/10-14, 23-30

ST76/1-53

ST85/8-13, 25, 26

ST86/1, 8, 9, 13, 15-18, 25, 27, 33-42, 44-47, 49-51, 53-71

ST87/8, 9, 11-20, 32, 35, 36, 38, 39

Schedule of Borehole and Geotechnical Data

The locations of site investigation reports, wells and boreholes are shown on thematic Map 14. Wells and boreholes are accurately sited on 1:10 560 reference maps in the B.G.S. Records Department at Keyworth.

Confidential data are marked by an asterisk *.

Map Reference and Numbers	Data Source	Locality
ST65NE		
Site investigations		
AV88	Avon C.C. Lab. Rep. 65/78 ACC	Stoneage Bridge, Carlingcott
AV91	Exploration Associates	Bristol Road, Radstock
ST75NE		
Site investigations		
SCC6	Somerset County Council	Hinton Hill, Hinton Charterhouse
Boreholes, wells, shafts		
1-4*	Laporte Industries	Wellow
5-6*	Laporte Industries	Hinton Charterhouse
7-11	B.G.S. Archive	Norton St Philip
12-22*	Laporte Industries	Twinhoe
ST75NW		
Site investigations		
SCC4	Somerset County Council	Writhlington Bridge,Radstock
WW1	C.J.Associates for Wessex Water Authority	Peasdown St John
Boreholes and Wells		
1	B.G.S. Archive	Dunkerton No.2 (Withyditch) borehole
2	B.G.S. Archive	Dunkerton No. 1 borehole
3	B.G.S. Archive	Braysdown colliery shaft
4	B.G.S. Archive	Lower Writhlington colliery shaft

Map Reference and Numbers	Data Source	Locality
6	B.G.S. Archive	Foxcote colliery shaft
7	B.G.S. Archive	Shoscombe pit shaft
8-21*	Laporte Industries	Wellow
22-24	B.G.S. Archive	Baggridge
25	B.G.S. Archive	Braysdown Colliery
26	B.G.S. Archive	Woodborough Colliery shaft
27*	Laporte Industries	Wellow
28*	Laporte Industries	Combe Hay
29-30	Somerset C.C. (SCC4)	Writhlington Bridge
31	B.G.S. Archive	The Crest, Batk Hill, Wellow
32	Bristol Water Works Co.	Shoscombe pumping station
33	Ammerdown Estate Co.	Home Covert Faulkland
34-38	Wessex Water Authority (WW1)	Cam Valley Sewage Treatment Works

ST76NE

Site investigations

AV93	Exploration Associates	A46 Swainswick Hill
BCC1	Bath City Council	Larkhall Bath
BGS1	B.G.S. Archive	Snowhill redevelopment site Bath.
BGS2	B.G.S. Archive	Vulcan House, St. John's Road, Bath
BGS3	Bath Corporation Water Works	Bathampton Meadows
C.J.1	C.J.Associates	Claremont, Bath
C.J.2	C.J.Associates for Avon C.C.(AV68)	Banner Down, Bath
COU1	Coulson Ltd. for Somerset C.C.	A36 at Bathampton
FAI 1	Fairclough Civil Engineering Ltd	Pulteney Road
FE3	Foundation Engineering FG69/977/2	A46 Swainswick
FE4	Foundation Engineering F69/977/3	Swainswick site II
FE6	-ditto- for Mander, Raikes & Marshall	Upper Swainswick to A420
GE4	Geotechnical Engineering for British Avon River Authority	River Avon, Bath
GE7	- ditto -	Whitewells Nursery Estate

Map Reference and Numbers	Data Source	Locality
GE8	Geotechnical Engineering for Clarke Nicholls and Marcell	Midsummer Road Bath
GE11	- ditto - for Bath C.C. Estates Department.	Tyning Lane, Bath
GE12	Geotechnical Engineering	Camden Road, Bath
GE13	- ditto - for Bath C.C.2935	London Street, Bath
GIB 1	Sir Alexander Gibb and Partners	Batheaston Bypass-M4 link
GIB 3	Le Grand Sutcliff and Gell for S.W.R.C.U.	Batheaston By pass
GIB 4	Foundation Engineering 69/651	Bath to M4
GIB 7	Foundation Engineering 69/651	Batheaston Bypass/Tunnel Approach
GIB 8	Tarmac Construction	Batheaston Bypass
GIB 9	Mander Raikes Marshall	Swainswick
GIB 10	Foundation Engineering	Batheaston Bypass (Swainswick)
GIB 11	Foundation Engineering	Batheaston Bypass
GKN 2	GKN Reinforcements Ltd. for Somerset C.C.	A363 Sally-in-the-Woods
GKN 4	GKN Foundations Ltd. for Somerset C.C.	Wooley Mill
GRE 2	Ground Explorations Ltd.	A46 Swainswick
J.P.B.1	Johnson Poole & Bloomer 580F	Holcombe Close, Bathampton
SCC2	Somerset County Council	Bathford, footbridge
SCC3	Somerset County Council	Mount Road, Bath
SM1	Soil Mechanics Ltd.	Hedgemead Park
SS2	Strata Surveys Ltd.for M.P Kent	The Towers, Beacon Hill
SS3	Structural Soils for Somerset C.C. AV20	Dry Arch Landslip
SUB 1	Sub Soil Surveys 6013	Butchers Wood, Swainswick
SWIRL 5	S.U.C. (Bath Univ.) contr. Nott.Brodie	Sally-in-the-Woods
TW1 *	C.J. Associates 31229	St Johns Road, Bath
WIM3	Wimpey	SPA Nurses Home, Bath

Map Reference and Numbers	Data Source	Locality
WIM 5	Wimpey S6277	Rosehill Est.,Larkhall, Bath
WIM 7	Wimpey S6534	Underpass Bath
WIM 8	Geotechnical Engineering for Wimpey	Vehicular Tunnel Bath
WIM 10	Wimpey	Vehicular Tunnel Bath
CEM	Cementation	Bathampton Down Reservoir
Boreholes, wells, shafts		
164	B.G.S. Archive	Batheaston B.H. or shaft
<u>ST76SE</u>		
Site investigations		
AV21	Avon County Council 1983	Limpley Stoke Hill
AV92	Exploration Associates 1976	Limpley Stoke Hill
CAR	D.O.E. Cardington	Fox Hill
CDL 1	Contract Drilling Ltd. for B.S. Associates	George's Heath Bathwick Hill
CJ 3	C.J.Associates 611 for Avon C.C.	Ralph Allen Drive Bath
CJ 4	C.J.Associates for Hastings Clements and Associates	Abbeygate/Swallow streets, Bath
CJ 5	C.J. Associates for Norwest Holst Ltd.	Abbeygate Street,
CL 1	Cryer Liddiard	Trinity Street, Bath
EA 1	Exploration Associates S1479	A36 Claverton
FE 2	Foundation Engineering for L. G. Mouchel	Claverton Street Relief Scheme Bath
GCM 1	G.C.Mander & Partners for Bath C.C.	Bath Southern Loop Road, Combe Down
GE1	Geotechnical Engineering for Bath C.C. 1974	Calton Road Bath
GE2	- ditto - 1365	Pulteney Road Railway Bridge
GE17	- ditto - for Bath C.C.	Roman Reservoir Bath
GE18	- ditto - for L.G. Mouchel	Pump Room/York Street Bath
GE19	- ditto -	Bathwick Railway Tunnel
GE20	- ditto - for L.G. Mouchel	Bath Pump Room
GE21	- ditto - Avon River Auth.	Flood protection scheme
GKN 1	GKN Reinforcements Ltd. for Somerset C.C.	A363 Sally-in-the-Woods

Map Reference and Numbers	Data Source	Locality
GKN3	GKN Reinforcements Ltd. for Somerset C.C.	A363 Sally-in-the-Woods
GKN5	GKN Foundations for Module 2 Ltd	North Parade Road, Bath
G55	Geostrata for Costains	Claverton Street, Bath
GTS8	Geotesting Services for Parsons Brown	Broad Quay Bath
GTS9	Geotesting Services for Concept Homes 7318	The Priory, Bathwick Hill Bath.
HS1	Soil Mechanics for Harris and Sutherland	Bath University
HS2	- ditto -	Bath University
MR1	C. J. Associates	Longwood House, Claverton Down Road, Bath
NB	Nott Brodie for Parsons Brown	Broad Quay Bath
SM2	Soil Mechanics 3722/1	New Stores at Bath
SM3	- ditto - for Ove Arup 5398/1	Southgate Street Bath
SM5	- ditto - 4734	Calton Rd/Holloway Rd. Bath
SRE1	Soil and Rock Engineering for Stature Investments	Manvers Street, Bath
SS4	Strata Surveys B40409	Ham Gardens, Bath
SWIRL4	SWIRL (Bath Univ.) for Avon C.C.	Limpley Stoke Viaduct
SWIRL5	SWIRL (Bath Univ.)contr. Nott Brodie	Sally-in-the-Woods A363
VE1	Veryard and Partners	Sports ground Brass Knocker
WIM1	Wessex Water Authority contr. Wimpey S14111	Brass Knocker Lane, Limpley Stoke
WIM2	- ditto - S/13919	Tucking Mill, Bath
WIM4	Wimpey for L.G. Mouchel & Ptnrs.	New Avon Bridge, Bath
GS6	Geostrata for Bath C.C.	Greendown Place, Combe Down Bath
CJ7	C.J. Associates	P.O. Sorting Office, Manvers Street.
CJ8	C.J. Associates for C.H.Beazer	Combe Road, Combe Down Bath
Boreholes and shafts		
11	B.G.S. Archive	Bristol Avon Water Authority
95-97	B.G.S. Archive	11 Fox Hill Drainage

Map Reference and Numbers	Data Source	Locality
ST76SW		
Site investigations		
AV124	Avon County Council	Combe Hay Slip
BCC2	City of Bath	Corporation Dep, Midland Rd.
BCC5	Mouchel & Partners for B.C.C.	Newbridge R.Avon, Bath
BCC6	Geotechnical Engineering Rep. 1836, Elmot Ltd. for B.C.C.	Lansdown view, the Hollow and Whiteway Drainage
B.R.C.1	British Reinforced Concrete for Ove Arup.	Bath Technical College
BU1	Bristol Univ.(Engineering Lab)	S.I.Housing Estate, Kingsway
C.J.6	C.J. Associates for Hastings Clements and Associates.	Wells Road, Bath
FE1	Foundation Engineering	Bath vehicular tunnel approach roads.
GS15*	Geotechnical Engineering for Fullers Earth Union 276	Sulis Manor
GE16	-ditto- for Bath C.C.Estates Dept.	Wellesway Bath
GE23	-ditto- for Bath C.C.	Seven Dials redevelopment
GE24*	-ditto- for P.Brett Assoc.2079	Locksbrook Road, Bath
GE25	-ditto- for Bath C.C. 2261	Argyle Works, Lower Bristol Road, Bath.
GE26*	-ditto- for British Rail 2932	Locksbrook Road, Bath
GE27*	-ditto- for Theatre Royal 2988	Theatre Royal, Bath
GE28*	-ditto- for Clarke, Nicholls and Marcel 3134	Old Bond St/Trim St.Bath
GE29	-ditto- for Avon C.C. 3321	Hawthorn Grove, Bath
GE30*	-ditto- for Mowlem 3350	Bath Spa restoration
GE31*	-ditto- for Nobles of Gloucester	Westgate Buildings, Bath
GE32	-ditto- for Bath C.C. 3586	Englishcombe Lane, Bath
GE33	-ditto- 2087	Berewyke Estate, Bath
GE37	-ditto- V.Toogood Property Ltd	Odd Down Lodge, Bath
GS1	Geostrata Ltd. for C.H.Beazer	Kingsway Estate
GS2	Geostrata for Alan Grout & Ptrs.	New King Street, Bath
GS3	Geostrata for K.J. Halloway	Odd Down, Bath

Map Reference and Numbers	Data Source	Locality
GS4	Geostrata for S.Revesz Assoc.	Cut Route, Bath
GS6	Geostrata for D.Jubb & Partners	Oolite Road, Odd Down, Bath
LG1*	C.J. Associates 21130	Midland Bridge Road, Bath
LK1*	C.J. Associates	Stanway Close, Odd Down, Bath
MIN1	Ministry of Works	Bath Crown Building, Charles Street.
NB1	Nott Brodie & Co.for E. Ireland Ltd.	Broad Quay, Bath
OAK1	Oakley Soils and Concrete Eng.Ltd.	Midford Road, Combe Down, Bath
PB3	Parsons Brown (contr.Geostrata)	Avon Street Carpark, Bath
PB5	Parsons Brown for Star Developments	Kingsmead Square, Bath
PFD	Pre Foundation Design Ltd. for E. Green and Partners	Green Park Station, Bath
SCC1	Somerset County Council	Brook Road Footbridge, Bath
SS1	Strata Surveys Ltd.B41202	Southdown and South Twerton
SS5	Structural Soils for M.P Kent 4438	Twerton, Bath
WC1*	Wilcox Cooper contr. GKN Keller	Magdalen Avenue
WSA1	W.S.Atkins and Partners	Weston Island, Bath
WIM7	Wimpey S/6534	Underpass, Bath
WIM11	Wimpey S7045	Lansdown View, The Close, Twerton, Bath
SM4	Soil Mechanics Rep. 6173	Calton Road, Bath
MB1	Avon C.C.	Millbrook Training Centre, Twerton
MPK1	M.P.Kent for Bath C.C.	Calton Road, Bath
Boreholes, wells shafts.		
2	B.G.S. Archive	Rush Hill No. 5
3*	- ditto -	Combe Hay
11,12,13,14*	- ditto -	English Combe
25*	- ditto -	Combe Hay
26*	- ditto -	Combe Hay
27/28	- ditto -	Twerton Colliery shafts 1, 2
30	- ditto -	Combe Hay Pumping Station
31	- ditto -	Twerton Mill

Map Reference and Numbers	Data Source	Locality
ST76NW		
Site investigations		
BCC2	City of Bath	Corporation Depot, Midland Road
BCC3	City of Bath	
BCC4	City of Bath	The Mount, Beacon Hill
FE1	Foundation Engineering Ltd.	Bath Vehicular tunnel approach roads.
FE5	Foundation Engineering Ltd. F69/723	A4 Globe Inn to Twerton Fork
GAS1	Gas Board	New V.R House Bath Gas Works
GE3	Geotechnical Engineering	Bath District Hospital
GE5	Geotechnical Engineering for Avon Water Authority	River Avon Bath
GE6*	-ditto- for Clark, Nichols & Marcel	Combe Park Hospital
GE9	Geotechnical Engineering	River Avon Bath
GE10	Geotechnical Engineering	Newbridge Works, Bath
GE14	Geotechnical Engineering	River Avon
GRE1	Ground Explorations Ltd.	The Maltings, Bath
GTS1	Geotesting Services Ltd.	Ormonde House, Bath
GTS2	Geotesting Services Ltd.	Winifred Lane, Bath
HD1	C.J. Associates 11010	Onega Garage, Upper Bristol Road, Bath
NB2	Nott Brodie and Co. for Bath C.C.	Ballance Street, Bath
PB4	Parsons Brown (contr.Nott Brodie)	Cavendish Lodge, Bath
SCC5	Somerset County Council	Lansdown Road, Bath
SWIRL1	SWIRL(Bath Univ)for County of Avon	A4-A36 Link at Windsor Bridge, Bath
SWIRL2	- ditto -	- ditto -
SWIRL3	- ditto -	St Stephens Road, Bath
WSA2	W.S.Atkins and Partners	Old Gas Works
WIM6	Wimpey S/20651	Lansdown Grove, Bath
WIM7	Wimpey S6534	Underpass, Bath
WIM9	Wimpey S7496	Underpass, Bath

Map Reference and Numbers	Data Source	Locality
Boreholes, wells, shafts		
28	B.G.S. Archive	Newton Meadows
29	B.G.S. Archive	Bath Racecourse Lansdown
30	B.G.S. Archive	Lansdown golf course
31	B.G.S. Archive	Bath Brewery Co.
32	B.G.S. Archive	Western Maltings, Bath
33	B.G.S. Archive	Beckfords Tower well
34	B.G.S. Archive	Charlcombe Grove Farm
35	B.G.S. Archive	Kingswood School Lansdown
ST85NE		
Site investigations		
GTS6*	Geotesting Services 7508	Bowyers Factory Trowbridge
GTS7*	- ditto - 7757	- ditto -
ST85NW		
Site investigations		
CGS72	Cementation Ground Engineering Ltd	Somerset Bridges, Farleigh Hungerford
Boreholes, wells, shafts		
2	B.G.S. Archive	Old Court Hotel, Avoncliffe
3	B.G.S. Archive	Slawford Mill Farm, Wingfield
4	B.G.S. Archive	Snorlton Farm, Wingfield
5,6	B.G.S. Archive	Wingfield House, Wingfield
7	B.G.S. Archive	Arnolds Farm, Wingfield
8	B.G.S. Archive	Trowbridge and Melksham Water Board
9	B.G.S. Archive	Badgers Brake, Vagg's Hill
10	B.G.S. Archive	Trowbridge Sewage Works
11,12,13	B.G.S. Archive	Westwood Mine
ST86NE		
Site investigations		
GE35*	Geotechnical Engineering Rep.2104	S.I. Housing of Potley
CEGB*	CEGB Rep.DC/MTS/SM335(confidential)	S.I.Melksham substation
Boreholes, wells, shafts		
22	B.G.S. Archive	B.G.S. Atworth, (Denleys Farm)
23	B.G.S. Archive	Lacock

Map Reference and Numbers	Data Source	Locality
24	B.G.S. Archive	Lacock
26	B.G.S. Archive	Spring quarry
27	B.G.S. Archive	Wadswich Road
28	B.G.S. Archive	Greenhill
29	B.G.S. Archive	Gastard Estate
30	B.G.S. Archive	Vauxhall Farm
31	B.G.S. Archive	Gastard
32	B.G.S. Archive	Gastard Estate
33	B.G.S. Archive	Hayes House
34	B.G.S. Archive	Snow Hill House
35	B.G.S. Archive	Gastard Estate
36	B.G.S. Archive	Mendip Eng.Co.
37	B.G.S. Archive	Shawshill House
38	B.G.S. Archive	Corsham
39	B.G.S. Archive	Corsham

<u>ST86SE</u>

Site investigations

GE34*	Geotechnical Engineering for British Rail	Holt Junction
WCC	Structural Soils Ltd. for Wilts C.C	Melksham (Railway Bridge)
WEM1	Wembley Labs. Ltd. for W.C.C	Semmington Bridge, Wilts.
CEGB2	Ground Exploration for Elec.Board	Holt Junction

Boreholes, wells, shafts.

1	B.G.S. Archive	Holt
2	B.G.S. Archive	Holt
3	B.G.S. Archive	Chalfield
4	B.G.S. Archive	Chalfield
5	B.G.S. Archive	Norrington
6	B.G.S. Archive	Nestles Co.Ltd. Staverton
7	B.G.S. Archive	Holt
8	B.G.S. Archive	Bedding factory Holt
9	B.G.S. Archive	Holt
10	B.G.S. Archive	Beavins Ltd. The Tanyard Holt
16	B.G.S. Archive	Norrington Common
17	B.G.S. Archive	Cooperative Wholesale Depot

Map Reference and Numbers	Data Source	Locality
ST86SW		
Site investigations		
GRE3	Ground Explorations Ltd. for Thurlow Lucas and Jones	Bradford on Avon
GE36*	Geotechnical Engineering for British Waterways 3290	Bradford on Avon
AM*	A. Masters and Associates	Berryfield Park
Boreholes, wells, shafts.		
4	B.G.S. Archive	Chalfield
5	B.G.S. Archive	Farleigh
6-9	B.G.S. Archive	North Wilts.Water Board
10	B.G.S. Archive	Belcombe P.S. Winsley
11	B.G.S. Archive	Cumberwell Farm
12	B.G.S. Archive	Woodley Grange
ST86NW		
Site investigations		
WCC1	Wiltshire County Council	A4 Trunk Road at Box
PSA3	Foundations and Ground Engineering Branch of PSA Rep.FGE.250	MAC Building Copenacre
GTS	Geotesting Services for Bovis	Fiveways reservoir
Boreholes and wells		
1	B.G.S. Archive	Hulberts Farm, Middlehill
2	B.G.S. Archive	Middlehill
3	B.G.S. Archive	Ennox Wood, Corsham
4	B.G.S. Archive	Lower Hill, Box
5	B.G.S. Archive	Dapston Lease, Farleigh
6	B.G.S. Archive	Hobbs Bottom Farm, Atworth
7	B.G.S. Archive	Hobbs Bottom Farm, Atworth
8	B.G.S. Archive	Kingsdown Asylum, Box.
ST87SE		
Site investigations		
PSA1	Exploration Associates Ltd.	RNSD Copenacre
Boreholes, wells, shafts.		
1	B.G.S. Archive	Biddestone
2	B.G.S. Archive	Hartham Park Corsham
3	B.G.S. Archive	Corsham Court Estate

Map Reference and Numbers	Data Source	Locality
4	B.G.S. Archive	Corsham Court Estate
5	B.G.S. Archive	- ditto -
6	B.G.S. Archive	Pickwick Brewery water
7	B.G.S. Archive	Allington

ST87SW

Site investigations

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Boreholes, wells, shafts

1	B.G.S. Archive	Lucknam
2	B.G.S. Archive	Duncombe Hill
3	B.G.S. Archive	Colerne

ST96SW

Site investigations

GTS3	Geotesting Services for Rush and Tomkins	Avon Rubber Co.
GTS4	Geotesting Services 7949	Avon Rubber Co.
GTS5	Geotesting Services 8372	Avon Rubber Co.

GLOSSARY

Activity A
The contribution of the clay mineral types present to the overall plasticity. (A = P.I./% clay size). Ref. Skempton, 1953.

Adit
A level entrance tunnel to a mine.

Aggressive water
Water containing sulphates in solution or acids which are liable to attack engineering materials, in particular concrete and steel.
Refs: CP2004, 1972. BS5930, 1981.

Alluvium
Detrital material which is transported by a river and deposited at points along the flood plain of a river. Commonly composed of clays, silts, sands and gravel.

Aquiclude
An impermeable stratum which acts as a barrier to the passage of water.

Aquifer
A bed or group of strata which yields water, either because of its porosity or because it is pervious.

Artesian structure
A series of sedimentary rocks disposed in such a way that an aquifer holds water under a pressure head between two layers of impermeable strata.

Atterberg Limits
The liquid limit, plastic limit and shrinkage limit. These are all water contents of clay, each in a certain condition defined in B.S. 1377.

Bedding plane
A bedding plane is a surface parallel to the surface of deposition which may or may not have a physical expression.

Block drop out
Type of roof fall from mine where single blocks bounded by joints fall from roof bed.

California Bearing Ratio (C.B.R.) test
A standardised testing procedure for comparing the strengths of base courses of roads and airstrips.

Camber
The result of the slow downward movement of strata due to the removal or plastic deformation of the underlying strata by relatively deep seated processes under glacial or periglacial conditions.

Carbonate test
A test to measure the amount of carbonate (usually calcium carbonate) in a soil.

Casagrande chart

A graph for fine-grained soils of Plasticity Index (P.I.) v. Liquid Limit (L.L.) which demonstrates degree of plasticity and distinguishes between organic and silty soils. It forms parts of the "British Soil Classification for Engineering Purposes" (BSCS).
Ref. BS5930, 1981

Caving (in mining)

Mining method involving the removal of mineral without leaving support in the void created. The roof is allowed to collapse into the void.

Characteristic angle

Characteristic angles are slope angles that occur most frequently either on all slopes, under particular conditions of lithology or climate, or in a particular area.

Chert

A rock composed mainly of a very finely crystalline form of silica.

C.L.A.S.P.

Consortium of Local Authorities Special Building Program, a system of building devised to minimise the effects of coal mining induced subsidence on structures.

Clay Minerals

Those constituents of a clay which produce its plastic properties. Generally occur as minute platy or, more rarely, fibrous crystals. An important characteristic is the ability to lose or take up water according to temperature and the amount of water present.
Some clay minerals contain loosely bonded cations which can easily be exchanged for others (base exchange).

Cohesive Soil

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

Compaction Test

A test to find maximum dry density of a fill or granular soil by standard mechanical effort at different moisture contents. There are several versions of this test (see BS 1377).

Competent Strata

A rock layer which during folding flexes without appreciable flow or internal shear.

Conchoidal

Describes a form of curved, concentrically ribbed fracture of certain rocks.

Cone Penetration test

The testing of soils by pressing a standard cone into the ground under a known load and measuring the penetration.

Conglomerate

A coarse-grained rock consisting of rounded rock fragments, generally in a matrix of finer sediment.

Conjugate Shears

Two sets of shear planes symetrically inclined to the principal stress direction after the failure of a rock mass under load.

Crinoidal Limestone

A limestone in which the fossil remains of marine animals known as crinoids are common.

Crown Hole

Circular subsidence feature on the ground surface due to upward migration of a collapse in underground workings (also Post Hole).

Deformation Moduli

The ratio of stress (force) to strain (deformation) for any material. Moduli are quoted for elasticity, shear, and compressibility.

Dip

The true dip of a plane is the angle between the plane and the horizontal measured at right angles to the strike of the plane (strike = intersection of plane and the horizontal).

Dip-and-fault structure

A structure in which competent rock strata are broken into blocks by numerous minor faults which are aligned parallel to cambered valley slopes; the inter-fault blocks tilt valleywards.

Drift deposits

Superficial deposits of variable thickness and distribution.

Effective Cohesion (C')

Non frictional component of shear strength, characteristic of clays in a drained condition. Units: KPa (=KN/M^2)

Elasto-plastic analysis

A model of the behaviour of a soil or rock based on two stages:
1) elastic (i.e. recoverable) deformation and 2) plastic (i.e. non-recoverable) deformation or flow.

Electro Osmotic Forces

Weak forces which act between clay minerals and cations.

Factor of Safety

The stress at which failure is expected, divided by the design stress. In the case of slopes, the calculated shear strength of the slope divided by the shear stress acting on the slope.

Fault

A fracture in rock along which there has been an observable amount of displacement.

Fill

Superficial material artificially placed. May be natural material e.g. coal spoil and rock waste or artificial material e.g. slag, building rubble. Properties variable.

Fireclay

A fossil clay soil found in association with coal seams.

Fracture Spacing Index (If)

A measure of the average length of intact rock core pieces. The unit length divided by the number of fractures within the unit.

Freestone
A rock which can be sawn in any direction and which is suitable for carving and moulding.

Friction Angle
For dry or submerged sands the angle of internal friction equals the angle of repose. Angle of internal friction is related to the roughness and relative size of the particles.

Fuller's Earth
A clay rich in the clay mineral montmorillonite and capable of absorbing oils and grease.

Ground Water
Water contained in the soil or rock below the water table.

Gull
A tensional gash associated with cambering. The fissure often tapers downwards and is filled with debris.

Head
Superficial material; the result of solifluction, hill wash, soil creep. Locally derived.

Induration
Process by which soft sediment becomes hard rock.

Ironshot
Rocks containing ooliths rich in ferric iron compounds.

Isocline
A line which joins points of equal slope angle on a slope.

Isopachyte
A line joining points of equal bed thickness.

Joint
A fracture in a rock between the sides of which there is no observable relative movement.

Landslip
The perceptible downslope movement of rock and soil by falling, sliding or flowing under the influence of gravity as a result of relatively shallow processes.

Limiting Equilibrium
A state where the forces promoting a process are in exact balance with the forces resisting it.

Liquidity Index (L.I.)

$$= \frac{\text{water content of sample-water content at plastic limit}}{\text{Plasticity Index}}$$

It is 1.0 for a clay at the Liquid Limit and 0 for a clay at the Plastic Limit.

Liquid Limit
The moisture content at the point between the liquid and the plastic state of a clay.

Lithostratigraphy
The characteristics of sediments, their relationships in time and their correlation.

Longwall
Type of mining where a mineral is extracted along a working face several hundred metres long and the extracted area is allowed to collapse as the face advances.

Marl
A calcareous mudstone having between 35% and 65% carbonate content. Keuper Marl, having less than 35%, is not strictly a marl.

Mass Permeability
The permeability of a soil or rock formation as a whole (i.e. including discontinuities) as opposed to the permeability of the fabric alone.

Montmorillonite
Group of clay minerals also called the fuller's earth or smectite group. The group is notable for the way it takes up and loses water.

Oolite
A rock composed mainly of small spherical particles (resembling the roe of a fish).

Organic Test
Test to determine the organic content of silts and clays. Organic silts and clays have very low bearing capacities being highly compressible.
Ref. BS1377, 1975.

Overconsolidation
Overconsolidated clay is one that in previous geological times was loaded more heavily than now and consequently has a tendency to expand if it has access to water.

Overconsolidation Ratio (O.C.R.)
The O.C.R. is the maximum previous overburden pressure divided by the present overburden pressure. An 'overconsolidated' soil thus has an O.C.R. greater than unity.

Overthrust
A low-angle fault in which older rocks are laterally displaced and come to overlie younger rocks.

Paper shale
A shale which splits uniformly into very thin laminae.

Particle Size Analysis
The proportions by weight of the different particle sizes in soil or sand determined by mechanical analysis so as to build up a grading curve.

Peak Strength
Maximum strength of a material which is shown immediately before failure.

Periglacial

Term applied to the region adjacent to an ice sheet. Temporary snow caps and permafrost may develop in these areas.

Piezometric surface

An imaginary surface above or within the ground at which the water level would settle in a tube whose lower end passes below the water table. It indicates the level to which the water from an artesian well could rise.

Pillar

Mining term for the block of unworked mineral which is left to support the roof of the working.

Pisolite

A rock composed mainly of large spherical particles.

Plasticity Index

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

Plastic Limit

The water content at the lower limit of the plastic state of a clay. It is the minimum water content at which a soil can be rolled into a thread 3mm in diameter without crumbling.

Point Load test

Index test to give an indication of strength usually carried out on rock core.

Post Hole

See Crown hole.

Potentiometric surface

The surface that joins all the points to which groundwater rises in wells and boreholes in a particular aquifer. It includes the piezometric surface in a confined aquifer and the water table in an unconfined aquifer.

Proctor Compaction Test

See Compaction Test.

Pyrite

A widespread mineral composed of iron and sulphur. Produces acidic breakdown products on weathering.

Relic Shears

Shear surfaces formed during ancient movements but which may still be at residual shear strength.

Residual Shear strength

The shear strength retained by a material after failure. The residual shear strength may be much lower than the peak shear strength in many cases.

Rock Fabric
The rock fabric refers to the condition of the rock as a whole including structural properties such as jointing, bedding.

Rock Mass
The rock considered as an entirety including petrology, structure and gross properties.

Rock Penetration test (R.P.T.)
Penetration test for rock adapted from the standard penetration test for soil.

Rock Quality Designation (R.Q.D.)
A measure of core recovery incorporating only those pieces of sound core ⩾100mm in length.

Sensitive (Clay)
A clay whose strength decreases significantly when disturbed.

Sensitivity Ratio
A measure of how much remoulding may affect a clay. It is the ratio of the unconfined compressive strength in the undisturbed state to that in the remoulded state.

Septarian nodule
Large nodules of muddy limestone containing calcite-filled veins.

Shear Box
Equipment used in the laboratory to determine the shear strength and residual shear strength of a soil.

Shear Strength
The stress at which a material fails in shear.

Shortwall
Type of mineral extraction (see longwall) along a face some tens of metres long.

Slope shaft
An inclined entrance tunnel to a mine.

Smectite
See Montmorillonite

Soil
In the engineering sense, soil is gravels, sands, silts, clays, peats and all other materials including topsoil down to bedrock.

Solifluction
The slow downhill movement of superficial material as a result of the alternate freezing and thawing of the contained water.

Spalling
The superficial flaking of rock under stress.

Stall
The volume between supporting pillars in a mine from which mineral has been extracted (see also room).

Standard Penetration Test
An in-situ test for soil where the number of blows with a standard weight falling through a standard distance to drive a standard cone or sample tube a set distance is counted. A measure of a soils bearing capacity.

Subsidence
Downward movement of the ground surface for any reason.

Subsurface water
Any water below the ground surface.

Superficial material
Any material lying on bedrock.

Surcharge
Pressure due to additional permanent or temporary load applied to the ground.

Swelling
Any soils which swell when they take in water and shrink when they dry out may cause disruption of building foundations. Unusual in northern Europe. Usually applies to clays containing active clay minerals.

Terrace
An alluvial deposit left on the lower valley slopes after an episode of down cutting by the river.

Triaxial Test
A test of the shear strength of a soil sample contained in a rubber membrane surrounded by liquid under pressure. A load is applied by a piston to one end and the deformations, loads and pressures are recorded.

Unconfined Compressive Test
A crushing test on a soil or rock which is carried out without lateral restraint. The uniaxial compressive strength is measured.

Unconformity
A break in the history of sedimentation represented by missing strata and often by a structural contrast between superimposed sets of strata.

Undrained shear strength
A shear box or a triaxial compression test of a cohesive soil carried out without allowing the sample to drain. Applies to clays and silts.

Uniaxial Compressive Strength
The stress at the point of failure of a rock or soil in an unconfined compressive test.

Valley bulge
A structure in which incompetent strata are forced upwards in valley floors, induced by stress relief.

Vane Shear test
A four bladed vane is inserted into a soil. It is then rotated with a measured force until the soil shears. This test gives shear strengths either in situ or in the laboratory.

Water Table

The surface of the standing water level. The water table is the boundary between the zone of saturation below it and the zone of aeration above it.

Youngs Modulus

The modulus of elasticity of a material (i.e. stress ÷ strain).

BIBLIOGRAPHY

General Geology

Anstie, J. 1873
Somersetshire and Gloucestershire Coal-fields. Sections of shafts sunk in the Upper Series of Coal Measures.
Vert. Sect. Sheets No. 48 and 49,
Geol. Surv. G.B.

Arkell, W.J. 1933
The Jurassic System in Great Britain, 681 pp.
(Oxford: Clarendon Press).

Arkell, W.J. and Donovan, D.T. 1952
The Fuller's Earth of the Cotswolds and its Relation to the Great Oolite.
Q.J.G.S. Lond., 107, Pt.III, 227-253

Buckman, J., 1879
On the so-called Midford Sands.
Q.J. London, Vol. 35, 210-316

Buckland, W. and Conybeare, W.D., 1824
Observations on the South-Western Coal District of England
Trans. Geol. Soc. London, Ser. 2, 1, 210-316

Cantrill, T.C. and Pringle, J., 1914
On a boring for coal at Hemington, Somerset.
Summ. Prog. Geol. Surv. G.B. for 1913, 98-101.

Cave, R. and Cox, B.M., 1975
The Kellaways Beds of the area between Chippenham and Malmesbury, Wiltshire
Bull. Geol. Surv. G.B., No. 54, 41-66

Cox, L.R., 1941.
Easter field meeting, 1940. Bath
Proc. Geol. Assoc., Vol. 52, 16-35

Donovan, D.T., 1948.
Some exposures in the Jurassic Rocks at Bath
Proc. Bristol. Nat. Soc., Vol. 27, Pt. 4, 329-342

Donovan, D.T., 1954
A Bibliography of the Palaeolithic and Pleistocene Sites of the Mendips, Bath and Bristol Area.
Proc. Univ. of Bristol Spelaeol. Soc., 1954, 7(1)

Donovan, D.T., 1955
The Zonal Stratigraphy of the Blue Lias around Keynsham, Somerset
Proc. Geol. Ass., Vol. 66, Pt. 3, 182-211

Donovan, D.T., 1964. The Great Oolite and Forest Marble near Bath. In the Cotswold Hills.
Geol. Assoc. Guide, No. 36, 25-34

Donovan, D.T., 1960.
Gravels below the Flood Plain of the Bristol Avon at Keynsham.
Proc. Bristol Nat. Soc., Vol. 30, 55-66

Donovan, D.T. and Kellaway, G.A., 1984.
Geology of the Bristol district special sheet: The Lower Jurassic rocks.
Mem. Brit. Geol. Surv.

Fry, T.R., 1970.
Section of Lias below the Midford Sand at Bitton Hill, Bitton, Gloucestershire.
Proc. Bristol Nat. Soc., Vol. 31, Pt. 6, 631-634

Gorham, A., 1930.
The Upper and Lower Junctions of the Midford Sands at Limpley Stoke, south-east of Bath.
Geol. Mag., Vol. 67, 289-297.

Green, G.W. In press
Bristol and Gloucester District (British Regional Geology).
3rd Edit.

Green, G.W. and Donovan, D.T., 1969.
The Great Oolite of the Bath Area.
Bull. Geol. Surv. G.B., Vol. 30, 1-63.

Greenwell, G.C. and McMurtrie, J. 1864.
The Radstock Portion of the Somersetshire Coalfield.
(Newcastle-On-Tyne).

Hawkins, A.B., 1966.
The geology of the Keynsham By-pass.
Proc. Bristol Nat. Soc., Vol. 31, Part 2, 195-202

Hawkins, A.B., 1976.
'Jurassic Rocks of the Bath Area' in Geological Excursions in the Bristol District.
Edit. Savage, R.J.G. Publ. University of Bristol, 1977.

Hawkins, A.B. & Kellaway, G.A., 1970.
"Field meeting at Bristol & Bath with Special reference to New Evidence of Glaciation".
Proc. Geol. Ass. 82 pp 267-292

Hull, E., 1857.
Geology of parts of Wiltshire and Gloucestershire (sheet 34).
Mem. Geol. Surv.

Kellaway, G.A. (In prep.)
Geology of the Bristol District (special sheet)
Mem. Brit. Geol. Surv.

Kellaway, G.A. and Welch, F.B.A., 1955.
'Upper Old Red Sandstone and Carboniferous' in Bristol and its adjoining counties'.
E.P. Publishing Company, Wakefield, Yorkshire.

Lonsdale, W., 1832.
On the Oolite District of Bath.
Trans. Geol. Soc. London, Ser. 2, Vol. 3, Part 2, 241-276

Moore, L.R., 1938
The Sequence and Structure of the Radstock Basin.
Proc. Bristol Nat. Soc., Vol. 8, Pt. 3 (1937), 267-305

Moore, L.R., 1941.
The presence of the Namurian in the Bristol District
Geol. Mag., Vol. 78, 279-292

Moore, L.R. and Trueman, A.E., 1937.
The Coal Measures of Bristol and Somerset.
Q.J. London, Vol. 93, 195-240.

Moore, L.R. and Trueman, A.E., 1939.
The Structure of the Bristol and Somerset Coalfields.
Proc. Geol. Assoc., Vol. 1, Pt. 1, 46-67

Palmer, L.S., 1930
The Pleistocene Deposits of the Bristol District.
In the Geology of the Bristol District,
Bristol Association Handbook, 48-56.

Penn, I.E., Merriman, R.J. and Wyatt, R.J., 1979.
A Proposed Type-section for the Fuller's Earth (Bathonian), based on the Horsecombe Vale No. 15 Borehole near Bath, with details of contiguous strata.
Rep. Inst. Geol. Sci., No. 78/22, 1-24.

Penn, I.E. and Wyatt, R.J., 1979.
The Stratigraphy and Correlation of the Bathonian Strata in the Bath-Frome Area.
Rep. Inst. Geol. Sci., No. 78/22, 25-88.

Pringle, J., 1922.
On a Boring for Coal at Westbury, Wiltshire.
Summ. Prog. Geol. Surv. G.B. for 1921. 146-155.

Ramsay, A.C. and others. 1858.
Geology of parts of Wiltshire and Gloucestershire.
Mem. Geol. Surv. G.B.

Reynolds, S.H., 1912.
A geological Excursion Handbook for the Bristol District.
Bristol.

Richardson, L., 1907.
The Inferior Oolite and contiguous deposits of the Bath-Doulting District.
Q.J. Geol. Soc. London, Vol. 63, 383-436.

Richardson, L., 1909.
On the Sections of Inferior Oolite and the Midford-Camerton Section of the Limpley Stoke Railway, Somerset.
Proc. Geol. Ass., Vol. 21, 97-100.

Richardson, L., 1910.
The Inferior Oolite and Contiguous Deposits of the South Cotteswolds.
Proc. Cott. Nat. Field Club, Vol. 17, 63-136.

Richardson, L., 1911.
The Rhaetic and Contiguous Deposits of West, Mid and Part of East Somerset.
Q.J. London, Vol. 67, 1-74.

Richardson, L. 1925.
Section of No. 1 Pit, Dunkerton Collieries, Dunkerton, Somerset.
Proc. Somerset Arch. Nat. Hist. Soc., Vol. 70, 117-121.

Richardson, L. 1935.
Some Sections of the Fuller's Earth in the South Cotteswolds.
Proc. Cott. Nat. field Club, Vol. 25, 279.

Richardson, L., 1947.
On the Lias at the Monkswood Reservoir. Bath City Waterworks.
Proc. Cott. Nat. Field Club, Vol. 29, 80-81.

Tate, R. 1875.
On the Lias about Radstock.
Q.J. London, Vol. 31, 493-510.

Tawney, E.B., 1875.
Notes on the Lias in the neighbourhood of Radstock.
Proc. Bristol Nat. Soc., New Ser., Vol. 1, Part 2, 167-189.

Torrens, H.S., 1967.
'Some Fuller's Earth Sections in the South Cotteswolds'.
Proc. Bristol Naturalists Soc., Vol. 31, Pt 4, 429-438.

Tutcher, J.W., 1919.
Excursion to the Bristol District. The Lias and Coal Measures of the Radstock District.
Proc. Geol. Assoc., Vol. 30, 116-118.

Tutcher, J.W., 1923.
Some Recent Exposures of the Lias (Sinemurian and Hettangan) and Rhaetic about Keynsham.
Proc. Bristol Nat. Soc., Vol. 5, 268-278.

Tutcher, J.W., 1929.
Excursion to the Bristol District - Dundry and Radstock.
Proc. Geol. Assoc., Vol. 40, 174-176.

Tutcher, J.W. and Trueman, A.E., 1925.
The Liassic Rocks of the Radstock District (Somerset).
Q.J. London, Vol. 81, 595-666.

Vaughan, A. and Tutcher, J.W., 1903.
The Lower Lias of Keynsham.
Proc. Bristol Nat. Soc. (New Ser.), Vol. 10, 2-55.

Winwood, H.H., 1909.
Notes on a Well-sinking in the Great Oolite of Lansdown, Bath.
Geol. Mag. (Dec.5), Vol. 6, 119-120.

Winwood, H.H. and Wickes, W.H., 1893.
Excursion to Bath, Midford, etc.
Proc. Geol. Ass., Vol. 13, 132-137.

Woodward, H.B., 1876.
Geology of East Somerset and the Bristol Coalfields.
Mem. Geol. Surv.

Woodward, H.B., 1887.
The Geology of England and Wales, with notes on the physical features of the country.
670 pp (London; G. Philip).

Woodward, H.B., 1894.
The Jurassic Rocks of Britain, Part 4, The Lower Oolite Rocks of England (Yorkshire excepted).
Mem. Geol. Surv. G.B.

Mineral Resources

Bath Stone Firms Ltd. 1896.
Bath Stone Quarries.
The Quarry.

Forster, A. and McCann, D.M., 1976.
An Assessment of the Effects of Resin Impregnation on the Physical Properties of Some Common Building Stones.
Inst.Geol. Sci. Rep. 76/3.

Green, G.W. and Donovan, D.T., 1969.
The Great Oolite of the Bath Area.
Bull. Geol. Surv. G.B., Vol. 30, pp 1-63.

Hallam, A. and Sellwood, B.W., 1968.
Origin of Fuller's Earth in the Mesozoic of Southern England.
Nature, London, Vol. 220, 1193-1195.

Harris, G.F., c. 1893-4.
Manuscript Notes of Bath Stone Quarries.
B.G.S. Library.

Harris, G.F., 1895.
Bath Stone.
The Builder, London, Vol. 68, Pt. 1, 273-8; Pt. 2, 291-5.

Highley, D.E., 1972.
Fuller's Earth.
Mineral Dossier No. 3, H.M.S.O.

Hudson, K., 1971.
The Fashionable Stone.
Bath 120 pp.

Jeans, C.V., Merriman, R.J. and Mitchell, J.G., 1977.
The Origin of Middle Jurassic and Lower Cretaceous Fuller's Earth in England.
Clay Miner, Vol. 12, 11-44.

Leary, E., 1983.
The Building Limestones of the British Isles.
Building Research Establishment Report, 91 pp.

Newton, E.F., 1934.
Petrography of Fuller's Earth Deposits.
Econ. Geol., 29, 307-308.

Newton, E.F., 1937.
The Petrography of some English Fuller's Earths and the Rocks Associated with Them.
Proc. Geol. Ass., Vol. 48, 175-197.

Penn, I.E., Merriman, R.J., Morgan, D.J. and Wyatt, R.J., 1978.
Fuller's Earth Provings near Baggridge, Avon.
Open-file Rep. Inst. Geol. Sci., No. 1978/1.

Powell, J., 1978.
Fuller's Earth from Midford.
Journal of Bristol Industrial Archaeology Soc., Vol. 11, pp.22-25.

Robertson, R.H.S., 1961.
The Origin of English Fuller's Earths.
Clay Miner Bull., Vol. 4, 282-287.

Schaffer, R.J., 1955.
The Weathering, Preservation and Restoration of Stone Buildings (Contor Lecture).
Journ. R. Soc. Arts, Vol. 103, 843-67.

Schaffer, R.J., 1932.
The Weathering of Natural Building Stones.
Sci. and Industr. Res. Dep., 18.

South-West Regional Fuller's Earth Conference, Bristol 1952.

The Contract Journal. 1891.
The Bath Stone Industry.
pp. 219-221.

Watson, J., 1911.
British and Foreign Building Stones. A descriptive catalogue of the specimens in the Sedgwick Museum, Cambridge.
Cambridge University Press.

Williams, A.E., 1948.
Fuller's Earth. Some notes on its mining, preparation and properties.
The Mining Journal, pp. 238-242.

Woodward, H.B., 1894.
Lower Oolite Rocks of England (Yorkshire excepted).
Mem. Geol. Surv., U.K., pp 488-91.

Wyatt, R.J. and Merriman, R.J., 1978.
The Fuller's Earth Deposits at Combe Hay, near Bath.
Guide for field excursion E5 from the International Clay Conference

Honeyborne, D.B. and Harris, P.B., 1958.
The structure of Porous Building Stones and its Relation to Weathering Behaviour.
The Colston Papers 10.

Simpson, J.W., Horrobin (eds) 1970.
The Weathering and Performance of Building Materials.
(M.T.P.) Aylesbury.
November 19, 1974 symposium:
Preservation of Stone.
Eng. Geol. Div. of Geol. Soc. Am.

Clarke, B.L. and Ashurst, J., 1972.
Stone Preservation Experiments.
Building Research Establishment.

Bowles, O.
The Stones Industries.

Warnes, A.R.
Building Stones, their properties decay and preservation.

Mining

Bath and Portland Stone Firms
9 Bath Stone.

Bell, F.G. (edit). 1975.
Site Investigations on Areas of Mining Subsidence.
(Newnes-Butterworths).

Butcher, A. and Mehew, R., 1971.
Combe Down Freestone Mines, Bath.
Shipton Mallet Caving Club. Journ. 5, No. 1

Cotterell, T.S., 1904.
Paper read at the Sixty-first Congress of the British Archaeological Association, Bath.

Dearman, W.R., Baynes, F.J. and Pearson, R., 1977.
Geophysical Detection of Disused Mineshafts in the Newcastle upon Tyne Area, North-east england.
Q. J. Eng. Vol. 10, 257-269.

Down, C.G. and Warrington, A.J., 1971.
The History of the Somerset Coalfield.

Hemmings, P., 1982-3.
The Stone Industry in Bath.
Dissertation.

Huggins, G.M. and Pickford, R.F., 1975.
Bath Stone. A Quarry History.

Irwin, D.J. and Knibbs, A.J., 1977.
Mendip Underground.

Kingston Minerals Ltd., Bath, 1970.
A Guide to the History, Geology and Extraction of Bath Stone.

Loupekine, I.S., 1955.
Mining and Quarrying in the Bristol District.
Proc. Bristol Nat. Soc., Vol. 29, Pt. 2, 155-161.

Maxwell, G.M., 1976.
Old Mines Shafts and their Location by Geophysical Surveying.
Q. J1. Engng. Geol., Vol. 9, 282-290.

Mehew, R., 1976.
Combe Down Stone Mines.
Shepton Mallet Caving Club, Spring (6) 1.

National Coal Board, 1975.
The Subsidence Engineers Handbook.
N.C.B. London.

Perkins, J.W., Brooks, A.T. and McR Pearce, A.E., 1979.
Bath Stone, a quarry history.

Pollard, D.
Bath Stone Quarry Railways 1795/1830.

Price, Liz., 1984.
Bath Freestone Workings.
The Resurgence Press (Bath).

Quarry Managers Journal. 1962.
Building Stone from Underground.
No. 46, 175-184.

Symons, M.V., 1977.
Source of Information for Preliminary Site Investigation in Old Coal Mining Areas.
In Large Ground Movements and Structures, edit. by James D. Geddes (Pentech Press).

Tucker, J.H., 1966.
Stone Quarries in the Corsham-Neston - Box Area of North-west Wiltshire.
Oxbridge Caving Group and Archaeological Soc., pp.8-16.

Tucker, R.J., 1968.
Quarries (Wiltshire).
Speleomundus Free Togophile Assoc., Vol. 1(2), 1-7.

Tucker, R.J., 1972-3.
Box Mines - The Current Position.
Cotham Spelaeological Soc., Vols. 7 and 8, 20-25

Tucker, R.J., 1972-3.
Copenacre Store Depot.
Cotham Spelaeological Soc., Vols. 7 & 8, 16-19

Tucker, R.J., Bater, R.J. and Mansfield, R.W.., 1968-9.
Box Stone Mines.
Mem. Cotham Caving Group.

Wooster, P., 1978.
The Stone Industry at Bath.
Jnl. Bristol Industrial Archaeological Soc., Vol. 2, 5-13.

Hydrogeology

Acts of United Kingdom Parliament Control of Pollution, 1974.

Anon, 1979.
The Protection of Groundwater against Pollution Caused by Certain Dangerous Substances.
Council Directive of 17 December 1979.
Off. Journ. of E.E.C. No. L20/4348.

Glanvil, J., 1969.
Observations Concerning the Bath Springs.
Philos. Trans. R. Soc. London. Vol. 4, No 49, 977-982.

Monkhouse, R.A., 1983.
Vulnerability of Aquifers and Groundwater Quality in the United Kingdom.
Draft Report (Unpublished) for E.E.C.

Monkhouse, R.A. and Richards, H.J.
Groundwater Resources of the United Kingdom.
Commission of the E.E.C.
Publ. Th Schafer GmbH Hannover, pp 252.

Richardson, L. 1928.
Wells and Springs of Somerset.
Mem. Geol. Surv.

Richardson, L. 1930.
Wells and Springs of Gloucestershire.
Mem. Geol. Surv. G.B.

Richardson, L., 1945.
The Water Resources of Gloucestershire from a Geological Standpoint.
Proc. Cott. Nat. Field Club, Vol. 29, 20-28.

Swinnerton, C.J., 1984.
Protection of Groundwater in Relation to Waste Disposal in Wessex Water Authority.
Q.J. Eng. Geol. London. Vol. 17, 3-8.

Whitaker, W. and Edmunds, F.H., 1925.
The Water Supply of Wiltshire.
Mem. Geol. Surv.

Engineering Geology

Ackermann, K.J. and Cave, R., 1967.
The Superficial Deposits and Structures, including Landslip in the Stroud District, Gloucestershire.
Proc. Geol. Ass., 78, 567-586.

Attewell, P.B. and Farmer, I.W., 1976.
Principles of Engineering Geology.
Publ. Chapman and Hall.

Barden, L., 1972.
The Relation of Soil Structure to the Engineering Geology of Clay Soil.
Q.J.Eng.Geol., London, 5, pp 85-102.

Bell, F.G. (ed), 1975.
Site Investigation in Areas of Mining Subsidence.
Publ. Newnes-Butterworth.

Bishop, A.W. and Henkel, D.J., 1976.
The Measurement of Soil Properties in the Triaxial Test.
Publ. Edward Arnold.

Bjerrum, L., 1967.
Mechanism of Progressive Failure in Slopes of Overconsolidated Plastic Clays and Clay Shales.
J. soil. Mech. and Found. Div.
A.S.C.E., Vol. 93, pp 1-49.

Broms, B.B., 1975.
Landslides.
In Foundation Engineering Handbook ed. by Winterkorn, H.F. and Fang, H.Y.
publ. van Nostrand Reinhold Co 1975.
(chapter 11, pp 373-401).

Burland, J.B., Broms, B.B. and de Mello, V.F.B., 1977.
Behaviour of Foundations and Structures - State of the Art Report.
Proc. 3rd Int. Conf. on S.M.F.E., Tokyo, 2, pp 495-546.

Carson, M.A., and Petley, D., 1970.
The existence of threshold hillslopes in the denudation of the landscape.
Trans. Inst. Br. Geogr., 49, 71-96.

Carter, M., 1983.
Geotechnical Engineering Handbook.
Publ. Chapman and Hall, New York.

Chandler, R.J., Birch, N. and Davis, A.G., 1968.
Engineering Properties of Keuper Marl.
Construction Industry Research and Information Assoc.,
London.

Chandler, R.J., Kellaway, G.A., Skempton, A.W., Wyatt, R.J.
Valley Slope Sections in Jurassic Strata near Bath, Somerset.
Phil. Trans. R. Soc. London A 283, 527-556, 1976.

Chandler, R.J. and Skempton, A.W., 1974.
The Design of Permanent Cutting Slopes in Stiff Fissured Clays.
Geotechnique 24 (1974) No 4, pp 457-466.

Chandler, R.J., 1970.
Solifluction on Low-angled Slopes in Northamptonshire.
Q.J.Eng.Geol., Vol. 3, 1970, pp 65-69.

Chandler, R.J. 1972.
Lias Clays: Weathering Processes and their Effect on Shear Strength.
Geotechnique 22, pp 403-31.

Chandler, R.J., 1974.
Lias Clay: the Long Term Stability of Cutting Slopes.
Geotechnique 24, pp 21-38.

Chandler, R.J., 1976.
The History and stability of two Lias Clay slopes in the upper Gwash Valley, Rutland.
Phil. Trans. Roy. Soc. Lond. A283 pp.463-491.

Chandler, R.J. 1979.
Stability of Structure Constructed in a Landslide: Selection of Soil Strength Parameters.
Design Parameters in Geotechnical Engineering VII
E.C.S.M.F.E., 1979, Brighton, Vol.

Church, H.K., 1981.
Excavation Handbook.
Publ. McGraw-Hill.

Clark, A.R. and Johnson, D.K., 1975.
Geotechnical Mapping as an Integral Part of Site Investigation - Two Case Histories.
Q.J.Eng.Geol., 1975, Vol. 8, pp 211-224.

Clayton, C.R.I., Simons, N.E. and Matthews, M.C., 1982.
Site Investigation.
Publ. Granada.

Collins, R.J., 1983
Concrete from crushed Jurassic Limestone.
Quarry Management and Products, March 1983
publ: Building Research Establishment.

Conway, B.W., 1979.
The Contribution made to Cliff Instability by Head Deposits in the West Dorset Coastal Area.
Q.J. Eng. Geol. 1979, Vol. 12, pp. 267-275

Conway, B., Forster, A., Northmore, K., Barclay, W., 1980
South Wales Coalfield Landslip Survey
Vols. 1 & 2. Rep. No. EG80/4

Cook, D.A., 1973.
Investigation of a Landslip in the Fuller's Earth Clay, Landsdown, Bath.
Q.J. Eng. Geol. 6, pp 233-40.

Cording, E.J. (ed), 1971.
Stability of Rock Slopes.
Proceeding 13th Symp. on Rock Mechanics, Univ. of Illinois.
American Society of Civil Engineers.

Cripps, J.C. and Taylor, R.M., 1981.
The Engineering Properties of Mudrocks.
Q.J.Eng. Geol., London 1981, Vol. 14, pp 325-346.

Davis, A.G., 1971.
The Settlement of structures founded on weathered soft rocks with particular reference to Keuper Marl.
The Interaction of Structures & Foundations
(Midland Soc. Foundn. Eng. Soil Mech. Birmingham) 18-29

Denness, B., 1972.
The Reservoir Principle of Mass Movement.
Rep. Inst. Geol. Sci. No. 72/7, pp 13.

Denness, B. and Cratchley, C.R., 1972.
The Degradation of Selected Jurassic Clay Slopes in Southern England
24th I.G.C., 1972, Section 13, pp 97-106.

Dumbleton, M.J. and West, G., 1966.
The Influence of the Coarse Fraction on the Plastic Properties of Clay Soils.
Report No. LR 36, T.R.R.L. Crowthorne.

Early, K.R. and Skempton, A.W., 1972.
Investigation of the Landslide at Waltons Wood, Staffs.
Q.J.Eng.Geol., Vol. 5 No 1 (1972), pp 19-42.

Farmer, I.W., 1968.
Engineering Properties of Rocks.
Publ. E. and F.N. Spon Ltd.

Fang, Hsai-Yang, 1975.
Stability of Earth Slopes.
in Foundation Engineering Handbook ed. by Winterkorn, H.F. and Fang, H.Y.
Publ. van Nostrand Reinhold Co. 1975.
(chapter 10, pp.354-371)

Fookes, P.G., Hinch, L.W., Huxley, M.A. and Simons, N.E., 1975.
Some Soil Properties in Glacial Terrain-The Taff Valley, South Wales.
in The Engineering Behaviour of Glacial Materials 2nd ed. 1978.
Proc. Symp. Univ. of Birmingham, April 1975.
Gibbs, Sir Alex & Partners, A4/A46/A36 Batheaston, Swainswick Bypass. Rep. to D.O.T. 1983.

Gibb, Sir Alexander & Partners. 1984.
A4/A46 Batheaston/Swainswick ByPass and A36 Link.
Site investigations interpretation report.

Gibbs, H.W. & Holtz, W.A. (1957)
Research on determining the density of sands by spoon penetration testing.
Proc. 4th Int. Conf. S.M.F.E. London, 1957, Vol. 1, pp 35-39.

Gallois, R.W. & Horton, A., 1981.
Field Investigation of British Mesozoic and Tertiary mudstones.
Q.J.Eng. Geol., Vol. 14, No 4.

Hardy, R.M., 1965.
Identification and Performance of Swelling Soil Types.
Canadian Geotechnical Journal, Vol. 11, No. 2, 1965.

Hawkins, A.B., 1977.
The Hedgemead Landslip, Bath, Avon.
Large Movements and Structures edit. Geddes, D.

Hawkins, A.B. and Privett, K.D., 1981.
A Building site on Cambered Ground at Radstock, Avon. Q.J.E.G.
Vol. 14, No. 3, 151-168.

Higginbottom, I.E. and Fookes, P.G., 1970.
Engineering Aspects of Periglacial Features in Britain.
Q.J.Eng. Geol., Vol. 31971, pp 85-117.

Hobbs, P.R.N., 1980.
Slope Stability Studies in the Avon Valley (Bath to Limpley Stoke).
British Geological Survey Unpublished Report
Engineering Geology Report EG80/10.

Hobbs, P., Horseman, S.T., McEwen, T.J. and Yeow, H.Y., 1982.
Swelling Behaviour of Harwell Mudrocks.
B.G.S. Report No. E.N.P.U. 82/11.

Hoek, E. and Bray, J.W., 1974.
Rock Slope Engineering.
Publ. Institution of Mining and Metallurgy.

Hoek, E. and Brown, E.T., 1980.
Underground Excavations in Rock.
Publ. Institution of Mining and Metallurgy.

Horseman, S.T., Hobbs, P., McEwen, T.J., Avery, L. and Forster, A., 1982
Basic Geotechnical Properties of core from the Harwell Borehole
B.G.S., Rep. E.N.P.U. 82/7.

Horswill, P. and Horton, A., 1976.
Cambering and Valley Bulging in the Gwash Valley at Empingham Rutland.
Phil. Trans. R. Soc. Lond., A283, 1976, pp 427-462.

Hunt, R.E., 1984.
Geotechnical Engineering Investigation Manual.
McGraw-Hill.

Hutchinson, J.N., 1967.
The free degradation of London Clay cliffs.
Proc. Geotech. Conf. Oslo, 1967, 1, 113-18.

Hutchinson, J.N., 1974.
Periglacial Solifluction: an approximate mechanism for clayey soils.
Geotechnique 24, pp 438-43.

Hutchinson, J.N., and Bhandari, R.K., 1971.
Undrained Loading. A fundamental mechanism of mudflows and other mass movements.
Geotechnique 21, No 4, pp 353-358.

Hutchinson, J.N., 1981.
Methods of Locating Slip Surfaces in Landslides.
Symposium Bled.

Hvorslev, M. Juul, 1949.
Subsurface Exploration and Sampling of soils for Civil Engineering Purposes.
Waterways Experiment Station, Vicksburg, Miss., 191.

Ingold, T.S., 1975.
The Stability of Highways in Landslipped Areas.
The Highway Engineer, May 1975.

Institution of Civil Engineers. 1977.
Ground Subsidence. pp 99.

Jackson, J.O. and Fookes, P.G., 1974.
The relationship of the estimated former burial depth of the Lower Oxford Clay to some Soil Properties.
Q.J.Eng. Geol., Vol. 7, pp 137-179.

Joyce, M.D., 1982.
Site Investigation Practice.
Publ. E. & F.N. Spon.

Kellaway, G.A. and Taylor, J.H., 1968.
The Influence of Landslipping on the Development of the City of Bath, England.
23rd Int. Geol. Congr. Czechoslovakia, Vol. 12, 1968. pp 65-76.

Lupini, J.F., Skinner, A.E. and Vaughan, P.R., 1981.
The Drained Residual Strength of Cohesive Soils.
Geotecnique 31 No 2, pp 181-213.

Meigh, A.C., 1976.
The Triassic rocks with particular reference to predicted and observed performance of some major foundations.
Geotechnique 26 No. 3, 391-452.

Molina, B.F., 1974.
A Rapid and Accurate Method for the Analysis of Calcium Carbonate in Small Samples.
J. Sedim, Petrology, Vol 44, pp 589-590.

Moore, C., 1880.
The Hedgemead Landslip.
Proc. Bath Nat. Hist. Antiq. Fld. Club, Vol. 4, 249-58.

Norman, J.W., Leibowitz, T.H. and Fookes, P.G., 1975.
Factors Affecting the Detection of Slope Instability with Air Photographs in an Area near Sevenoaks, Kent.
Q.J. Eng. Geol. 1975, Vol. 8, pp. 159-176.

Peck, Hanson and Thornburn, 1974.
Foundation Engineering. 2nd ed.
Publd. John Wiley & Sons, New York.

Perloff, W.H. and Baron, W., 1976.
Soil Mechanics - principles and applications.
Publ: Ronald Press Co., New York.

Poulos, H.G. and Davis, E.H. 1974.
Elastic Solutions for Soil and Rock Mechanics.
John Wiley & Sons.

Privett, K.D., 1980
The Engineering Geology of Hillslopes in the South Cotswolds.
Unpublished Ph D thesis, Bristol University.

Rouse, W.C., 1969.
An investigation of the stability and frequency distribution of slopes in selected areas of West Glamorgan.
Unpubl. Ph D. thesis, Univ. of Wales.

Rouse, W.C., 1975.
Engineering Properties and slope form in granular soils.
Eng. Geol, 9, 221-35.

Sanglerat, G., 1972.
The Penetrometer and Soil Exploration.
Developments in Geotechnical Engineering, 1, Elsevier.

Schuster, R.L. and Krizek, R.J., 1978.
Landslides Analysis and Control.
Special Report 176, Transport Research Board. National Academy of Science

Shadbolt, C.H., 1977.
Mining Subsidence.
Symp. Large Ground Movements, Cardiff.

Sherwood, P.T. and Hollis, B.G., 1966.
Studies of the Keuper Marl: Chemical Properties and Classificiation Test.
Road Research Laboratory.
R.R.L. Report No. 41.

Simons, N.E. and Menzies, B.K., 1975.
A Short Course in Foundation Engineering.
I.P.C. Science and Technology Press.

Skempton, A.W., 1953
"The Colloidal activity of Clay
Proc. 3rd Intern. Conf. Soil. Mech. & Foundation Engineering, vol. 1
Switzerland

Skempton, A.W. 1970,
First time slides in over consolidated clays.
Geotechnique 20, pp 320-4.

Skempton, A.W. and Delory, F.A., 1957.
Stability of Natural Slopes in London Clay.
Proc. 4th Int. Conf. Soil Mech. (London) 2, pp 378-81.

Skempton, A.W. and Hutchinson, J. 1969.
Stability of Natural Slopes and Embankment Foundations.
7th Int. Conf. Soil Mech.
State of the Art, Vol. 291-340.

Spangler, M.G. and Handy, R.L., 1982.
Soil Engineering.
4th ed. publ. Harper & Row, 1982.

Stewart, M. Celis CA, 1976.
The Use of Geophysics in Landslide Studies.
Lab. Rep. Transport and Road Research Laboratory. LR 703.

Taylor, R.K. and Spears, D.A., 1981.
Laboratory Investigation of Mudrocks.
Q.J. Eng. Geol., London, 1981, Vol. 14, pp 291-309.

Terzaghi, K. and Peck, R.B., 1967.
Soil Mechanics in Engineering Practice.
2nd Ed. John Wiley & Sons Inc., New York.

Thomas, G.G., 1981.
The Engineering Geology of some Selected Fuller's Earth slips in the South Cotswolds.
MSc Thesis Bristol University.

Trantina, J.A., 1963.
Investigation of Landslides by Seismic and Electrical Resistivity Methods.
ASTM Special Publ. No 322, 1963.

Vaughan, P.R., 1976.
The Deformations of the Empingham Valley Slope.
Phil. Trans. Roy. Soc., A283, 1976.

Vickers, B., 1983.
Laboratory Work in Soil Mechanics.
2nd edn. publ., Granada, 1983.

Wardell, K., 1953.
Some Observations on the Relationship Between Time and Mining Subsidence.
Trans. Inst. Min. Eng.

Weeks, A.G., 1969.
The Stability of Natural Slopes in S.E. England as affected by Periglacial Activity.
Q.J.Eng. Geol., Vol. 2, 1969, pp 49-61.

Working Party Report, 1972.
The Preparation of Maps and Plans in Terms of Engineering Geology.
Q.J.Eng. Geol. London 5, 293-382.

Wroth, C.P. and Wood, D.M., 1978.
The Correlation of Index Properties with Some Basic Engineering Properties of Soils.
Canadian Geotechnical Journal, Vol. 15, pp 137-145.

Yong, R.N. and Warkentin, B.P., 1975.
Soil Properties and Behaviour.
Developments in Geotechnical Engineering, 5, publ. Elsevier 1975.

Young, A., 1961.
Characteristic and limiting slope angles.
Z. Geomorph., 5, 126-31.

Young, A. 1972.
Slopes.
Longmans.

B.S. 1377. 1975.
Methods of Testing for Soils for Engineering Purposes.
British Standards Institution Publ., April, 1975.

B.S. 5930. 1981.
Code of Practice for Site Investigations (formerly CP 2001).
British Standards Institution Publ.

C.P. 2004. 1972.
Code of Practice for Foundations.
British Standards Institution Publ. Sept. 1972.

Report On the Sub-Committee on Standardisation of Penetration Testing in Europe.
Proc. 9th I.G.S.M.F.E., Vol. 3, 1977, Tokyo (App. 5).

Miscellaneous

Anderson, M.G. and Richards, K.S., 1981.
Geomorphological Aspects of Slopes in Mudrocks in the United Kingdom.
Q.J.Eng. Geol. Vol. 14, No 4, 363-372.

Bromley, J. and Williams, B.P.J., 1976.
Hydrogeological Characteristics of the Great and Inferior Oolite Limestone Aquifers in the Southern Cotswolds.
Q.J.Eng. Geol., Vol. 9, pp 339-342.

Buchanan, R.A., 1969.
The Industrial Archaeology of Bath.
Bath University Press, 1969.

Chandler, R.J., Kellaway, G.A., Skempton, A.W., and Wyatt, R.J., 1976.
Valley slope Sections in Jurassic Strata near Bath, Somerset.
Phil. Trans. R. Soc. Lon. A. 283, 527-556.

Clew, K., 1970.
The Somersetshire Coal Canal & Railways.
Newton Abbott, David & Charles.

Clew, K., 1970 b.
The Kennet & Avon Canal.
Publ. David & Charles.

Davey, N., 1976.
Building Stones of England & Wales.
Bedford Square Press.

Davis, J.C., 1973.
Statistics and Data Analysis in Geology.
Publ: John Wiley & Sons.

Dumbleton, M.J. & West, G., 1970.
Air Photograph Interpretation for Road Engineers in Britain.
T.R.R.L. Laboratory Report No 369.

Dumbleton, M.J. and West, G., 1972.
Preliminary Sources of Site investigation for Roads in Britain.
Q.J.Eng. Geol. Vol. 5 No 1, 1972, pp 15-18.

Forster, A. and McCann, D., 1976.
An Assessment of the Effects of Resin Impregnation on the Physical Properties of Some Common Building Stones.
Engineering Geology Unit, Institute of Geological Sciences,
Report No. 76/3.

Hawkins, A.B., 1972.
Some Gorges of the Bristol District.
Proc. Bristol Nat. Soc., Vol. 32, Pt. 2, 167-185.

Hawkins, A.B., 1973.
The Geology of Slopes of the Bristol Region.
Q.J. Eng. Geol. 6, 195-205.

Hawkins, A.B., 1977.
Jurassic Rocks in the Bath Area.
in Savage R.J.G. (ed)
Geological Excursions to the Bristol District.
B.U.P. 119-320.

Hawkins, A.B. and Privett, K.D., 1979.
Engineering Geomorphological Mapping as a Technique to Elucidate Areas of Superficial Structures on the Northamptonshire Ironstone field.
Q.J. London 100, 1-46.

McCann, D.M., Baria, R., Jackson, P.D., Culshaw, M.G., Green, A.S.P., Suddaby, D.L. and Hallam, J.R.
The Use of Geophysical Methods in the Detection of Natural Cavities Mineshafts and Anomalous Ground Conditions.
B.G.S. Engineering Geology Report 82/5.

Philips, J., 1844.
A Memoir of William Smith.

Russell, D.J., 1977.
The Effects of Weathering on the Physical and Chemical Properties of some Mesozoic Clays.
Ph D Thesis (unpublished), University of Reading.

Stow, D.A.V., 1981.
Fine-grained Sediments: terminology.
Q.J. Eng. Geol., Vol. 14, No 4, pp 243-244.

Torrens, H., 1976.
The Somersetshire Coal Canal Caisson Lock.
Bristol Industrial Arhaeology Soc. Journal, 1976.

Tucker, J.H., 1964.
Caves in the Jurassic Limestone Outcrop of the North West Wiltshire/North East Somerset Border Area.
Arbridge Caving Group & Archaeological Soc., pp 10-23.

Wakeling, T.R.M., 1972.
The Planning of Site Investigations for Highways.
Q.J.Eng. Geol., Vol. 5, No 1 (1972), pp 7-14.

BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 1 SOLID LITHOSTRATIGRAPHY

SCALE 1:25000

Based on geological survey at 1:10 560 scale between 1944 and 1958 by W.Bullerwell, G.W.Green, G.A.Kellaways, D.R.A.Ponsford and F.B.A.Welch.
Compiled by R.J.Wyatt

Yards 1000 — 0 — 1 — 2 Miles
Scale 1:25000
Metres 1000 — 0 — 1 — 2 — 3 Kilometres

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Nevertheless, the possibilities of undetected anomalous conditions and uncharted shallow workings and mineshafts are always present. There is no substitute for the knowledge provided by detailed surveys and the drilling of trial boreholes that take into account the extent, nature and location of a proposed development.

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

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

GENERALIZED VERTICAL SECTION

Scale 1:500 (1cm to 5m)

				Lithology
JURASSIC		OxC	OXFORD CLAY up to 25m	Dark grey stiff clays, mudstones and shales
JURASSIC		KlC	KELLAWAYS CLAY 21m	Mainly dark grey, shelly, silty clays and shaly mudstones; some sandy clays and beds of sand; hard calcareous sandstone at top
JURASSIC	GREAT OOLITE GROUP	Cb	CORNBRASH 1.5 to 6.0m	Rubbly, shelly, fine-grained limestones
JURASSIC	GREAT OOLITE GROUP	FMb (S, L)	FOREST MARBLE 16 to 30m	Mainly grey and greenish calcareous clays and mudstones, commonly with sandy bands and partings; also thick lenticular bodies of a) fine- to coarse-grained sand and sandstone b) coarse-grained, oolitic, shell-fragmental limestones with shelly marl partings
JURASSIC	GREAT OOLITE GROUP	GO	GREAT OOLITE 0 to 39m: UPPER RAGS AND BATH OOLITE 0 to 20m	Buff and whitish, streaky, shell-fragmental oolites and coralline limestones; overlying massive oolites and oolite freestones
JURASSIC	GREAT OOLITE GROUP	Tw	GREAT OOLITE: TWINHOE BEDS 0 to 13m	Grey, fine-grained detrital limestones, overlying buff, marly, pisolitic limestones; ironshot pisolitic limestones or marl at base
JURASSIC	GREAT OOLITE GROUP	GO	GREAT OOLITE: COMBE DOWN OOLITE 0 to 17.5m	Mainly medium and coarse-grained, shell-fragmental oolites and oolitic limestones, including oolite freestones
JURASSIC	GREAT OOLITE GROUP	FrC	FROME CLAY (FrC) 22m	Grey calcareous mudstones and stiff clays with some thin muddy limestone bands
JURASSIC	GREAT OOLITE GROUP	FE	FULLER'S EARTH 28 to 44m: UPPER FULLER'S EARTH 12 to 29m	Grey calcareous mudstones and stiff clays with some thin muddy limestone bands; bed of commercial fuller's earth in the upper part at and south of Bath
JURASSIC	GREAT OOLITE GROUP	FER	FULLER'S EARTH: FULLER'S EARTH ROCK 1 to 5m	Rubbly, fine-grained, shelly, muddy limestones with marl interbeds
JURASSIC	GREAT OOLITE GROUP	FE	FULLER'S EARTH: LOWER FULLER'S EARTH 10 to 16m	Grey calcareous mudstones and stiff clays with some thin muddy limestone bands and shell beds
JURASSIC	INFERIOR OOLITE GROUP	InO	INFERIOR OOLITE 12 to 18m	Cream massive oolites, overlying whitish coralline limestones with clay bands; hard sandy, very shelly, locally ironshot limestones at base
JURASSIC	LIAS GROUP	MS	MIDFORD SANDS 0 to 31m	Yellowish brown silt and silty sand with bands of hard calcareous sandstone concretions
JURASSIC	LIAS GROUP	DyS	DYRHAM SILTS 0 to 12m	Grey laminated silts and clayey silts
JURASSIC	LIAS GROUP	LLi	LOWER LIAS CLAY 12 to 110m	Bluish grey stiff clays, mudstones and shales with a few argillaceous limestone bands; clay ironstone nodules in upper part
JURASSIC / TRIASSIC	LIAS GROUP	BLi	BLUE LIAS 2 to 19m	Interbedded bluish grey muddy limestones and mudstones or shales
TRIASSIC	PENARTH GROUP	PnG	PENARTH GROUP (UNDIVIDED) 8 to 9m	Pale grey fine-grained limestones (formerly White Lias); overlying greenish grey marls and limestones, with dark grey fossilferous shales at base (formerly Rhaetic)
TRIASSIC	MERCIA MUDSTONE GROUP	MMG	MERCIA MUDSTONE GROUP (UNDIVIDED) 0 to 77m	Mainly red silty and sandy mudstones (formerly Keuper Marl) with c.3m of greenish grey beds at top (formerly Tea Green Marl); variable thicknesses of limestone breccia with a red sandy mudstone matrix at base (Dolomitic Conglomerate)

Unconformity

N.B. Oxford Clay and Kellaways Clay are mapped as one unit in National Grid square ST 85 NW, and are symbolized by OxC.

GENERALIZED VERTICAL SECTION

continued at scale 1:5000 (1cm to 50m)
Proved mainly in boreholes and shafts

			Lithology
CARBONIFEROUS	UPPER COAL MEASURES	RADSTOCK FORMATION 340m	Mainly grey shales and mudstones with subordinate sandstones, fire-clays and coal seams (the last indicated on section)
CARBONIFEROUS	UPPER COAL MEASURES	BARREN RED FORMATION 140m	Brown and red shales and mudstones; grey measures towards top and base include sandstones and sandy shales
CARBONIFEROUS	UPPER COAL MEASURES	FARRINGTON FORMATION 340m	Mainly grey shales and mudstones with subordinate sandstones, fire-clays and coal seams (the last indicated on section)
CARBONIFEROUS	UPPER COAL MEASURES	MANGOTSFIELD FORMATION 240m	Mainly coarse-grained sandstones
		Unproved sequence about 430m	
CARBONIFEROUS	UPPER COAL MEASURES	De: DOWNEND FORMATION 175m	Mainly coarse-grained sandstones with some coal seams
		Unproved sequence about 400m	
CARBONIFEROUS	MIDDLE COAL MEASURES	250m	Mainly grey shales and mudstones with subordinate sandstones, fire-clays and coal seams (the last indicated on section)
		Unproved sequence about 530m	
CARBONIFEROUS	CARBONIFEROUS LIMESTONE	93m	Hard grey and pink fine-grained limestones, crinoidal in part; with some shale and sandstone

KEY

Geological boundary, Drift: used for limits of 'foundered strata where they do not coincide with Solid geological boundaries

Geological boundary, Solid

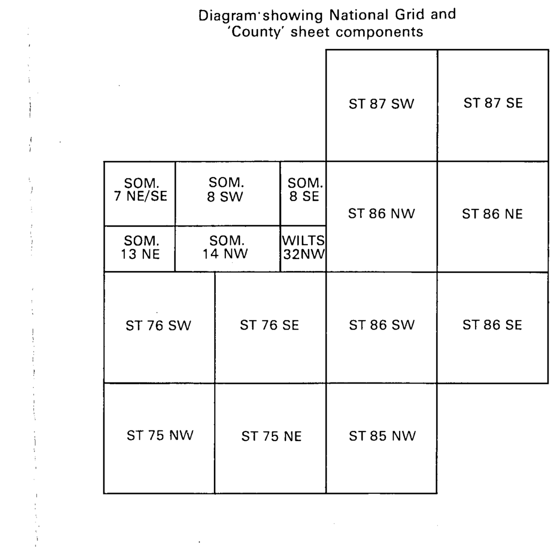
Fault at surface; crossmark indicates downthrow side

Broken lines denote uncertainty

'Foundered strata' (see accompanying report for definition)

N.B. Map 15 in this set revises the area shown provisionally on this map as 'foundered strata', in terms of landslip, cambered ground and formational boundaries.

Diagram showing National Grid and 'County' sheet components



BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 2 DRIFT DEPOSITS: EXTENT, LITHOLOGY AND THICKNESS

SCALE 1:25000

KEY

	ALLUVIUM	Variable deposits of clay, silt, and silty or sandy loam; locally with organic clay and peat beds; gravel interbeds or lenses may occur, and basal gravels are common.
	ALLUVIAL FAN	Angular loamy gravel of local origin.
1-3	RIVER TERRACE DEPOSITS	Mainly sand and gravel, locally with a veneer of sandy loam.
	HEAD	Variable unsorted deposits of local origin including silty, sandy and gravelly loams; clays containing varying proportions of silt, sand and gravel; gravels.
	DEPOSITS OF UNKNOWN AGE	High level plateau deposits of unsorted clayey sand and gravel.

The sparcity and uneven distribution of borehole data preclude the drawing of isopachytes. Thicknesses (in metres) are based upon field observations and such borehole data as are available. Generally, the Drift deposits shown are greater than 1 m in thickness. Head deposits, not included here, are known from boreholes to be very extensive on the steep valley slopes in and around Bath. Thicknesses of up to 3m are not uncommon; greater thicknesses occur locally.

Scale 1:25000

Yards 1000 0 1 2 Miles

Metres 1000 0 1 2 3 Kilometres

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Nevertheless, the possibilities of undetected anomalous conditions and uncharted shallow workings and mineshafts are always present. There is no substitute for the knowledge provided by detailed surveys and the drilling of trial boreholes that take into account the extent, nature and location of a proposed development.

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

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

WA/va/85/8

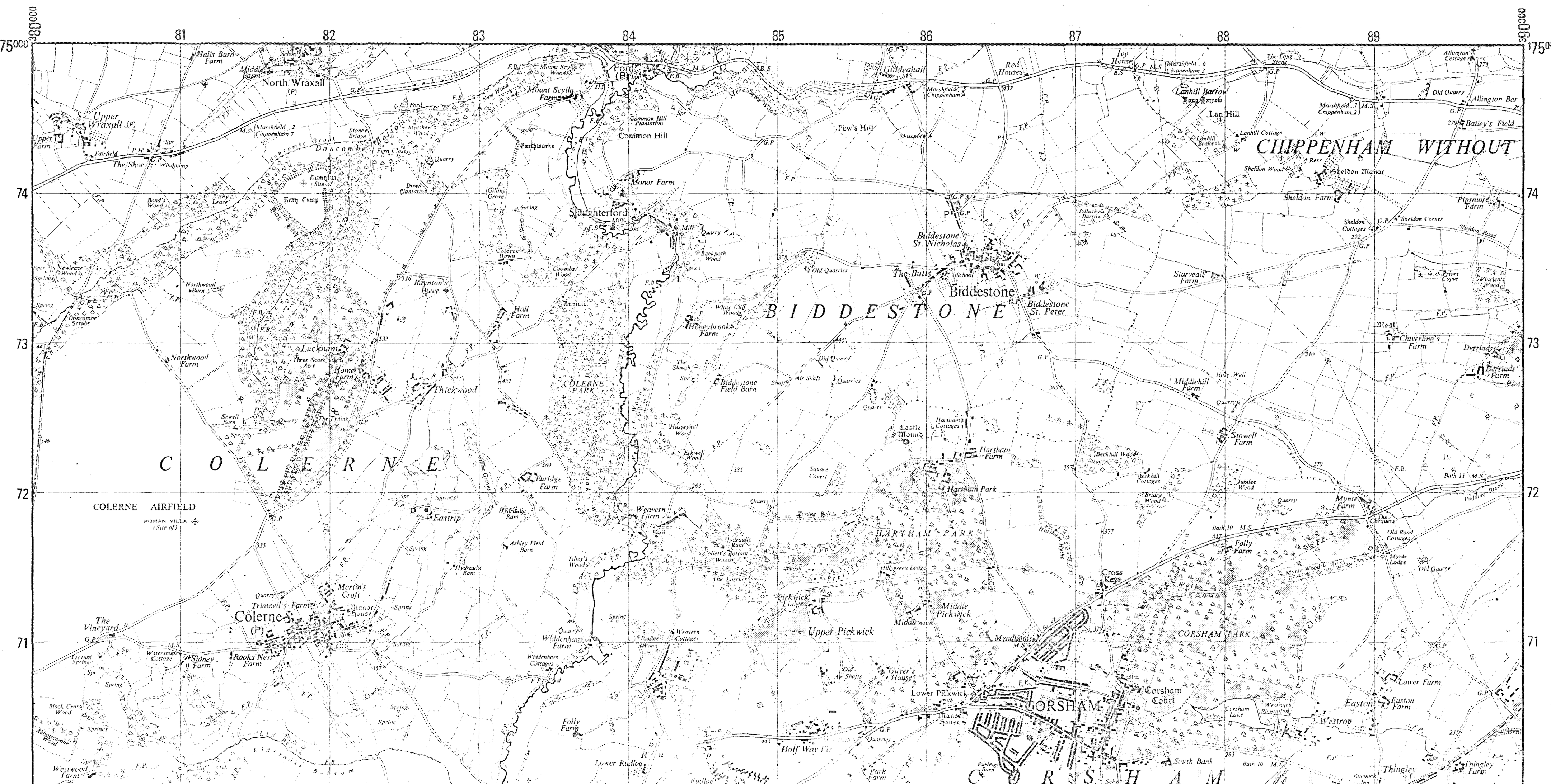
BRITISH GEOLOGICAL SURVEY

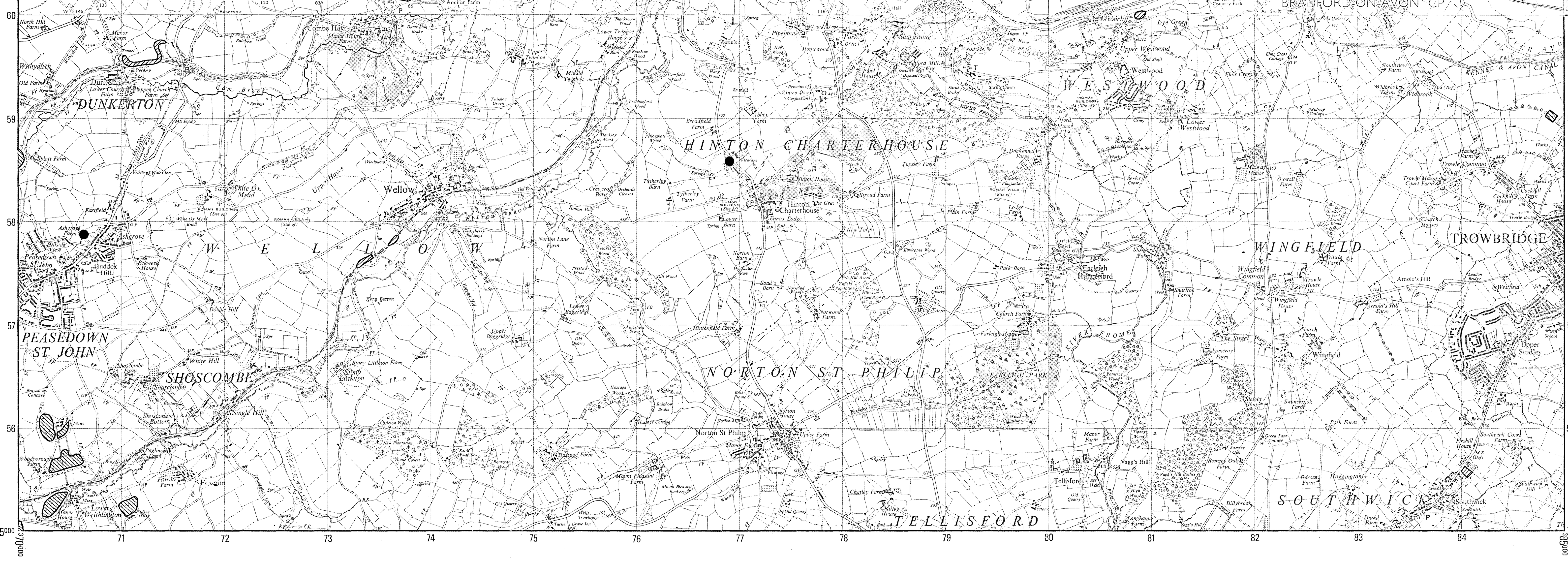
ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 3 LOCATION OF MADE GROUND AND INFILLED LAND

SCALE 1:25000





Drawn by A.H.Myers

KEY

- Made Ground (artificial deposits upon original ground surface)
- ▲ Approximate position of Made Ground where no site plan is available
- Infilled Land (artificial deposits filling old quarries and railway cuttings)
- ● Approximate position of Infilled Land where no site plan is available

N.B. The artificial deposits comprise excavation, demolition and construction wastes, and also domestic refuse. See accompanying report for tabulated details of Land Fill sites. A variable thickness of made ground is to be expected throughout the urban area of Bath.

Scale 1:25000

Yards 1000 — 0 — 1 — 2 Miles

Metres 1000 — 0 — 1 — 2 — 3 Kilometres

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Nevertheless, the possibilities of undetected anomalous conditions and uncharted shallow workings and mineshafts are always present. There is no substitute for the knowledge provided by detailed surveys and the drilling of trial boreholes that take into account the extent, nature and location of a proposed development.

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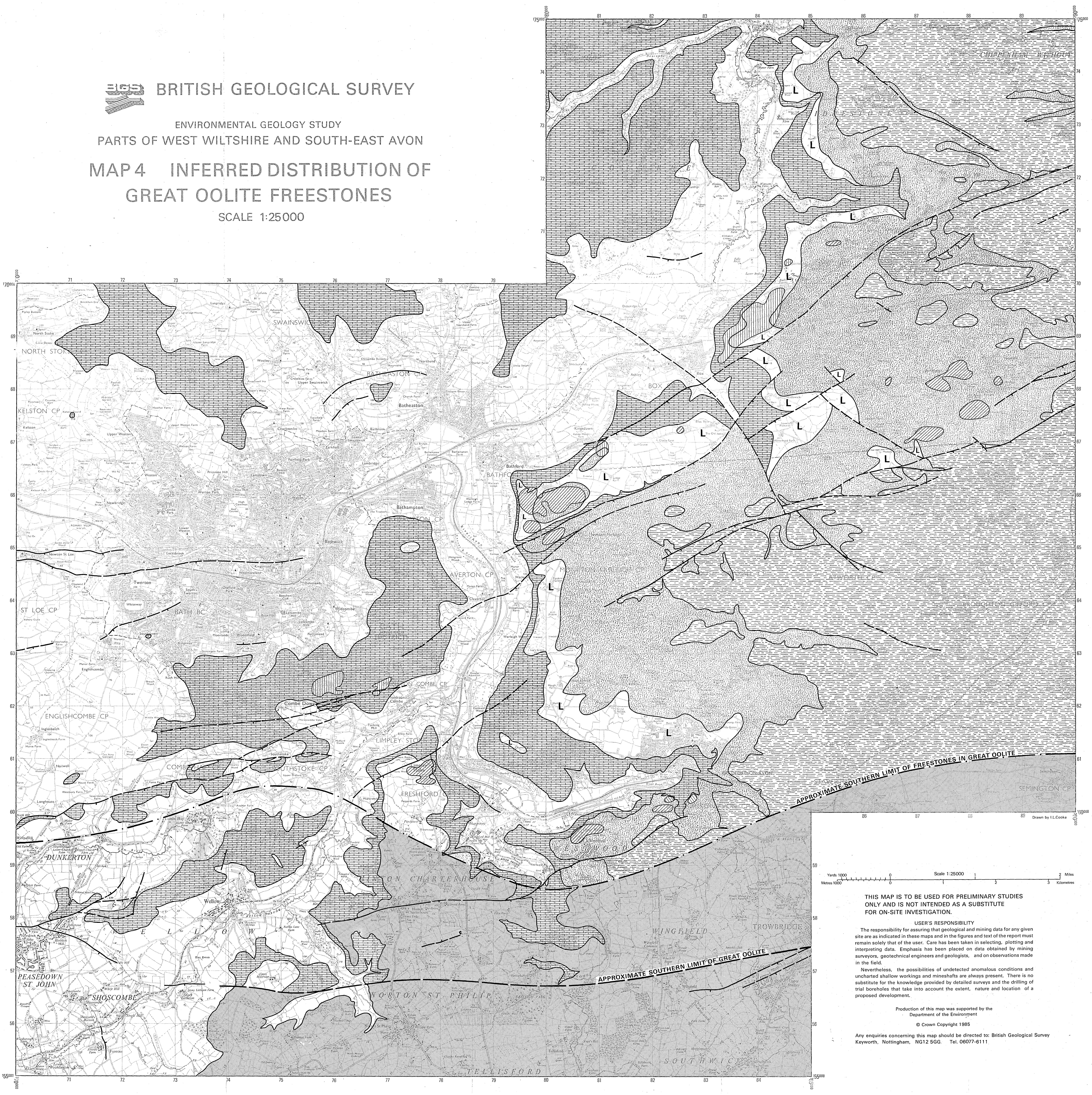
BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY
PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 4 INFERRED DISTRIBUTION OF GREAT OOLITE FREESTONES

SCALE 1:25000



Scale 1:25000

Yards 1000 0 1 2 Miles
Metres 1000 0 1 2 3 Kilometres

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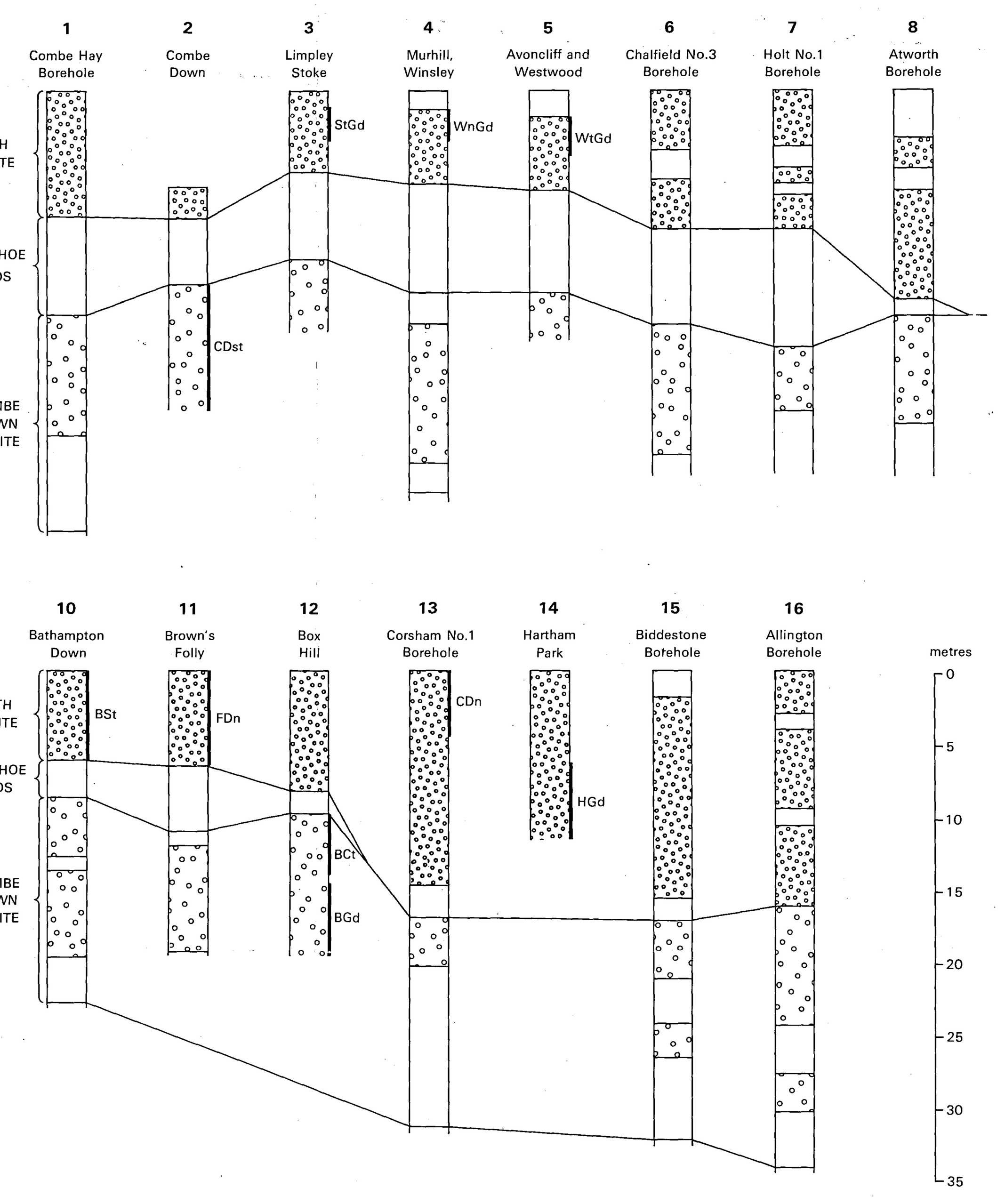
COMPARATIVE VERTICAL SECTIONS THROUGH THE GREAT OOLITE (EXCLUDING THE UPPER RAGS)

(To show the relationship between worked freestones and the overall distribution of oolites)

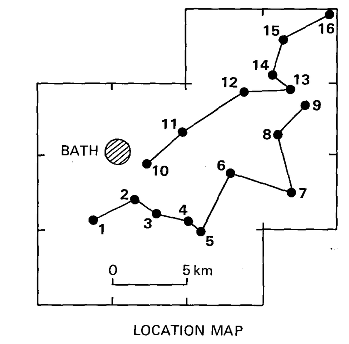


Freestones are shown by black ruling beside the columns; names are abbreviated as follows:-

BCt	Box Corngrit
BGd	Box Ground Stone
BSt	Bathampton Stone
CDn	Corsham Down Stone
CDst	Combe Down Stone
FDn	Farleigh Down Stone
HGd	Hartham Ground Stone
MPk	Monk's Park Stone
StGd	Stoke Ground Stone
WnGd	Winsley Ground Stone
WtGd	Westwood Ground Stone

OOLITES IN BATH OOLITE MEMBER

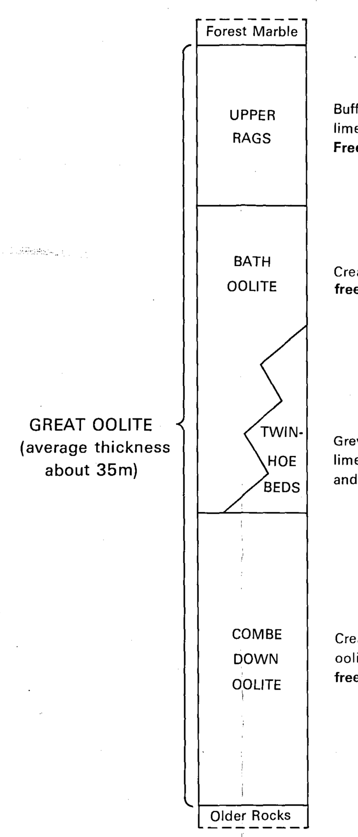
OOLITES IN COMBE DOWN OOLITE MEMBER



LOCATION MAP

Adapted from Green and Donovan (1969, Plate VI)

GENERALIZED SECTION OF THE GREAT OOLITE TO SHOW LITHOLOGIES AND SOURCE BEDS OF BATH FREESTONE



UPPER RAGS: Buff and white, streaky, shell-fragmented oolites and oolitic limestones. Locally with coralline limestone at top or base. **Freestones** restricted to Bradford district.

BATH OOLITE: Cream and grey, oolites and oolitic limestones, including oolite **freestones.**

TWINHOE BEDS: Grey, fine-grained detrital limestones; overlying buff, marly, pisolitic limestones; ironshot limestone or marl at base (absent north of Box and Corsham).

COMBE DOWN OOLITE: Cream and grey, massive, shell-fragmental oolitic limestones and oolites; commonly with clay-filled burrows in lower part; oolite **freestones** in upper part.

KEY TO MAP FACE

- Outcrop of Great Oolite.
- L: Great Oolite overlain by permeable basal Forest Marble limestones.
- Great Oolite and basal Forest Marble limestones (where present) overlain by impermeable Forest Marble clays. Cover on Bath Oolite 0 - 30m.
- Great Oolite and Forest Marble overlain by Cornbrash and younger rocks. Cover on Bath Oolite >25m throughout.
- Rocks older than Great Oolite.
- Rocks younger than Great Oolite (or it's equivalent) beyond the southern limit of freestones.
- Worked out areas in Combe Down Oolite mines.
- Worked out areas in Bath Oolite mines.
- Worked out areas in Upper Rags mines.
- Fault at surface; crossmark indicates downthrow side. Broken lines denote uncertainty.

N.B.
This map should be studied in conjunction with the accompanying report. The occurrence of Great Oolite limestone does not necessarily constitute an economic resource

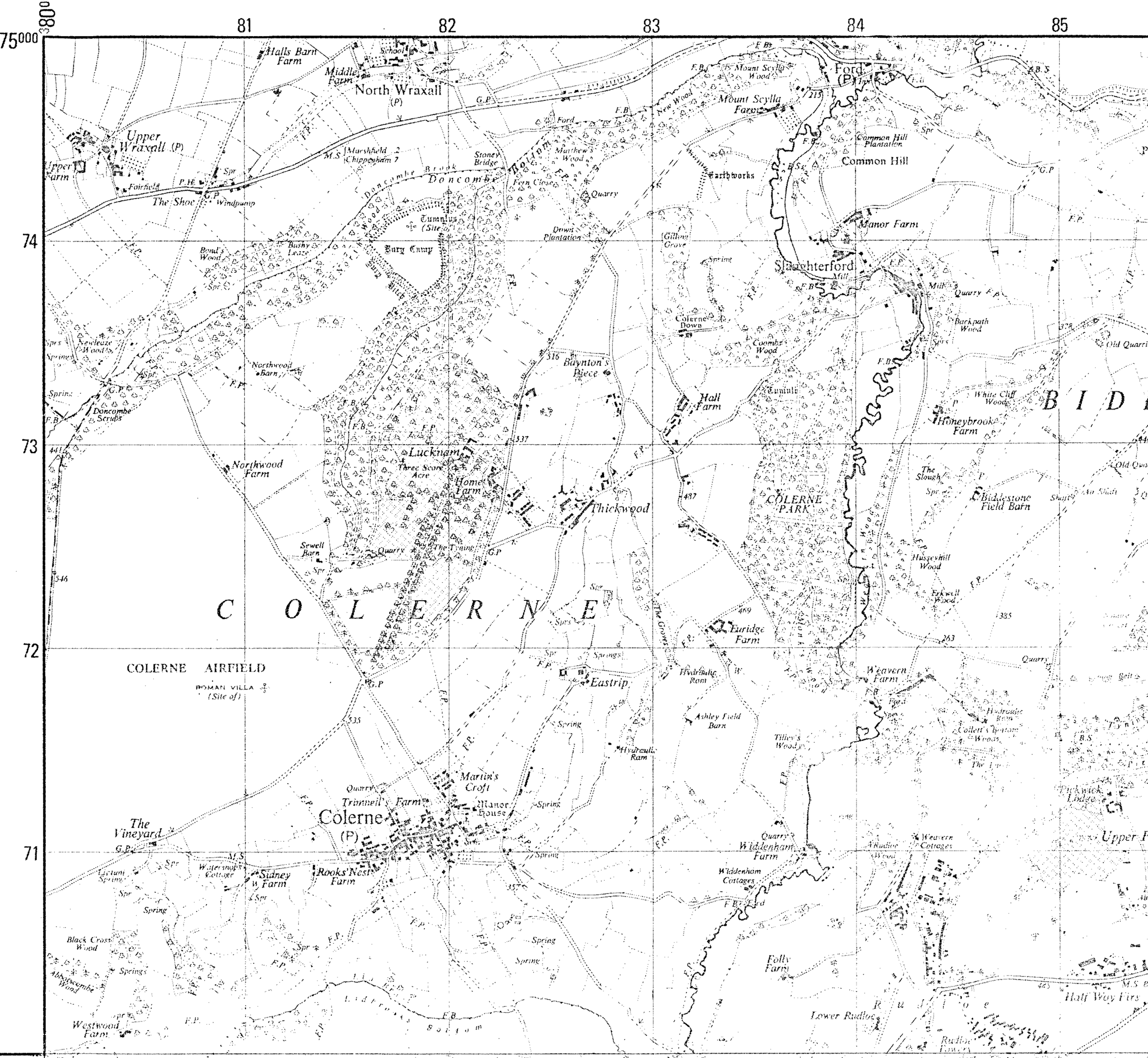
BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 5 INFERRED DISTRIBUTION OF FULLER'S EARTH

SCALE 1:25000



KEY

Fuller's earth present; sterilized by surface development and public amenity within Bath City area	Fuller's earth present; proved at outcrop and in boreholes
Fuller's earth probably present; assessment based on minimal borehole data and on regional geological considerations	Fuller's earth possibly present; assessment based on regional geological considerations; no borehole data
Areas of worked out fuller's earth	Area of partly worked out fuller's earth

N.B. This map should be studied in conjunction with the accompanying report. The occurrence of fuller's earth does not necessarily constitute an economic resource. Only a small part of the outcrop of the Fuller's Earth formation shown on Map 1 is fuller's earth in the mineralogical sense.

Scale 1:25000

Yards 1000 0 1 2 Miles

Metres 1000 0 1 2 3 Kilometres

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WA/VG/85/8

BGS BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 6 GROUNDWATER

SCALE 1:25000

KEY

Symbol	Description
d	Drift
KlC+OxC	Kellaway's Clay and Oxford Clay
FMb+Cb	Forest Marble and Cornbrash
	Great Oolite (Major Aquifer)
FrC	Frome Clay
FE	Fuller's Earth
	Inferior Oolite (Major Aquifer)
	Midford Sands (Major Aquifer)
L+PnG	Lias Group (excluding Midford Sands) and Penarth Group
MMG	Mercia Mudstone Group
CM	Coal Measures

- Observation site (Rest Water Level)
- OC78 Operation ceased, with year
- Well or borehole
- Approximate site of well or borehole
- Spring
- Thermal spring
- Spring used for public supply
- Well or borehole used for public supply
- Cross indicates disused
- Collector trench (disused)

—60— Contours on the potentiometric surface (metres Above Ordnance Datum) These are shown for part of the confined Great Oolite limestone Aquifer, before recharge September 1976

The potentiometric surface is that which joins all points to which groundwater rises in wells and boreholes in a particular aquifer.

- Geological boundary, Drift
- Geological boundary, Drift: used for limits of 'foundered strata' where they do not coincide with Solid geological boundaries
- Geological boundary, Solid
- Fault at surface; crossmark indicates downthrow side

Broken lines denote uncertainty

'Foundered strata' (see accompanying report for definition)

N.B. Map 15 in this set revises the area shown provisionally on this map as 'foundered strata', in terms of landslip, cambered ground and formational boundaries.

Yards 1000 0 Scale 1:25000 1 2 Miles
Metres 1000 0 1 2 3 Kilometres

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BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 7 GROUND CONDITIONS IN RELATION TO GROUNDWATER

SCALE 1:25000

KEY

- Bedrock Generally Impermeable
- Bedrock Generally Permeable
- Maximum Recorded Flooded Area
- Actual or Potential Spring Line

HYDRO-STRATIGRAPHIC UNIT	GROUND CONDITIONS
1	This unit comprises Oxford Clay, Kellaways Clay, Cornbrash limestone and Forest Marble. It is generally impermeable clay but with some permeable sand and broken thin limestones. A surface drainage regime tends to maintain saturated conditions in superficial material, but is subject to seasonal variation. It forms gently undulating ground in the east and south east.
2	This unit comprises the permeable limestones of the Great Oolite and basal Forest Marble. Free underdraining maintains a low water table in superficial material, although the water level is subject to seasonal variation. The water table is perched on valley sides, and groundwater issues from a spring line at the base of the Great Oolite. This unit forms hilltops and a dissected plateau running North East to South West across the study area.
3	This unit comprises Fuller's Earth and Frome Clay. They are generally impermeable clays, but with some thin limestone beds that may carry water. Outcrops are on upper valley sides. Superficial deposits may be maintained in a saturated condition, fed by a spring line at the base of the Great Oolite.
4	This unit comprises Inferior Oolite limestone and Midford Sands. They are generally permeable strata which form the lower slopes of the main valleys. Free drainage maintains a low water table in superficial materials. A spring line may occur at the junction of the Midford Sands and the Lower Lias clay.
5	This unit comprises Lower Lias clay, Blue Lias, Penarth and Mercia Mudstone groups. These are generally impermeable strata forming low ground in the valley bottoms in the western part of the area. A high water table is maintained in superficial materials.
~	Alluvium and terrace deposits in valley bottoms and on lower valley sides. They are free draining but the water table is close to the surface in valley bottoms. The older terraces on lower valley slopes are free draining and above the water table.

N.B. Areas marked 'INSUFFICIENT DATA' correspond to the 'foundered strata' (see Map 1). Map 15 in this set revises these areas in terms of landslip, cambered ground and formational boundaries.

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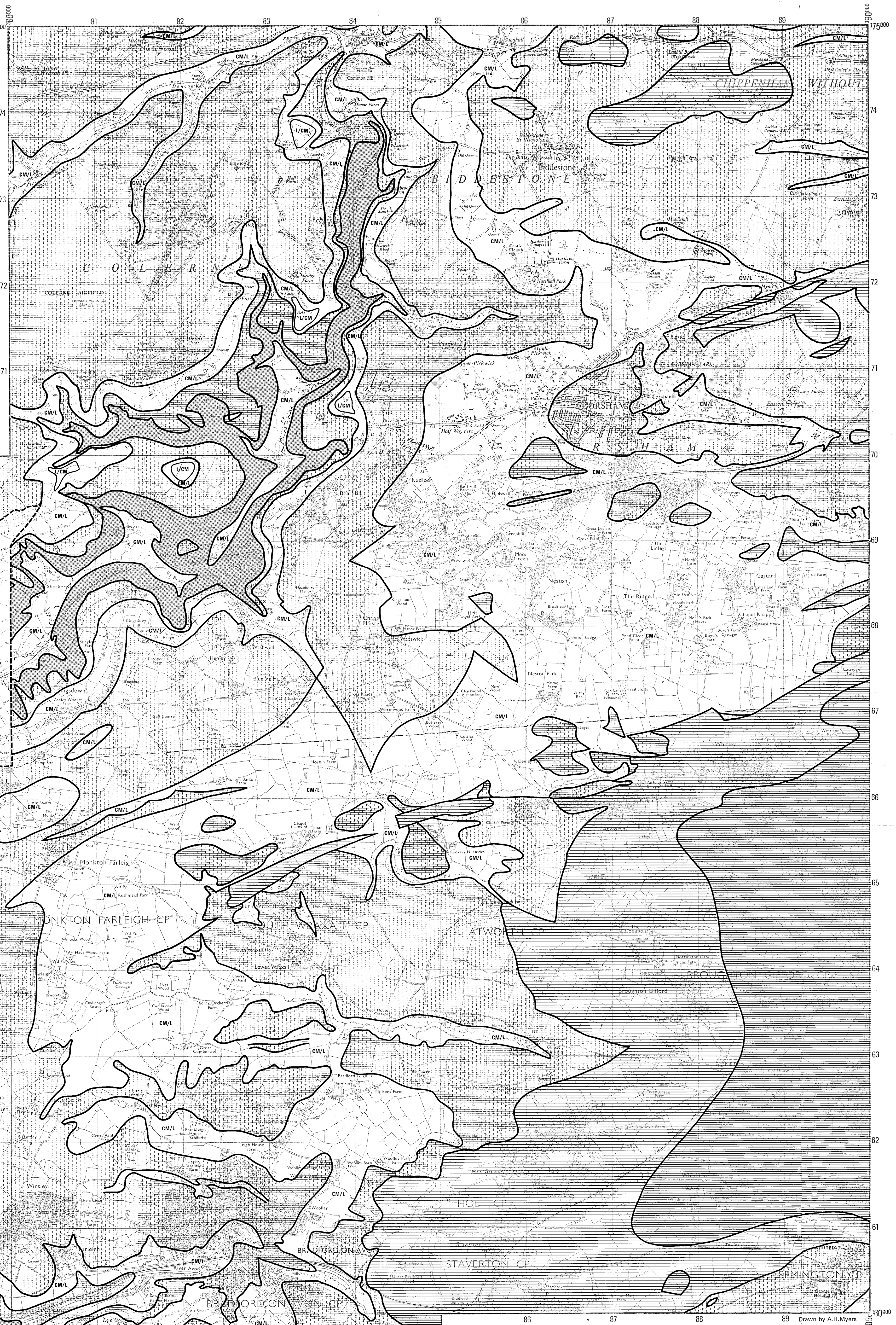
BGS BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 8 GEOTECHNICAL PROPERTIES OF BEDROCK

SCALE 1:25000



Scale 1:25000

KEY

Boundary to Geotechnical Unit

Boundary to Geotechnical Sub-unit

Boundary to 'Foundered strata'

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DEFINITION OF TERMS

L	LIMESTONE
S	SAND SANDSTONE { S_s SAND, S_H SANDSTONE
C	CLAY
M	MUDSTONE SILTSTONE SHALES
F.I.	Fracture spacing Index (mm)
R.Q.D.	Rock Quality Designation (%)
C.R.	Core Recovery (%)
S.P.T.	Standard Penetration Test
N	Number of blows for 30cm penetration
R.P.T.	Penetration in mm for 50 blows
Su	Undrained shear strength (kPa)
Øu	Undrained angle of internal friction (degrees)
C'r	Effective residual cohesion (kPa)
Ø'r	Effective residual angle of internal friction (degrees)
Ei	Youngs Modulus of Elasticity (initial) (MPa)
Mv	Coefficient of volume compressibility (m/MN)
k	Permeability (m/s)
k1	primary permeability
k2	secondary permeability
SO_3	Total sulphate content (%) (B.S. 1377, 1975 Test 9)
ORG.	Total organic content (%) (B.S. 1377, 1975 Test 8)
CARB.	Total carbonate content (%) (J. Sedimentary Petrology, 1974)
pH	pH of soil suspension (B.S. 1377, 1975 Test 1)
M	Mudstone component
L	Limestone component
‡	Su for Dyrham Silt member
w	Weathered
*	Extrapolation from data outside the study area
comp	Compressive strength (MPa) (see table)
1	Number of observation or test results
#	Cotham Bed (shear plane Clay)

Rock Quality Definitions

R.Q.D.(%) = 100 × (Lengths of rock recovered in sound lengths ≥100mm) / (Length of core run)

C.R.(%) = 100 × (Length of core recovered) / (Length of core run)

F.I.(mm) = (Unit length) / (Number of fractures)

Rock Quality Designation (%)

R.Q.D.(%)	Description
0 to 25	Very poor
25 to 50	Poor
50 to 75	Fair
75 to 90	Good
90 to 100	Excellent

Compressive Strength of Rock

Compressive strength (MN/m²)	Description
<1.25	Very weak
1.25 to 5.0	Weak
5.0 to 12.5	Moderately weak
12.5 to 50	Moderately strong
50 to 100	Strong
100 to 200	Very strong
>200	Extremely strong

SO_3 Total sulphates (CP2004) in soil

Class	
1	<0.2%
2	0.2 to 0.5%
3	0.5 to 1.0%
4	1.0 to 2.0%
5	>2%

Compressibility (Soils)

Description	Mv (m²/MN)
Very low	<0.05
Low	0.05 to 0.1
Medium	0.1 to 0.3
High	0.3 to 1.5
Very high	>1.5

Standard Penetration Test (Terzaghi and Peck) (Soil)

	RELATIVE DENSITY	N (blows/foot)
SAND and SILT	very loose	<4
	loose	4 to 10
	medium	10 to 30
	dense	30 to 50
	very dense	>50
	CONSISTENCY	
CLAY	very soft	<2
	soft	2 to 4
	medium	4 to 8
	stiff	8 to 15
	very stiff	15 to 30
	hard	>30

KEY A

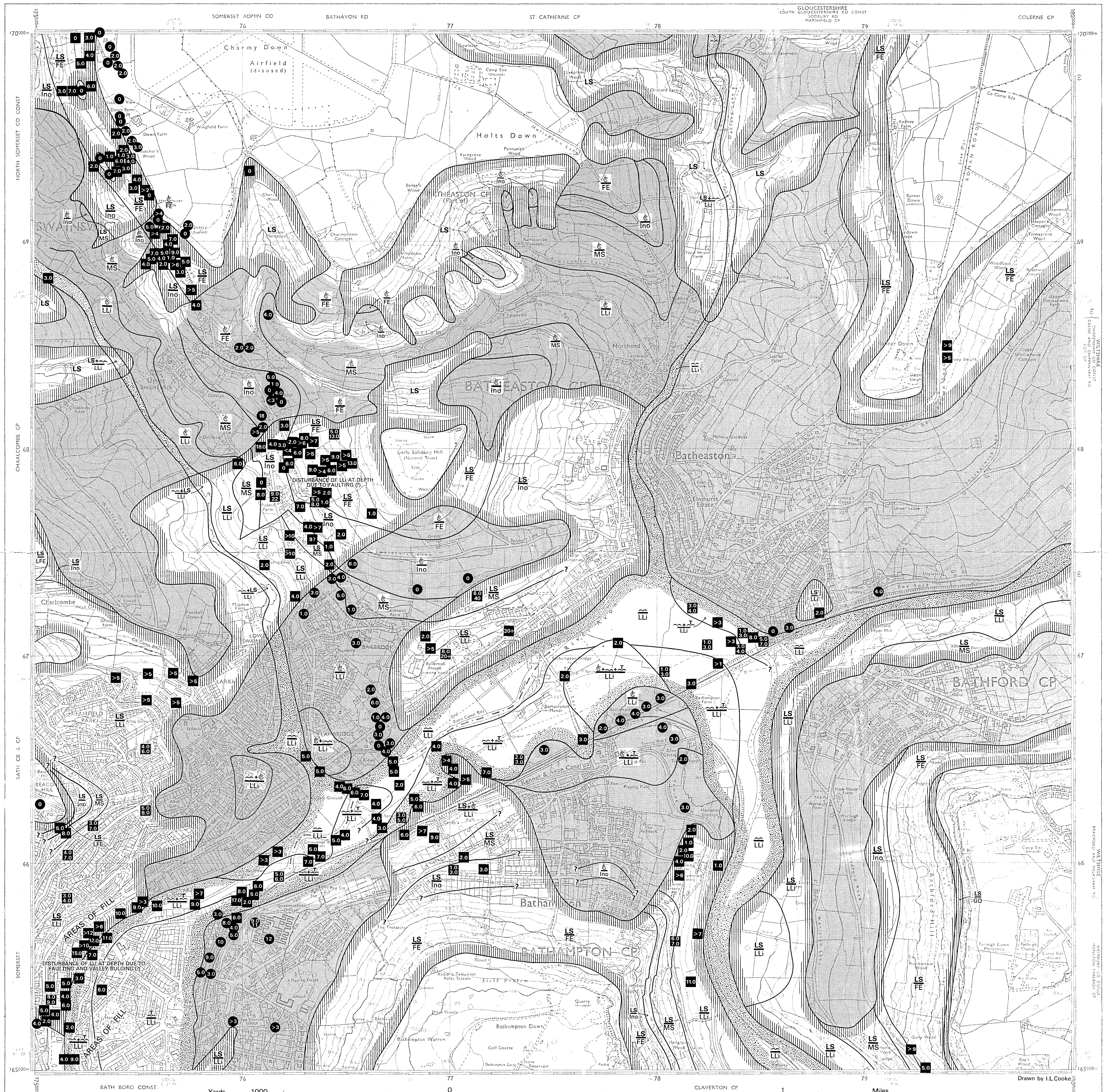
GEO-TECHNICAL UNIT	GEO-TECHNICAL SUB-UNIT	STRATIGRAPHY NAME (not in order) (thickness in metres)	SUB-UNIT ELEMENTS	DESCRIPTION
	L	GREAT OOLITE (32 to 35m)		Massive oolitic and shelly LIMESTONE with few thin marl bands
		INFERIOR OOLITE (12 to 18m)		Massive to flaggy oolitic, sandy coralline LIMESTONE with very shelly, conglomeratic LIMESTONE at base; thin MARL bands
		CORNBRASH (1.5 to 6m)		Fine-grained massive to flaggy shell-detrital LIMESTONE with few MARL partings
		FOREST MARBLE LST.		Variable shell-fragmental & oolitic LIMESTONE with marl bands
	S_s/S_H	MIDFORD SANDS (12 to 25m)		Uniform fine-grained silty SAND and sandy SILT with bands and lenses of soft friable SANDSTONE and SILTSTONE and irregular lenses of hard calcareous SANDSTONE. Intermittent hard shelly oolitic LIMESTONE at base (Junction Bed)
		HINTON SANDS (maximum 10m)		Lenticular bodies of soft clayey SAND and SANDSTONE
	S_H	DOWNEND FORMATION (175m)		Massive GRIT and SANDSTONE with coal seams
	C/M	OXFORD CLAY (25m)		Laminated highly overconsolidated CLAY, clay SHALE and MUDSTONE. Fossil packed partings
	M/C	MERCIA MUDSTONE (KEUPER MARL) (77m?)		Silty, sandy MUDSTONE and overconsolidated CLAY with variable thickness of limestone breccia (in sandy mudstone matrix at base)
	L/CM	BLUE LIAS (1.5 to 19)	C+M=50 to 80% L_1=20 to 50% L_2=55 to 95%	Interbedded hard muddy LIMESTONE, MARLSTONE and CLAY/SHALE. A dominantly clayey division (Saltford Shales) separates upper and lower LIMESTONE-rich divisions
		FULLER'S EARTH ROCK (1 to 5m)	C+M=50% L=50%	Rubbly, shelly and marly LIMESTONE with bands of shell fragmental calcareous MUDSTONE; conglomeratic at base
	CM/L	FOREST MARBLE (16 to 30m mostly 22 to 25m)	?	Very variable both vertically and laterally silty CLAY and calcareous MUDSTONE with bands of sandy LIMESTONE
		FROME CLAY (22m)	?	Stiff CLAY and calcareous MUDSTONE with bands of thin muddy LIMESTONE
		LOWER LIAS CLAY (18 to 135m)	C+M=81% L=5 to 29% (Mean 19%)	Silty micaceous and calcareous CLAY with bands of muddy LIMESTONE. Clays become weak MUDSTONE at depth. Micaceous and clayey SILT at top (Dyrham Silt)
		FULLER'S EARTH UPPER (12 to 29m)	C=35% M=46% L=19%	Silty CLAY interbedded with MUDSTONE, with bands of muddy LIMESTONE. Band of bentonitic clay (3m) (Commercial Fuller's Earth) locally. Clay is overconsolidated
		FULLER'S EARTH LOWER (10 to 16m)	C=60% M=10% L=30%	Silty CLAY interbedded with MUDSTONE, with bands of muddy LIMESTONE and shelly MUDSTONE. Clay is overconsolidated
		PENARTH GROUP (WHITE LIAS, RHAETIC) (9 to 12m)	C=60% L=40%	Rubbly to well-bedded LIMESTONE with CLAY partings (top). Shelly MARLS with LIMESTONE bands (middle) and thinly bedded very fossiliferous SHALES with bands of LIMESTONE (base)
	C/S_s	KELLAWAYS CLAY (21m)	C=85% S=15%	Very soft to firm sandy CLAY and shaly MUDSTONE with intermittent beds of clayey silty SAND and SANDSTONE particularly at top

KEY B GEOTECHNICAL ASSESSMENT

GEO-TECHNICAL UNIT	GEO-TECHNICAL SUB-UNIT	STRATI-GRAPHY NAME (not in order)	ROCK QUALITY R.Q.D. [C.R.%]	F.I. (mm)	UNDRAINED TOTAL SHEAR STRENGTH Su [Øu]	RESIDUAL SHEAR STRENGTH C'r & Ø'r	ELASTIC MODULUS Ei (MPa)	S.P.T. N (blows/30cm)	LIQUID LIMIT (B.S. 5930)	VERTICAL COMPRESS-IBILITY (SOILS) Mv (m²/MN)	pH	SO_3%	ORG%	CARB%		EFFECT OF WATER ON ENGINEERING BEHAVIOUR	WEATHERING	EXCAVATION	FOUNDATIONS	SLOPE CONDITIONS
L	L	GREAT OOLITE			7.6 to 19.0		12000 to 24000	30 to 300mm RPT			7.7w				SOLUTION	Generally free draining (joints/gulls)	Very suseptible to cavities: dissolution in fissures and gulls	Hard Oolitic LIMESTONE softens on exposure Flaggy LIMESTONE possibly unstable	Very good Bridging of gulls/fissure may be required Thin surface 'brash' (rubble in soft matrix)	Possibility of cambering near outcrop edge Block slides/rock falls
		INFERIOR OOLITE	50w	9.9w							7.8	0.040				Small artesian pressures possible	May be strongly weathered to rubbly LIMESTONE in soft clayey matrix	Very variable due to slope conditions	Very variable	Stronger possibility of cambering and infilled gulls Block/slab slides
		CORNBRASH			0.7 to 15.9							trace*				k1=Very low k2=High *	Weathering results in flaggy zone with soft joint infill	High overbreak Flaggy	Good Good fill Poor aggregate	Forms scree on steep slopes
		FOREST MARBLE LIMESTONE	0 to 85	60 to 220				8 to 12 w								Very variable due to clayey pockets	Very variable Weathers to 'brash'	May be very hard Very variable	Very variable due to clayey pockets	No evidence of movement
S	S_s/S_H	MIDFORD SANDS	[43]		Øu=[38°]	C'r=0 Ø'r=32		18 to 36	LOW		7.6	0.010				Particle size varies locally from coarse SILT to fine SAND k=Very low to low (10^{-5} to 10^{-8})*	Weather from grey to yellow Spring line at base	Possibly running sand in excavations below water table Boiling/piping under artesian pressures Well sorted (poorly graded)	Fair to good (very good if well cemented or with major SANDSTONE bands)	Little movement when undisturbed and above water table but liable to camber, flow slides and spring sapping when below water table
		HINTON SANDS							LOW*							ditto	ditto	ditto	ditto	No evidence of movement
	S_H	DOWNEND FORMATION			100 to 2000*					VERY LOW*						k1=Very low* k2=High*	Resistant to weathering except along joints*	May be very hard*	Very good*	No evidence of any movement
C, M	C/M	OXFORD CLAY			20 to 150	C'r=0* Ø'r=13 to 17*	40 to 140*	34	HIGH	0.08 to 0.5 (LOW to HIGH)	7.0 to 8.0	0.075 to 0.195	0 to 10*	0 to 50*		Low to moderate swelling/shrinkage potential k1=Low k2=low*	Considerable reduction in shear strength due to weathering particularly for mudstones and shales Increase in strength anisotropy due to weathering	Possibly stress-relief fissuring resulting in long term instability Overconsolidated	Good (Approximate depth of wethering 5m) Anisotropic compressibility	No evidence of significant movement in the study area
	M/C	MERCIA MUDSTONE			72 to 478	Ø'r=18 to 30*	100 to 1200* 10 to 100*w		LOW to INTERMEDIATE	0.025 to 0.30 (VERY LOW to MEDIUM)w	6.8 to 8.2	0.160	0.01 to 1.0*	(MOD-HIGH) 5 to 20*		Possible loss of strength due to dissolution of carbonates in marly bands. Clay forms agglomerations which may break down	Considerable reduction in shear strength and deformation modulus with weathering Increase in plasticity; loss of brittleness and effects of over consolidation	Heavily overconsolidated Softens and heaves on stress relief	Good Elastic settlement when fresh May be sensitive to disturbance Good fill if stabilized with cement	No evidence of movement in the study area
C, M & L	L/CM	BLUE LIAS	31 to 77 (CM/L) 42 to 91 (L/CM)		24 to 233; 9 to 76 L; 0.7 to 1.4 M		17.8 to 62.7 (CLAY)	38 to 600	INTERMEDIATE to HIGH	0.07 to 3.26 (LOW to VERY HIGH)	6.5 to 6.6	0.350 to 0.960				Moderate swelling/shrinkage potential (CLAYS) k=Low to High, variable* Solution of LIMESTONE	Weathering in proximity of LIMESTONE bands	Frequent changes in hardness and strength with depth Directional stability of tunneling is a problem	Variable according to zone in question Uppermost and lowermost zones most suitable (higher LIMESTONE content)	No evidence of movement in the study area
		FULLER'S EARTH ROCK		5.5	222			60+	LOW to HIGH							ditto	ditto	Probably unimportant due to lack of thickness	Presence uncertain Foundations may require special measures due to thickness and variability	May cause low scarp feature Generally discontinuous May be broken up by slipping
	CM/L	FOREST MARBLE						10 to 400+; 8 to 13 w	HIGH		7.0 to 9.5	0.005 to 0.010				Moderate to High swelling/shrinkage potential	Highly variable Weathers in proximity of LIMESTONE bands	Highly variable	Highly variable Moderately good where uniform	No evidence of movement in the area
		FROME CLAY														ditto	ditto	ditto	ditto	ditto
		LOWER LIAS CLAY	57 [91]	8.0 to 56.0	25 to 565; 183 to 240‡	C'r=0 to 98; Ø'r=12 to 35	14.5 to 66.2 (CLAY)	0 to 175; 43 to 400 L	LOW to VERY HIGH	0.03 to 0.65 (VERY LOW to HIGH)	6.5 to 8.3	0.01 to 0.85	1.7 (0.8 to 3.5)			Medium to High swelling/shrinkage potential Low seepage except in LIMESTONE bands Perched water tables Small artesian pressures	Weathering produces paper shale at base Weathers in proximity of LIMESTONE bands Loss of shear strength due to weathering Possible solifluction disturbance near upper surface?	Overconsolidated Concrete segment tunnel lining Shield driving? Small scale softening/distortion of strata at depth may cause instability in deep excavations	Good Rapid increase of strength with depth, but note disturbed/softened strata at depth	Movement may occur if oversteepened
		(upper) FULLER'S EARTH	28 to 76	6.1 to 7.5	11 to 286	C'r=0 to 30 Ø'r=13 to 32		64 to 400	LOW to EXTRA HIGH	0.08 to 0.22 (LOW to MEDIUM)	7.0 to 7.4	0.04 to 0.58		3 to 90		Medium to high swelling/shrinkage potential very high (Commercial Fuller's Earth) Perched water tables ?	Fissured Weathers to softened yellow CLAY Decrease in shear strength High moisture content	Swelling pressure may distort temporary support	Poor to good Shear strength reduces from approximately 5m to surface where weathered	Significant possibility of cambering and other slope movement
		(lower)			21 to 423	C'r=4 to 10 Ø'r=11 to 24		37 to 400	LOW to VERY HIGH	0.05 to 0.19 (LOW to MEDIUM)	7.0 to 8.5	0.05 to 0.34		33 to 83		Moderate swelling/shrinkage potential				
		PENARTH GROUP			139 to 367; 80 L	Ø'r=5 to 11 C'r=4 to 14‡			EXTRA HIGH‡							Highly variable k	Highly variable	Highly variable	Highly variable	No evidence of movement in the study area
C, S	C/S_s	KELLAWAYS CLAY			Øu=[30° to 40°] (SAND)				(SAND) LOW to INTERMEDIATE (CLAY) HIGH			trace*				Nil to moderate swelling/shrinkage potential k=Low to Very high*	Little evidence of weathering	Possible boiling under artesian pressure and piping in excavation of sand layers Potentially unstable below water table	Variable Low remoulded shear strength	No evidence of movement in the study area

N.B. Table for L/CM and CM/L sub-units descibes clay or shale component unless stated otherwise kPa=kN/m² and Mpa=1000kN/m²

WA/VG/85/8



Yards 1000 0 1 Miles
Metres 1000 0 1 2 Kilometres

Scale 1:10 000

BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 9a (ST 76 NE)

ENGINEERING PROPERTIES OF SUPERFICIAL DEPOSITS

GEO-TECHNICAL UNIT	DESCRIPTION	GEO-TECHNICAL SUB-UNIT	DESCRIPTION	PLASTICITY L.L. (%)	S.P.T. N (blows/30cm)	UNDRAINED STRENGTH Su (kPa)		CHEMICAL ANALYSIS
HEAD	Heterogeneous slope deposit derived from the bedrock by periglacial freeze-thaw action (e.g. solifluction). Head is dominantly a sandy CLAY-SILT deposit charged with rock clasts of all sizes (gravel to boulder). Content is determined by local bedrock lithologies. Clasts tend to be angular. Moderate sorting of sands and gravels occurs locally. Head deposits contain relic shear surfaces. Thickness reaches 6m and tends to be greatest on shallow slopes.	FE HEAD ON FULLER'S EARTH	Silty CLAY with gravel to boulder sized fragments of GREAT OOLITE and FULLER'S EARTH ROCK limestones. Locally high plasticity due to commercial FULLER'S EARTH bed.	LOW to EXTREMELY HIGH 60 (28 to 118) [SD:20] 52	ALL HEAD: MEDIUM DENSE to DENSE 25 (10 to 51) [SD:11.5] [SK:0.7] 29	ALL HEAD: 76 (3 to 210) [SD:57] [SK:1.3] 63	26 (4 to 100) 14	
		InO HEAD ON INFERIOR OOLITE	Cobble and small boulder sized fragments of INFERIOR OOLITE limestone in a matrix of INFERIOR OOLITE sand-sized ooliths, with clay and silt of INFERIOR OOLITE and possibly FULLER'S EARTH origin. Some underdrainage.	INTERMEDIATE (35 to 49) 3				
		MS HEAD ON MIDFORD SANDS	Rubble of INFERIOR OOLITE limestone in a matrix of reworked clayey sand SILT and silty SAND (MIDFORD SANDS origin) possibly with fragments of MIDFORD SANDS sandstone.	LOW to INTERMEDIATE 31 (23 to 50) [SD:9] 20				
		LLi HEAD ON LOWER LIAS	Reworked sandy SILT with few limestone and sandstone fragments on upper slopes; and silty sandy CLAY with limestone fragments (LOWER LIAS origins) on lower slopes.	LOW to HIGH 46 (24 to 69) [SD:12.1] 46			90 (16 to 207) [SD:45] 35	
	Areas of bedrock probably overlain by Head (boundary uncertain). Slope angle 0 to 15°	MMG HEAD ON MMG	Compact gravelly sandy CLAY and SAND.	(27 to 46) 4			80 (9 to 180) 11	
LANDSLIP LS	Deposit formed as a result of mass movement. Content is determined by slip type and lithology. Deep rotational slip may retain partly undisturbed material, but which is, as a whole, in a state of limiting equilibrium. Shallow translational slip may contain totally reworked material (e.g. hillwash). All types feature shear planes or zones containing strain-softened material at its minimum strength (residual strength). Likely to be overlain by mantle of head. [Refer to Map 10]	LS/FE LANDSLIP ON FULLER'S EARTH	Similar to weathered unslipped FULLER'S EARTH; contains GREAT OOLITE and FULLER'S EARTH ROCK limestones. Slips usually of shallow transitional type.	LOW to EXTREMELY HIGH*		VERY SOFT to HARD		pH: 7.0 to 8.5 *10 SO_3: 0.04 to 0.58 8
		LS/InO LANDSLIP ON INFERIOR OOLITE	Similar to above. Underlying INFERIOR OOLITE may be cambered with open or infilled gulls (tension cracks). Some underdrainage. Moderately well graded. Relatively low moisture content.	LOW to VERY HIGH*				pH: 7.8 *1 SO_3: 0.04 1
		LS/MS LANDSLIP ON MIDFORD SANDS	Similar to unslipped MIDFORD SANDS but with higher moisture content and in a looser state. Slips are usually of a shallow flow type. Moderately well graded.	LOW to HIGH*				pH: 7.6 *1 SO_3: 0.01 1
		LS/LLi LANDSLIP ON LOWER LIAS	Similar to unslipped LOWER LIAS clay except where source material is MIDFORD SANDS (see above). Slips are either of a deep rotational, translation or shallow flow type	LOW to HIGH*		FIRM to STIFF (VERY SOFT IN SHEAR ZONE)		pH: 6.5 to 8.3 56 SO_3: 0.01 to 0.85 51
ALLUVIAL DEPOSITS	Two groups of alluvial deposits may be broadly distinguished: i) Terrace Gravels including 'sub-alluvial gravels' are found overlying bedrock at three levels and underlying Alluvium at the lowest level (T).	ALLUVIUM RECENT	Silty sandy CLAYS, organic CLAYS/SILTS with lenses of silty SAND and PEAT. Desiccated crust gives increased strength at surface. Clays and silts are very soft to stiff at depth. Thickness may exceed 10m. Alluvium may overlie lobes of Head adjacent to valley sides.	LOW to EXTREMELY HIGH 53 (28 to 116) [SD:17] [SK:1.0] 140	SOFT to HARD 17 (3 to 74) [SD:17] 36	VERY SOFT to HARD 45 (3 to 209) [SD:37] [SK:1.8] 204		ALL ALLUVIUM: pH: 7.5 (6.9 to 8.3) 34 SO_3: 0.05 (0.001 to 0.150) 37
	ii) Alluvium is underlain by Terrace Gravels (T), occasionally infilling channels in the gravels, and occasionally overlying bedrock directly. [Refer to Map 2]	T "TERRACE GRAVELS"	Sandy silty and clayey fine to coarse GRAVELS up to 4m thick on LOWER LIAS, and infilling channels therein. Gravels and sands are medium dense. Terrace gravel may be overlain by lobes of Head adjacent to valley sides. [Strength and plasticity data refer to SILT/CLAY]	LOW to HIGH 46 (19 to 64) 32	LOOSE to VERY DENSE 31 (6 to 100+) 32	VERY SOFT to HARD 39 (12 to 245) [SD:53] [SK:1.7] 34		
(blank)	Areas of bedrock probably not overlain by Head, but having a surface layer consisting of partially weathered bedrock material of gravel to boulder size in a matrix of totally weathered material of sand, silt and clay size. Slope angle 0 to 5° [Refer to Maps 1 and 8]							
FILL F	Man made deposit including quarry infill, made-ground, waste tips and building rubble. The thickness and content of this deposit is unpredictable. Fill is commonplace in urban areas. The deposit may be in a loose state. [Refer to Map 3]							
F	As above, but boundary uncertain. The extent, thickness and content of this deposit is unpredictable.							

3.0 Depth to bedrock underlying Landslip, Alluvium or Fill (in metres)
2.0 Depth to bedrock underlying either Head or weathered bedrock.
3.5/5.5 Range of depth to bedrock

STRATIGRAPHY [Refer to Maps 1 and 8]	ABBREVIATIONS USED IN KEY
GO Great Oolite	SO_3 Total Sulphate content (B.S.1377)
FE Fuller's Earth	* Bedrock data (Map 8)
UFE Upper Fuller's Earth	L.L. Liquid Limit
FER Fuller's Earth Rock	P.I. Plasticity Index
LFE Lower Fuller's Earth	[SD] Standard Deviation (statistical)
InO Inferior Oolite	[SK] Coefficient of Skewness (statistical)
MS Midford Sands	S.P.T. Standard Penetration Test
LLi Lower Lias	
BLi Blue Lias	STATISTICAL NOTATION: 20 (3 to 74) 4 — mean, range, number of tests
MMG Mercia Mudstone Group	
PnG Penarth Group	

PLASTICITY (B.S.5930)	L.L.(%)
LOW	20 to 35
INTERMEDIATE	35 to 50
HIGH	50 to 70
VERY HIGH	70 to 90
EXTREMELY HIGH	>90
CONSISTENCY (B.S.5930)	**Su(kPa)**
VERY SOFT	<20
SOFT	20 to 40
FIRM	40 to 75
STIFF	75 to 150
VERY STIFF/HARD	>150

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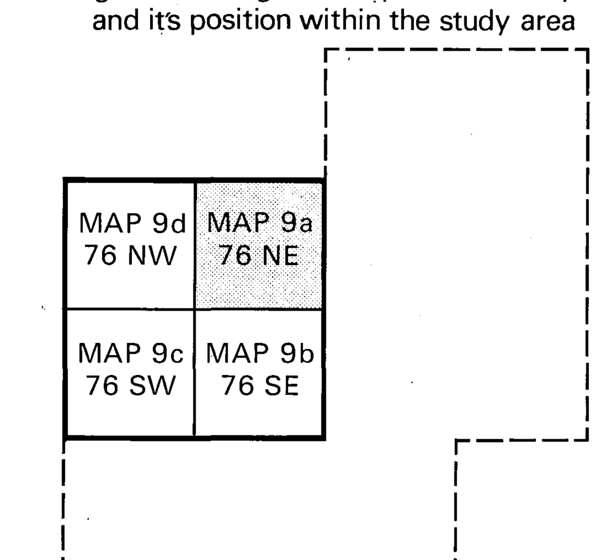
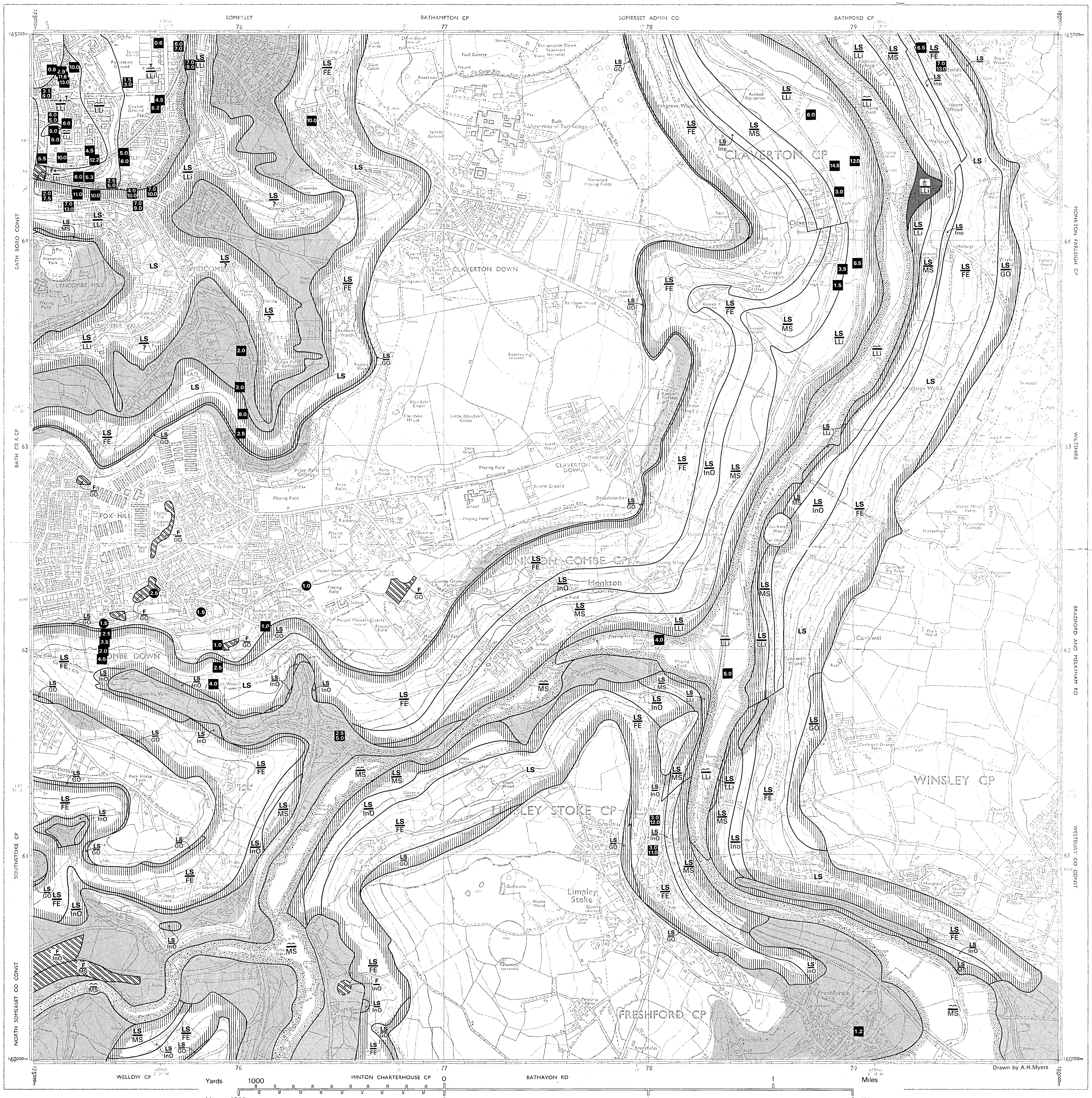
Nevertheless, the possibilities of undetected anomalous conditions and uncharted shallow workings and mineshafts are always present. There is no substitute for the knowledge provided by detailed surveys and the drilling of trial boreholes that take into account the extent, nature and location of a proposed development.

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

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

Diagram showing the composition of Map 9 and it's position within the study area





BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 9b (ST 76 SE)

ENGINEERING PROPERTIES OF SUPERFICIAL DEPOSITS

GEO-TECHNICAL UNIT	DESCRIPTION	GEO-TECHNICAL SUB-UNIT	DESCRIPTION	PLASTICITY L.L. (%)	S.P.T. N (blows/30cm)	UNDRAINED STRENGTH Su (kPa)	CHEMICAL ANALYSIS
HEAD	Heterogeneous slope deposit derived from the bedrock by periglacial freeze-thaw action (e.g. solifluction). Head is dominantly a sandy CLAY-SILT deposit charged with rock clasts of all sizes (gravel to boulder). Content is determined by local bedrock lithologies. Clasts tend to be angular. Moderate sorting of sands and gravels occurs locally. Head deposits contain relic shear surfaces. Thickness reaches 6m and tends to be greatest on shallow slopes.	HEAD ON FULLER'S EARTH ($\frac{\text{Ȼ}}{\text{FE}}$)	Silty CLAY with gravel to boulder sized fragments of GREAT OOLITE and FULLER'S EARTH ROCK limestones. Locally high plasticity due to commercial FULLER'S EARTH bed.	LOW to EXTREMELY HIGH 60 (28 to 118) [SD:20] 52	ALL HEAD: MEDIUM DENSE to DENSE 25 (10 to 51) [SD:11.5] [SK:0.7] 29	ALL HEAD: 76 (3 to 210) [SD:57] [SK:1.3] 63; 26 (4 to 100) 14	
		HEAD ON INFERIOR OOLITE ($\frac{\text{Ȼ}}{\text{InO}}$)	Cobble and small boulder sized fragments of INFERIOR OOLITE limestone in a matrix of INFERIOR OOLITE sand-sized ooliths, with clay and silt of INFERIOR OOLITE and possibly FULLER'S EARTH origin. Some underdrainage.	INTERMEDIATE (35 to 49) 3			
		HEAD ON MIDFORD SANDS ($\frac{\text{Ȼ}}{\text{MS}}$)	Rubble of INFERIOR OOLITE limestone in a matrix of reworked clayey sand SILT and silty SAND (MIDFORD SANDS origin) possibly with fragments of MIDFORD SANDS sandstone.	LOW to INTERMEDIATE 31 (23 to 50) [SD:9] 20			
	Areas of bedrock probably overlain by Head (boundary uncertain). Slope angle 0 to 15°	HEAD ON LOWER LIAS ($\frac{\text{Ȼ}}{\text{LLi}}$)	Reworked sandy SILT with few limestone and sandstone fragments on upper slopes; and silty sandy CLAY with limestone fragments (LOWER LIAS origins) on lower slopes.	LOW to HIGH 46 (24 to 69) [SD:12.1] 46		90 (16 to 207) [SD:45] 35	
		HEAD ON MMG ($\frac{\text{Ȼ}}{\text{MMG}}$)	Compact gravelly sandy CLAY and SAND.	(27 to 46) 4		80 (9 to 180) 11	
LANDSLIP (LS)	Deposit formed as a result of mass movement. Content is determined by slip type and lithology. Deep rotational slip may retain partly undisturbed material, but which is, as a whole, in a state of limiting equilibrium. Shallow translational slip may contain totally reworked material (e.g. hillwash). All types feature shear planes or zones containing strain-softened material at its minimum strength (residual strength). Likely to be overlain by mantle of head. [Refer to Map 10]	LANDSLIP ON FULLER'S EARTH ($\frac{\text{LS}}{\text{FE}}$)	Similar to weathered unslipped FULLER'S EARTH; contains GREAT OOLITE and FULLER'S EARTH ROCK limestones. Slips usually of shallow transitional type.	LOW to EXTREMELY HIGH*		VERY SOFT to HARD	pH: 7.0 to 8.5 * 10; SO_3: 0.04 to 0.58 8
		LANDSLIP ON INFERIOR OOLITE ($\frac{\text{LS}}{\text{InO}}$)	Similar to above. Underlying INFERIOR OOLITE may be cambered with open or infilled gulls (tension cracks). Some underdrainage. Moderately well graded. Relatively low moisture content.	LOW to VERY HIGH*			pH: 7.8 * 1; SO_3: 0.04 1
		LANDSLIP ON MIDFORD SANDS ($\frac{\text{LS}}{\text{MS}}$)	Similar to unslipped MIDFORD SANDS but with higher moisture content and in a looser state. Slips are usually of a shallow flow type. Moderately well graded.	LOW to HIGH*			pH: 7.6 * 1; SO_3: 0.01 1
		LANDSLIP ON LOWER LIAS ($\frac{\text{LS}}{\text{LLi}}$)	Similar to unslipped LOWER LIAS clay except where source material is MIDFORD SANDS (see above). Slips are either of a deep rotational, translation or shallow flow type	LOW to HIGH*		FIRM to STIFF (VERY SOFT IN SHEAR ZONE)	pH: 6.5 to 8.3 56; SO_3: 0.01 to 0.85 51
ALLUVIAL DEPOSITS	Two groups of alluvial deposits may be broadly distinguished: i) Terrace Gravels including 'sub-alluvial gravels' are found overlying bedrock at three levels and underlying Alluvium at the lowest level (T). ii) Alluvium is underlain by Terrace Gravels (T), occasionally infilling channels in the gravels, and occasionally overlying bedrock directly. [Refer to Map 2]	ALLUVIUM RECENT	Silty sandy CLAYS, organic CLAYS/SILTS with lenses of silty SAND and PEAT. Desiccated crust gives increased strength at surface. Clays and silts are very soft to stiff at depth. Thickness may exceed 10m. Alluvium may overlie lobes of Head adjacent to valley sides.	LOW to EXTREMELY HIGH 53 (28 to 116) [SD:17] [SK:1.0] 140	SOFT to HARD 17 (3 to 74) [SD:17] 36	VERY SOFT to HARD 45 (3 to 209) [SD:37] [SK:1.8] 204	ALL ALLUVIUM: pH:7.5 (6.9 to 8.3) 44; SO_3: 0.05 (0.001 to 0.150) 37
		"TERRACE GRAVELS" (T)	Sandy silty and clayey fine to coarse GRAVELS up to 4m thick on LOWER LIAS, and infilling channels therein. Gravels and sands are medium dense. Terrace gravel may be overlain by lobes of Head adjacent to valley sides. [Strength and plasticity data refer to SILT/CLAY]	LOW to HIGH 46 (19 to 64) 32	LOOSE to VERY DENSE 31 (6 to 100+) 32	VERY SOFT to HARD 39 (12 to 245) [SD:53] [SK:1.7] 34	

	Areas of bedrock probably not overlain by Head, but having a surface layer consisting of partially weathered bedrock material of gravel to boulder size in a matrix of totally weathered material of sand, silt and clay size. Slope angle 0 to 5° [Refer to Maps 1 and 8]
FILL (F)	Man made deposit including quarry infill, made-ground, waste tips and building rubble. The thickness and content of this deposit is unpredictable. Fill is commonplace in urban areas. The deposit may be in a loose state. [Refer to Map 3]
F	As above, but boundary uncertain. The extent, thickness and content of this deposit is unpredictable.
3.0	Depth to bedrock underlying Landslip, Alluvium or Fill (in metres)
2.0	Depth to bedrock underlying either Head or weathered bedrock.
3.5 / 5.5	Range of depth to bedrock

STRATIGRAPHY [Refer to Maps 1 and 8]		ABBREVIATIONS USED IN KEY	
GO	Great Oolite	SO_3	Total Sulphate content (B.S.1377)
FE	Fuller's Earth	*	Bedrock data (Map 8)
UFE	Upper Fuller's Earth	L.L.	Liquid Limit
FER	Fuller's Earth Rock	P.I.	Plasticity Index
LFE	Lower Fuller's Earth	[SD]	Standard Deviation (statistical)
InO	Inferior Oolite	[SK]	Coefficient of Skewness (statistical)
MS	Midford Sands	S.P.T.	Standard Penetration Test
LLi	Lower Lias		
BLi	Blue Lias		STATISTICAL NOTATION: 20 (3 to 74) 4 — mean, range, number of tests
MMG	Mercia Mudstone Group		
PnG	Penarth Group		

PLASTICITY (B.S.5930)	L.L.(%)
LOW	20 to 35
INTERMEDIATE	35 to 50
HIGH	50 to 70
VERY HIGH	70 to 90
EXTREMELY HIGH	>90
CONSISTENCY (B.S.5930)	**Su(kPa)**
VERY SOFT	<20
SOFT	20 to 40
FIRM	40 to 75
STIFF	75 to 150
VERY STIFF/HARD	>150

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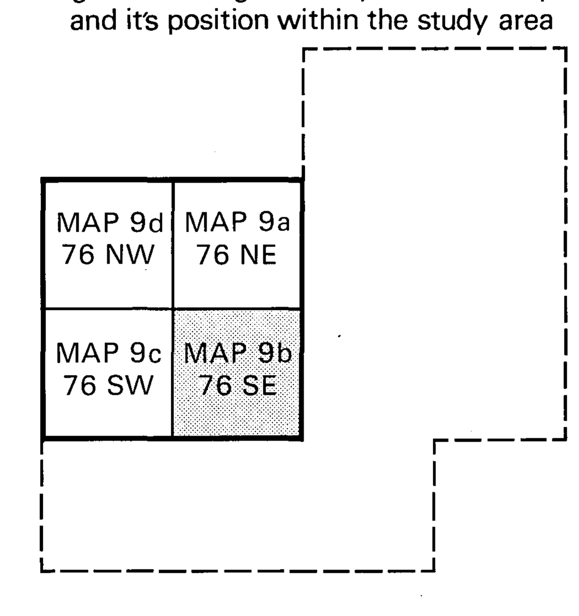
Diagram showing the composition of Map 9 and it's position within the study area



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

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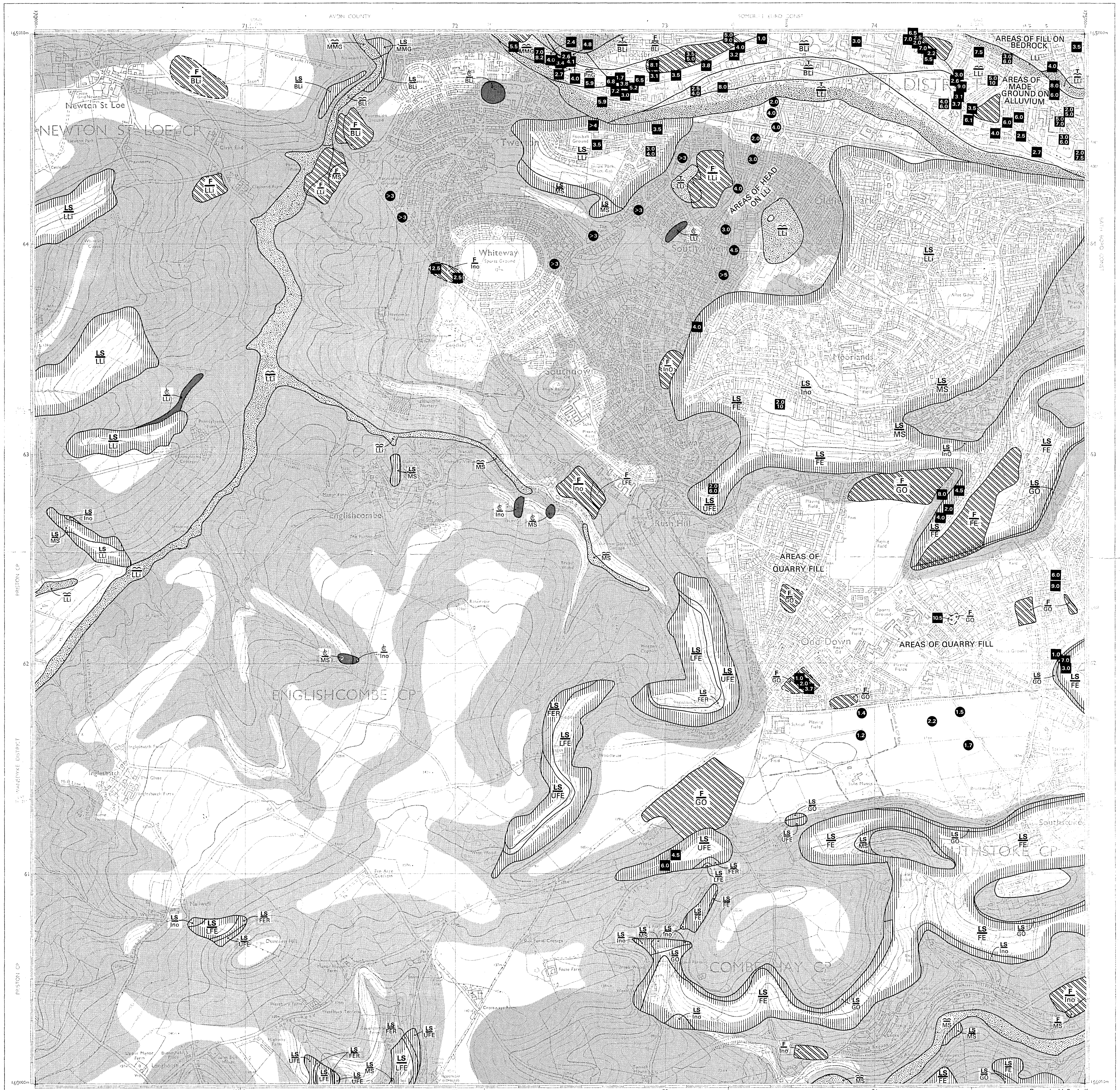
WA/VG/85/8



Yards 1000 0 1 Miles
Metres 1000 0 1 2 Kilometres
Scale 1:10 000

BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 9c (ST 76 SW)

ENGINEERING PROPERTIES OF SUPERFICIAL DEPOSITS

GEO-TECHNICAL UNIT	DESCRIPTION	GEO-TECHNICAL SUB-UNIT	DESCRIPTION	PLASTICITY L.L. (%)	S.P.T. N (blows/30cm)	UNDRAINED STRENGTH Su (kPa)	CHEMICAL ANALYSIS
HEAD	Heterogeneous slope deposit derived from the bedrock by periglacial freeze-thaw action (e.g. solifluction). Head is dominantly a sandy CLAY-SILT deposit charged with rock clasts of all sizes (gravel to boulder). Content is determined by local bedrock lithologies. Clasts tend to be angular. Moderate sorting of sands and gravels occurs locally. Head deposits contain relic shear surfaces. Thickness reaches 6m and tends to be greatest on shallow slopes.	Hd/FE HEAD ON FULLER'S EARTH	Silty CLAY with gravel to boulder sized fragments of GREAT OOLITE and FULLER'S EARTH ROCK limestones. Locally high plasticity due to commercial FULLER'S EARTH bed.	LOW to EXTREMELY HIGH 60 (28 to 118) [SD:20] 52	ALL HEAD: MEDIUM DENSE to DENSE 25 (10 to 51) [SD:11.5] [SK:0.7] 29	ALL HEAD: 76 (3 to 210) [SD:57] [SK:1.3] 63; 26 (4 to 100) 14	
		Hd/InO HEAD ON INFERIOR OOLITE	Cobble and small boulder sized fragments of INFERIOR OOLITE limestone in a matrix of INFERIOR OOLITE sand-sized ooliths, with clay and silt of INFERIOR OOLITE and possibly FULLER'S EARTH origin. Some underdrainage.	INTERMEDIATE (35 to 49) 3			
		Hd/MS HEAD ON MIDFORD SANDS	Rubble of INFERIOR OOLITE limestone in a matrix of reworked clayey sand SILT and silty SAND (MIDFORD SANDS origin) possibly with fragments of MIDFORD SANDS sandstone.	LOW to INTERMEDIATE 31 (23 to 50) [SD:9] 20			
		Hd/LLi HEAD ON LOWER LIAS	Reworked sandy SILT with few limestone and sandstone fragments on upper slopes; and silty sandy CLAY with limestone fragments (LOWER LIAS origins) on lower slopes.	LOW to HIGH 46 (24 to 69) [SD:12.1] 46		90 (16 to 207) [SD:45] 35	
	Areas of bedrock probably overlain by Head (boundary uncertain). Slope angle 0 to 15°	Hd/MMG HEAD ON MMG	Compact gravelly sandy CLAY and SAND.	(27 to 46) 4		80 (9 to 180) 11	
LANDSLIP LS	Deposit formed as a result of mass movement. Content is determined by slip type and lithology. Deep rotational slip may retain partly undisturbed material, but which is, as a whole, in a state of limiting equilibrium. Shallow translational slip may contain totally reworked material (e.g. hillwash). All types feature shear planes or zones containing strain-softened material at its minimum strength (residual strength). Likely to be overlain by mantle of head. [Refer to Map 10]	LS/FE LANDSLIP ON FULLER'S EARTH	Similar to weathered unslipped FULLER'S EARTH; contains GREAT OOLITE and FULLER'S EARTH ROCK limestones. Slips usually of shallow transitional type.	LOW to EXTREMELY HIGH*		VERY SOFT to HARD	pH: 7.0 to 8.5 * 10 SO_3: 0.04 to 0.58 6
		LS/InO LANDSLIP ON INFERIOR OOLITE	Similar to above. Underlying INFERIOR OOLITE may be cambered with open or infilled gulls (tension cracks). Some underdrainage. Moderately well graded. Relatively low moisture content.	LOW to VERY HIGH*			pH: 7.8 * 1 SO_3: 0.04 1
		LS/MS LANDSLIP ON MIDFORD SANDS	Similar to unslipped MIDFORD SANDS but with higher moisture content and in a looser state. Slips are usually of a shallow flow type. Moderately well graded.	LOW to HIGH*			pH: 7.6 * 1 SO_3: 0.01 1
		LS/LLi LANDSLIP ON LOWER LIAS	Similar to unslipped LOWER LIAS clay except where source material is MIDFORD SANDS (see above). Slips are either of a deep rotational, translation or shallow flow type	LOW to HIGH*		FIRM to STIFF (VERY SOFT IN SHEAR ZONE)	pH: 6.5 to 8.3 56 SO_3: 0.01 to 0.85 51
ALLUVIAL DEPOSITS	Two groups of alluvial deposits may be broadly distinguished: i) Terrace Gravels including 'sub-alluvial gravels' are found overlying bedrock at three levels and underlying Alluvium at the lowest level (T).	ALLUVIUM RECENT	Silty sandy CLAYS, organic CLAYS/SILTS with lenses of silty SAND and PEAT. Desiccated crust gives increased strength at surface. Clays and silts are very soft to stiff at depth. Thickness may exceed 10m. Alluvium may overlie lobes of Head adjacent to valley sides.	LOW to EXTREMELY HIGH 53 (28 to 116) [SD:17] [SK:1.0] 140	SOFT to HARD 17 (3 to 74) [SD:17] 36	VERY SOFT to HARD 45 (3 to 209) [SD:37] [SK:1.8] 204	ALL ALLUVIUM: pH:7.5 (6.9 to 8.3) 41 SO_3: 0.05 (0.001 to 0.150) 37
	ii) Alluvium is underlain by Terrace Gravels (T), occasionally infilling channels in the gravels, and occasionally overlying bedrock directly. [Refer to Map 2]	"TERRACE GRAVELS"	Sandy silty and clayey fine to coarse GRAVELS up to 4m thick on LOWER LIAS, and infilling channels therein. Gravels and sands are medium dense. Terrace gravel may be overlain by lobes of Head adjacent to valley sides. [Strength and plasticity data refer to SILT/CLAY]	LOW to HIGH 46 (19 to 64) 32	LOOSE to VERY DENSE 31 (6 to 100+) 32	VERY SOFT to HARD 39 (12 to 245) [SD:53] [SK:1.7] 34	
	Areas of bedrock probably not overlain by Head, but having a surface layer consisting of partially weathered bedrock material of gravel to boulder size in a matrix of totally weathered material of sand, silt and clay size. Slope angle 0 to 5° [Refer to Maps 1 and 8]						
FILL F	Man made deposit including quarry infill, made-ground, waste tips and building rubble. The thickness and content of this deposit is unpredictable. Fill is commonplace in urban areas. The deposit may be in a loose state. [Refer to Map 3]						
F	As above, but boundary uncertain. The extent, thickness and content of this deposit is unpredictable.						
3.0	Depth to bedrock underlying Landslip, Alluvium or Fill (in metres)	3.5 5.5	Range of depth to bedrock				
2.0	Depth to bedrock underlying either Head or weathered bedrock.						

STRATIGRAPHY [Refer to Maps 1 and 8]		ABBREVIATIONS USED IN KEY	
GO	Great Oolite	SO_3	Total Sulphate content (B.S.1377)
FE	Fuller's Earth	*	Bedrock data (Map 8)
UFE	Upper Fuller's Earth	L.L.	Liquid Limit
FER	Fuller's Earth Rock	P.I.	Plasticity Index
LFE	Lower Fuller's Earth	[SD]	Standard Deviation (statistical)
InO	Inferior Oolite	[SK]	Coefficient of Skewness (statistical)
MS	Midford Sands	S.P.T.	Standard Penetration Test
LLi	Lower Lias		
BLi	Blue Lias		STATISTICAL NOTATION: 20 (3 to 74) 4 — mean, range, number of tests
MMG	Mercia Mudstone Group		
PnG	Penarth Group		

PLASTICITY (B.S.5930)	L.L.(%)
LOW	20 to 35
INTERMEDIATE	35 to 50
HIGH	50 to 70
VERY HIGH	70 to 90
EXTREMELY HIGH	>90
CONSISTENCY (B.S.5930)	**Su(kPa)**
VERY SOFT	<20
SOFT	20 to 40
FIRM	40 to 75
STIFF	75 to 150
VERY STIFF/HARD	>150

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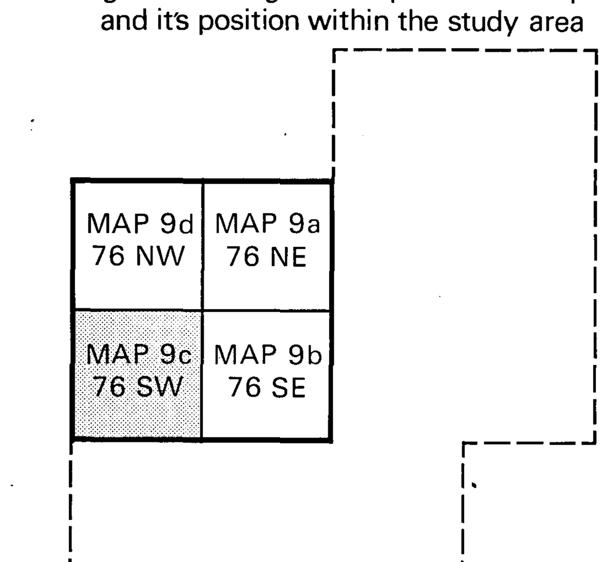
Diagram showing the composition of Map 9 and it's position within the study area



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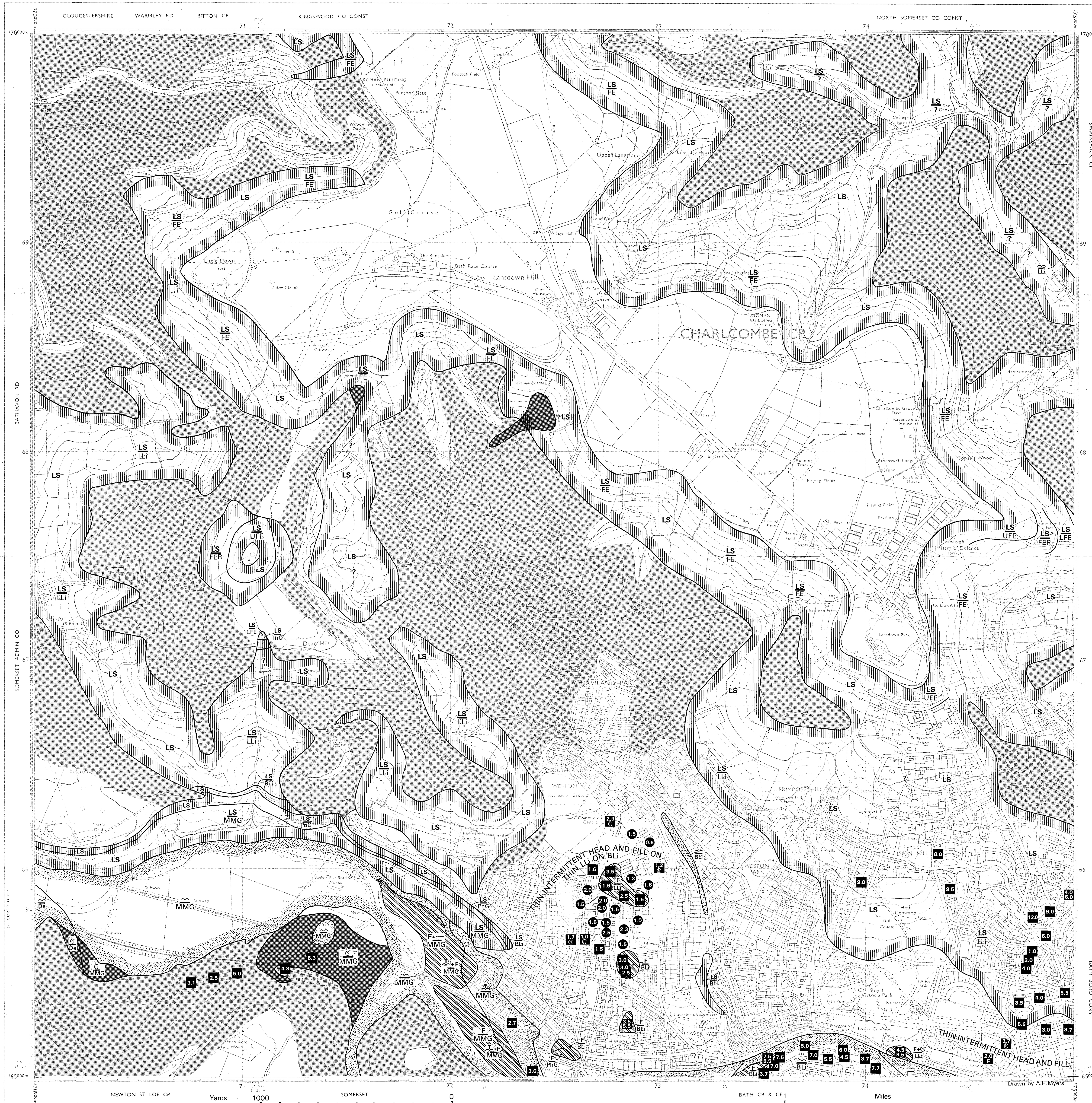
WA/VG/85/8



Yards 1000 0 Miles
Metres 1000 0 1 2 Kilometres

Scale 1:10 000

BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 9d (ST 76 NW)

ENGINEERING PROPERTIES OF SUPERFICIAL DEPOSITS

GEO-TECHNICAL UNIT	DESCRIPTION	GEO-TECHNICAL SUB-UNIT	DESCRIPTION	PLASTICITY L.L. (%)	S.P.T. N (blows/30cm)	UNDRAINED STRENGTH Su (kPa)	CHEMICAL ANALYSIS
HEAD	Heterogeneous slope deposit derived from the bedrock by periglacial freeze-thaw action (e.g. solifluction). Head is dominantly a sandy CLAY-SILT deposit charged with rock clasts of all sizes (gravel to boulder). Content is determined by local bedrock lithologies. Clasts tend to be angular. Moderate sorting of sands and gravels occurs locally. Head deposits contain relic shear surfaces. Thickness reaches 6m and tends to be greatest on shallow slopes.	Hd/FE HEAD ON FULLER'S EARTH	Silty CLAY with gravel to boulder sized fragments of GREAT OOLITE and FULLER'S EARTH ROCK limestones. Locally high plasticity due to commercial FULLER'S EARTH bed.	LOW to EXTREMELY HIGH 60 (28 to 118) [SD:20] 52	ALL HEAD: MEDIUM DENSE to DENSE 25 (10 to 51) [SD:11.5] [SK:0.7] 29	ALL HEAD: 76 (3 to 210) [SD:57] [SK:1.3] 63; 26 (4 to 100) 14	
		Hd/InO HEAD ON INFERIOR OOLITE	Cobble and small boulder sized fragments of INFERIOR OOLITE limestone in a matrix of INFERIOR OOLITE sand-sized ooliths, with clay and silt of INFERIOR OOLITE and possibly FULLER'S EARTH origin. Some underdrainage.	INTERMEDIATE (35 to 49) 3			
		Hd/MS HEAD ON MIDFORD SANDS	Rubble of INFERIOR OOLITE limestone in a matrix of reworked clayey sand SILT and silty SAND (MIDFORD SANDS origin) possibly with fragments of MIDFORD SANDS sandstone.	LOW to INTERMEDIATE 31 (23 to 50) [SD:9] 20			
		Hd/LLi HEAD ON LOWER LIAS	Reworked sandy SILT with few limestone and sandstone fragments on upper slopes; and silty sandy CLAY with limestone fragments (LOWER LIAS origins) on lower slopes.	LOW to HIGH 46 (24 to 69) [SD:12.1] 46		90 (16 to 207) [SD:45] 35	
	Areas of bedrock probably overlain by Head (boundary uncertain). Slope angle 0 to 15°	Hd/MMG HEAD ON MMG	Compact gravelly sandy CLAY and SAND.	(27 to 46) 4		80 (9 to 180) 11	
LANDSLIP (LS)	Deposit formed as a result of mass movement. Content is determined by slip type and lithology. Deep rotational slip may retain partly undisturbed material, but which is, as a whole, in a state of limiting equilibrium. Shallow translational slip may contain totally reworked material (e.g. hillwash). All types feature shear planes or zones containing strain-softened material at its minimum strength (residual strength). Likely to be overlain by mantle of head. [Refer to Map 10]	LS/FE LANDSLIP ON FULLER'S EARTH	Similar to weathered unslipped FULLER'S EARTH; contains GREAT OOLITE and FULLER'S EARTH ROCK limestones. Slips usually of shallow transitional type.	LOW to EXTREMELY HIGH*		VERY SOFT to HARD	pH: 7.0 to 8.5 * 10 SO_3: 0.04 to 0.58 8
		LS/InO LANDSLIP ON INFERIOR OOLITE	Similar to above. Underlying INFERIOR OOLITE may be cambered with open or infilled gulls (tension cracks). Some underdrainage. Moderately well graded. Relatively low moisture content.	LOW to VERY HIGH*			pH: 7.8 * 1 SO_3: 0.04 1
		LS/MS LANDSLIP ON MIDFORD SANDS	Similar to unslipped MIDFORD SANDS but with higher moisture content and in a looser state. Slips are usually of a shallow flow type. Moderately well graded.	LOW to HIGH*			pH: 7.6 * 1 SO_3: 0.01 1
		LS/LLi LANDSLIP ON LOWER LIAS	Similar to unslipped LOWER LIAS clay except where source material is MIDFORD SANDS (see above). Slips are either of a deep rotational, translation or shallow flow type	LOW to HIGH*		FIRM to STIFF (VERY SOFT IN SHEAR ZONE)	pH: 6.5 to 8.3 56 SO_3: 0.01 to 0.85 51
ALLUVIAL DEPOSITS	Two groups of alluvial deposits may be broadly distinguished: i) Terrace Gravels including 'sub-alluvial gravels' are found overlying bedrock at three levels and underlying Alluvium at the lowest level (T). ii) Alluvium is underlain by Terrace Gravels (T), occasionally infilling channels in the gravels, and occasionally overlying bedrock directly. [Refer to Map 2]	ALLUVIUM RECENT	Silty sandy CLAYS, organic CLAYS/SILTS with lenses of silty SAND and PEAT. Desiccated crust gives increased strength at surface. Clays and silts are very soft to stiff at depth. Thickness may exceed 10m. Alluvium may overlie lobes of Head adjacent to valley sides.	LOW to EXTREMELY HIGH 53 (28 to 116) [SD:17] [SK:1.0] 140	SOFT to HARD 17 (3 to 74) [SD:17] 36	VERY SOFT to HARD 45 (3 to 209) [SD:37] [SK:1.8] 204	ALL ALLUVIUM: pH: 7.5 (6.9 to 8.3) 44 SO_3: 0.05 (0.001 to 0.150) 37
		"TERRACE GRAVELS"	Sandy silty and clayey fine to coarse GRAVELS up to 4m thick on LOWER LIAS, and infilling channels therein. Gravels and sands are medium dense. Terrace gravel may be overlain by lobes of Head adjacent to valley sides. [Strength and plasticity data refer to SILT/CLAY]	LOW to HIGH 46 (19 to 64) 32	LOOSE to VERY DENSE 31 (6 to 100+) 32	VERY SOFT to HARD 39 (12 to 245) [SD:53] [SK:1.7] 34	
	Areas of bedrock probably not overlain by Head, but having a surface layer consisting of partially weathered bedrock material of gravel to boulder size in a matrix of totally weathered material of sand, silt and clay size. Slope angle 0 to 5° [Refer to Maps 1 and 8]						
FILL (F)	Man made deposit including quarry infill, made-ground, waste tips and building rubble. The thickness and content of this deposit is unpredictable. Fill is commonplace in urban areas. The deposit may be in a loose state. [Refer to Map 3]						
(F)	As above, but boundary uncertain. The extent, thickness and content of this deposit is unpredictable.						
3.0	Depth to bedrock underlying Landslip, Alluvium or Fill (in metres)						
2.0	Depth to bedrock underlying either Head or weathered bedrock.						
3.5/5.5	Range of depth to bedrock						

STRATIGRAPHY [Refer to Maps 1 and 8]		ABBREVIATIONS USED IN KEY		PLASTICITY (B.S.5930)	L.L.(%)
GO	Great Oolite	SO_3	Total Sulphate content (B.S.1377)	LOW	20 to 35
FE	Fuller's Earth	*	Bedrock data (Map 8)	INTERMEDIATE	35 to 50
UFE	Upper Fuller's Earth	L.L.	Liquid Limit	HIGH	50 to 70
FER	Fuller's Earth Rock	P.I.	Plasticity Index	VERY HIGH	70 to 90
LFE	Lower Fuller's Earth	[SD]	Standard Deviation (statistical)	EXTREMELY HIGH	>90
InO	Inferior Oolite	[SK]	Coefficient of Skewness (statistical)	CONSISTENCY (B.S.5930)	Su(kPa)
MS	Midford Sands	S.P.T.	Standard Penetration Test	VERY SOFT	<20
LLi	Lower Lias			SOFT	20 to 40
BLi	Blue Lias		STATISTICAL NOTATION: 20 (3 to 74) 4 — mean, range, number of tests	FIRM	40 to 75
MMG	Mercia Mudstone Group			STIFF	75 to 150
PnG	Penarth Group			VERY STIFF/HARD	>150

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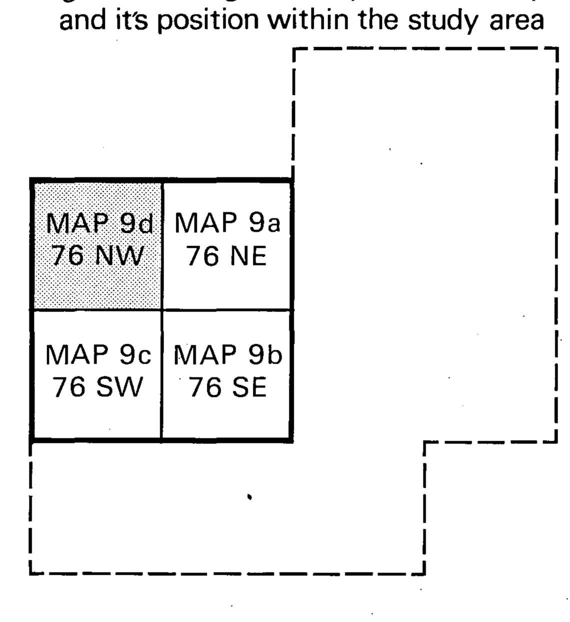
Diagram showing the composition of Map 9 and it's position within the study area



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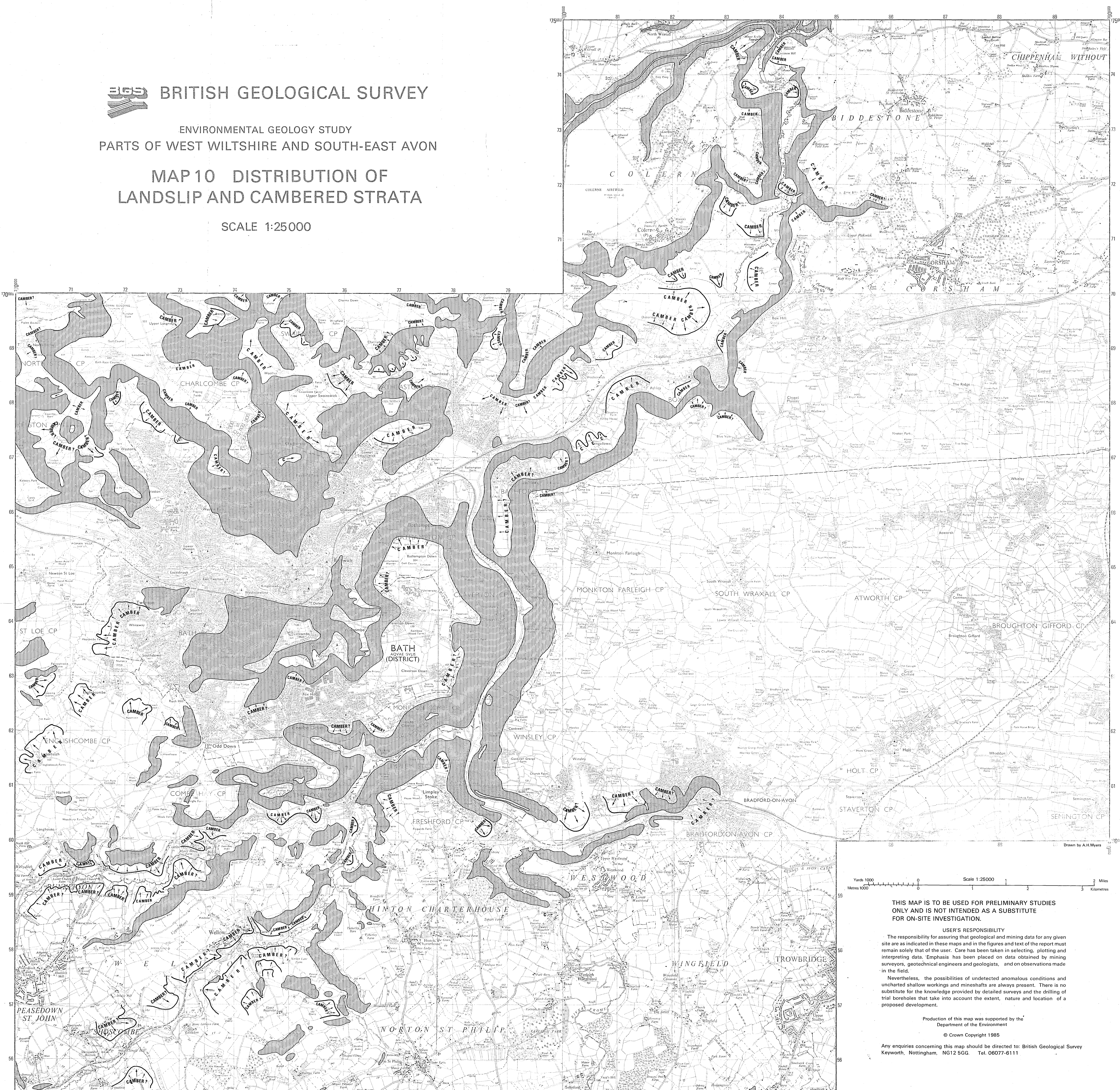
BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 10 DISTRIBUTION OF LANDSLIP AND CAMBERED STRATA

SCALE 1:25000



Scale 1:25000

Yards 1000 0 1 2 Miles

Metres 1000 0 1 2 3 Kilometres

LANDSLIPPED GROUND

The areas shown with vertical lines are those which by field survey and/or aerial photographic interpretation are considered to have undergone perceptible downslope movement of earth or rock by falling, sliding or flowing under the influence of gravity as a result of relatively shallow processes.

The areas so indicated are rarely affected by a single movement but are commonly a combination of numerous movements. These result from several failure types which have occured at different times. The landslips in the study area are normally shallow but deeper failures are present, often associated with oversteepening of the valley by the River Avon.

Areas of landslip other than those indicated may be present, but are unidentified because natural degredation and the effects of cultivation have subdued their topographic expression.

CAMBERED STRATA

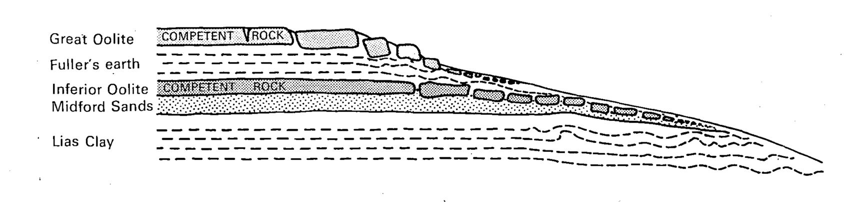
Cambering is the slow downward movement of strata due to the removal or plastic deformation of underlying weaker strata by relatively deep seated processes under glacial and periglacial conditions.

Camber commonly occurs on a large scale and typically manifests itself by the fracturing and tilting downslope of strong competent rocks on or above valley slopes.

On the map the direction of tilt is shown by arrows and the approximate outcrop of the competent layer is indicated. Cambering will also have affected the strata above and below the indicated horizon.

Camber which has been determined by field survey is shown without qualification. Where camber is inferred by the relationship of outcrop to topography, the term camber is qualified by a question mark, thus ' **CAMBER?** '

Diagramatic Representation of Cambering in the Bath Area



The cambering of strata and much of the landslipping took place in the remote past and the depiction of landslips and cambering does not neccessarily imply that the processes are active nor will become so in the future.

N.B. Map 15 in this set revises the area shown on Map 1 as 'foundered strata'. It includes revisions to the location and extent of landslip and cambered strata as shown on this map.

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ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 11 DISTRIBUTION OF SLOPE ANGLE

SCALE 1:25000

CATEGORY	SLOPE ANGLE RANGE	INTERPRETATION
(blank)	0° to 5°	Generally stable ground formed by alluvium/terrace deposits on valley floors, Great Oolite limestone plateaux between main valleys, and the subdued topography of the Great Oolite, Forest Marble, Cornbrash, Kellaways Clays and Oxford Clay outcrops in the eastern part of the area.
(light stipple)	5° to 10°	Generally stable ground composed of minor valley slopes, cambered margins of the Great Oolite plateaux, cambered outcrops of Inferior Oolite, parts of the lower Fuller's Earth and Lias clay outcrops, and small areas on the margins of ancient landslips.
(medium stipple)	10° to 15°	The ground falling within this category is variable but generally stable. Bedrock lithologies include Lower Fuller's Earth clays, Inferior Oolite limestones, Midford Sands, and Lias clay. Large areas of landslipped material are also found in this slope zone. The potential for mass movement here depends upon the nature of the bedrock, the superficial material and the depth of the local water table below ground surface. The Lower Fuller's Earth/Lias clays and the landslipped material are particularly susceptible to movement if the ground is subjected to loading or the drainage regime is disrupted.
(dark stipple)	above 15°	The ground within this category includes upper valley slopes, free rock faces and landslip backscars. It is composed mainly of Great and Inferior Oolite limestones, Upper Fuller's Earth clay and Midford Sands. Large areas of landslipped material are included in this zone. Many areas of this zone are liable to become unstable as a result of quite small changes in conditions. The Upper Fuller's Earth is particularly vulnerable.

Tick indicates downslope side

Drawn by A.H.Myers

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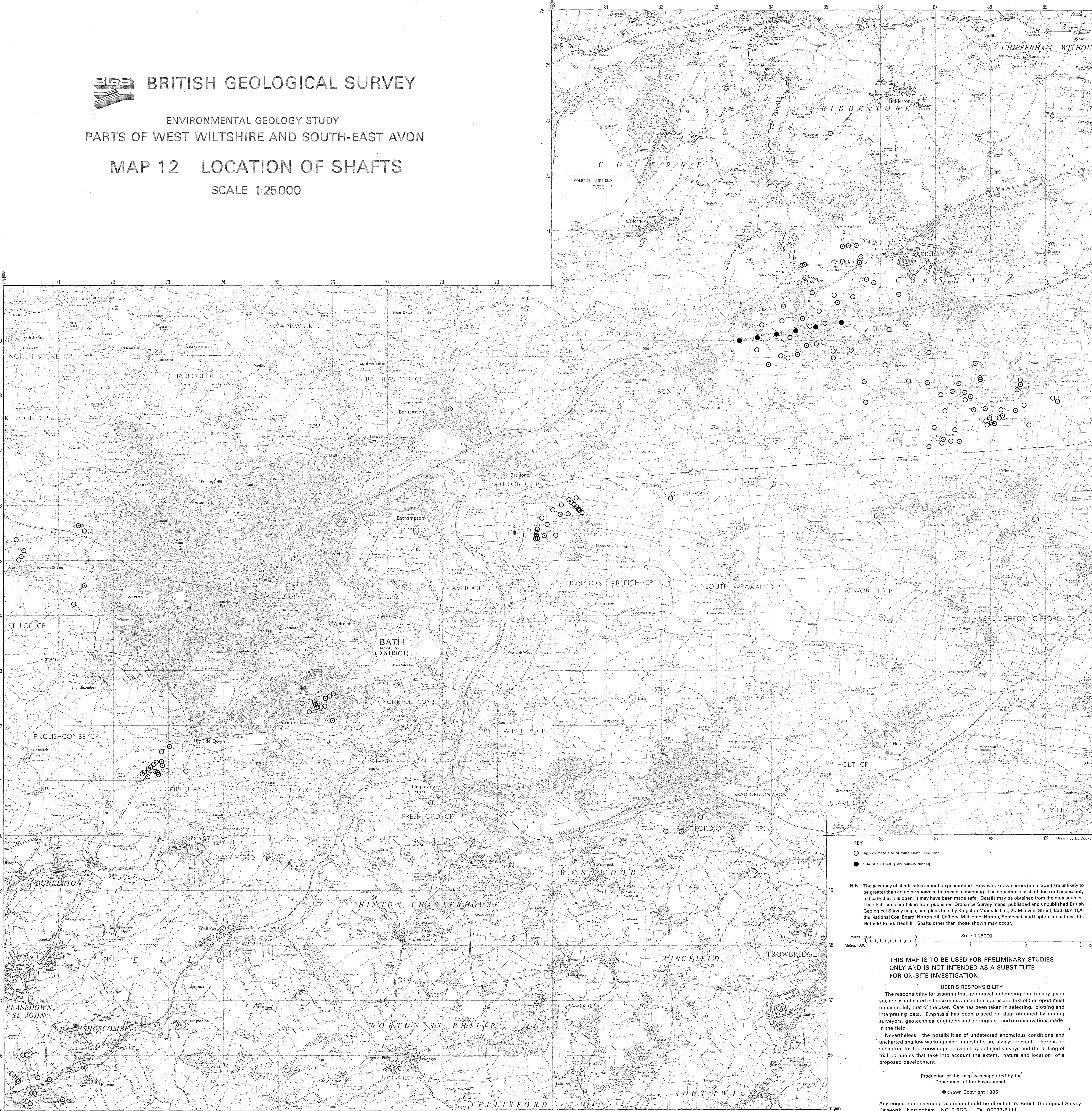
PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 12 LOCATION OF SHAFTS

SCALE 1:25000



KEY

Approximate site of mine shaft (see note)

Site of air shaft (Box railway tunnel)

N.B. The accuracy of shafts sites cannot be guaranteed. However, known errors (up to 30m) are unlikely to be greater than could be shown at this scale of mapping. The depiction of a shaft does not necessarily indicate that it is open; it may have been made safe. Details may be obtained from the data sources. The shaft sites are taken from published Ordnance Survey maps, published and unpublished British Geological Survey maps, and plans held by Kingston Minerals Ltd., 20 Manvers Street, Bath BA1 1LX; the National Coal Board, Norton Hill Colliery, Midsomer Norton, Somerset; and Laporte Industries Ltd., Nutfield Road, Redhill. Shafts other than those shown may occur.

Scale 1:25000

Yards 1000 0 1 2 Miles

Metres 1000 0 1 2 3 Kilometres

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ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 13 EXTENT OF UNDERGROUND MINING

SCALE 1:25000

KEY

- Areas underlain by 'Bath Stone' workings. Names of mines indicated.
- Approximate area within which 'Bath Stone' has been mined. Limits of workings uncertain or unknown.
- ● Sites of minor 'Bath Stone' workings of very limited extent.
- Areas underlain by fuller's earth workings. Names of mines indicated.
- Area within which fuller's earth has been mined. Limits of workings unknown.
- * Sites of minor fuller's earth workings of very limited extent.
- Areas underlain by coal workings. Names of mines indicated.
- Approximate area within which coal has been mined. Limits of workings unknown.

Data sources:
Bath City Council; British Geological Survey; Kingston Minerals Ltd., Bath; Laporte Industries Ltd., Redhill; National Coal Board.

N.B
Certain undermined areas are omitted, but plans are held in confidence by British Geological Survey. There is no guarantee that all underground workings, for which there are no abandonment plans, have been identified.

Scale 1:25000

Yards 1000 0 1 2 Miles
Metres 1000 0 1 2 3 Kilometres

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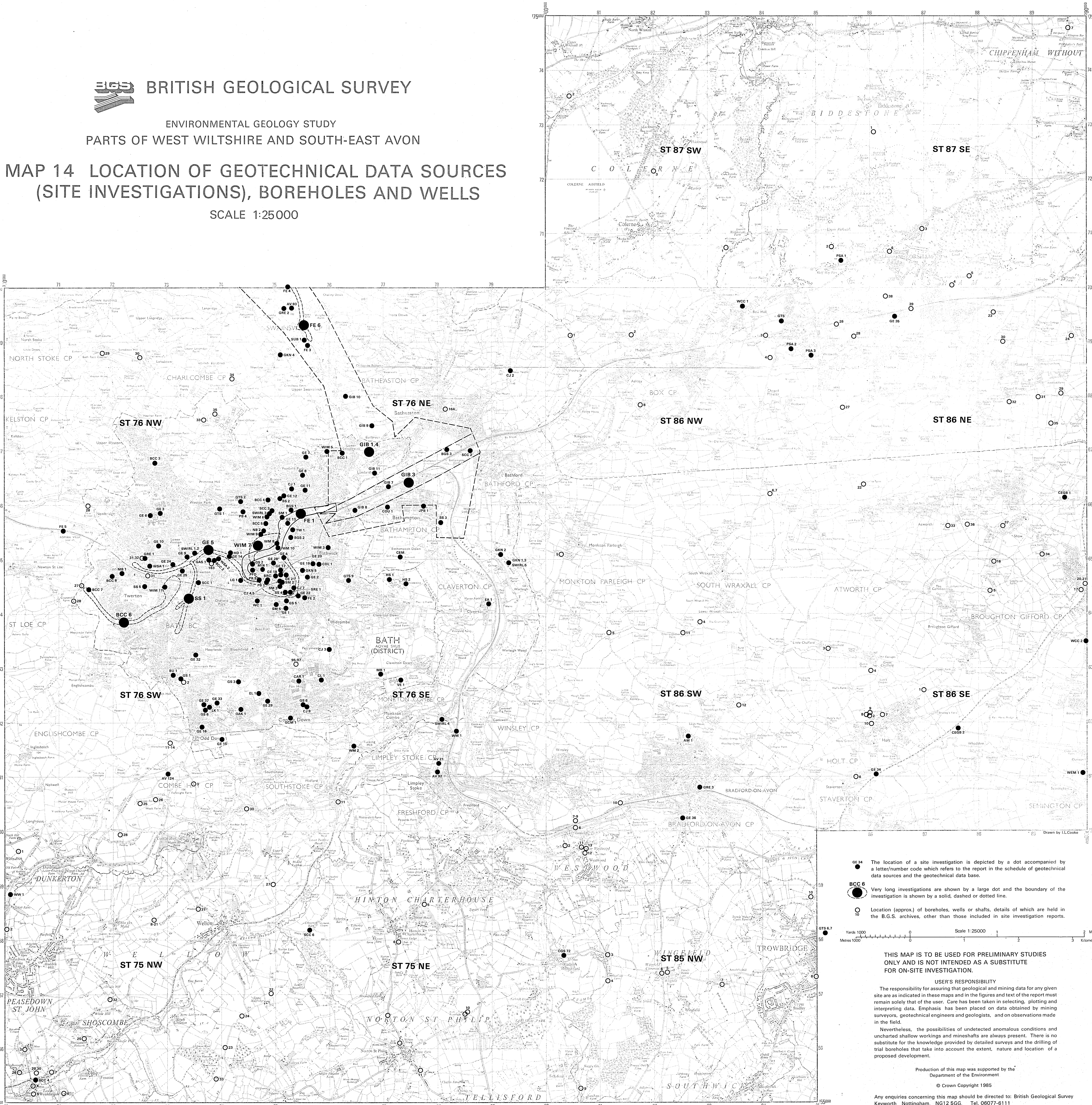
BGS BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 14 LOCATION OF GEOTECHNICAL DATA SOURCES (SITE INVESTIGATIONS), BOREHOLES AND WELLS

SCALE 1:25000



GE 34 — The location of a site investigation is depicted by a dot accompanied by a letter/number code which refers to the report in the schedule of geotechnical data sources and the geotechnical data base.

BCC 6 — Very long investigations are shown by a large dot and the boundary of the investigation is shown by a solid, dashed or dotted line.

10 — Location (approx.) of boreholes, wells or shafts, details of which are held in the B.G.S. archives, other than those included in site investigation reports.

Scale 1:25000

Yards 1000 0 1 2 Miles

Metres 1000 0 1 2 3 Kilometres

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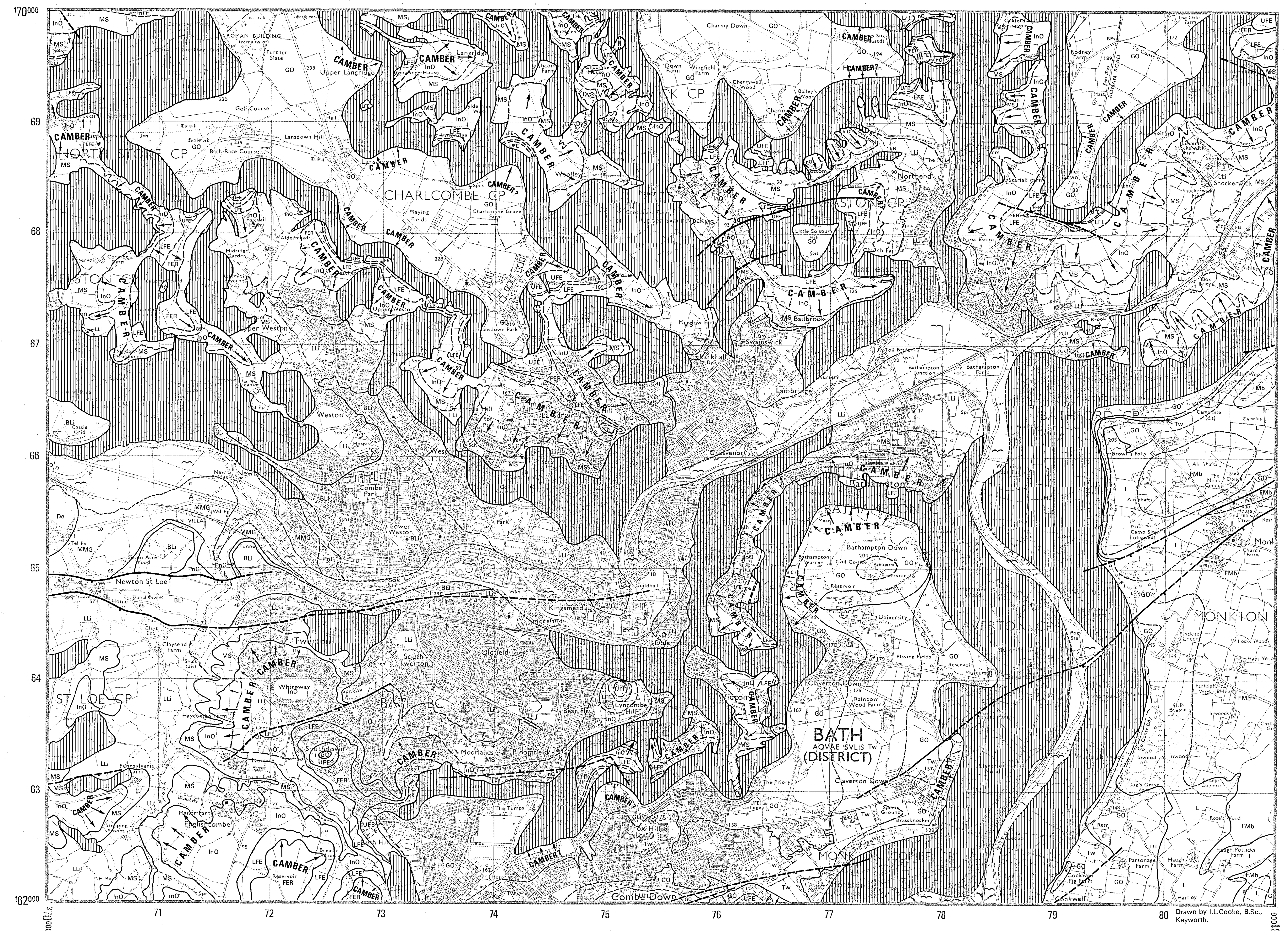

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Scale 1:25000 — Yards 1000, 0, 1, 2 Miles; Metres 1000, 0, 1, 2, 3 Kilometres

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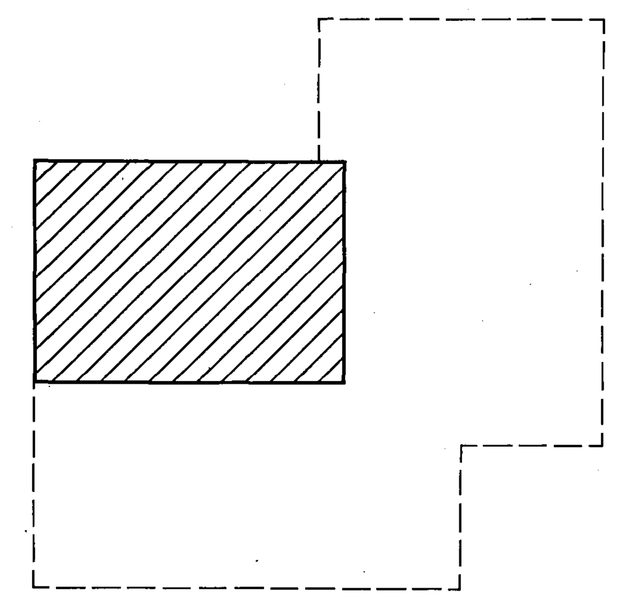
Diagram showing the position of Map 15 within the study area



BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY STUDY

PARTS OF WEST WILTSHIRE AND SOUTH-EAST AVON

MAP 15 SOLID LITHOSTRATIGRAPHY, LANDSLIP AND CAMBERED STRATA

(Incorporating re-survey of 'foundered strata')

SCALE 1:25000

Based on geological survey at 1:10 560 scale between 1944 and 1958 by G.W.Green, G.A.Kellaway, D.R.A.Ponsford and F.B.A.Welch.
Re-survey of 'foundered strata' by R.J.Wyatt in 1985.
Compiled by R.J.Wyatt in 1985.

GENERALIZED VERTICAL SECTION
Scale 1:1000 (1cm to 10m)

JURASSIC	GREAT OOLITE GROUP	FMb, L	FOREST MARBLE 16 to 30m		Calcareous clays and mudstones, commonly with sandy bands and partings; oolitic, shell-fragmental limestone with marl partings at base locally
		GO	GREAT OOLITE 0 to 39m	UPPER RAGS AND BATH OOLITE 0 to 20m	Buff and whitish, shell-fragmental oolites and coralline limestones; overlying massive oolites and oolite freestones
		Tw		TWINHOE BEDS 0 to13m	Grey, fine-grained detrital limestones, overlying buff, marly, pisolitic limestones; ironshot pisolitic limestones or marl at base
		GO		COMBE DOWN OOLITE 0 to 17.5m	Mainly medium and coarse-grained, shell-fragmental oolites and oolitic limestones, including oolite freestones
		UFE	FULLER'S EARTH 28 to 44m	UPPER FULLER'S EARTH 12 to 29m	Grey calcareous mudstones and stiff clays with some thin muddy limestone bands; bed of commercial fuller's earth in the upper part at and south of Bath
		FER		FULLER'S EARTH ROCK 1 to 5m	Rubbly, fine-grained, shelly, muddy limestones with marl interbeds
		LFE		LOWER FULLER'S EARTH 10 to 16m	Grey calcareous mudstones and stiff clays with some thin muddy limestone bands and shell beds
	INFERIOR OOLITE GROUP	InO	INFERIOR OOLITE 12 to 18m		Cream massive oolites, overlying whitish coralline limestones with clay bands; hard sandy, very shelly, locally ironshot limestones at base
	LIAS GROUP	MS	MIDFORD SANDS 0 to 31m		Yellowish brown silt and silty sand with bands of hard calcareous sandstone concretions
		DyS	DYRHAM SILTS 0 to 12m		Grey laminated silts and clayey silts
		LLi	LOWER LIAS CLAY 12 to 110m		Bluish grey stiff clays, mudstones and shales with a few argillaceous limestone bands; clay ironstone nodules in upper part
		BLi	BLUE LIAS 2 to 19m		Interbedded bluish grey muddy limestones and mudstones or shales
TRIASSIC	PENARTH GROUP	PnG	PENARTH GROUP (UNDIVIDED) 8 to 9m		Pale grey fine-grained limestones (formerly White Lias); overlying greenish grey marls and limestones, with dark grey fossiliferous shales at base (formerly Rhaetic)
		MMG	MERCIA MUDSTONE GROUP (UNDIVIDED) 0 to77m		Mainly red silty and sandy mudstones (formerly Keuper Marl) with c.3m of greenish grey beds at top (formerly Tea Green Marl); variable thicknesses of limestone breccia with a red sandy mudstone matrix at base (Dolomitic Conglomerate)

Unconformity

Scale 1:5000 (1cm to 50m)
Proved mainly in boreholes and shafts

CARBONIFEROUS	UPPER COAL MEASURES	De, COAL, COAL, COAL, COAL, COAL	DOWNEND FORMATION 175m	Mainly coarse-grained sandstones with some coal seams

N.B. This Generalized Vertical Section is reproduced from Map 1; the thickness ranges shown are therefore not necessarily appropriate to the area depicted on this map. For subsurface succession refer to Map 1.

KEY

Alluvium (major tracts only)

Geological boundary, Drift

Geological boundary, Solid

Fault at surface; crossmark indicates downthrow side

Broken lines denote uncertainty

LANDSLIPPED GROUND

The areas shown with vertical lines are those which by field survey and/or aerial photographic interpretation are considered to have undergone perceptible downslope movement of earth or rock by falling, sliding or flowing under the influence of gravity as a result of relatively shallow processes.

The areas so indicated are rarely affected by a single movement but are commonly a combination of numerous movements. These result from several failure types which have occurred at different times. The landslips in the study area are normally shallow but deeper failures are present, often associated with oversteepening of the valley slope by the River Avon.

Areas of landslip other than those indicated may be present, but are unidentified because natural degradation and the effects of cultivation have subdued their topographic expression.

CAMBER

CAMBERED STRATA

Cambering is the slow downward movement of strata due to the removal or plastic deformation of underlying weaker strata by relatively deep seated processes under glacial and periglacial conditions.

Camber commonly occurs on a large scale and typically manifests itself by the fracturing and tilting downslope of strong competent rocks on or above valley slopes.

On the map the direction of tilt is shown by arrows on the competent formation. Cambering will also have affected the strata above and below the indicated horizon.

Camber which has been determined by field survey is shown without qualification. Where camber is inferred by the relationship of outcrop to topography, the term camber is qualified by a question mark, thus 'CAMBER?'