Fifty, or so, years of engineering geology in the British Geological Survey, 1967 to 2019

Engineering Geology Programme

Open Report OR/23/046

BRITISH GEOLOGICAL SURVEY

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Engineering Geology Unit staff in the engineering geology laboratory, Exhibition Road, London, 1974

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Foreword

This report attempts to summarise the main activities in the initially named Engineering Geology Unit (EGU) from its creation in 1967 to 2019, after which the BGS structure shifted from discipline to challenge based groupings. The abbreviation ‘EGU’ is used throughout the report though the actual name of the management grouping for engineering geology changed many times between 1967 and 2019. Only four of the authors were employed by the Natural Environment Research Council at the British Geological Survey (BGS) until October 2019 when the management structure changed completely; they were Dave Gunn and Pete Hobbs, who both retired at the end of June 2021, Marcus Dobbs and Claire Dashwood. Stuart Duncan left at the end of February 1979, Dave McCann at the end of April 1997, Martin Culshaw at the end of March 2008, Kevin Northmore in April 2012, June Page in February 2013, Tony Cooper in March 2014, Tom Dijkstra in September 2017, Dave Entwisle in March 2019 and Jon Busby in May 2021. Richard Ellison was never a member of EGU but collaborated on many projects from the 1970s onwards. Consequently, there are more details covering the years up to around 2010 than on the work in the last decade. The EGU paper records have been examined and sorted out by Kevin Northmore, Martin Culshaw and Stuart Duncan and form part of the BGS’s paper archives. However, these documents only cover the ‘paper’ rather than the ‘digital’ years and, in any case, are not complete.

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1 Background

As a branch of applied geology, engineering geology had been practiced in Europe and North America since the start of the 19th Century. For example, William Smith, a surveyor, engineer and geologist, who was involved in the building of canals, could be regarded as the first British engineering geologist. Indeed, his profile forms the logo of the Engineering Group of the Geological Society. However, few geologists before the 20th Century would have referred to themselves as engineering geologists, though Sergeev (1984) pointed out that the combination of the words 'engineer' and 'geologist' first occurred in Russia in 1886 and Fookes et al. (2005) noted that William Henry Penning (who worked at the Geological Survey of Great Britain [GSGB]) wrote a book entitled 'Engineering Geology' in 1880 (Penning 1880). Penning's engineering geological contribution is discussed by Culshaw & Forster (2021). Following the 1st World War with the increasing number of 'large' engineering projects, particularly in the USA, the importance of geology to their successful construction and operation was becoming apparent. In the UK, while the importance of geology to civil engineering was recognized, few engineering geologists were practicing and engineering geology did not develop as a sub-discipline in its own right. However, even as late as 1967, Austen Woodland, (later to become Director of the Institute of Geological Sciences [IGS]) in his Presidential address to the Yorkshire Geological Society, stated that "This preoccupation with empirical tests on rocks based very largely on the laboratory, appears to have widened the gulf between civil engineers (including those who call themselves engineering geologists) and geologists whose main study is the behaviour of rocks in the field." (Woodland 1968).

In the UK, particularly in relation to the Geological Survey, three events changed this. First, in 1948, the British Geotechnical Society (now British Geotechnical Association) was formed and second, it began publication of the journal Géotechnique. In his forward to the first part Terzaghi (1948) stressed the importance of engineering geology and emphasised the need for observation as well as theory in civil engineering. Third, on 21st October 1966, the failure of a colliery spoil tip at Aberfan, south Wales, resulted in the death of 144 people, including 116 children: the Tribunal of Inquiry into the Aberfan Disaster recommended that *"statutory qualifications for managers and surveyors should be amended to include awareness of the rudiments of soil mechanics and hydrogeology, in addition to the geology already comprised in the syllabus"* (Davies et al., 1966). These events led to the development of engineering geology as an important sub-discipline of geology in the UK and the establishment of five Master of Science postgraduate courses in engineering geology in the 1960's and 1970's (at Imperial College, London and Durham, Leeds, Newcastle and Portsmouth Universities [initially Portsmouth Polytechnic]). The Engineering Group of the Geological Society was formed in 1964 and in 1968 the Geological Society commenced publication of the Quarterly Journal of Engineering Geology (QJEG) (now the Quarterly Journal of Engineering Geology and Hydrogeology [QJEGH]). In 1969 the Engineering Group set up its first Working Party to make recommendations for the logging of boreholes and trial pits. In 1972, a second Working Party published a report on the preparation of engineering geological maps and plans and on soil and rock classification (Anon., 1972); this was followed by a more theoretical report on engineering geological maps and a further report on soil and rock classification (Anon., 1976, 1981), both by the International Association of Engineering Geology (which, itself, was formed in 1964 under the International Union of Geological Sciences [IUGS]). These reports established international standards for applied mapping.

A further significant event was the publication, in 1972, of the Rothschild Report into the funding of science in British research centres and surveys. This report recommended that approximately 30% of the core funds be transferred from the centres and surveys to central government departments which would then 'commission' work back from the centres and surveys. Previously, the amount of applied geological mapping carried out by the British Geological Survey (BGS) had been minimal. Most mapping was of the traditional litho-stratigraphical type. As far as the development of geological maps was concerned, two significant commissions were placed. Though work had begun before Rothschild, the first of these was that the Department of Trade and Industry (DTI) took over funding of the geochemical survey of Britain

(GBase). This involved the collection of stream samples on a regular grid basis starting in the northernmost parts of Scotland and systematically working southwards. Samples were analysed for a range of elements (mainly metals) and element distribution maps were published. The objective was to provide background levels of these elements to assist in the identification of potential mineral resources. During the work the emphasis switched from the identification of resources to environmental concerns over the distribution of potentially contaminating elements. In addition, urban centres, that had initially been excluded, were covered but at higher sampling densities. This change from a resource-based to an environmental-based approach has been highly significant to the development of geological maps in the latter part of the 20th Century.

The second important commission was from the Department of the Environment (DoE) for engineering geological mapping of the site and hinterland of the then proposed third London airport in south-east Essex. This formed part of the Department of the Environment's research contract on engineering geology set up following the Rothschild Report which created a 'rolling programme' of engineering geological projects funded by the Department of the Environment as well as the Welsh Office and the Scottish Development Department. A suite of more than forty maps of a wide variety of types was produced for south-east Essex (Anon., 1977) and experiments made into some forms of digital geological contouring (Coe & Cratchley, 1979). The intended users of the report included both civil engineers and planners. This work led, a few years later, to a fifteen-year programme of applied geological mapping of urban areas for planning purposes. The outputs of this programme have been described by Culshaw et al., (1988, 1990) and Smith & Ellison (1999). However, the key point about it was that the maps were specifically produced to meet the needs of the land-use planner, as specified by land-use planners. An additional output was a regional landslide mapping project in the South Wales Coalfield that identified a specific problem, relevant to planning in that area (Conway et al. 1980). This led to the commissioning by the DoE and the Welsh Office of similar studies on other geohazards – abandoned mining (other than coal), natural cavities, coastal erosion and deposition, and soil behaviour (swell-shrink, compressibility, collapse, and corrosivity). Engineering geologists at the BGS did not lead on any of these contracts (private sector consultants were contracted – Ove Arup, Applied Geology Ltd., Rendel Geotechnics and Wimpey, respectively) but did contribute information to several of them.

The DoE's 'rolling programme' lasted until 31 March 1981. The contract was worth £160-170k (in 1979) of which £70-80k was spent in Scotland. This contract would be worth just under £880,000 at 2020 prices according to the Bank of England’s Inflation Calculator. The three main projects following the SE Essex engineering geological mapping contract were:

i. Landslide investigations in the South Wales Coalfield;
ii. Regional assessment of foundation conditions for industrial development in the Forth Estuary;
iii. Geophysical research into indirect methods of assessing ground conditions for civil engineering purposes, particularly cavity location.

The 'rolling programmes' in Scotland and Wales came to a contractual conclusion, but that in England was ended as a result of a review of the value of the programme. W G B Phillips of the Systems Analysis Research Unit (DoE) stated in a DoE position paper dated 16 July 1979 that “DOE (England) receives little direct benefit from this programme. Engineering geology is a site specific rather than a general subject. Our needs would be better served by letting special contracts for particular projects rather than retaining a rolling programme. We therefore recommend that this programme be terminated with effect from 31 March 1981.” The influence of the change of government on public funding following the 1979 general election, naturally, is not mentioned. Nor is any reference made to the Rothschild recommendations (see above) that transferred funds from the IGS to DoE that were then meant to be used to commission work from the IGS, or to any money being handed back! However, it is clear from the files (letter from Malcolm Rutherford [DoE] to Roger Cratchley 3 June 1980) that the cessation of the programme in 1981 was due to the cutback of funding by the DoE in London.

Thus began a new era of 'Commissioned Research' in which the contracts were no longer allocated as part of a 'rolling programme' but mainly won competitively with private consultancies and, initially, university departments, being the main competitors. This situation has continued to the present, though income has varied following the ups and downs of the national (and indeed international) economy. The arrival of David Falvey as Director in the late 1990s saw licensing of information become an important source of income. Engineering geology played a big part in this being heavily involved in the development of the GeoSure geohazard information system. By 2006/7, and the arrival of another new Director (John Ludden), the emphasis began to swing again to a greater focus on applied research in preference to relatively routine commercial work. This emphasis on research continued until John Ludden left the BGS at the end of August 2019.

The departure of John Ludden also coincided with a major BGS organisation restructure, which resulted in many of the staff and facilities within the Engineering Geology and Infrastructure 'Theme' being subsumed into the new Multi-Hazards and Resilience (MHR) challenge area. Subsequently, a new Engineering Geology Team was formed and currently sits within MHR.

2 From the beginning…

The Engineering Geology Unit (EGU) was founded on around 1 August 1967 (Hackett 1999) under the leadership of Roger Cratchley and he was joined, by the end of that year, by its first two members of staff, Bernard Conway and Jon Hallam (now both deceased). The creation of the Unit followed the formation of the Natural Environment Research Council (NERC) in 1965 and the merging of the Geological Survey of Great Britain (GSGB) with the Overseas Geological Survey (OGS) to form the IGS, which was a research institute within the NERC, as well as a geological survey. According to Dave McCann, it is likely that the Chief Geophysicist, Bill Bullerwell, was instrumental in setting up the Unit although probable that his intention was to create a laboratory and research team that focused on the measurement and interpretation of the physical properties of rocks. However, a future Director of the Survey, Austen Woodland (1968), hoped that the new EGU would “make the accumulation of site investigation records one of its main tasks...” Roger Cratchley was responsible for broadening the remit of the Unit to cover both engineering geology and what came to be known as engineering geophysics.

The Unit expanded rapidly recruiting Dave McCann (now deceased), a senior research engineering geophysicist (in January 1968), Bruce Denness, a senior soil mechanics research engineer, and a number of young geologists and engineering geologists including Alan Forster (1970) (now deceased), Peter Grainger (who moved to Exeter University), Martin Culshaw (December 1971), Kevin Northmore (1972), Stuart Duncan and Dick Godson (who moved to an applied geophysical consultancy in Australia). Arthur Harding managed the Unit’s geotechnical and geophysical laboratories with the assistance of Peter Collins but both resigned from IGS in the late 1970s. Mike Sarginson and Jon Darwell were recruited in the early-1970s along with Peter Hobbs and Diana Worrall and then, for North Sea investigation work, John Lambert and Janet Patterson (now deceased). Peter Jackson (an engineering geophysicist, now deceased) and Paul Gostelow (an engineering geologist) joined in 1976, the latter replacing Bruce Denness who had left to become a professor at the University of Newcastle the year before, where he was joined by John Darwell in 1976. Later, Stuart Hassett joined to provide technical support and Steve Horseman came in as a rock mechanics researcher. When EGU moved with the rest of BGS to Keyworth, Nottingham, many of the staff left, including Stuart Duncan (who moved to the International Energy Agency after being transferred to the Edinburgh office) and Janet Patterson (to teaching), while Paul Gostelow and John Lambert had moved to the Edinburgh office as part of EGU to develop engineering geological research and consultancy in Scotland. John Lambert subsequently left to join a consultancy in Vancouver, Canada. Local recruitment took place in Scotland, including Karen Tindale, Ian Moore (who left in October 1981), Dave Long and Sheila Alexander.

In its first 16 years the Engineering Geology Unit concentrated on three main areas of work. These were:

i. engineering geology mapping;

ii. slope stability studies;

iii. research into the application of geophysical methods to engineering.

In part, this approach adopted a suggestion from John Knill of Imperial College London that Jurassic rocks would make a suitable long-term research project. The late 1967 proposal had two parts:

i. An overall scientific investigation of the geotechnical and other physical properties of the Jurassic strata from Dorset to Yorkshire. This would involve sampling and testing of a range of lithologies.

ii. Engineering investigations including, particularly, the use of geophysical techniques and the production of ‘geotechnical’ maps. Research was to include geohazards such as landslides and cambering. Milton Keynes and Northampton were suggested as possible locations for this work.

By 1968/69, the work was underway, in Milton Keynes (geotechnical mapping) (see Appendix 1), on the Dorset Coast (landslide studies) and up and down the Jurassic outcrop investigating acoustic and geotechnical properties of Jurassic clays. However, Denys Brunsden of King's College London was also looking at landslides on the Dorset coast and this introduced an element of competition into the research being carried out there. Because engineering geological research was only just beginning in UK universities, this competition was unusual and unfortunate!

The Unit's new rock mechanics, soil mechanics, geophysical properties and electronics laboratories were commissioned in 1970 and opened by Professor V C Wynne Edwards FRS, the Chair of the Natural Environment Research Council (NERC) on 4 February 1971. A ten page booklet was published with a map of the laboratory layout in the basement of the Geological Museum on Exhibition Road, South Kensington, London (Appendix 2). The Soils Index Testing Laboratory became the social focus of the EGU with coffee and tea breaks taking place there!

From its earliest days, the EGU collaborated with a number of public bodies (mainly local authorities) acting, effectively, as a geological consultant. One example of this was work done for/with Edinburgh City Council on the Edinburgh Corporation sewage treatment scheme. This involved a series of large new tunneled sewers both onshore and out into the Firth of Forth at Leith. The onshore work was carried out in collaboration with the South Lowlands Unit based in the IGS's Edinburgh Office. This Unit was one of three geological mapping units and covered southern Scotland (the other two Units were the North Lowlands Unit and the Highlands and Islands Unit). The Unit Head was Innes Lumsden who, in the 1980s became Director of the Survey. He and his staff had developed a good working relationship with various local authorities.

The work on the sewage scheme was in two parts. In 1971 work was carried out on the onshore tunnels. This work involved Roger Cratchley and Peter Grainger from EGU. This work was in three parts:

i. General geology of the tunnel line, carried out by Bill Tulloch (SLU), with additional contributions by Cratchley and Grainger on engineering geological aspects;
ii. summary of mechanical properties of rocks and soils, involving interpretation of the site investigation contractor's report and providing a summary of properties and characterisitcs of engineering geological units with a summary table;
iii. and a discussion of ground conditions including a description of chainages in terms of engineering geology units and geohazards including groundwater (See scan 1970s-1 of a summary of a meeting held at IGS Edinburgh on 10 September 1971).

A report (EG/71/8) was produced by Cratchley and Grainger for the engineering geological input. The Engineering Geological archives in Keyworth hold various source data and comments on these various activities. A magnetic survey of the Firth of Forth in the vicinity of the tunnel was carried out and a report (EG/71/4) produced by Bernard Conway.

In the spring of 1972, the site investigation for the offshore sewer tunnel from Leith was carried out. Again, Bill Tulloch carried out the geological logging and description, while the engineering geological logging of the core and its interpretation was carried out by Martin Culshaw from EGU who produced a report (EG/72/4). Drilling was carried out from a barge 24 hours a day, 7 days a week. The contractor was Wimpey and their engineering geologist, Dave Johnston, also logged the cores and produced the contractor's factual report. Edinburgh Council also employed John Knill as an engineering geological reviewer and advisor.

In the early 1980's work in engineering seismology was started in Greece, funded through IGS's own funds as one of six research projects initiated by the then Director, Malcolm Brown. While the EGU was concerned with 'mainstream' investigations for hydroelectric projects, roads, etc., both in the UK and abroad, on repayment or through Overseas Development Administration (ODA) (now the Department for International Development, DfID) funds, this did not form a major part of the EGU's work because there were many private companies specialising in the investigations, either as geotechnical specialists, or as expert sections within firms of consulting engineers. The growth of such expertise was a direct response to a need brought about by difficulty of construction in a variety of different geological situations, ranging, for example, from the poor foundation properties of the soft Carse Clay of the Grangemouth area in the Forth

Estuary, Scotland, to the extremely hazardous rock tunneling conditions found in the Himalayan Boundary Thrust zone of Northern India where many of that country's hydroelectric schemes were, and continue to be, constructed.

However, the development of engineering geology in commercial practice was also greatly accelerated by the communication between engineer and geologist that was fostered by the Engineering Group of the Geological Society with its journal (the QJEG), which is circulated throughout the world. One of the themes that the Engineering Group encouraged, particularly in its early years, was the preparation of engineering geology maps (see above) (Anon. 1972) and indeed the Group's Working Party set up to make recommendations in this area did much to encourage the development of such maps, particularly in such organisations as the IGS and the Geological Survey Department in Cyprus. One other topic that should be mentioned is the standardisation of descriptions and classifications of rocks and soils without which effective communication between engineers and geologists is impossible and which, again, the Engineering Group supported (Anon. 1970).

Against this background, then, the EGU tended to concentrate on the strategic approach to regional problems and so concerned itself with regional studies of foundation conditions in new urban developments and the like and landslide surveys and stability analyses, both for planning purposes and to guide the subsequent site investigation for design. Some examples of this approach are given below. In addition, some parts of the research programme in geophysical methods had relevance to the seismic hazard element that has to be considered in earthquake prone areas.

The engineering geophysical work carried out differed in approach in that it was more akin to a series of academic research projects. Initially, the research was focused on the use of downhole and cross-hole geophysical methods for the development of 3D geological and geotechnical models. EGU had its own drilling rig – involving rotary augers and hollow-stem augers (which produced thin-walled samples). The drilling machine, mounted on a Bedford truck chassis, was operated by Jon Hallam and in the late 1960s and early 1970s he and Dave McCann visited several locations on Jurassic rocks to drill several boreholes and then carry out cross-hole seismic scanning using equipment developed by Dave McCann. This research was also carried on as part of the South East Essex project. Some work was also carried out using resistivity methods to monitor 3D change in landslides on the coast at Charmouth in Dorset (Denness et al. 1975). Subsequently, EGU received commissioned research funding from the Department of the Environment to investigate the identification of cavities using geophysical methods.

In 1976, Peter Jackson joined EGU. He was a post-doctoral researcher at the University of Bangor where he had carried out offshore geophysical work using various methods. He focused mainly (but not solely) on the development and use of electrical methods.

One consequence of being a largely government-funded centre for engineering geology and geophysics was that senior staff were asked by international bodies to take part in visits to other countries to advise local geologists. In May/June 1979, Roger Cratchley visited the Institute of Geology and Mineral Exploration (IGME) in Greece under a United Nations Special Service agreement to advise the Engineering Geology Department in the organization of the Department, to make suggestions as to its future programme and to provide training via lectures and practical site visits (Cratchley 1979). Although the visit resulted in many recommendations, none of them related specifically to hazards from earthquakes. However, as a result of the contacts made, IGME and the IGS made a joint proposal for a research project relating to earthquakes and their consequences in the Volos area of Greece. This is discussed below.

Another example of the provision of advice internationally was when, in June 1982, the United Nations Development Programme approached Roger Cratchley to join a study tour to China on behalf of the Preparatory Committee for the establishment of a Regional Centre for Quaternary Geology in China (letter from Ernest P Du Bois, UNDP Regional Offshore Prospecting in East Asia, 2 June 1982). The trip involved three days in the field in South China, four days of visits to scientific institutes in Guangzhou, Shanghai and Beijing and four days of seminars and discussions. The visit took place over two weeks in the latter half of November 1982 and a report of recommendations was produced.

Gradually, through the 1980s the original survey and research directions evolved in response to new environmental, resource, political and financial drivers. However, the long-term nature of much of the work meant that many of the original intentions endured as the need for better knowledge of the disposition of geological formations, their properties and how they were influenced by natural and anthropogenic processes is a permanent requirement from users of engineering geological information.

The survey and research work carried out by engineering geologists and geophysicists at the (now) BGS can be conveniently divided into four broad sub-themes:

i. Engineering geological mapping and urban geoscience;
ii. Geotechnical properties of soils and rocks;
iii. Engineering geophysics;
iv. and Geohazards.

It is interesting to note that under the new operational structure of the BGS introduced in November 2007, these themes still endure as the Urban Geoscience, Engineering Properties and Processes, Geohazard and Risk Teams within the Land Use and Development Science Theme (Appendix 3). At the end of 2008, these Teams were renamed as Urban Development led by Simon Price, Geoengineering Properties and Processes led by Helen Reeves and Shallow Geohazards and Risk led by Tony Cooper. The LUD Science Theme also included a fourth team – 'Sustainable Soil Management' (in the pedological sense) – led by Barry Rawlins but its presence under the 'Engineering Geology' banner was short-lived. The three main themes remained until the dissolution of the Engineering Geology and Infrastructure Directorate in 2019.

The arrival in 2006 of John Ludden brought about another significant change. Until that year, most of the reports written by staff were published as Engineering Geology Technical Reports, Laboratory Reports or Project Notes. For the remainder of EGU's existence, such reports were published as BGS Research Reports, Commissioned Reports or Internal Reports. Most of these various report types are listed in Appendices 14 – 18. The EGU reports were stored in K Block room 013 following the closure of the EGU library that was created on the ground floor of C Block after the move from London in 1982. In 2006, EGU was moved from A and C Blocks and paper copies of the EG Laboratory Report Series, the EG Technical Report Series and the EG Project Note Series were moved to NGRC.

Around 2005, NGRC hired about four temporary staff to scan all of the BGS Group Report Series. The EG Secretary, June Page, copied all the scanned reports and pasted them from that NGRC drive to the EG shared drive, known as the 'W' drive, where they are still available for BGS staff to access.

2.1 STRATEGY

As has been discussed above, the main emphasis in the early days was on:

- engineering geology mapping;
- slope stability studies;
- research into the application of geophysical methods to engineering.

Specifically, following John Knill's suggestions, the research was focused on:

- An overall scientific investigation of the geotechnical and other physical properties of the Jurassic strata from Dorset to Yorkshire. This would involve sampling and testing of a range of lithologies.
- Engineering investigations including, particularly, the use of geophysical techniques and the production of 'geotechnical' maps. Research was to include geohazards such as `locations for this work.

However, partly because of government changes in 1970, the BGS was required to carry out a series of government applied research contracts. The first of these was an engineering geological mapping study of the site of the proposed 3rd London airport in south-east Essex. That project is discussed below. The consequence of these government contracts was that EGU was unable to carry out the so-called Science Budget funded applied research and at one point was around 80% funded by Commissioned Research.

In around 1982, Roger Cratchley wrote a document that was really a description of the first 15 years work of the EGU presented at a seminar with the Cyprus Geological Survey, with whom the EGU was collaborating (Appendix 3). The projects described were divided into:

- mapping for new town projects;
- foundation conditions for industry (mostly in Scotland);
- seabed stability studies;
- geophysical studies;
- engineering geology and seismic risk studies;
- and slope stability studies.

No conclusions were reached but Roger Cratchley clearly saw what had been done as a success and justification for the EGU and that this type of work would carry on into the future.

Though there were significant management changes over the next few years, most notably the forced retirement of Roger Cratchley, no evidence has come to light of what the new head of EGU (Mike Price) wanted the Group to do. It was not until 1991 that Dave McCann and Martin Culshaw wrote “Engineering Geology and Geophysics Group – Forward Look.” The driver for this was that John Knill had become Chief Executive of NERC. John Knill had previously been a Professor of Engineering Geology at Imperial College and one of the UK’s most eminent engineering geologists.

The proposed Core Programme of the Group was divided into three main projects:

i. Engineering geology of British soil and rock formations. At the time of the Forward Look (late 1991), one project, on the Gault Clay, was already near completion (scheduled for the end of March 1992). It was proposed that projects on other formations should be carried out and the Oxford Clay, the London Clay, the Mercia Mudstone, the Coal Measures and the Chalk were all suggested, together with certain Quaternary deposits such as Glacial Till, Head and Alluvium. The intention was to investigate the lateral and vertical variation in geotechnical and geophysical properties in relation to the geological processes that have acted on the formations. The intention was to highlight particular hazards or problems and constraints on development. It was hoped that sponsorship by CIRIA might be obtained, though this never happened.
ii. Determination of the geomechanical properties of the rock mass by geophysical methods. This would be done by:
    - measurement of the geophysical properties of rock and soil materials both at ambient conditions and at elevated pressures and temperatures, and determination of their relationship to geotechnical properties;
    - geophysical borehole logging and cross-hole seismic and electrical surveying to provide data on the physical and mechanical properties of the rock mass, including the degree of fracturing and in situ dynamic elastic moduli;
    - and development of high resolution, surface geophysical methods to determine variations in the structure and geology of the rock mass at a site scale.
iii. Geotechnical/geophysical properties database. Though various attempts at developing such a database had been tried previously, software limitations had prevented the creation of a strategic database that conforms to BGS-wide standards. A key change envisaged was that data should not simply come from Core Programme projects but that additional data would need to be extracted from original site investigation reports to provide nearer to national data coverage. It was also proposed to include geophysical as well as geotechnical data.

The Forward Look also discussed current Research and Development projects and the Group's commercial potential. This included services that could be provided by the Group's geotechnical and geophysical testing laboratories and by geophysical borehole logging. An Annex discussed areas of expertise.

The complete forward look document is reproduced in Appendix 4 together with a short report by Dave McCann to Steve Foster (then the Assistant Director responsible for the Engineering Geology and Geophysics Group (and others) that discussed a meeting held between the Director of the BGS (Peter Cooke) and Sir John Knill (Appendix 5). The main outcomes of the meeting were:

- The Group should be visited by two senior engineering geologists from industry to review the range of current activities and to advise on where the Group should concentrate its future activities.
- The laboratories should concentrate on high grade complex tests for generating commercial income.
- The Group had a low external profile and so senior engineering geologists should adopt a more outward looking attitude and present more papers at conferences and publish them in conference proceedings and journals.
- The name should be changed to Engineering Geology Group but the Director disagreed with this.
- Regional engineering geology studies, such as the Gault Clay project, should be expanded to cover other geological formations.

In 1997, the Engineering Geology and Geophysics Group (EGG Group) was merged with the Coastal Geology Group to form Coastal and Engineering Geology (CEG). The geophysics part of the old EGG Group was transferred into the Regional Geophysics Group. As a result, a new science strategy had to be developed. Five elements to the new engineering geology core programme were identified:

i. Engineering behaviour of UK rocks and soils – this was an existing long-term project to characterize in geotechnical terms UK rock and soil formations that are important from the viewpoint of the geotechnical engineering industry. For each geological formation studied, a monograph was to be produced that described its geological, geotechnical, groundwater and geochemical characteristics, largely on the basis of existing data. The project covered four formations – the Gault Clay, the Mercia Mudstone Group, the Lambeth Group and the Lias Group. In terms of downloads from the NORA system, the programme remained highly successful for the next 20, or so, years even though the programme was eventually terminated.

ii. Land instability – geological hazards, their assessment and identification of risk. The DoE/DETR funded a number of research projects based on existing data. Geohazards covered included: landslides, shallow undermining, natural cavities, natural contamination, seismicity, foundation conditions and coastal erosion and deposition. Outputs included national and regional maps at 1:625k and 1:250k scale, reports on occurrences, case histories, investigative methods, methods of remediation and planning implications. This project would seek to extend the databases by primary survey and create national databases that were properly maintained in the long-term. The project would also be concerned with landslide susceptibility studies either using deterministic or probabilistic methods, or both. Regional studies of geohazard susceptibility were considered necessary to extend the coverage of the geohazard occurrence surveys. Research was also required to determine swell-shrink properties of the most susceptible mudrock formations but also the relationships between these properties and simple index tests to allow easy and cheap assessment of their swell/shrink potential. Survey and research was deemed to be necessary to investigate different cambering mechanisms and styles and their legacy with respect to associated major near-surface voids and fissures. Research into the geological controls on coastal erosion processes around the UK coast. It was also proposed to set up a rapid response capability for important geohazard events within 24 hours of their occurrence and to reply to media enquiries.

iii. Urban geology. Although studies were carried out of the applied geology of around fifty urban areas in Britain, funded by DoE/DETR, the Welsh Office and the Scottish Office, much of the country had not been adequately studied and, indeed, many of the areas had simply been remapped geologically. The intention was to improve the quality and consistency of the information gathered for urban areas.

iv. Maintenance of geotechnical capability. The intention of this project was to develop indirect (geophysical) investigation methods to offer the potential to improve our ability to investigate the variation in geotechnical properties in the rock mass in terms of individual parameters and overall rock quality. It was proposed that the project should concentrate on developing best practice at the interface between geophysics and geotechnics, on the development of specific equipment and methods, on establishing improved relationships between geophysical and geotechnical properties, particularly from downhole measurements, and on the databasing of physical properties.

v. Creation of a National Geotechnical (properties) Database utilizing the nationally accepted AGS format, to help underpin site investigation. A geophysical properties database, linked to the geotechnical properties database was also proposed.

This strategy, with modifications, was to underpin engineering geological activity at the BGS for the next twenty plus years.

In 1999-2000 the organization of engineering geology changed again with the creation of the Urban Science and Geological Hazards Programme and the strategy evolved further. The aim of the Programme was to provide the user community with information on, understanding of, and solutions to its problems with ground conditions and land quality, particularly in urban areas. These problems included:

- the likely occurrence of geological hazards;
- geotechnical and engineering characteristics of rock and soil formations;
- physical and mechanical properties of materials.

Three sub-programmes were created:

i. **Urban geoscience (UG).** Provision of comprehensive applied geoscientific information for urban Britain in a form that meets the needs of a wide range of non-geological users. There were three generic projects:

   - 3D Rock Mass Characterisation
   - Surface Deposit Characterisation
   - Development of Improved IT Systems

   A number of thematic projects:

   - Contaminated Land – Swansea/Port Talbot
   - 3D Modelling of Rock Mass Properties – London
   - Legacy of Mining – North-East England
   - GIS and 3D geology modelling – Manchester
   - Urban Minerals Supply – Midland Valley of Scotland
   - Land Stability – Bristol and Bath

   The three generic projects were all completed along with the Swansea, London and Manchester projects. Whilst abandoned mineworkings were investigated in parts of the north-east of England, and a number of reports written, no project report was completed. The same applied to the project on land stability in Bristol and Bath. The project in the Midland Valley of Scotland was superseded by a major project in Glasgow.

   Urban geochemistry project:

   - GSUE (Swansea, Glasgow, Manchester, Stoke)

ii. **Geohazard and risk (H&R).**

Generic projects:

- Assessment of geohazard and georisk
- Development of geohazard databases

Hazard specific projects:

- Mass movement on slopes:
    - Landslides
    - Cambering and deep-seated movements
- Adverse geotechnical properties
    - Swelling and shrinkage
    - Collapse
    - Compressibility
- Dissolution of more soluble rocks
- Undermining
    - Shafts
    - Subsidence/collapse/fault reactivation
    - Groundwater levels
    - Pollutants
    - Gases (stythe gas)
- Erosion and flooding
- Coastal erosion/recession
    - (including cliff stability [as part of Coastal Geoscience Programme])
    - Hillslope erosion
    - Flood-prone areas

iii. **Engineering geology of UK rocks and soils (EG).** The characterization of British soil and rock formations in geotechnical terms and to improve understanding of the relationship between geophysical and geotechnical properties. This incorporates two main projects:

- the engineering geological characterisation of UK geological formations
- geophysical/geotechnical properties relationships.

Projects were:

- Gault clay (completed)
- Mercia Mudstone (completed)
- Lambeth Group (completed)
- Lias Group (completed)
- Brickearth (completed)
- Geophysical/geotechnical properties relationships

In August 2009 (by which time Engineering Geology was now named the Land Use, Planning and Development Science Programme, and later Engineering Geology Directorate and then Engineering Geology and Infrastructure Directorate) the strategy was revisited by the Programme Manager, Helen Reeves. Four thematic areas were identified:

i. Shallow geohazards – predicting geological hazards (landslides, flooding, ground shrinkage, cavities and soluble rocks, subsidence) and understanding the processes that cause such events.

ii. Geo-engineering properties and processes – assessing and understanding the physical and mechanical properties and processes of strategically important geological materials (rock and soil formations) and how they respond to anthropogenic and environmental change, with respect to sustainable development (e.g. infrastructure).

iii. Urban development – understanding the geological processes that contribute to anthropogenic and environmental change within the urban environment.

iv. Sustainable soils – assessing processes that control the distribution of soil properties across the landscape and their influence and control on functions such as carbon storage and filtering of water to ensure the sustainable use of soils.

With the restructuring of the various Science Programmes in 2019, further strategies were not required. Instead, three global challenges were created by the Director, John Ludden:

i. Decarbonisation and Resource Management (DRM).

ii. Environmental Change, Adaption and Resilience (ECAR).

iii. Multi-hazards and Resilience (MHR).

Most of the engineering geological thematic areas fell under MHR, but with Urban Development (now called Urban Geoscience) forming part of ECAR (and as of 2024, now part of National and international Geoscience).

2.2 THE ENGINEERING GEOLOGICAL LABORATORIES

The opening of the soil mechanics, rock mechanics, geophysical and electronics laboratories in 1970 is described briefly above. The engineering geology laboratories have, from their inception, been capable of a wide range of geotechnical and geophysical tests. These include simple index tests to complex strength tests and geophysical characterization on rocks and soils. Some of the research scientists have designed new equipment required to further their research and where there has been nothing suitable available. It is important to state that much of this new equipment invented required the support of the engineering workshops who enabled the manufacture of it either in-house or by others. Three of the main researchers were Pete Hobbs (mainly soils), Steve Horseman (mainly rocks) and Pete Jackson (mainly geophysical properties). Geophysical electronics research was led by Pete Jackson assisted by Rob Flint.

In EGU's first home in the Geological Museum in London, the laboratories were located in the basement because of the loads imposed by some of the equipment. Pete Collins was the main laboratory technician, with Arthur Harding joining to manage the laboratories in around 1971. After Pete Collins and Arthur Harding left, Jon Darwell came in as Laboratory technician and, a year or two before EGU moved to Keyworth, Nottingham, Stuart Hassett took over responsibility for managing the laboratories. After Stuart Hassett left there was no specific laboratory manager with specific scientists being responsible for the laboratories in which they carried out their research. After EGU moved to Keyworth the laboratories were located on the ground floor of K-block.

The engineering geology laboratories' work has been (and still is) highly variable from routine testing to complex research. Much of the geotechnical and geophysical properties resulting from routine testing is found in laboratory reports on the BGS W:drive at W:\teams\GPP\GeoengPropProcProjMgmt\Data\Geotechnical_Labs\Lab Jobs.

The older laboratory testing reports are listed in W:\teams\GPP\GeoengPropProcProjMgmt\Data\Geotechnical_Labs\LabJobs\Old lab report system/REPORT LAB REPORT SERIES.

A list of the older reports is also found in Appendix 16. Unfortunately, the titles are rather enigmatic as they, generally, do not include any of the tests carried out giving only a place or a borehole name and in some cases just the materials tested. After 1985 a new report numbering system giving the year of reporting and the report titles often giving more detail in the report titles.

Many of the reports contain data on the rock density, porosity, induced magnetic susceptibility and primary wave (P-wave) velocity. These data were, and still are, used to aid the interpretation of regional gravity, seismic and magnetic modelling of deep structures. Other reports contain data on geotechnical index tests such as particle size, plasticity and particle density. However, a significant number of more complex tests were carried out such as consolidation or effective stress triaxial testing, for instance for the Tropical Red Clay soils and the Gault Formation (see below).

More specialist testing on soils and very weak rock includes high load oedometer tests (to 32 MPa), shrinkage limit tests (see below), and effective stress testing on soils to loads of up to 17 MPa. Rock testing, as well as simple index testing includes uniaxial compressive strength, triaxial strength sometimes with deformation measurements and Brazilian disc indirect tensile strength.

As indicated, the laboratories were, from their inception, capable of a wide range of geotechnical and geophysical tests. These included simple index tests to complex strength and deformation tests and geophysical characterization on rocks and soils. Some of the research scientists designed new equipment to further their research and where there was no suitable commercial equipment available. It is important to state that much of this new equipment invented required the support of the BGS engineering workshops who enabled the manufacture of it either in-house or by others.

2.2.1 High stress soil mechanics

The so-called 'soil cannon' was designed by Steve Horseman for effective stress testing of very stiff soils to very weak rocks. It was a system that included a 35 MPa rated triaxial cell with back pressure and pore water pressure measurement and transducers for measuring vertical and lateral stresses. Pressure was supplied by two state-of-the-art fine control oil pumps via a bank of three intensifiers that produced the confining stress, the vertical stress via a hollow hydraulic ram and the back pressure, which was set at half the confining stress. The volume change of the cell pressure and back pressure were measured using transducers. The axial stress was measured using a load cell at the base of the triaxial cell. A large bank of electronics took the measurements, which were stored on an HP45 computer. The 'soil canon' was painted red and the intensifiers blue.

The system was originally designed and constructed in the early 1980's with a view to using it on samples from the Harwell borehole core as part of the research into the feasibility of mudstone as a host material for low and intermediate radioactive waste disposal (see Engineering geology and nuclear waste disposal research projects). This project was mostly based at the Harwell laboratories. However, the safety requirements at the Harwell laboratory meant that its use was delayed until after the Harwell project had finished. The equipment was then moved to the rock mechanics laboratory at BGS Keyworth and used on the European Communities radioactive waste repository project on the Boom Clay from Belgium. As some of the testing required tests at elevated temperature, up to 80°C, to simulate heating by radioactive waste, heater jackets were designed, constructed and fitted along with additional power and monitoring electronics. The work on the Boom Clay started in 1985 and the final report was completed in 1986 (Horseman et al. 1986, 1993). The work was carried out by Steve Horseman and Mike Winter, then a student in the Civil Engineering Department at Nottingham Trent University and on his industrial training year who later moved to the Transport Research Laboratory in Edinburgh.

3 Engineering Geological Mapping, Site Investigation and Urban Geoscience

3.1 MAPPING FOR NEW TOWN PROJECTS – MILTON KEYNES

An early example of this type of work was in the designated area for the new city of Milton Keynes some 50 miles north-west of London. A projected population of 250,000 was to be accommodated in a completely new urban area set in a rural environment. From the geological point of view the disadvantage of this setting was the lack of existing subsurface data in the form of boreholes so that knowledge of the three-dimensional data was limited to the few borehole and geophysical measurements that there were the resources to make. However, it was able to give guidance on the best routes for a sewer tunnel, on the main drainage line (so as to avoid running sands) and on general foundation conditions in the different rock and soil types in the area (Cratchley & Denness 1972). The study also enabled EGU to develop the principles on which later engineering geological maps were produced. More details of this study are to be found are to be found in Appendix 1. According to a memo from Roger Cratchley to Geoff Kellaway (a mapping geologist) on 23 June 1971, the study seems to have been scaled back because of impending EGU involvement in a study of the Third London Airport site in south-east Essex (see below).

3.2 SOUTH EAST ESSEX – THIRD LONDON AIRPORT

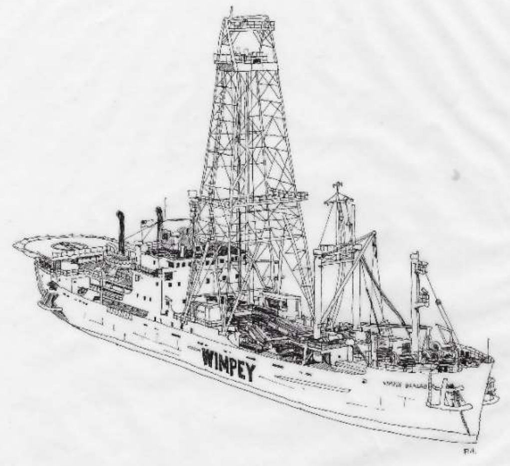
A second major example was in connection with the then proposed Third London Airport development at Foulness/Maplin Sands in south Essex. In September 1972, IGS was commissioned by the Department of the Environment to undertake a regional geological and geotechnical study of the area of some 450 km^2 between the Crouch and Thames estuaries designated for urban and industrial development, associated with the proposed new airport. The work was completed in August 1975 and published as a twelve-part report with a wallet of over 50 maps. The twelve reports, together with the four principal maps (Engineering Geology Map of South Essex, Sheet 1 [western part] and Sheet 2 [eastern part], Landslip and Slope Map and Engineering Planning Map) were made available for a price of £120. The four maps were available as a package for £10. This project gave the opportunity of experimentation with different ways of presenting the three-dimensional geology, particularly emphasising the variations in physical, lithological and geotechnical characteristics of the sediments and sedimentary rocks of the area. It also gave us the opportunity to set up a major database from existing and new boreholes put down to sample the various strata, which ranged from soft alluvial clays, sands, gravels of Quaternary age to the stiff fissured London Clay (Cratchley 1977). Of particular interest, and some engineering significance, were the loess-like Pleistocene deposits called ‘Brickearth’, which occur as terrace deposits in the centre of the area, and which have the characteristic of collapsing under heavy foundation loads when saturated with water. Determination of the characteristics of these deposits, of the disposition and nature of the alluvial deposits, with their very poor foundation and tunnelling properties, and of the whereabouts of landslip enabled BGS to produce a suite of maps at 1:25,000 scale illustrating the three-dimensional geology, lithology and engineering behaviour, together with an engineering planning map at the same scale. This map subdivides the area into 25 zones each having its own engineering characteristics in terms of foundations, excavation, tunnelling, suitability for fill, drainage, etc. The results of this survey gave significant guidance to planners on the best geological/geotechnical options for the proposed rapid transit route to the airport, areas for heavy industry, etc. The complete data set was also organised in such a way that very rapid appraisals could be made by Civil Engineering Consultants of the feasibility of undertaking certain engineering operations such as bridge/tunnel crossing of buried channels infilled with alluvium. Finally, guidance on site investigation and laboratory testing requirements for deposits such as the unusual loessic Brickearth were given (Cratchley et al., 1979). Other research papers were published on the brickearth (Northmore et al. 1996), the Claygate Member and the Bagshot Formation (Northmore et al. 1999) and on the summary engineering geology map produced for South Essex (Culshaw & Northmore 2002).

The curtailment of the airport project meant that the survey was not utilised for its original purpose. However, it has obvious relevance to other development in South Essex. Eventually, the information may come to fulfil its original purpose. In early 2009, the government decided to go ahead with a third runway at London Heathrow airport. However, opposition to this was at a high level and the then Mayor of London was in favour of building a new airport in the Thames Estuary, rather than expanding Heathrow.

In the early 1970s, attempts were made to encourage other New Towns to collaborate with the EGU in the carrying out of engineering geological mapping. Approaches were made to the Warrington New Town Corporation, to the Central Lancashire New Town, to Redditch New Town and to Stonehouse New Town, Lanarkshire, but without success. However, work was carried out for the Telford New Town Corporation, but on slope stability issues (see below).

3.3 SEABED STABILITY STUDIES

Another type of mapping project was EGU's collaboration with the Continental Shelf Division of the IGS in providing geological maps with geotechnical interpretations of the seabed of the UK Continental Shelf. This programme was a long-term one funded mainly by the then Department of Energy and aimed to complete coverage of the shelf within a decade. EGU was involved from approximately 1970 to 1982. Cruises to which Engineering Geology Unit staff contributed included the Forties Field (Wimpey Sealab [Figure 1]), a Pockmarks Survey, the M. S. Ferder cruise, the Emerald cruise, a cruise in the South West Approaches, the Little Minch, the Cormorant North west area, St Magnus Bay, Shetland, Foula, the Whitethorn Cruise, the Ferder and Mariner Cruises. Later, between 1990 and 2004, EGU contributed to seabed stability investigations with the Marine Geology Unit in Edinburgh (for example, Hobbs et al. 1997).



THE DRILLSHIP
"WIMPEY SEALAB"

FIG. 1B

Figure 1 Original sketch by Peter Hobbs of the Wimpey Sealab drilling ship.

The work was prompted by a desire to improve the knowledge of the shallow geology, geomorphology and geohazards on the seabed relevant to the burgeoning oil and gas exploration industry and the routing of supply pipelines to shore. The discovery of seafloor features called 'pockmarks' in the North Sea prompted intensive research efforts and theories as to their origin. The work usually consisted of sampling and testing sediment recovered by drilling (to 300m below seabed) or by shallow coring, up to 6m below seabed, both from purpose-built drilling ships and from converted merchantmen (Figure 2) and trawlers. The drilling ships were operated by Wimpey Laboratories Ltd and by Norwegian and Dutch companies and included MV's: Whitethorn, Ferder, Mariner, Surveyor, Emerald and Wimpey Sealab. All the work was funded by the UK Government. Engineering geology staff involved included David Long, John Lambert, Jon Hallam, Peter Hobbs, Alan Forster, Kevin Northmore, Ian Moore and Janet Patterson. The studies included examination of the seepage of shallow gas in marine sediments and contributed to understanding the glacial history of the UK continental shelf.

The earlier work was orientated towards the provision of additional geotechnical data on the various lithological units identified below the sea-floor either by drilling or by sampling with a vibrocorer or gravity corer. The work was related to the stability, in general terms, of structures such as oil production platforms founded on the seabed and the ease of excavation and stability of pipeline trenches. Particular hazards that can be encountered on the seabed of the North Sea include soft clay silts that can contain gas that apparently causes 'pock mark' features (Lambert & Hallam 1976), infilled channel deposits of soft clay that can only be located accurately and economically by the use of specialised geophysical tools like the deep tow boomer, mobile sand-waves and scouring out from beneath pipelines, foundered strata at depth that might lead to subsidence in superficial deposits on the seabed.

A major problem with this type of project was the lack of data and the difficulty and cost of acquiring new data. Secondly, the rather crude sampling methods caused disturbance to the samples that questioned the validity of some of the geotechnical data obtain from testing these cores. This has had two consequences: it was not possible to produce the type of engineering geology map that can be produced for land areas but, perhaps more importantly, it led to the setting up of a research programme in collaboration with others such as the Marine Science Laboratory, University College of North Wales, to find methods of indirectly determining properties of rocks and sediments by geophysical methods.

In 1995 a joint industry group, the Western Frontiers Association, was formed by BGS with 14 oil companies focussing on geohazards associated with exploration and development in deep-water beyond the shelf edge west and north of the UK (Long 2001, Gatliff & Ritchie, 2005) (areas less well understood than the North Sea), and then expanded to the area north of Latitude 62N and the Rockall Trough as exploration licence areas were opened up (Holmes et al. 1997, Stoker et al. 1998, Wilson et al. 2005). Seabed stability studies were made of submarine 'landslides' including the large 'Peach' slide and the smaller 'AFEN' slide (Figure 3), a 14 km long sub-aqueous mass movement related to displacements along bedding within sheeted contourites in the Faroe-Shetland channel. Key factors in producing a 'shallow geology model' to address the many problems with deep-water drilling were those affecting the timing and distribution of shallow submarine landslides and the presence of methane hydrates. Other seabed features were also mapped and classified. Engineering geology staff included David Long, Peter Hobbs, David Gunn, Peter Jackson and David McCann. Various offshore pipeline geohazard/feasibility studies in Shetland and the English Channel were also made.

Figure 2 Actual drilling ship M. V. Whitethorn.

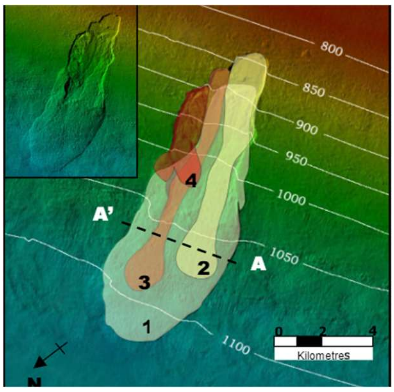


Figure 3 Image of AFEN slide from seabed picks of 3D seismic data overlain by outline of the four stages of failure labelled in order of occurrence, 1-4 (Wilson et al., 2005; Figure 2).

3.4 UNDERGROUND STORAGE, HUNTERSTON, AYRSHIRE

A study took place at Hunterston in Ayrshire, Scotland in the mid-1970s, in collaboration with the Hydrogeological Unit and the South Lowlands Unit, on the suitability of rock masses for underground storage. The work was, basically, a geotechnical and hydrogeological site investigation. Various boreholes were drilled by a rather lackadaisical site investigation contractor that only worked Monday morning to Friday lunchtime. However, the distance from London meant that EGU staff had to stay over weekends in three-week postings. The report summarised the geotechnical and hydrogeological factors that affected site suitability, the rock classification systems that allow these factors to be estimated and the investigation procedures necessary in the field. Unfortunately, once the report (EG/76/14) had been submitted to the SDD nothing further followed. The work was somewhat ahead of its time given the more recent interest in utilisation of underground storage for hydrocarbons and the disposal of nuclear waste.

3.5 BANDA ACEH, INDONESIA, ENGINEERING GEOLOGICAL MAPPING

Banda Aceh is located at the northern tip of Sumatera, Indonesia. In 1975, a UK aid project, funded by the then Overseas Development Administration, was begun to geologically map the whole of North Sumatera north of the equator. In 1976 it was decided to add an engineering geological mapping project centred on the Banda Aceh basin and the city of Banda Aceh. The work was carried out between late 1976 and mid-1978.

The large flood plain area is composed mainly of alluvial deposits and the investigation consisted of surface geological mapping, cored boreholes roughly on a grid, hand auger holes and expanding resistivity surveys at selected locations. Geotechnical properties were measured on samples from the cored and augered boreholes. The laboratory testing was carried out at a number of laboratories.

The geotechnical property data were entered into a digital database. The process was somewhat slow and cumbersome in that data were first entered onto standard paper coding forms; the data were then transferred on to punched cards that were transferred onto a mainframe computer. A program called G-EXEC was used to handle the data and programs written to process it. Because of the lack of computer facilities in Bandung, Java, where the Geological Survey of Indonesia was (and is) based, the data processing had to be carried out on a computer in Jakarta. The database was transferred onto a large reel-to-reel tape which, ultimately, was transferred to the IGS (BGS) in the UK. However, Stuart Duncan who managed the processing was unable to quite complete the work as access to the mainframe computer in Jakarta was lost just before the project ended. Subsequently, the digital data tape was lost or destroyed so that only the reports and data held in the BGS archives remain. A search of the Indonesian archives following the 2004 tsunami failed to find the original data deposited there. Paper copies of all the data, including hand-drawn maps were brought back to the UK and are archived at the BGS. A major report was completed, and a paper was published (Culshaw et al. 1979a and b).

Following the 2004 Indian Ocean earthquake and the tsunami that destroyed Banda Aceh, the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) in Hannover, Germany [Federal Institute for Geosciences and Natural Resources] repeated much of the previous work and copied the data into their archives. They published a series of reports and papers on the engineering geology of the Banda Aceh basin.

3.6 FOUNDATION CONDITIONS FOR INDUSTRY

Further ideas were developed by Paul Gostelow, in the next major phase of engineering geological mapping in the Scottish estuaries which began in 1977. This project was related to the requirements of the Scottish Development Department to plan and offer the most suitable sites for industrial and oil and gas related developments mainly on the east coast of Scotland in estuaries such as the Forth, Cromarty and Tay where it was likely that gas gathering pipelines from the North Sea oilfields would be brought ashore. The proposed development areas were discussed in a paper published in August 1974 (Scottish Development Department 1974). The studies were intended to “equip the planning machine with the necessary knowledge.” (Quote from a SDD paper dated 25 June 1979 [probably drafted by Malcolm Rutherford] entitled: “Engineering geology in the UK: proposals for 1981+. Planning for UK oil related developments: The Scottish Coast”). The paper also listed the objectives “for a rolling programme of systematic work on the engineering geology of the broad east coast areas most likely to be involved in development” as:

- To assess geological conditions affecting heavy industrial structures.
- To identify geological hazards to development and the areas favourable and unfavourable to development and to describe the characteristics of particular strata.
- To give guidance for the detailed site investigations to be made by developers.
- To give guidance for land use planning at national and local levels and in particular to provide a basis for advice to Ministers on the best use of limited resources of land and infrastructure.

These objectives were similar to those given in an earlier paper (26 October 1977) entitled: Engineering geology. Scottish Development Department interest 1978-79 onwards” also by Malcolm Rutherford.

In mid-1978 Paul Gostelow produced a costed, prioritised proposal that identified the areas on the east coast of Scotland to be investigated between 1978 and 1984. The estimated cost was £200,000 per year. Priority 1 was the Upper Forth, Bandeath to Forth Road Bridge. Priority 2 was a) Cromarty Firth, north side, and b) Outer Forth, north side. Priority 3 was the Peterhead area and Priority 4 the Tay Estuary, north side (Barry Buddon). In the event, Priorities 1 and 2a were completed, but not the rest.

Whereas in South Essex BGS were required to present data relevant to a variety of possible engineering operations, in the Forth Estuary for example, specific information on the suitability or otherwise of the subsoil to withstand the heavy foundation pressures (in excess of 200 kN/m2) associated with petrochemical development was required and necessitated a different approach. The initial work took place at Bothkennar, in the Forth estuary area, where the main study was on the engineering geology of the superficial deposits, particularly the highly compressible Carse Clay (Hallam et al. [1977a and b], Lambert & Gostelow [1978], Gostelow & Lambert [1978], Suddaby [1979]).

Out of the Forth work came the concept of the 'geotechnical profile' and the mapping of this area in terms of these profiles, which take into account the geological and geotechnical history of the deposits, their resulting consolidation characteristics and hence the overall bearing capacities and settlement that each profile can accommodate. The area is complicated by the presence of past and present mine workings, both for coal and oil shales in the solid rocks beneath the Forth Estuary, leading to the necessity to have two additional categories of foundation (E & F) at the low end of the scale, A to D already established for the Cromarty Firth.

These two studies were more-or-less completed by the end of March 1981 and the programme ended (Gostelow & Tindale [1980a, b], Smellie [1980]). Staff moved on to environmental geological mapping (EGM) work, pioneered by the Glenrothes study. Initial studies were in Peterhead, Greenock, Falkirk and Grangemouth and in Hamilton. Staff shortages limited EGU inputs. Indeed, initially, there was little enthusiasm for this type of work. Roger Cratchley argued in a paper dated 11 June 1981 that “It is thus clear that most of the EGU expertise in sound scientifically based engineering geological mapping, built up over the last 12 years is not appropriate to the new style of mapping required by DOE which is essentially simplistic and based on limited and partial data...” This is an unfortunate statement given that EGM work continued until 1996 and became a significant EGU activity, though with much disagreement with the Land Survey over leadership of such projects.

The Applied Geology Mapping Programme carried on in Scotland throughout the 1980s but with less engineering geological content. This contrasted with the situation in England and Wales where there was a substantial engineering geological input to a dozen applied geology mapping maps and reports. In addition, applied geological research contracts were also carried out for the Department of the Environment and the Welsh Office. Areas of research included the use of geophysics for the detection of cavities and a survey of landslides in the South Wales Coalfield.

3.7 GEOTECHNICAL MAP OF SOUTHERN NICOSIA (NOW LEFKOSIA) CYPRUS

The purpose of the Geotechnical Map of Nicosia was to provide a simple map, covering Greater Nicosia, from which site investigations could be planned in what was becoming a rapid rate of urban and suburban development within, and beyond, the south of the capital city during the 1980’s. The map marked the beginning of a period of fruitful collaboration between the Cyprus Geological Survey Department (GSD) and the BGS’s Engineering Geology Unit as part of an urban plan for Nicosia funded by the United Nations. However, prior to the mapping of Nicosia, two training visits were made by GSD staff to the IGS in 1978 and 1979 and one by an IGS staff member to the GSD in 1980. It was decided at this point to embark on a joint GSD/IGS project aimed at providing engineering geological maps for engineers and planners covering the major centres of building development in Cyprus.

The Nicosia map (funded by the UK’s Overseas Development Administration) was based on techniques developed at BGS and attempted to group and classify geological materials having similar characteristics, rather than the more traditional basis of geochronology. Samples for identification and geotechnical and mineralogical testing were taken during the mapping phase. This was augmented by a programme of drilling by the GSD. Engineering properties related to potential foundation conditions were included in a simplified form but, whilst considered, shrink/swell, dissolution and slope stability were not. The principal bedrock materials were marls, calcarenites, limestones, sandstones and cemented gravels. These typically formed cuestas and plateaux having cemented caprocks. Superficial deposits were subdivided into ‘cohesive’ and ‘non-cohesive’. Added interest was provided by the presence (underground) of archaeological qanats (man-made chains of interconnected wells) and their associated well shafts, and open and infilled quarries. Wide, seasonally dry and flooded water courses, in particular the Pedieos River, were a feature.

The field work was carried out in 1981 and 1982 by Peter Hobbs and Ian Moore (BGS) with George Loucaides and Maria Charalambous (GSD) under the guidance of George Petrides (GSD). Fortunately, the area was provided with good quality topographic map coverage, aerial photography and the results of an earlier hydrological mapping project. The final, full colour printed map (Figure 4; Cratchley et al., 1982) was turned around in a matter of weeks at 1:25,000 scale by the GSD's drawing office from 1:10,000 scale 'field slips' and presented in a short seminar in 1982 (Anon. 1983). The map was accompanied by descriptive reports published by GSD (Hobbs & Loucaides 1983) and BGS (Hobbs & Loucaides 1982).

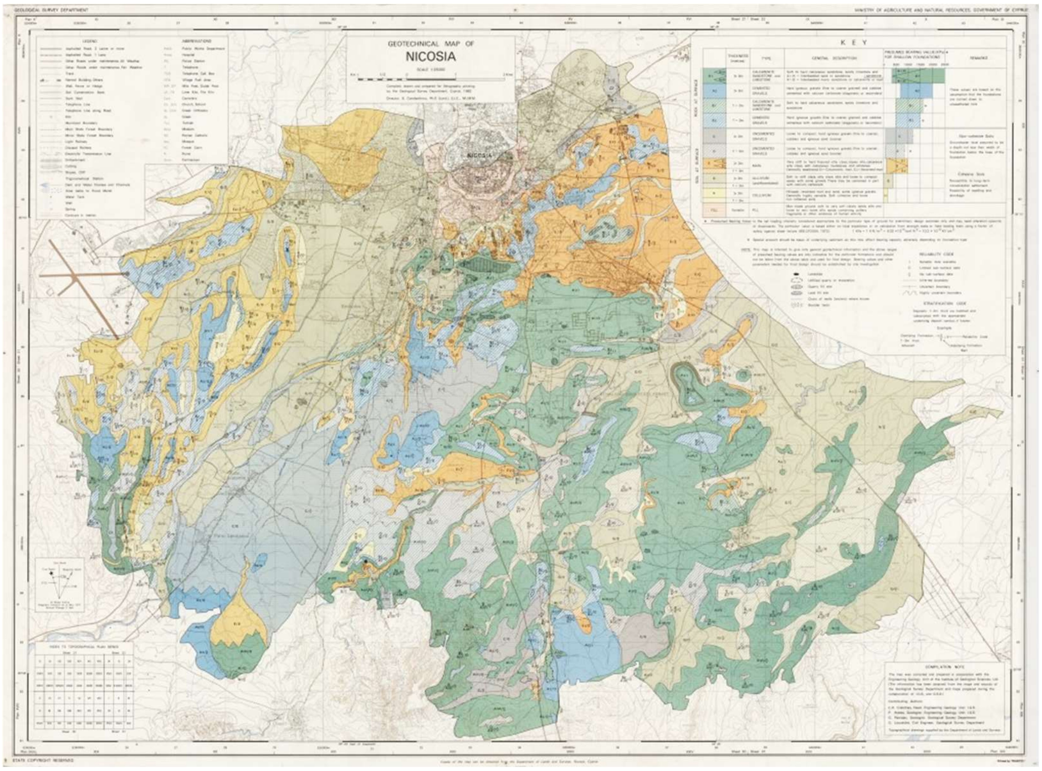
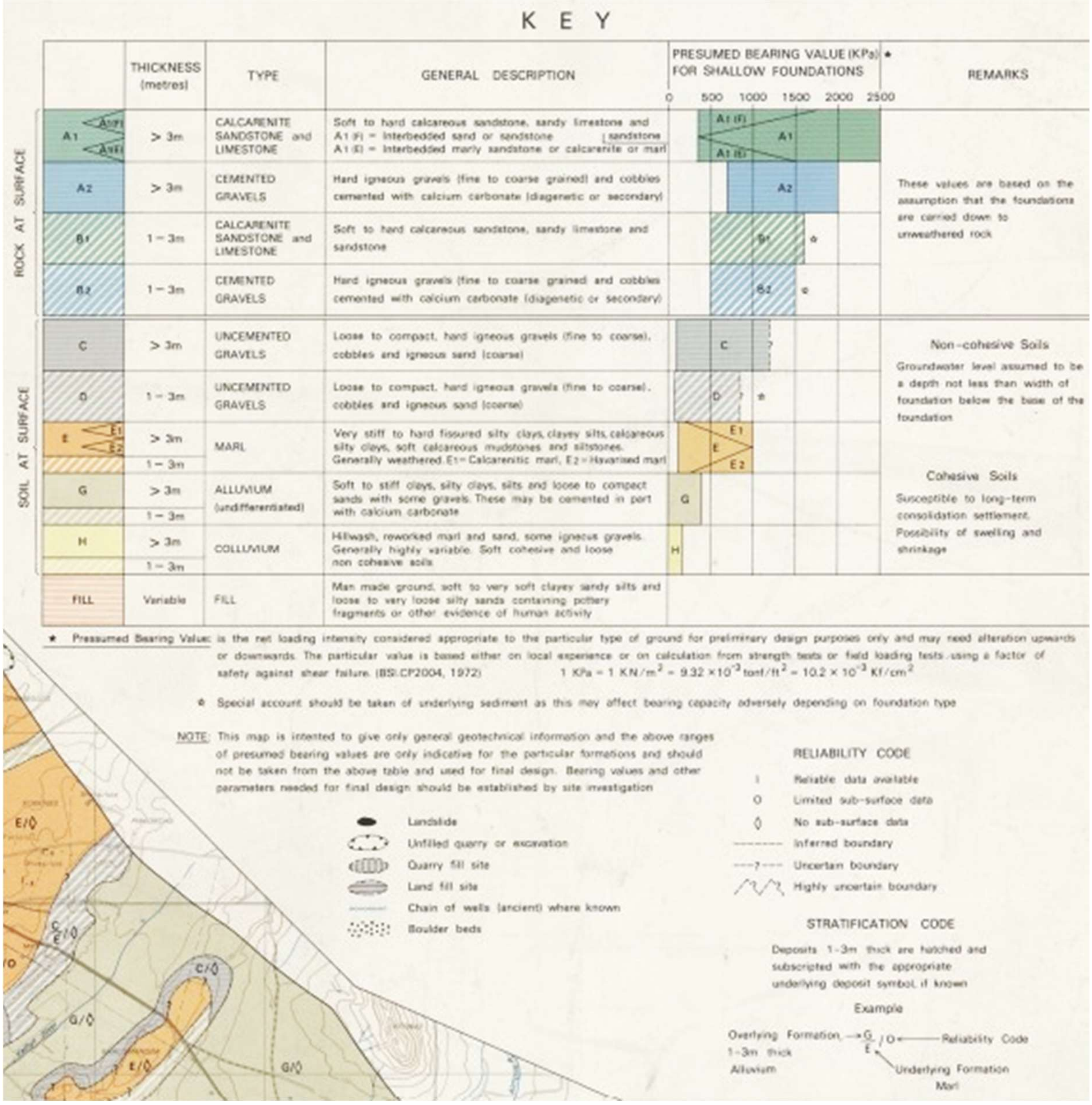


Figure 4 Geotechnical Map of Nicosia (the 11-pointed 'star' of Nicosia's Venetian city walls is clearly seen; Cratchley et al., 1982). Reproduced with permission of the Geological Survey Department, Cyprus. © Republic of Cyprus.

The map (Figure 4) included a 'stratification code' and a 'reliability code' both of which were shown as symbols on the map, for example, 'G/E/O' indicating alluvium (G) overlying marl (E) with a poor reliability rating (O); the superficial and bedrock lithostratigraphic classes having been labelled in a simple alphabetic scheme ordered according to bearing capacity in the key (Figure 5). In effect, this provided a simple pseudo-3D assessment mapped at 2D, combined with a 'thematic' approach focused on likely foundation conditions. Such schemes had been pioneered at the Engineering Geology Unit at BGS for similar 'thematic' maps in the UK. The map key indicated the 'Presumed Bearing Value' of each class based on the definition of the then British Code of Practice (CP2004, 1972). These ratings were mainly based on local knowledge and records provided by the GSD as well as current Cypriot practice in engineering foundation design. A depth 'cut off' of 3 m was chosen as the basis for the stratification code; again, based on local experience.



K E Y

		THICKNESS (metres)	TYPE	GENERAL DESCRIPTION	PRESUMED BEARING VALUE (KPa) ★ FOR SHALLOW FOUNDATIONS 0 500 1000 1500 2000 2500	REMARKS
ROCK AT SURFACE	A1 A1(F) A1(E)	> 3m	CALCARENITE SANDSTONE and LIMESTONE	Soft to hard calcareous sandstone, sandy limestone and sandstone A1 (F) = Interbedded sand or sandstone A1 (E) = Interbedded marly sandstone or calcarenite or marl	A1 (F) A1 A1 (E)	These values are based on the assumption that the foundations are carried down to unweathered rock
	A2	> 3m	CEMENTED GRAVELS	Hard igneous gravels (fine to coarse grained) and cobbles cemented with calcium carbonate (diagenetic or secondary)	A2	
	B1	1 – 3m	CALCARENITE SANDSTONE and LIMESTONE	Soft to hard calcareous sandstone, sandy limestone and sandstone	B1 ⊛	
	B2	1 – 3m	CEMENTED GRAVELS	Hard igneous gravels (fine to coarse grained and cobbles cemented with calcium carbonate (diagenetic or secondary)	B2 ⊛	
SOIL AT SURFACE	C	> 3m	UNCEMENTED GRAVELS	Loose to compact, hard igneous gravels (fine to coarse), cobbles and igneous sand (coarse)	C ?	Non-cohesive Soils Groundwater level assumed to be a depth not less than width of foundation below the base of the foundation
	D	1 – 3m	UNCEMENTED GRAVELS	Loose to compact, hard igneous gravels (fine to coarse), cobbles and igneous sand (coarse)	D ? ⊛	
	E E1 E2	> 3m 1 – 3m	MARL	Very stiff to hard fissured silty clays, clayey silts, calcareous silty clays, soft calcareous mudstones and siltstones. Generally weathered. E1 = Calcarenitic marl, E2 = Havarised marl	E1 E E2	Cohesive Soils Susceptible to long-term consolidation settlement. Possibility of swelling and shrinkage
	G	> 3m 1 – 3m	ALLUVIUM (undifferentiated)	Soft to stiff clays, silty clays, silts and loose to compact sands with some gravels. These may be cemented in part with calcium carbonate	G	
	H	> 3m 1 – 3m	COLLUVIUM	Hillwash, reworked marl and sand, some igneous gravels. Generally highly variable. Soft cohesive and loose non cohesive soils	H	
	FILL	Variable	FILL	Man made ground, soft to very soft clayey sandy silts and loose to very loose silty sands containing pottery fragments or other evidence of human activity		

★ Presumed Bearing Value: is the net loading intensity considered appropriate to the particular type of ground for preliminary design purposes only and may need alteration upwards or downwards. The particular value is based either on local experience or on calculation from strength tests or field loading tests using a factor of safety against shear failure. (BS:CP2004, 1972) 1 KPa = 1 KN/m^2 = 9.32 × 10^{-3} tonf/ft^2 = 10.2 × 10^{-3} Kf/cm^2

⊛ Special account should be taken of underlying sediment as this may affect bearing capacity adversely depending on foundation type

NOTE: This map is intented to give only general geotechnical information and the above ranges of presumed bearing values are only indicative for the particular formations and should not be taken from the above table and used for final design. Bearing values and other parameters needed for final design should be established by site investigation

⬬	Landslide
◌	Unfilled quarry or excavation
▥	Quarry fill site
▤	Land fill site
┈	Chain of wells (ancient) where known
⁘	Boulder beds

RELIABILITY CODE

I	Reliable data available
O	Limited sub-surface data
◊	No sub-surface data
-------	Inferred boundary
---?---	Uncertain boundary
/\/\	Highly uncertain boundary

STRATIFICATION CODE

Deposits 1-3m thick are hatched and subscripted with the appropriate underlying deposit symbol, if known

Example

Figure 5 Key for Geotechnical Map of Nicosia (Cratchley et al., 1982). Reproduced with permission of the Geological Survey Department, Cyprus. State Copyright reserved. © Republic of Cyprus.

3.8 ENGINEERING GEOLOGICAL MAPPING OF SITES FOR HEAVY INDUSTRY IN SCOTLAND - BOTHKENNAR

This site was the first of a number of potential Scottish industrial development areas to be assessed by the EGU. The main objectives were:

- to identify potential geological hazards;
- to provide foundation information for the development of heavy industry.

The Bothkennar site is located about 3 km to the north of Grangemouth on the southern side of the Upper Forth estuary. The site is underlain by tidal flats in the east and to the south by a narrow belt of alluvium associated with the River Carron. However, most of the site is underlain by Post-Glacial inter-tidal flats (the Carse Clay).

The geological succession is:

Post Glacial	Recent tidal flat clay and river alluvium	5 m
	Carse Clay	3 - ?20 m
Late Glacial	Buried gravel	? - ?3 m
	Late Glacial laminated clays	0 – 30 m
	Boulder Clay (Glacial Till) with associated sands and gravels	0 – 60 m
Solid Geology	Productive Coal Measures	c. 200 m
	Millstone Grit	c. 340 m
	Carboniferous Limestone Series	c. 660 m
	Calciferous Sandstone Series	

Abandoned mineworkings lie beneath the site at depths from 25 – 100 m below O.D. There are a number of disused mineshafts.

During the 1976 project agreement reached between the Scottish Development Department, the Department of the Environment and the IGS, it was decided that, within the general framework of a regional engineering assessment of the Firth of Forth, assessment of a number of preferred industrial development zones and specific sites should be made to:

- assess the geological conditions affecting development (especially heavy industrial structures;
- include in the assessment an identification of the geological hazards affecting development, as well as identifying area favourable and unfavourable for development and describing the characteristics of particular strata;
- locate and use all existing information on the selected areas;
- and provide conclusions guiding the overall planning of the area and also guiding the detailed site analysis that will be undertaken by developers.

Bothkennar was the first site to be investigated under this programme. A desk study report was produced in May 1977 (Hallam et al. [1977a]) based on pre-existing records compiled between February and April 1977. It follows on from a report by Bill Read (a geological mapper) in 1972. Then a fuller report was produced in June 1977 (Hallam et al. [1977b]). This contains a lot of information but no specific conclusions other than the zonation of the area for deep foundations. As well as discussion of the geology, engineering geology and hydrogeology, the report discusses the abandoned mineworkings.

The two main project reports were produced in 1978 (Lambert & Gostelow [1978], Gostelow & Lambert [1978]). These discuss how site investigations should be designed to determine:

- the basic geotechnical properties of the superficial deposits with a high degree of accuracy;
- how the vertical variation in lithology can be logged with sufficient certainty to identify individual geotechnical and stratigraphic units;
- how the lateral geotechnical/geological variations of the units can be obtained;
- how possible constraints from the geological hazards can be obtained;
- an assessment (using factors above) can be made of different foundation types based on allowable pressures.

The two reports were, essentially, parts 1 and 2 of the main report. Part 1 concentrated on general foundation conditions while Part 2 was a more research orientated geotechnical description of the Quaternary deposits. Volume 1 of Part 1 summarised the site investigation data and outlined recommendations for foundation types. Volume 2 of Part 1 consists of eight appendices with all the field and laboratory test results. Part 2 also includes proposals for the general Firth of Forth engineering geological study due for completion at the end of 1980.

The two main reports concluded that two basic approaches were needed in the investigation of sites for development:

i. Regional engineering geology for planning – upgrading standard geological maps at 1:50,000 and 1:10,000 scale to show:
   - 3D drift geology in terms of lithology and geotechnical index properties;
   - ground assessment categories using allowable bearing pressure;
   - geotechnical types cross sections;
   - a summary of existing building foundations in similar stratigraphic situations.

ii. Site investigation involving closely spaced boreholes with sampling and laboratory testing and recommendations regarding foundation types.

In 1979, Di Suddaby carried out investigations in Bothkennar to test the use of resistivity surveys and conductivity surveys (EM31) in this environment (Suddaby [1979]). The resistivity surveys were successful in detecting the surface desiccation layer and the Boulder Clay (Glacial Till) and also the bedrock if at shallow depth. The resistivity surveys were also sensitive to variations in salinity and clay mineral content. EM31 surveys were also successful in the Bothkennar environment but only to depths of about 6 m.

3.9 FEASIBILITY STUDY FOR A DRAINAGE TUNNEL NEAR SHANTALLOW, NORTHERN IRELAND

In September 1983, EGU was appointed by the Department of Agriculture for Northern Ireland as engineering geological consultants for a feasibility study for a drainage tunnel near Shantallow, Northern Ireland. EGU was requested to “determine a suitable line for a drainage tunnel between two points which could be established on the ground and provide geological advice on the design and construction of the tunnel.”

Design of the proposed site investigation was completed in October 1983, contract awarded in May 1984 and the site investigation began in June 1984. The site investigation was completed at the end of August 1984. The report covers all aspects of the site investigation, discusses the expected ground conditions along the proposed tunnel routes and includes recommendations for the optimum tunnel route and for further site investigation at the design stage. Maps and other data are presented in the four appendices of the report (Northmore et al. 1984). Construction methods and estimated costs of construction of the tunnel are in a separate report by Binnie and Partners dated December 1984.

3.10 MAPPING FOR REGIONAL AND URBAN PLANNING

By the late 1970s/early 1980s, the engineering geological mapping work evolved into a programme of work funded by the Department of the Environment (DoE), the Welsh Office (WO) and the Scottish Development Department (SDD). This programme of work continued for some 15 years. Not all the projects were led by BGS (a few were contracted to private consultants) and most of the BGS contracts were led by Land Survey Groups. However, the engineering geologists had a significant input to many of them.

From about 1980 till 1996, the UK Government's Department of the Environment (it had many different names during the period, but the key point was that it was responsible for land-use planning policy) and the SDD funded a series of more than 60 studies of the applied geology/environmental geology of British urban areas. The philosophy behind the research was discussed by Brook & Marker (1987). For each area a report and a series of maps were produced. An initial study (Nickless et al. 1982) was commissioned for the Glenrothes area of Fife, Scotland.

Some of the studies were fairly basic but later ones were much more sophisticated and comprehensive and included quite a lot of engineering geology. No two studies were the same as geological conditions obviously vary but as the work was labelled 'research' each study had to do something new! Some of the reports ended up being published, or part published, in the scientific literature (for example, Forster et al. 1987, 2004). However, most were not, though the library of the BGS has a complete set of reports and most/many of the maps have been digitally scanned. The research programme was discussed, in part, in a paper by Culshaw et al. (1990) and more completely by Smith & Ellison (1999). The latter paper contains reference to all the reports for England & Wales. More reports exist for Scotland (see Culshaw et al. 1990) but by the time of the Smith & Ellison paper we had devolution and Scotland was not part of the DoE's remit!

3.10.1 Bath - environmental geological mapping

The city of Bath has 'world heritage site' status and contains famous Roman remains and Georgian architecture dominated by the use of local Bath stone. The countryside to the north and east of the city is designated an Area of Outstanding Natural Beauty (AONB). The area's industrial heritage is also of interest, in particular stone mining and canals, but also coal and fuller's earth extraction. The 'father' of British geology, the engineer/geologist William Smith, lived and worked in the area and, in 1799, produced the world's first stratigraphic map of the city and its environs clearly showing the main sub-divisions of the Jurassic and Permo-Triassic (Figure 6). The map shows the country 5 miles around Bath (originally) at 1½ inches to the mile scale, and was 'coloured geologically' by William Smith. It was presented to the Geological Society in 1831 and is believed to be the first map ever produced showing accurately the outcrop of strata according to an ordered stratigraphic sequence. Lias (blue), Great Oolite (yellow), Trias (red).

The 'Bath environmental geological mapping' project was initiated in 1984 and funded by the DoE as part of its applied geology/environmental geology research programme. It was one of a series of studies commissioned by the DoE from the early 1980s to the mid-1990s (see above). A similar programme of applied mapping was commissioned by the SDD. The various projects, and the maps from them, were discussed by Culshaw et al. (1988, 1990, 1994).

The 'Bath' project was led by Reg Wyatt (a mapping geologist) and EGU project members of staff included Peter Hobbs (who had worked previously on the landslides in the area [Hobbs 1980]) and Alan Forster. Another mapping geologist, Dick Monkhouse, also worked on the project. The project involved a large desk study and significant amounts of fieldwork, particularly to try to resolve the issue of 'foundered strata' (see below).

The mapping was required to provide an applied geological assessment for the city and its environs in the form of 'thematic' maps, two reports (Forster et al. 1985, Wyatt 1985) and a database. The output was intended to be used by land-use planners but also to be understandable to people not trained in geology and yet to contain detailed information required by specialists concerned with the environment and its development.

A desk study and list of site investigation reports (up to 1985) for the whole area and a comprehensive geotechnical/lithological database were produced (Forster et al., 1985). During the project an understanding of the processes of cambering and associated landsliding in the Bath area was built on the key paper by Chandler et al. (1976). Under current climatic conditions many slopes are only marginally stable (Forster et al. 1985, 1987, Chandler et al., 1976). This means that small adverse changes to the climate or slope profile may initiate re-activation, as has been demonstrated in several well-documented historical cases within the city where slope profiles or drainage have been altered.

The environmental geological mapping project was reported in the form of fifteen black & white 1:25,000 scale ‘thematic’ maps (Table 1), some featuring a form of pseudo-3D point annotation to depict conditions or strata at depth based on site investigation boreholes and field (geological & geomorphological) mapping (Table 1, Map 9). The maps covered topics such as solid and superficial lithostratigraphy, hydrogeology, landslides and cambering, slope angle classification, geotechnical properties and mining. The maps were produced on die-line film from which paper die-line copies were printed. Map 15 dealt with the re-mapping by field geologist Reg Wyatt of the controversial ‘foundered strata’. Previous geological mapping (by Geoff Kellaway and others) had struggled to distinguish between landsliding and cambering. As a result, the two forms of mass movement were lumped together as 'foundered strata.'

In 2004 further geomorphological work was carried out in the Bath area concentrating on specific, representative slope profiles and landslides using aerial photography and the (at the time) novel approach of terrestrial LiDAR (Hobbs & Jenkins 2008). A 2-stage cambering regime was demonstrated with landslides developing downslope (Figure 7). As a result of earlier detailed cave mapping by speleologists, cambering in the Great Oolite caprock was found to have created ‘gull caves’ many tens of metres into the hinterland and large enough to be accessible.

Map No.	Title	Scale
1	Solid lithostratigraphy	1:25,000
2	Drift deposits (extent, lithology & thickness)	1:25,000
3	Made ground & infilled land	1:25,000
4	Inferred distribution of Great Oolite freestones	1:25,000
5	Inferred distribution of Fuller’s Earth	1:25,000
6	Groundwater	1:25,000
7	Ground conditions in relation to groundwater	1:25,000
8	Geotechnical properties of bedrock	1:25,000
9	‘Engineering geology’ maps (x4)	1:10,000
10	Distribution of landslip & cambered strata	1:25,000
11	Distribution of slope angle (4 classes)	1:25,000
12	Location of shafts	1:25,000
13	Extent of underground mining	1:25,000
14	Location of geotechnical data sources	1:25,000
15	Solid litho-stratigraphy, landslip & cambered strata (incorporating re-survey of ‘foundered’ strata)	1:25,000

Table 1 Environmental geological maps.

Figure 6 William Smith's 1799 map of Bath.

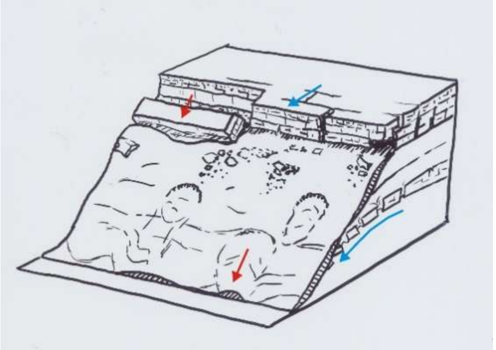


Figure 7 Block schematic diagram showing 2-stage cambering, rock fall and landsliding (from Hobbs & Jenkins 2008).

3.11 ENGINEERING GEOLOGICAL CONTRIBUTIONS TO OTHER DOE MAPS FOR PLANNING AND TO BGS 1:50,000 SCALE MAPS

From the early 1990s, EGU was asked by the Land Survey to make engineering geological contributions to 1:50,000 scale geological map descriptions and memoirs. This happened because there was a change in emphasis in terms of what geological mapping should cover. These descriptions varied depending upon the nature of the geology and the Science Budget funds available to cover the staff costs. Most of the sheets covered are listed below.

Also, during the 1980s and first half of the 1990s, the BGS was contracted by the Department of the Environment (the name of the Department changed from time to time) to produce reports relevant to urban planning in towns and cities. Each report focused on a specific city. The development of these reports together with the BGS's capability to produce digital 3D maps, ultimately led to the creation of an Urban Geology section in EGU in the early 2000s (see below).

Engineering geological contributions to map sheet explanations and environmental geology project reports for the Department of the Environment:

- Forster, A. 1991. The engineering geology of the area around Thame, Berkshire, 1:50,000 geological map sheet No. 237. Engineering Geology Report WN91/14.
- Forster, A. 1991. The engineering geology of the Exeter area. 1:50,000 geological map sheet No. 325. Engineering Geology Report WN/91/16.

- Forster, A. 1992. The Engineering geology of the area around Nottingham.1:50,000 geological map sheet No. 126. Engineering Geology Report WN/92/7.
- Forster, A. 1995. Engineering geology of the Minehead area. 1:50,000 geological map sheet No. 278. Engineering Geology Report WN/95/23.
- Forster, A. 1995. The Engineering Geology of the Cirencester area. 1:50,000 geological map sheet No. 235. Engineering Geology Report No. WN/95/42.
- Forster, A. 1996. Engineering geology of Bristol. Comments for ALGI. Engineering Geology Report No. WN/96/44.
- Forster, A. 1997. The engineering geology of the London area. 1:50,000 geological map sheets Nos. 256, 257, 270 and 271. Engineering Geology Report No. WN/97/27.
- Forster, A. 1998. The engineering geology of the Sidmouth District. 1:50,000 geological map sheets Nos. 326/340. Engineering Geology Report No. WN/98/1.
- Donnelly, L. J. 1998. The engineering geology of the Morpeth District. 1:50,000 geological map sheet No. 14. Engineering Geology Report No. WN/98/2.
- Hobbs, P. R. N. 1998. Engineering geological assessment of Loughborough. 1:50,000 geological map sheet No. 141. Engineering Geology Report No. WN/98/7.

BGS geological sheet explanations with engineering geology:

- Barron, A. M. J., Morigi, A. M. & Reeves, H. J. 2006. Geology of the Wellingborough district: a brief explanation of the geological map sheet 186 Wellingborough. Nottingham, UK: British Geological Survey, 34pp. (Explanation: England and Wales Sheet 186).
- Barron, A. J. M., Sumbler, M. G., Morigi, A. N., Reeves, H. J., Benham, A. J., Entwisle, D. C. & Gale, I. N. 2010. Geology of the Bedford district: a brief explanation of the geological map Sheet 203 Bedford. Nottingham, UK: British Geological Survey, 38pp. (Explanation: England and Wales sheet 203).
- Barron, A. J. M., Sheppard, T. H., Gallois, R. W., Hobbs, P. R. N. & Smith, N. J. P. 2011. Geology of the Bath district: a brief explanation of the geological map sheet 265 Bath. Nottingham, UK: British Geological Survey, 35pp. (Explanation, England & Wales Sheet 265).
- Carney, J. N., Ambrose, K., Cheney, C. S. & Hobbs, P. R. N. 2009. Geology of the Leicester district: sheet description of the British Geological Survey 1:50,000 series Sheet 156 Leicester. Nottingham, UK: British Geological Survey, 110pp. (Explanation: England and Wales Sheet 156).
- Crofts, R. G., Hough, E., Humpage, A. J., Reeves, H. J. 2012. Geology of the Manchester district: a brief explanation of the geological map Sheet 85 Manchester. Nottingham, UK: British Geological Survey, 45pp. (Explanation: England & Wales Sheet 85).
- Herbert, C., Barron, A. J. M., Reeves, H. J. & Smith, N. J. P. 2005. Geology of the Kettering district: a brief explanation of the geological map sheet 171 Kettering. Nottingham, UK, British Geological Survey, 34pp. (Explanation: England & Wales Sheet 171).
- Hough, E., Lake, R. D. & Hobbs, P. R. N. 2007. Geology of the Barnsley district: a brief explanation of the geological map sheet 87 Barnsley. Nottingham, UK: British Geological Survey, 32pp. (Explanation: England & Wales Sheet 87).
- Howard, A., Hough, E., Crofts, R. G., Reeves, H. J. & Evans, D. 2007. Geology of the Liverpool district: a brief explanation of the geological map Sheet 96 Liverpool. Nottingham, UK: British Geological Survey, 42pp.
- Lawrence, D. J. D., Dean, M. T., Entwisle, D. C., Kimbell, G. S. & Butcher, A. 2011. Geology of the Rothbury district: a brief explanation of the geological map Sheet 9

Rothbury. Nottingham, UK: British Geological Survey, 38pp. (Explanation, England & Wales Sheet 9).

- Millward, D., McCormac, M., Soper, N. J., Woodcock, N. H., Rickards, R. B., Butcher, A., Entwisle, D. C. & Raines, M. G. 2010. Geology of the Kendal district: a brief explanation of the geological map Sheet 39 Kendal. Nottingham, UK, British Geological Survey, 34pp. (Explanation: England and Wales Sheet 39).
- Morigi, A M, Woods, M A, Reeves, H J, Smith, N J P & Marks, R J. 2005 Geology of the Beaconsfield district: a brief explanation of the geological map sheet 255 Beaconsfield. Nottingham, UK: British Geological Survey, 34pp. (Explanation: England and Wales Sheet 255).

BGS geological memoirs with Engineering Geology:

- Ellison, R. A., Woods, M. A., Allen, D. J., Forster, A., Pharaoh, T. C. & King, C. 2004. Geology of London: special memoir for 1:50,000 geological sheets 256 (North London), 257 (Romford), 270 (South London) and 271 (Dartford) (England and Wales). Nottingham, UK: British Geological Survey, 114pp.
- Horton, A., Sumbler, M. G., Cox, B. M., Ambrose, K., Barron, A. J. M., Lake, R. D. Samuel, M. D. A., Wood, C. J., Woods, M. A., Wyatt, R. J., Allsop, J. M., Forster, A., Cheney, C. S., Allen, P., Parker, A. & Ivimey-Cook, H. C. 1995. Geology of the country around Thame: memoir for 1:50,000 geological sheet 237 (England & Wales). Nottingham, UK: British Geological Survey

BGS Regional Guide with Engineering Geology:

- Stone, P., Millward, D., Young, B., Merritt, J. W., Clarke, S. M., McCormac, M. & Lawrence, D. J. D. (with contributions from R. P. Barnes, A. S. Butcher & D. C. Entwisle). 2010. British Regional Geology: Northern England. Fifth edition. Nottingham, UK: British Geological Survey.

Engineering geological contributions to environmental/urban geology project reports for the Department of the Environment:

- Culshaw, M. G. & Crummy, J. A. 1988. The engineering geology of the Deeside area. Engineering Geology Report WN/88/7.
- Forster, A. 1989. The engineering geology of the Nottingham area. Engineering Geology Report WN/89/4.
- Culshaw, M. G. & Crummy, J. A. 1990. S.W.Essex - M25 corridor. Engineering Geology. Engineering Geology Report WN/90/2.
- Northmore, K. J. 1990. Engineering Geology of the Castleford - Pontefract area. Engineering Geology Report WN/90/8.
- Culshaw, M. G., Waine, P. & Hallam, J. R. 1990. Engineering Geology of the Wrexham area. Engineering Geology Report WN/90/10.
- Culshaw, M. G., Hallam, J. R. & Waine, P. 1990. Engineering Geology of the Stoke on Trent area. Engineering Geology Report WN/90/11.
- Northmore, K. J. 1991. The engineering geology of South Central Leeds. Engineering Geology Report WN/91/11.
- Forster, A. 1991. The engineering geology of Birmingham West (the Black Country). Engineering Geology Report WN/91/15.
- Fenwick, S. M. M. 1994. The engineering geology of the Coventry area. Engineering Geology Report WN/94/39.
- Forster, A., Culshaw, M. G., Arrick, A. & Johnston, M. 1995. A geological background for planning and development in Wigan.

- Vol. 1: A geological foundation for planning. Vol. 1 – A geological foundation for planning
- Vol. 2: A user's guide to Wigan's ground conditions.
- Engineering Geology Report WN/95/3.

3.12 ENVIRONMENTAL INFORMATION SYSTEM FOR PLANNERS

Following the end of DoE funding for geological maps of urban areas for land-use mapping purposes in the mid-1990s, the DoE funded other research projects relevant to land-use planning. One of these was the Environmental Information System for Planners (EISP). The system can be summarized as being: to develop a prototype demonstrator to support a range of environmental concerns that may influence planning decisions. This was a web-based system, developed by a BGS-led consortium (including the Centre for Ecology and Hydrology and the University of Nottingham) in collaboration with five local authorities. It was built as a 'proof-of-concept' system to demonstrate the value to urban planning of making information on environmental issues more widely accessible. The research was sponsored jointly by the NERC, through its URGENT Thematic Programme, and the Office of the Deputy Prime Minister (ODPM). The system aimed to incorporate relevant research outputs from URGENT and research directly commissioned by the ODPM. The EISP has been designed to support local authorities in carrying out pre-planning enquiries, development control decisions and strategic planning. The system incorporates eleven environmental topics, including air quality, shallow undermining, flood risk, land contamination and natural and man-made heritage. The design framework was based upon a series of decision flow diagrams, each covering one of the environmental themes. These decision flows took account of current planning procedures and link where environmental topics overlap. The system enables enquirers to quickly identify those environmental issues that are relevant to strategic planning and planning applications. The system also provides advice to enable planners make environmentally appropriate decisions and is discussed in detail by Culshaw et al. (2006). The research was led by Martin Culshaw with most of the system design work being carried out by Tim Duffy in the BGS Edinburgh Office.

3.13 3.13 URBAN GEOSCIENCE

In around 1999, Martin Culshaw formed the Urban Geoscience Section (first managed by Richard Ellison, then Dave Bridge, then Kate Royse, then Simon Price and most recently by Stephanie Bricker) with a remit to re-examine how urban areas should be mapped (that is, information gathered) and how information should be presented for a range of users (extending beyond planners). However, Brian Marker of the Department of the Environment should be credited with being the midwife of this advance! The Urban Geoscience Section was developed following recommendations to the BGS Board by Andrew Skinner in November 1999. The proposal had four main aims:

i. data collection – made ground/fill, superficial deposits and rock characterization and mapping;
ii. development of improved IT systems;
iii. underpinning research;
iv. and delivery of value added products.

The recommendations of this initial review of how urban geoscience should be carried out at BGS are discussed by Culshaw & Ellison (2002). However, events moved very quickly with the development of digital 3D modelling techniques and by 2005 the emphasis had changed (see Culshaw 2003, 2005). New research in urban areas is now firmly, but not exclusively, based around 3D modelling and the provision of environmental information for land-use planning has moved on to cover all/most types of environmental scientific information (for example, Culshaw et al. 2006) (see below).

Little or no research goes on in universities in urban geoscience. Rather, a broader canvas is being painted on which geology covers only a small corner, so to speak. The emphasis is now on developing sustainable cities, what that means, how it can be achieved for the future and how we know when we are being sustainable (see below)!

The initial applied research concerned four generic topics providing reference material, underpinning methodologies and recommendations for future thematic projects within the urban environment.

i. Development of improved IT systems for urban geoscience (Ellison et al. 2001). The key aspect of the development of IT is the use of GIS and the visualization of data. The corporate IT structures in place (at the time) were described. Consideration was given to collation of relevant data and the applicability of the scale at which the data are available. An important recommendation was that procedures adopted in the urban programme should be compatible with the workflow proposed for the digital capture of geoscientific data in the Lands and Resources Directorate that was responsible for the provision of digital geological map data. A series of eleven areas of work were identified for IT development. These included methodologies for building databases and analyzing datasets effectively, and methodologies for the delivery of specific derived outputs from thematic urban projects. These included mapping urban soils, determination of aquifer vulnerability and collation of information on land-use and potentially contaminated land.

ii. 3-D rock mass characterization in the urban environment (Bloomfield et al. 2001). The objectives of this project were to establish a methodology for the identification and collection of 3-D rock mass property data to enable subsequent 3-D modelling of the subsurface in urban areas and to provide clear guidance to current and future project managers and team members in urban areas on the key data types necessary for successful project outcomes. The term rock mass referred to all strata underlying natural and artificial superficial deposits. The principal datasets relevant to the rock mass were considered to be hydrogeological, lithological, mineralogical, geochemical, geotechnical, geophysical and structural. The report covers information about the modelling of the 3-D rock mass, identified urban issues that the principal earth science datasets need to address, the potential data sources and the BGS datasets that were currently available.

iii. Superficial deposits characterization in the urban environment: best practice guide to mapping and research (McMillan et al. 2001). The report describes the methodologies and datasets relating to superficial deposits relevant to thematic urban geoscientific projects. It provides guidance on sources of information and recommends procedures and standards that should form part of best practice when undertaking a project. Although specification of products for a commissioned project will vary according to the requirements of clients the underpinning practice, recording standards and classifications need to be defined. The report describes these parameters and highlights areas of future generic work that should improve BGS output.

iv. Ground characterization of the urban environment: a guide to best practice (Ellison et al. 2002). The report describes the methodologies and datasets relating to superficial deposits and bedrock geology relevant to urban geoscientific projects. The rationale for carrying out such projects is explained and the basis for good practice is laid out in generic terms. The report provides guidance on sources of information and recommends procedures and standards that should form part of best practice. Examples of this good practice are given in the form of illustrations of a range of outputs from a project being carried out in Manchester and Salford (see below).

These introductory projects were followed by a number of further projects each based on a specific geological topic in a specific geographical urban location. Initially, six potential projects were identified. One focused on 3-D modelling of ground conditions in the Manchester and Salford area (Bridge et al. 2010) and another on dealing with contaminated land in the Swansea-Neath-Port Talbot area (Waters et al. 2006). A pilot study in the Thames Gateway was also carried out (Royse et al. 2005). Other projects were intended to be carried out in the Glasgow area (urban minerals supply), north-east England (the legacy of mining) and the Bristol and Bath area (land stability). The last three were never started but a major project eventually took place in Glasgow (Entwisle et al. 2008, 2016) but the original momentum seems to have died. In later years EGU no longer controlled the overall urban projects.

In 2020, a brochure on the BGS website summarized the main completed urban geoscience projects since about 2006:

i. **Planning for Manchester and the Mersey**. The Lower Mersey Corridor, extending from Manchester to Liverpool, is a rapidly developing, predominantly urbanised, area with a long history of intense, largely unrestrained industrialisation. These activities have resulted in a legacy of contaminated land and groundwater pollution in what is one of the most densely populated areas of the UK. It is now an area undergoing major regeneration including projects such as MediaCityUK, Mersey Gateway and Liverpool Waters. To support the sustainable urban regeneration of Manchester and the Mersey corridor EGU developed 3D geo-environmental models that provide planners, regulators and utility companies with information on ground conditions, environmental considerations and risks to subsurface infrastructure. For central Manchester and Salford a 3D model that characterises the urban geology, geotechnical engineering, hydrogeology, geochemistry and land use was produced (Bridge et al. 2010). This geo-environmental information can be used to underpin assessments of ground instability, contamination and groundwater management in the urban area. In collaboration with the Environment Agency and United Utilities EGU's expertise was used to develop 3D ground models to assess the risk of pipe leakage on groundwater supplies in the Knowsley urban area. The vulnerability of the underlying aquifer to pollution was assessed by integrating foul and surface water pipeline data with our geological data (Price et al. 2008).

ii. **3D modelling for Crossrail**. A high-resolution geological model of the Crossrail Station at Farringdon in London was constructed, particularly focusing on the faulted bedrock. Understanding the faulting pattern was essential because it enabled the engineers to predict the potential occurrence of water-filled sand bodies, which are hazardous if excavated. During excavation, the geological model was validated and updated frequently. The outcome, an improved understanding and recognition of a complex fault pattern, optimised future ground investigation and had a significant impact upon the assessment of risks for construction, design and, ultimately, on final costs. The project is described in detail by Aldiss et al. (2012).

iii. **Subsurface planning in Abu Dhabi**. A 3D geological model of the Abu Dhabi urban area in the United Arab Emirates (UAE) was produced to support their 20-year development master plan. The model was commissioned by the UAE Federal Ministry of Energy, Department of Geology and Mineral Resources. It aimed to provide government, planners, developers and contractors with a geological framework for sustainable land-use planning, urban development and hazard assessment. The geological model was developed using existing ground investigation data provided by private and public sector organisations and agencies. The model showed the distribution, thickness and elevation of rock units beneath the Abu Dhabi urban area. The Ministry of Energy provides the geological model to those involved in construction and planning to ensure sustainable development, particularly in respect to units that are prone to dissolution.

iv. **Subsurface data for building information modelling (BIM)**. Unforeseen ground conditions are one of the major causes of delay to construction projects contributing to about one third of construction programme overruns. This can be attributed partially to limited availability of high-quality geotechnical data and subsequent interpretation. Vast amounts of geological and geotechnical data exist, particularly in urban areas, but often this resides in project archives. Building information modeling (BIM) is a relatively new concept that strives to improve the management of data and models throughout the life cycle of construction projects. The BGS has been involved in BIM-related projects for some years, for example in the Farringdon project (see above) and, more recently, completed a ground model for Tata Railways (http:// nora.nerc.ac.uk/509777/). Work also took place with Keynetix, whose expertise is in geotechnical data management and provision of geotechnical BIM software to the construction and engineering sectors, to directly apply the BIM process to ground investigation and subsurface infrastructure design. The two-year project was called ‘BIM for the subsurface’ and was funded by InnovateUK. It integrated the BGS’s national databases, methodologies and standards for 3D geological modelling directly with existing BIM software and workflows.

v. **Subsurface data exchange**. Ground investigations for urban development yield large amounts of valuable geological information. EGU worked closely with local authorities, geological consultants, environmental regulators and city service providers to implement digital geological data-transfer mechanisms using the Association of Geotechnical and Geoenvironmental Specialists (AGS) format and through BGS’s new geoscientific information system. This ensures that maximum benefit is obtained from the ground investigation data collected and from the geological models derived using the data. The BGS, including EGU, launched an ASK (Accessing Subsurface Knowledge) network in Glasgow in partnership with Glasgow City Council to develop and trial these concepts (see below) and ASK was extended to Cardiff in addition to bespoke projects with partners in London. These initiatives aim to transform the way in which cities exchange data and information for improved urban management. The engineering geological contribution to the Glasgow project is described below.

In the period 2008 to 2012, a second phase of the UAE work was carried out based mostly around 3D geological mapping and modelling in Abu Dhabi. The EGU contribution was led by Simon Price.

By the 2020s, BGS’s field of activity in urban geoscience had broadened and EGU had been abolished so the responsibility for urban geoscience came under the Directorate for Environmental Change, Adaptation & Resilience, rather than the Directorate for Multi-hazards and Resilience where the rest of the former EGU ‘resided.’ In 2021, the primary areas of activity were:

i. provision of geoscience data and information for urban planning in support of policy, legislation and the UN’s Sustainable Development Goal 11 (sustainable cities and communities);

ii. characterisation of ground conditions for major infrastructure projects to support options appraisal and analysis of risk;

iii. development of methods for sustainable management and use of urban subsurface space, including approaches for 3D and 4D geological characterisation;

iv. evaluation of anthropogenic pressures and interactions in urban environments.

3.13.1 Glasgow - Engineering geology and ground information for sustainable development

The long connection between the BGS Edinburgh office and Glasgow City Council led to a range of collaborations over the years. The 3D geological models produced during the 2000’s and 2010’s gave the opportunity to extend the use of these models for engineering geological purposes. The BGS is ideally placed to provide a wide range of data and information to aid desk studies either for planning or ground investigations. The addition of geotechnical and other data and information to a 3D geological model would be a great aid to many desk studies. The Ground Information for Sustainable Development project was instigated with the aim of creating methods that could be used for this purpose. After discussions and consideration of the aims of the project, it was decided that providing modelled parameter values in a 3D model was not appropriate, primarily because of the spatial and depth distribution and variability of the values. The presentation of the data for desk study purposes would allow the user to access the data and use it as they required.

This project was initially aligned with the Clyde Urban Super Project (CUSP), which underpinned the regeneration of ex-industrial areas in central and eastern Glasgow in partnership with Glasgow City Council and other organisations. The multidisciplinary project aimed to improve knowledge of the subsurface beneath the City of Glasgow and make geoscientific information more accessible to the wide range of users involved in the sustainable regeneration and development of the city.

To provide ground information for sustainable development it was decided that the easiest way would be via a GIS platform, as many different types of data and information could be presented. As part of this, data from the National Geotechnical Properties Database was presented in a range of graphs (including cross-plots, depth plots and extended box and whisker plots), as information in geological cross-sections with the data as live plots from a database within the GIS. The platform used was ArcGIS as it was the BGS's supported GIS and there were experts who could write the tools required. The initial tools were written for ArcGIS version 3.1 by Gerry Wildman, which were used for Glasgow geological sheet NS66NE (see Entwisle et al. 2008). This GIS worked very well and was provided to Glasgow City Council potentially to aid the Glasgow Gateway project. Work on extending the GIS to a 10 km x 10 km square of central Glasgow started when the version of ArcGIS supported by the BGS changed to version 9.x. This did not support the tools that had been originally developed, which needed to be rewritten. After the tools had been rewritten work on central Glasgow and eastern London began. The tools written were not as efficient as those for the ArcGIS 3.1 version; however, they did work. During further development of the GIS for Glasgow, a wider range of data was made available via the CUSP project, including mining information. The amount of data increased in the Glasgow area and with the extension into central London. Again, the version of ArcGIS changed and the tools needed to be rewritten, this time by Andy Hulbert who decided to use software that works within ArcGIS but is separate from it. A series of rules were also set up to underpin the GIS, and, hopefully, provide guidance as to how and where the data and information are set up. This was reported for the central Glasgow area in Entwisle et al. (2016).

3.14 SMALL-SCALE ENGINEERING GEOLOGICAL MAPS OF THE UNITED KINGDOM

Fully published engineering geological maps of the United Kingdom (UK) are not common. The term 'fully published' is used to distinguish these maps from the large number of engineering geological maps produced to accompany research or commercial reports. It is somewhat ironic for EGU that the first such map was produced by the Geological Survey of Northern Ireland at an unusual scale of 1:21 120 – 3 inches to 1 mile. Work on this map began in 1967, the year that the EGU was created!

The map was of the area around Belfast (Bazley & Manning 1971). On the front of the sheet it consisted of a standard litho-stratigraphic map but with isopachytes of the Estuarine Clay included. On the reverse were two tables, one showing summary soil and rock characteristics for each of the rock and soil groups (these included lithology, structure, geotechnical properties, economic materials, groundwater conditions and pedological soils) and the other condensed borehole logs of selected boreholes. There was also a map of rockhead contours in the city area. The map was discussed briefly by Bazley (1971).

In 1996-7, Kevin Northmore and Martin Culshaw collaborated with Professor Bill Dearman (Newcastle University) to develop a small-scale engineering geological map of the UK. Professor Dearman developed the methodology, first outlined in his 1982 paper with Eyles (Dearman & Eyles 1982) on an engineering geological map of the UK, using geological map information at 1:625,000 and 1:250,000 scales. The map was intended to have an extensive legend and a series of text boxes, block diagrams and sections that explained geological processes relevant to development and remediation. The initial interpretation was completed but, unfortunately, the map was not taken further due to lack of financial support from the BGS.

Fortunately, all the interpretative work that had been undertaken by Professor Dearman was retained by the BGS. The legacy was substantial. Professor Dearman had determined the engineering geological lithologies for both bedrock and superficial deposits, combined engineering geological lithologies using a system of stripes to create engineering geological map units, completed the geotechnical interpretation of the bedrock lithostratigraphy, largely completed the geotechnical interpretation of the superficial deposits lithostratigraphy and had drafted a key, that included detailed information on engineering considerations associated with each engineering geological lithology. In addition, a series of inset maps, text boxes and block diagrams had been agreed for inclusion with the map.

In late 2008 it was decided to revive the original interpretation and to apply it to a new digital version of the 1:625,000 scale geological map led by Marcus Dobbs with advice from Kevin

Northmore and Martin Culshaw. Two engineering geological maps were produced, for bedrock and for superficial deposits. The original igneous, sedimentary and metamorphic bedrock classification methodology was revised to better reconcile the classes to modern geological and engineering geological interpretations and classification systems. Mainly, this involved the reinterpretation of classes within the metamorphic and igneous groups and some reinterpretations and additions to the mudstone, sandstone and limestone classes within the sedimentary group. The original superficial deposits classification methodology was found to be largely compatible with modern geological and engineering geological interpretations and classification systems and so has been left largely un-amended apart from the addition of a number of sub-divisions of Glacial Till by Dave Entwisle. A third sheet (labelled ‘Extended Key for the Engineering Geology Maps of the United Kingdom’) was also produced that gave a large set of descriptions for each lithology shown on the two maps. This key gives an engineering geological description, foundation conditions, excavatability, use as engineered fill and site investigation issues. The development of the maps is described in detail by Culshaw et al. (2010) and Dobbs et al. (2012).

The maps are intended to be used mainly by geoscience, civil engineering and environmental science undergraduate and postgraduate students to aid understanding of the importance of geology to development and regeneration. The maps may also be useful to those engineering and environmental geologists and geotechnical engineers in the early stages of their careers who may not be familiar with the geology of the whole of the UK. It was intended that the maps should be made freely available as digital files and that printed versions should be provided to university departments and consultants/contractors and others to display in places of study and work.

Sadly, Professor Dearman died on the 6th of January 2009 before the maps described were completed and published in 2011.

3.15 SINGAPORE URBAN MAPPING

From 2012 to 2021, the BGS worked with the Geological and Underground Projects Department of the Building and Construction Authority of Singapore (BCA) to undertake a range of multi-disciplinary studies with the overall objectives of improving the knowledge of Singapore’s subsurface and communicating it to key geoscience stakeholders.

These studies culminated in a substantially revised interpretation of the geology, including a new International Commission on Stratigraphy (ICS)-compliant stratigraphy and structural framework. The research was published in five peer-reviewed articles (Chua et al. 2020, Dodd et al. 2019, 2020, Gillespie et al. 2019 and Leslie et al. 2019) and was synthesised in a new interactive map and memoir of Singapore geology. A companion volume: “Practitioners’ guide to the bedrock geology of Singapore” was also published to facilitate adoption of the new geological framework by industry professionals in 2021 (Leslie et al. 2021, Ritchie et al. 2021, and Gillespie et al. 2021). It is the intention of BCA that the trio of new publications are used by those working in the engineering construction and development planning sectors to make decisions that will reduce the cost and risk of construction, and to ensure future urban development in Singapore is both resilient and sustainable.

The engineering geology/engineering geophysics components included:

- Developing an AGS-compliant geotechnical database for BCA to store data from their deep ground investigation programme.
- Limited geomechanical testing of rock samples including triaxial compression and direct shear in the BGS rock mechanics and physics laboratory.
- A third-party review of 40 km of seismic reflection and refraction data acquisition, processing and interpretation, and subsequent reprocessing and reinterpreting of 20 km of seismic reflection data.
- Engineering geological evaluation of all units within the new geological framework developed by BGS, primarily using data collected by BCA during their deep ground investigation programme (over 3,400 in situ and laboratory tests; 20,000 m of logged borehole core). This involved:

    - Deriving non-parametric summary statistics (medians and centiles) for a range of physical and mechanical properties of soils, rocks and rock-masses. Where possible this was done for each weathering grade, of each lithology-type in each unit.
    - Identifying engineering geology considerations related to common civil engineering operations in Singapore including foundations, excavations (and, in particular, basements, tunnels and shafts), material re-use, ground investigation and geological interpretation.
- Finally, the engineering geology was summarised as a chapter within the new geological memoir and on an engineering geology bedrock layer within the new interactive 1:50,000 scale geological map. The geotechnical property summaries were also presented by unit within the new Practitioners' Guide that was created to assist those working in the civil engineering industry with adopting the new stratigraphy.

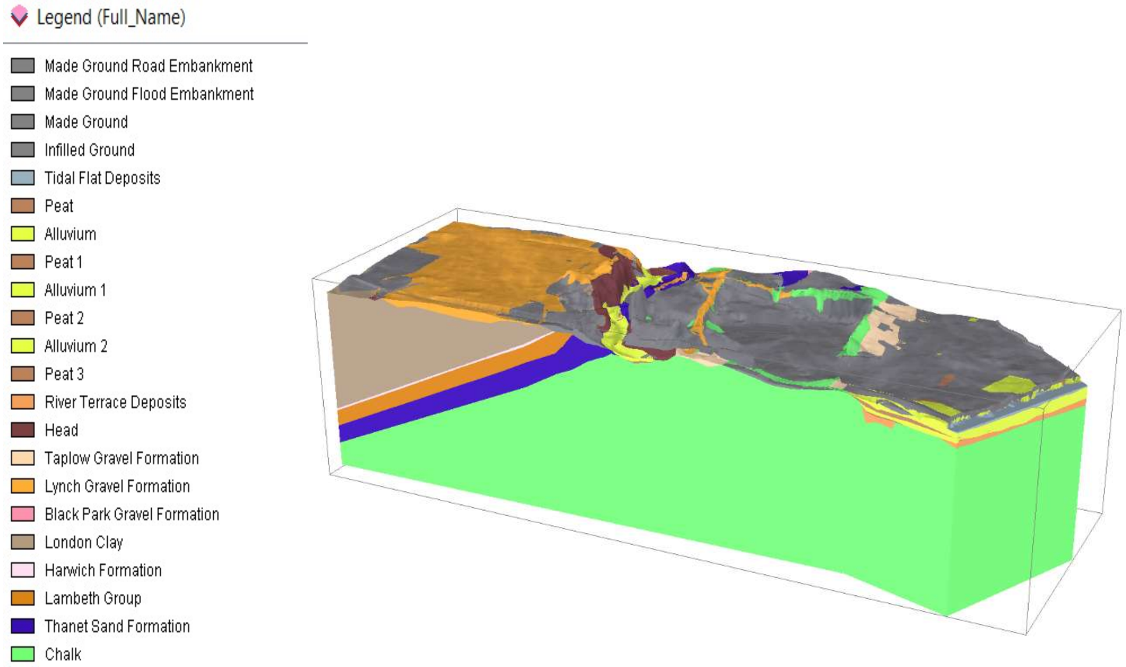
BGS engineering geology staff involved were Marcus Dobbs, Simon Price, Ben Dashwood, Sue Self, Dave Entwisle and Dave Boon.

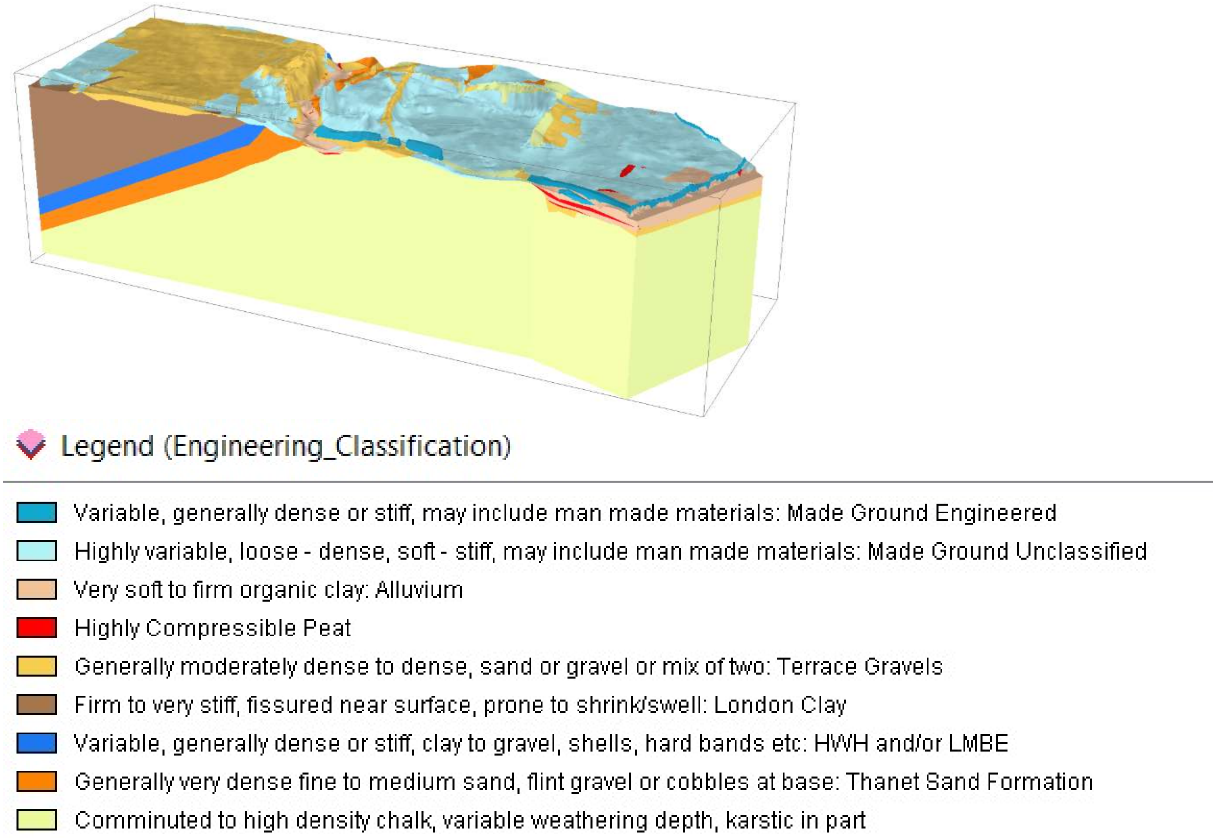
3.16 3D ENGINEERING GEOLOGICAL MODELLING

The production of 3D geological models by the BGS, starting in the 1990's onwards, provided a means of producing 3D engineering geological models. The engineering geology inputs into the DoE's area projects "Environmental Geology in Land Use Planning" (see above) used the lithostratigraphy as the basis for the different map themes. This was also done for the 1:625,000 scale national engineering geology maps with their themes (Dobbs et al. 2012) and the BGS Civils products at 1:50k scale. As a 2D surface geological map is a model for 2D engineering geology maps then the same principles could be used to populate 3D lithostratigraphical models.

The software used for Quaternary and relatively simple geological models, GSI3D, allows for a number of different themes to be described and shown in a model. The first model so populated was the Thurrock model east of London (Royse et al. 2009). In the example shown in Figure 8a, b and c. the modelled lithostratigraphy is shown also in terms of an engineering geology classification with short engineering geological descriptions and in terms of foundation conditions. However, care must be taken as the use of 3D models does suggest that the information given is relevant to the whole depth of the model.

In 2015, 3D models were produced for a commercial project for Tata Steel who were involved in the electrification of the Leeds to York railway line. The BGS was asked to produce a 3D geological (lithostratigraphical) model. The condition of the ground was important for assessing the foundation type needed and the construction method. The weathering of the bedrock and the changes from rock to soil were key factors and the engineering geological descriptions of the bedrock covered fresh and weathered rocks and soils for each of the units. As the depth of weathering was variable, two lines were drawn on the geological cross-section, one representing the likely minimum depth and the likely maximum depth of the defined weathering grade, between rock and soil. The evidence for the changes in weathering depth was obtained mainly from good quality ground investigation borehole descriptions with the boundary between soil and rock for a bedrock unit identified in the project GIS. The data nearer the section line were given a higher weighting. The weathering of the Pennine Coal Measures Group rocks is highly variable due to the different lithologies (primarily sandstone, siltstone and mudstone) their place in the landscape and, potentially, the effects of glacial and periglacial weathering. Also, weathering tends to be deeper in the vicinity of faults as noted by Lake et al. (1992). However, there were very few good quality borehole descriptions near, or along, the lines of the faults. The methods, results and products delivered to Tata Steel Projects are described in Burke et al. (2015).


Legend (Full_Name)
Made Ground Road Embankment
Made Ground Flood Embankment
Made Ground
Infilled Ground
Tidal Flat Deposits
Peat
Alluvium
Peat 1
Alluvium 1
Peat 2
Alluvium 2
Peat 3
River Terrace Deposits
Head
Taplow Gravel Formation
Lynch Gravel Formation
Black Park Gravel Formation
London Clay
Harwich Formation
Lambeth Group
Thanet Sand Formation
Chalk


Legend (Engineering_Classification)
Variable, generally dense or stiff, may include man made materials: Made Ground Engineered
Highly variable, loose - dense, soft - stiff, may include man made materials: Made Ground Unclassified
Very soft to firm organic clay: Alluvium
Highly Compressible Peat
Generally moderately dense to dense, sand or gravel or mix of two: Terrace Gravels
Firm to very stiff, fissured near surface, prone to shrink/swell: London Clay
Variable, generally dense or stiff, clay to gravel, shells, hard bands etc: HWH and/or LMBE
Generally very dense fine to medium sand, flint gravel or cobbles at base: Thanet Sand Formation
Comminuted to high density chalk, variable weathering depth, karstic in part

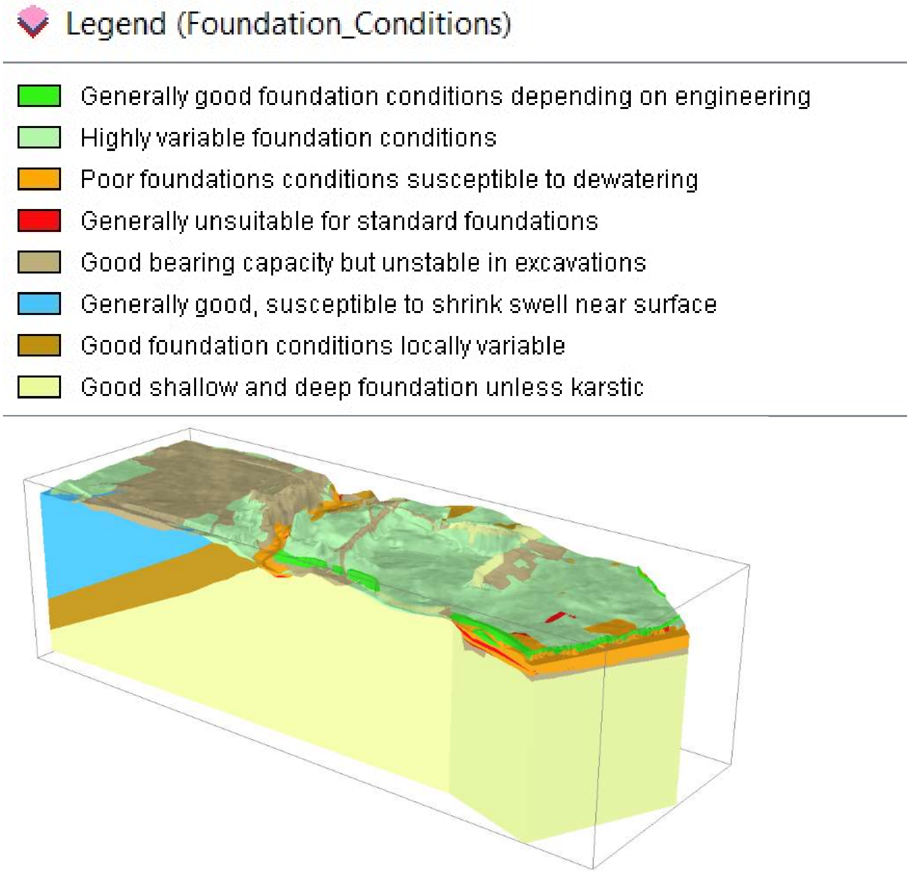


Figure 8 3D geological model with legend for part of the Thurrock area. B. 3D model with engineering classification. C. 3D model with foundation conditions. Model surface derived from NEXTMap Britain elevation data from Intermap Technologies.

4 Engineering Geological Databasing

Researchers in universities and geological surveys around the world had attempted to create geotechnical databases from around the late 1960s onwards. Indeed, such work began on the Milton Keynes project (see above and below) in the late 1960s. However, the development of a corporate and national database was hindered by the inadequate nature of the software and hardware available at the time. In the 1980s and 90s further local geotechnical properties databases were created, mostly on micro-computers (PCs) as part of the Applied or Thematic Geological Mapping projects of British urban areas, initially for the Department of the Environment, the Welsh Office and the Scottish Development Department. However, these, too, suffered from difficulties, mainly because the PC software was regularly being improved and was unsuitable for a long-term national database.

However, four projects, in the 1960s and 1970s, attempted to create digital geotechnical properties databases – the Milton Keynes engineering geological mapping project, the South Essex engineering geological mapping project, the offshore geotechnical investigations project and the Banda Aceh (Indonesia) engineering geological mapping project. None of the digital databases survived as the software (mainly G-EXEC) ceased use.

In April 1985, Mike Price, formerly of the Hydrogeology Unit, took over from Roger Cratchley as Head of EGU (now called the Engineering Geology and Reservoir Properties Research Group) In September 1985, he asked Martin Culshaw to prepare a project proposal for a 'Geotechnical Database.' Five options were suggested, though it was mentioned in the first sentence that "The creation of a geotechnical database within the BGS is constrained by the manpower and finance available to CS21."

The five options were:

i. Geotechnical parameter values measured in-house by CS21.
ii. Geotechnical parameter values measured in-house by BGS and those values held by BGS in reports by outside organisations.
iii. Geotechnical parameter values measured in-house and externally, whether the data were held by BGS or by outside organisations.
iv. Summary (rather than all) geotechnical parameter values for any of options 1 to 3.
v. Sources of geotechnical parameter values so that, whilst the individual values would not be stored, the titles and storage location of the reports, papers, theses, etc. (data sources) that contain the values would be held in the database, together with any appropriate engineering geological or other comments.

It was pointed out that strictly speaking Option 5 did not involve the creation of a geotechnical database, but of a bibliographical database of geotechnical data sources. Culshaw considered Option 5 to probably be a first step towards a national geotechnical database.

Because of the incompleteness of the database resulting from Options 1 and 2, and the amount of work required to build a complete data base in Options 3 or 4, Option 5 was preferred. At a meeting on 25 September 1985 a meeting to discuss facilities required for the database were discussed and Option 5 agreed. This was proposed to the Chief Geologist, E G Smith, next day.

It is not known what happened to the proposal for a database of geotechnical parameter value sources. However, the work on the various DoE projects, that required processing of geotechnical data values, led eventually in around 1991/2 to the development of a 'proper' geotechnical property values national database. This is described in more detail below.

Geohazard databases were not created until the turn of the century. Again, the driver for their development was the commissioning of two Department of the Environment projects on landslides and sinkholes/karst, both carried out by consultancy companies. The National Landslide Database and the National Karst Database evolved from these 1990s projects and were inherited by the BGS. Both are being continuously maintained and expanded at the present.

4.1 EARLY GEOTECHNICAL PROPERTIES DATABASING

Three of the four early geotechnical property databases were similar in their design, content and intended use. The odd one out was the offshore geotechnical properties database. Very little record of this database remains. The earliest documentation is a progress report dated 14-10-1975 by John Lambert and Janet Patterson, both members of EGU, on the "South Forties Data Bank." This was pilot study. Six separate data files were created:

i. Reference data. This file contained three dimensional co-ordinates for vibrocore locations – UTM co-ordinates and water depth.

ii. Index properties. The parameters included were density, moisture content, specific gravity and Atterberg Limits. Other parameters were calculated from some of these. The testing laboratory was also noted.

iii. Consolidation. Data from 35 cores tested using an oedometer to produce Mv and Cv values at different pressures.

iv. Strength parameters. Data from laboratory vane, hand vane, penetrometer and falling cone tests.

v. Particle sizes. Particle size analysis plots were created using phi sizes.

vi. Sound velocity in soil. Values of sound velocity down cores were recorded.

Five different testing laboratories were used and one of the conclusions reached in this progress report was that the data showed variations depending upon the laboratory providing the results. It was suggested that fewer separate laboratories should be used.

On 05-08-1976 Jon Hallam reported that all the geotechnical data from the South Forties and the Pockmarks (Whitethorn '75) surveys had been "databanked." The two databases were not identical in their design; each database was specific for the data collected. This confirms that the intended use of the databases was to summarise and plot data rather than to record it for posterity.

On 01-09-1976, John Lambert attended a "Working party on data banking of shallow commercial geological data." No mention is made of geotechnical data in the meeting minutes. Rather, the proposed database was intended to include information on traverses, maps, shallow boreholes and samples, site investigation and pipeline route surveys and reports. The database was intended for use by the Department of Energy and included commercially-derived information. It was hoped that BGS-derived information could be added.

Work on the Milton Keynes database must have begun in 1973 or 1974, sometime after the Milton Keynes mapping project had been completed. EGU files contain part of a 1974 proposal for the IGS Computer Unit's contribution to the database:

- Sets of cards were to be punched containing information from EGU
  - OD level of sample
  - Grid position of sample
  - Surface height
  - Stratigraphy
  - Depth to Cornbrash (OD)
  - nine engineering parameters
- Creation of a data bank using G-Exec
  - Simple statistics on the engineering parameters
  - Means
  - standard deviation
  - variances
  - correlations etc.
- Use of MAPT for calculating trends across the entire area for individual parameters
- A second stage was to estimate stratigraphic/lithological logs for positions where no borehole information existed; this involved interpolation between borehole points but required some software development.

In January 1977, Jon Hallam and Stuart Duncan wrote a report commenting on the outcome of the September 1976 meeting that John Lambert attended. Hallam and Duncan provided a number of comments on the proposed database:

- The overall objectives or terms of reference were not defined. They were concerned that it was not possible to effectively select data and formulate a structure for the database without considering what it will be used for.
- The required human resources for data entry and validation had not been properly considered.
- What was being discussed was, not so much a computerised database as a computer-compatible data indexing and cross-referencing system.

What happened to the proposal is not known to the authors

Hallam and Duncan's comments were based on their experiences of two databases for the Milton Keynes and South Essex engineering geological mapping projects. Initially, these two databases differed considerably in many respects. For Milton Keynes, around 90% of the input data came from commercial site investigation reports. The items that were indexed and databased were the original reports, the borehole locational data and the borehole logs (in manuscript). About 200 reports were indexed, containing about 3 500 boreholes. The database was used primarily for a detailed structural and lithological analysis. However, in the mid-1970s about 1,000 of the boreholes were selected and limited lithological and geotechnical data from them were added to the database.

For South Essex a comprehensive coding scheme was used to database virtually all the geological, geotechnical and geophysical data in great detail. Records relating to some 1,100 shallow boreholes in the South Essex area, both project-drilled and extracted from site investigation reports and well logs. The geology of each borehole was described in some detail, in an encoded form where possible, following the recommendations of the Engineering Group of the Geological Society's Working Party report on the logging of rock cores. The description included lithology, texture, colour, weathering, consolidation, up to five inclusions of minerals, ten descriptors of discontinuities and a stratigraphic classification. Other files contained geotechnical, geomechanical, geophysical and detailed grain size data for around 3,200 samples taken from boreholes. A considerable amount of time was devoted to the coding and its validation. A great variety of outputs were derived from the data, some requiring very sophisticated (for the time) processing. The outputs were included in the South Essex project reports and used for interpretation.

The reasons for establishing a computer database were given by Cratchley (1977) as:

- data recording in a uniform manner;
- rapid answering of enquiries about ground conditions;
- enabled the rapid reproduction of contour plots, sections and borehole logs as well as experimental maps and sections;
- statistical analysis, particularly multi-variate cluster analysis;
- ability to rapidly update the database with subsequent investigation data.

The information was recorded in nine data files:

i. borehole reference information;

ii. water levels;

iii. lithostratigraphic information;

iv. reference data on samples;

v. lithological descriptions of samples;

vi. geotechnical test data from samples analysed during the project;

vii. additional geotechnical test data;

viii. particle size analysis information;

ix. geotechnical consolidation data.

Data retrieval was performed by the G-EXEC system and display of data utilized the IBM 1,130 or a Univac 1,108 computer.

It is interesting to note that Cratchley's (1977) final conclusion states that "The type of complex data bank established for South Essex is probably not justified for the recording of available site investigation data in this country; a computer index system would suffice." This proved not to be the case as both a national borehole data base and a national geotechnical properties database now exist and are maintained.

The fourth geotechnical database during this period was for geotechnical data collected in Banda Aceh, Sumatera, Indonesia by Martin Culshaw and his Indonesian colleagues led by Nandang Sutarto. The project lasted nearly two years and Stuart Duncan joined Martin Culshaw in Indonesia for the last six months of the project. The nature of the overall project is given above.

The Banda Aceh geotechnical database was designed based on the experience of successfully developing the South Essex geotechnical database. Data were entered on to three forms. The first two were completed in the field and the third in the laboratory:

i. Field form: boreholes;
ii. Field form: lithological units;
iii. and Laboratory form: samples.

Each form was accompanied by a code list, though the lithological units form had four code lists. A coding manual was produced to explain how to complete the forms (Culshaw & Duncan 1977). A complete set of the forms and code lists can be found in the Engineering Geological Archive in the BGS archives at Keyworth, Nottingham. The data on each form were entered onto a punched card. The punched cards were read on a punched card reader to produce the digital information for subsequent processing. As indicated above, the processing of the data in Indonesia could not be completed before the project end but some processing was done at BGS, London. Further information can be found in Culshaw et al. (1979b). A fourth coding form was designed late in the project (the Interpretation Form) but was never used because of the loss of access to computer facilities. Consequently, the characterization of the different alluvial deposits found in the Banda Aceh basin in terms of their geotechnical properties was done manually.

All four G-EXEC-based geotechnical databases were destroyed, probably in the early to mid-1980s, because the BGS changed its databasing software and there were insufficient resources to transfer the original databases onto the replacement software.

4.2 THE NATIONAL GEOTECHNICAL PROPERTIES DATABASE (NGPD)

As engineering geologists worked on many of the BGS applied geology/environmental geology contracts for the DoE in the 1980s and 90s, the reports contained significant amounts of engineering geological input. Part of this input was in the form of geotechnical property databases. The Exeter, Deeside, Coventry, Nottingham, Bath, Castleford/Pontefract, Southampton (Laxton 1987) and the Black Country projects and the Thame 1:50,000 scale geological map all had these databases which, while not incorporated into the NGPD, form part of formal BGS data holdings and referred to as "Geotechnical Data from Applied Geology Projects."

In the late 1980's, following on from these early data collections, a further series of datasets were created for the applied mapping project areas of Wrexham, Leeds, SW Essex and Stoke. The data for each project was stored on a paper datasheet that was later input to a computerised spreadsheet (usually utilising 'SMART'© commercially available software) replicating the design of the paper datasheets. These spreadsheets were later combined, restructured and the data stored as a project database. Data from other projects (particularly Wigan and Bradford, produced at the end of the overall research project) were incorporated into the NGPD.

In 1990/91 the 'Engineering Geology of UK Rocks and Soils' (EGRS) sub-programme (or theme) was initiated under the Urban Geoscience and Geological Hazards (UGGH)

Programme, with the aim of characterizing the engineering properties and behaviour of key geological formations of particular relevance to planning and engineering development. The first unit studied was the Gault Formation. A geotechnical database necessary to underpin the study of this deposit was created in Microsoft Access with the same structure as the previously described project database. Data from site investigation boreholes located within the Gault Formation outcrop were extracted from site investigation reports and manually entered into the database.

The improvement in software in the 1980s and early 1990s, together with the availability of local databases for urban areas mentioned above meant that a new approach could be considered for transfer to new corporate databases. In early 1992 efforts were made to bring together and validate the local databases referred to above and a Geotechnical Properties Database Committee met for the first time on 20 February 1992. Minutes of the 2nd meeting, held on 2 April 1992 indicate that funding had been agreed for work to begin that year (1992-3) on geotechnical database design in ORACLE. This was the beginning of the development of the current corporate National Geotechnical Properties Database. International reference to this database probably was first made by Gunderson (1994) in an international inventory. The database is referenced as UK27.

One of the most interesting outputs of the early work on geotechnical property databasing was a report by Jon Hallam on the statistical analysis and summarization of data held in geotechnical databases (report WN/90/16). The recommendations of the report were summarized by Culshaw (2005). A number of recommendations were made of which probably the most important was that: “The most valuable tool for data analysis is the probability plot.” Traditionally, engineering geologists and geotechnical engineers had analysed geotechnical data using a classical parametric approach to statistics, that is, using mean and standard deviation. Jon Hallam recommended using a ‘robust’ approach using graphical displays such as probability plots. This methodology was summarized using extended box and whisker plots bases on those in Hallam (1990). Initially, the graphs were hand drawn but subsequently computer scripts were written in a couple of languages (MapInfo and R) resulting in computer drawn graphs were used. This system was used for the extended box and whisker plots used in the Engineering Geology of the Lias Group, Lambeth Group, Glasgow, London and Manchester projects.

The final version of the database was based on the Association of Geotechnical and Geonvironmental Specialists (AGS) data format version 3.1 as instigated by Jon Hallam. It was managed by Sue Self as part of BGS database projects until her retirement in March 2023. Kevin Northmore, Pete Hobbs and Dave Entwisle provided geotechnical and geological expertise and advice into the data requirements of projects such as the queries needed to extract data. The database is described in detail by Self & Entwisle (2006) and Self et al. (2012). For much of the last 25 years, the database had been managed by Sue Self.

By November 2019, the NGPD held approximately the following information:

- 178,000 geotechnical boreholes (mostly logged to Association of Geotechnical Specialists [AGS] standards);
- 930,000 geological descriptions;
- 870,000 geotechnical laboratory data values;
- 500,000 chemical data values.

4.3 THE NATIONAL LANDSLIDE DATABASE (NLD)

In the 1980s and 90s, the government’s Department of the Environment (DoE) (which had various name changes during this time) funded a large number of research projects of, particularly, urban geology for land use planning but later on a range of other topics including the development of a national landslide database covering England, Scotland and Wales. Projects were put out to tender and, as a result, the BGS only won a proportion of the contracts. One of those that the BGS did not win was the one for a national landslide database. Once the consultant responsible for the contract (Geomorphological Services Ltd. [GSL]) had completed the work they were allowed to operate the database commercially with users paying to access it. However, GSL passed the landslide database to a large geotechnical consultant, Rendels, to operate. The intention was that the income from users would be used to keep the database up-to-date. This didn't work and the database was used less and less and was not updated much. Also, the software used for the database became outdated and not maintained. In 1995, Martin Culshaw was approached by Brian Marker from the DoE and the database was passed to the BGS for a fee of £1! The database contained around 6,000 records. Once EGU staff looked at it, they realised that the database software was inappropriate and had to be changed. Eventually, all the entries were improved to cover the types of information listed below.

The BGS National Landslide Database (NLD) is the most extensive source of information on landslides in Great Britain (Foster et al. 2012). Each data point is regarded as a reference of a reported landslide event. The database currently holds over 18,000 records that are continually being updated. New records are added as landslide information is made available. The data comes from a variety of sources including social media, published BGS geological maps and active surveys (Pennington et al. 2015). Other sources include commissioned and research studies, information from the public and a number of regional databases BGS have inherited or compiled since the 1970s, including the Department of the Environment's (DoE) National Landslide Database constructed in the early 1990s.

Each landslide event is documented as fully as is possible, with information on:

- age
- damage caused
- full bibliographic reference
- location
- movement date
- name
- size/dimensions
- trigger
- type

The level of detail is determined by the source of the original reference. Where the record has been through the QA process, the original reference has been checked for the reported location information and the point location has been amended as appropriate. Figure 9 shows the geographical extent of landslides in the database.

4.4 THE NATIONAL KARST DATABASE (NKD)

The first version of the national karst database was created by a small geotechnical consultancy, Applied Geology Ltd. under contract from the DoE (Applied Geology Ltd. 1993). A significant part of the work was undertaken by Edmonds who joined them and included his PhD work in the study (Edmonds 1987) resulting in the DOE Natural Cavities Database (Edmonds et al. 1989, Applied Geology Ltd 1993). A copy of the database is held by the BGS as a legacy database. However, it continued to be offered as a technical service by Peter Brett Associates (Farrant & Cooper 2008) and is still offered by Edmonds as part of Stantec in an expanded form based largely on addition information about the Chalk.

On completion of the original DoE study the final database was passed to the BGS for open use. The database was built on published data and included BGS information from maps and publications such as the gypsum karst detailed by Cooper (1986, 1988, 1989). Tony Cooper was not part of Engineering Geology, but was then a field mapping geologist who became more involved with sinkholes and subsidence with the encouragement and guidance of Martin Culshaw (Cooper 1988, 1989, 1998, 2002, 2005, 2009; Patterson et al. 1995).

In the early 2000s it was decided to create a new National Karst Database and the DoE study was considered to see if it was suitable as a starting point. Cooper was joined by Andrew (Andy) Farrant, who joined BGS in 1996 as a field mapping geologist with a PhD and extensive experience of karst (Farrant et al. 1997).

The first annual report for the project by Tony Cooper for 2000-2001 described the achievements and ambitions thus:

“Starting in April 2000, the Ground Movements Dissolution project was set up to investigate and document geological hazards associated with karst utilising Geographic Information Systems (GIS). Under the overall control of Dr A Forster, the project in the year under review involved Dr Anthony Cooper, Dr Andrew Farrant, Keith Adlam, Jenny Walsby, Russell Lawley and John Howcroft. There was also some input from BGS Wallingford especially Andrew McKenzie.

“Britain has four main types of karstic rocks, limestone, chalk, gypsum and salt, each with a different character and associated problems. Subsidence problems, difficult engineering and foundation conditions are widespread on these rocks. The triggering of subsidence by water abstraction and the enhancement of dissolution processes are relevant to some areas. Aquifer vulnerability and pollution tracing are concerns in most areas, especially the chalk, which is the major aquifer in southern Britain.

“The existing Department of the Environment Natural Cavities database has been examined and converted into a format that can be used in both ArcView and MapInfo. This database contains about 8,000 entries for caves and dolines in the UK, but it represents only a small proportion of the actual karst features. On one small area, the Natural Cavities database had less than 50 entries, the BGS mapping showed about 1,200.

“The recent capture by BGS of 1:50,000 scale DigMapGB information has produced a platform on which other geological information can be built. In conjunction with this, the recording and assessment of geological hazards, including karst problems, are being undertaken to provide complementary digital information that enhances the basic map data. Digital map capture has been established at 1:10,000 scale using a customised interface with the ArcView GIS application - the Geological Spatial Database (GSD). For the karst geohazards, this application has been extended to allow the digitisation of the karst features and generation of local information tables that can be downloaded to populate the main BGS Oracle database.

“For each type of karst feature, recorded as a polygon or point, attribute information fields with suitable dictionaries have been defined. So far interfaces for dolines, stream sinks, springs, caves, dye traces and building damage have been developed. Cave survey and plan data derived from published sources may eventually be incorporated. From the factual data contained in the databases, interrogated by the GIS, hazard areas will be derived.

“When the GIS is fully established and populated, the system will highlight the presence of karst features to non-specialists and allow the rapid interpretation of potentially hazardous karst areas by geological, hydrogeological and engineering geologists. With suitable links to polygon feature descriptions, basic geological reports derived semi-automatically are also feasible. The GIS will act as a desktop data capture facility with the intention that it can, ultimately, be extended to the capture in the field of information when suitable portable, robust computers become available.”

The details of the database and interface were published by Cooper et al., (2001) and Cooper & Farrant in Earthwise (2002). Initially the database had a desktop only interface but to facilitate data capture “Filofax” loose leaf field recording sheets were introduced for the main data types in parallel with field recording sheets introduced for geological map data recording (Cooper 2008, Fig 7). The karst pages included bespoke sheets for sinkholes, springs, stream sinks, cavities (caves) and building damage (Cooper 2008a, Farrant & Cooper 2008). Cooper (2005a IR/05/029, 2008) extended the building damage scheme set up by the NCB to include more severe damage and allow the recording of building damage due to mining, karst and landslides. By 2011 the paper Filofax notebooks had become redundant and the migration had been made to digital capture in the field using the BGS SIGMAmobile PC interface on a waterproof tablet PC (Cooper et al. 2011). The database structure set up in 2000 and the subsequent use of notebook sheets allowed the simple transfer of the interface into the field data capture GIS (Cooper et al. 2011 Figs 2 and 3). The ambition raised in 2001 to gather the karst data digitally in the field was thus achieved. Over time new datasets have become available and the introduction of LiDAR (Light Detection And Ranging) data and detailed digital terrane models has allowed the rapid mapping of karst features. Used in conjunction with digital topographical maps large amounts of data was collected. Further information was also collected from building damage surveys (Cooper 2008b). By August 2023 the database contained 33,816 doline points and polygons, 11,330 springs, 2,366 stream sinks, 3,142 cave entrances and 1,649 entries detailing building damage, a total of over 50,000 entries. The BGS National Karst Database is now managed by Vanessa Banks. In addition to the 'raw' collection of karst data the database has informed the generation of the GeoSure data and the BGS enquiries system.

The generation of the karst database ran in parallel with the complete transition of all BGS maps into digital versions at either 1:50,000 scale or 1:10,000 scale. All the geological polygons for both the bedrock and the superficial deposits were attributed with a stratigraphical code and a lithological code. The initial studies started around 2003 (Forster et al. 2003 - IR/03/141R). The provision of these codes allowed the rapid extraction of the soluble rock type areas from the dataset. Overlaying the karst database information on these datasets allowed areas susceptible to sinkhole (doline) development to be identified. In addition, covered karst areas with non-soluble rocks, but sinkhole susceptibility marginal to the main soluble rocks, were also identified (Cooper, 2004a -IR/05/0004R and 2004b – IR05/0003R; Cooper, 2008a; Farrant & Cooper 2008; Cooper et al. 2011). The combination of the digital geological map, the karst database, manually digitised marginal areas and for some units the nature and thickness of the superficial deposits permitted the areas to be zoned by susceptibility into the 5 GeoSure classes A to E (see below).

In addition to providing via the GeoSure datasets, this information also allowed rapid assessment of areas for the BGS enquiries system and for items such as the suitability for ground source heat pump installation (Cooper et al. 2011).

Hazard rating	Advice for public	Advice for specialist
A — soluble rocks are either not thought to be present, or are not prone to dissolution. Dissolution features are unlikely to be present.	No actions required to avoid problems due to soluble rocks.	No special ground investigation required or increased construction costs or increased financial risk due to potential problems with soluble rocks.
B — soluble rocks are present but unlikely to cause problems except under exceptional conditions.	No actions required to avoid problems due to soluble rocks.	No special ground investigation required or increased construction costs. An increase in financial risk due to problems with soluble rocks is unlikely.
C — significant soluble rocks are present. Low possibility of localised subsidence or dissolution related-degradation of bedrock occurring naturally, but may be possible in adverse conditions such as high surface or subsurface water flow.	Consider implications for stability when changes to surface drainage or new construction are planned. Do not dispose of surface drainage to the adjacent ground.	New build — site investigation should consider potential for dissolution problems on the site and its surroundings. Care should be taken with local drainage into the adjacent bedrock. Existing property— possible increase in insurance risk due to soluble rocks. Some possibility of potential liability due to groundwater pollution may be present.
D — very significant soluble rocks are present with a moderate possibility of localised natural subsidence or dissolution-related degradation of bedrock, especially in adverse conditions such as concentrated surface or subsurface water flow.	Consider obtaining specialist advice before loading the land or undertaking building work. Do not dispose of surface drainage to the adjacent ground. Maintain drainage infrastructure.	New build — specialist site investigation and stability assessment may be necessary before construction. Construction work may cause subsidence. Isolate surface drainage from the karst system and groundwater. Increased construction costs are possible. Existing property— possible increase in insurance risk due to soluble rocks. Some possibility of potential liability due to groundwater pollution may be present.
E — very significant soluble rocks are present with a high possibility of localised subsidence or dissolution-related degradation of bedrock occurring naturally, especially in adverse conditions such as concentrated surface or subsurface water flow.	Obtain specialist advice to advise on need for stabilisation work and/or land management plan to maintain stability. Do not dispose of surface drainage into the adjacent ground. Maintain drainage infrastructure.	New build — specialist land stability assessment necessary. Investigation, remediation and/or mitigation works may be necessary to stabilise the area. Construction work may cause subsidence. Isolate surface drainage from the karst system and groundwater. Increased construction costs. Existing property — probable increase in insurance risk due to soluble rocks. Probable potential liability due to groundwater pollution.

Table 2 GeoSure classes with hazard descriptions and specific advice to the public and specialists.

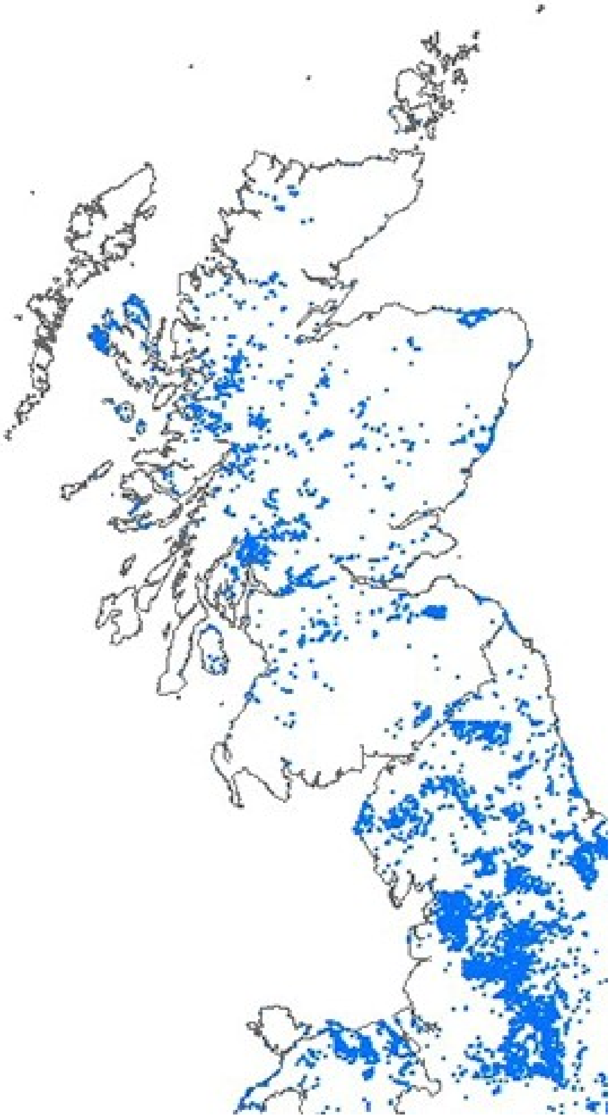


Figure 9 Landslide database map 2020. Contains OS data © Crown copyright and database right 2020.

4.5 PROPBASE

In 2005/6, Richard Shaw was asked to carry out a study to define the scope of, and assess the priorities for, the PropBase project. This project was intended to provide information on the physical, mechanical, chemical and mineralogical properties of UK rocks and soils and their inter-relationships. In part, this was to enable attribution of the 3D geological model and modelling of the properties themselves and to obtain a better understanding of how these properties change as a result of geological processes (Shaw et al. 2006). Also, PropBase could also play an important role in promoting increased awareness of, and greatly improved accessibility to, corporate rock and soil property data for external clients. The most important aspect of PropBase was seen as the development of a 'portal' that allows seamless access to, and extraction from, corporate rock and soil property information databases and the provision of tools to summarise these data for use in a range of project types. The 'PropBase Data Portal' was intended to be one of several, linked corporate portals providing easy access to BGS information without the need for specialist IT skills. Other 'portals' included the Digital Geoscience Spatial Model Portal and the Groundwater Portal.

In 2016, a published paper (Kingdon et al. 2016) described what had been achieved in the preceding decade. In 2016, PropBase held 28.1 million spatially enabled property data points from ten source databases (one of which was the National Geotechnical Properties Database) incorporating over 50 property data types with a vocabulary set that included 557 property terms.

While the PropBase project was not an engineering geological project, it was of importance in making information in the National Geotechnical Properties Database more available and useable both inside and outside the BGS.

4.6 BGS CIVILS (FORMERLY DIGMAP+)

As part of many of the engineering geological mapping projects (see above) the geological formations being mapped were classified according to a range of geotechnical properties (such as strength) and engineering characteristics (such as excavatability). Russell Lawley had the idea that BGS could provide a number of engineering themes to DigMap50. This was initially carried out for ‘strength’ for all the Lexicon Rock Classification Scheme (LexRCS) in DigMap50 by Helen Reeves in 2005 and later updated and expanded by David Entwisle in 2012. Between 2007 and 2019 a whole series of engineering geological themes were added to DigMap50.

In 2019, ‘BGS Civils’ was made available as a commercial product. The primary goal of the product was to provide the key engineering characteristics of the geology of Great Britain to professional users who need simple and rapid access to such information. For example, the potential user might be planning pipeline routes avoiding difficult ground conditions, calculating tender costs for trench excavation or might need knowledge of ground properties to plan daily activities.

The system consists of a suite of national maps of geotechnical properties and engineering characteristics based on geological data and the digital 1:50,000-scale geological map.

The system comprises eight layers:

i. bulking volume
ii. corrosivity (ferrous)
iii. discontinuities
iv. engineered fill
v. excavatability
vi. foundation conditions
vii. strength
viii. sulfate/sulfide

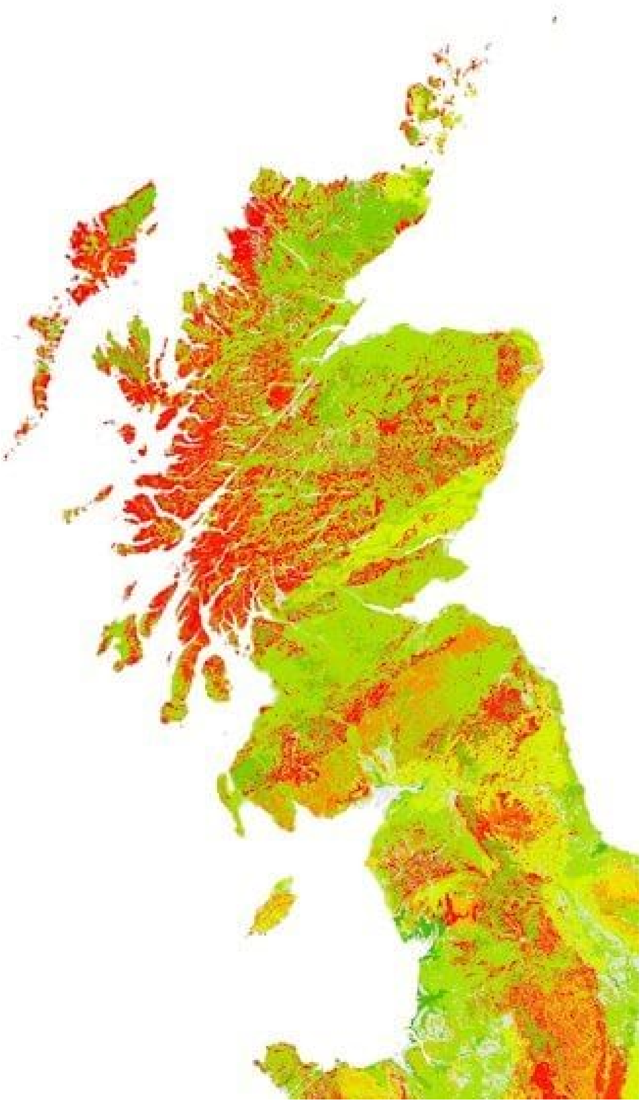


Figure 10 BGS Civils: strength coverage. BGS © UKRI – Contains OS data © Crown copyright 2020.

The data are provided as GIS shapefiles that are available to licence individually or as a bundle to meet the user's own requirements. Each layer has a methodology report and a user guide report, but only the latter is readily available from the BGS website.

Figure 10 provides information on zones of rock strength and the local factors controlling it as part of a suite of GIS layers for different engineering parameters. Red means higher strength and paler green lower strength. Similar maps are available for the other seven properties. The spatial model covers England, Scotland and Wales at 1:50,000 scale using the Lexicon Rock Classification (LexRCS) and is based upon archive data from the National Geotechnical Properties Database (see above) or other BGS datasets, the BGS Geology 50K dataset and industry standard information, or, where this is not available, other easily available information. Each property is defined as considered to be most useful for the user. For instance, 'Use as engineering fill' is based on the Highways Agency (now split into national areas) Specification for Highways Works Series 600 and knowledge of particle size and strength from the National Geotechnical Properties Database. The sulfate/sulfide uses geological descriptions, the NGPD data, which was then classified in Building Research documents, primarily Special Digest 1 (SD1).

Resistivity is the most complex parameter as the value for a LexRCS code can be highly variable depending on the lithological variation and changes in saturation in the upper 1 to 2 m. For this reason a probabilistic method was used (Busby et al. 2012 and White et al. 2014).

5 Geotechnical properties of soils and rocks

5.1 ENGINEERING GEOLOGY OF COHESIVE SOILS ASSOCIATED WITH OPHIOLITES IN CYPRUS (INCLUDING LANDSLIDES IN SOUTH-WEST CYPRUS)

Following the completion of the engineering geological mapping of southern Nicosia in 1981-2 (see above), work began in late 1982 to investigate the regional variations in the lithological, geotechnical and mineralogical properties of the main cohesive soil formations (comprising marls, bentonitic clays and 'melange') associated with the Troodos Ophiolitic Complex. The following areas were studied:

- the Nicosia Marls of central Cyprus;
- the Moni Formation bentonitic clays of southern Cyprus;
- the Polis marls of north-west Cyprus;
- the Kannaviou Formation bentonitic clays, the Mélange and other cohesive deposits derived from allochthonous Mamonia Complex rocks in the Phiti-Statos area of south west Cyprus.

Sample test data from existing Cyprus Geological Survey Department (GSD) surveys and from the collaborative BGS/GSD regional sampling and testing programme were also collected from sites across Cyprus to provide supplementary data 'external' to the main study areas. The result of the testing was a good understanding of the geotechnical and mineralogical properties of the different cohesive soil materials and how they varied across southern Cyprus.

In addition, the work in the Phiti-Statos area of south-west Cyprus also included the production of two 1:10,000 scale engineering geological maps of the two study areas that show that the major slope stability problems occur where weak, sheared montmorillonite clays and Melange deposits crop out on steep slopes in areas of high relief. Landslide development is exacerbated by high winter rainfall, permeable cap-rocks, earthquake shocks and active erosion associated with continued uplift of the Troodos Mountains. Limiting slope angles were about 8.5° in the Kannaviou clays and 11° in the Melange clays. Deep-seated failures are largely associated with faults.

The results of the research are contained in five technical reports all published in 1986 (WN/RR/86/1, 2, 3, 4 [including the two landslide maps] and 5). The overall research was summarized in report WN/RR/86/6. Pete Hobbs and Kevin Northmore provided the main BGS contributions, though Paul Gostelow carried out the research discussed in report WN/RR/8622. All the research was carried out with engineering geologists from the GSD, particularly George Petrides, George Loucaides and Maria Charalambous.

5.2 TROPICAL RED CLAY SOILS

This project ran in two parts from 1986 to 1989 and from 1989 to 1992. Tropical red clay soils are residual soils formed by the intensive weathering of volcanic rocks in warm, humid but well-drained conditions as part of the process of lateritisation. The presence of halloysite and allophane clay minerals and iron sesquioxides causes them to have unusual geotechnical properties and engineering behaviour such as susceptibility to collapse, anomalous compaction behaviour and high soil suctions. The objectives of the project were to investigate these properties by specialized and new tests, mainly on undisturbed samples and to relate the results to the geological provenance and their position in the weathering profile to enable a practical classification to be developed in relation to their engineering behaviour.

The field work involved mainly pitting, initially to depths of about 3 m but, later, to 5 m. The work took place mainly in Kenya and Java (Indonesia) but a small number of samples from Dominica in the West Indies and Fiji were also obtained. The project collaborated with staff from the (then) Transport and Road Research Laboratory (TRRL) who were also interested in the engineering aspects of tropical soils.

In 1989, a second phase of the project began which ran to 1992. The second phase took place in the Central and Western Provinces of Kenya where a highly selective drilling and sampling programme was carried out in conjunction with the collection of samples from further pits. The drilling involved the use of a prototype, specially designed core barrel for use in sensitive soils. Holes were drilled to a maximum depth of 20 m.

The main output of the two projects was a set of six reports which, as well as describing the work carried out and listing all the field and laboratory testing results made recommendations for how these soils should be sampled, prepared and tested. Methods for identifying types of tropical red clay soils and classifying them were also discussed.

5.3 UK ROCKS AND SOIL FORMATIONS – THE GAULT CLAY FORMATION, MERCIA MUDSTONE GROUP, LIAS GROUP, LAMBETH GROUP, BRICKEARTH AND GLACIAL TILL

As indicated earlier, the 'Engineering Geology of UK Rocks and Soils' (EGRS) sub-programme (or theme) was initiated in 1990/91. The aim was to characterize the engineering properties and behaviour of key geological formations of particular relevance to planning and engineering development to provide reference works on the engineering geology of important geological formations present in Britain. The first project was on the Gault Clay which outcrops roughly from the Wash down to Dorset and beneath the North and South Downs in Surrey, Kent and Sussex (and a few other places as well). The Gault Clay Formation was chosen because the outcrop is relatively narrow and the lithology is not very variable. However, the Gault Clay Formation is often very to extremely plastic and so very susceptible to shrinkage and swelling under the influence of water content variation. This can cause significant structural damage to buildings. The intention was to establish workable methods to characterise a formation in terms of geotechnical properties and engineering behaviour. The report, as well as providing information on the geology, mineralogy, summary geotechnical property data and groundwater conditions also provides advice on landsliding, clay shrinkage, chemical attack, excavation, cuttings and embankments and site investigation design. The results of the project were described by Forster *et al.* (1994).

On completion of the 'Gault' project work began on a much bigger challenge – the Mercia Mudstone Group project. Whilst this project was underway, the Construction Industry Research and Information Association (CIRIA) commissioned its own review project on the Mercia Mudstone Group. Though attempts were made to collaborate on the project CIRIA refused. The best that EGU got out of it was equal billing in a one-day meeting on "The engineering properties of the Mercia Mudstone Group" held at Pride Park, Derby on 25 November 1998 and co-authorship of the CIRIA report on "Engineering in Mercia mudstone" (Chandler & Forster 2000). Alan Forster spoke about the 'geology' and Dick Chandler (Imperial College) spoke on the 'engineering.' The project itself was reported on by Hobbs *et al.* (2002).

In the years that followed, further similar extensive reports were produced on the Lias Group (Hobbs *et al.* 2012) and the Lambeth Group (Entwisle *et al.* 2013). The intention was to continue the research on the Brickearth and glacial tills. The former was dealt with in a NERC research project in collaboration with the University of Birmingham and, for Glacial Tills, the geotechnical properties data were summarized in an extensive Geological Society paper (Culshaw *et al.* 2017). In some respects, the research on the engineering geological characteristics of British rock and soil formations was at the heart of what applied engineering geological research should be at a geological survey. For many years, the Mercia Mudstone Group report has been the most downloaded publication of the Natural Environment Research Council (NERC) via the NORA system and the other reports were also very popular: by October 2021, the Mercia Mudstone report had been downloaded over 51,000 times, the Lias Group report over 21,000 times, the Lambeth Group report nearly 14,000 times and the Gault Clay report over 5,000 times.

In the early 2000s, an undated strategy document was written for the engineering geological part of the Coastal and Engineering Geology Group. A long list of geological formations selected for detailed study was produced. The list included formations that were judged to be significant because they were hazard-prone or geographically extensive in areas of high population density and/or development activity. The proposed formations are listed in Table 2. It is sad that a few years later it was decided not to continue with a series of reports that were overwhelmingly popular with the professional user community.

Hazard-prone Formations	Geographically Extensive Fm.	Associated Hazard	Comments
Gault Clay		Mass movement; Shrink-swell	Reported
Mercia Mudstone	Yes	Weathering variability	Reported (see also Chandler & Forster 2000)
Lambeth Group (Woolwich and Reading Beds)		Rapid variability; Compressibility	Reported
Brickearth and Loess-like deposits		Collapsibility; Variability	See Culshaw *et al.* (2020)
Coal Measures mudrocks	Yes	Weathering variability; Subsurface voids; Mass movement	
Carboniferous Sandstones	Yes	Variable strength and discontinuities; Mass movement	
Lower Cretaceous clays (Weald, Atherfield, Wadhurst Clays)	Yes	Weathering variability Shrink-swell; Mass movement	
Estuarine Alluvium	Yes	Rapid variability; Compressibility; Low strength	
Lower Tertiary mixed Formations (Barton Gp., Bracklesham Gp.)		Rapid variability	
Mixed Eocene Formations (Claygate Beds, Bagshot Beds)		Rapid variability; Mass movement	
London Clay Fm.	Yes	Shrink-swell; Mass movement; Weathering variability	
Upper Jurassic clays (Kimmeridge Clay, Oxford Clay)	Yes	Shrink-swell; Weathering variability	
Lias Gp.	Yes	Weathering variability; Mass movement; Swell-shrink	Reported
Jurassic limestones	Yes	Dissolution; Mass movement; Variability	
Triassic sandstones	Yes	Variability; Running sands	
Silurian shales	Yes	Weathering variability; Mass movement	
Dalradian (metamorphic rocks)	Yes	Variable strength; Discontinuities	
Chalk	Yes	Dissolution; Weathering variability	See study by CIRIA (Lord *et al.* (2002)
Boulder Clay (Glacial Till)	Yes	Rapid variability	See Culshaw *et al.* (2017)

Table 3 List of geological formations proposed for future research under the project: ‘Engineering behaviour of UK rocks and soils.

5.4 NUCLEAR WASTE DISPOSAL RESEARCH

The BGS was involved in a number of aspects of the planning and the characterization of the subsurface for nuclear waste disposal. Many of the projects were managed by the then Environment Protection Unit (ENPU), which became the Fluid Processes Unit (FLUPU) and then Group. The EGU was involved primarily to provide engineering geological, geotechnical and geophysical support. The early work, carried out in the late 1970's and early 1980's. This was followed by work for the European Commission on Boom Clay from Belgium in the mid 1980's. The Nirex core characterisation laboratory work, the largest project, ran from 1990 to 1995. Other projects included the geotechnical characterisation of the granite and metasediments from the Altnabreac borehole and the Mesozoic clay and mudstone succession from the Harwell boreholes.

5.4.1 Crystalline rock – Core from Altnabreac

The determination of the geomechanical properties of rocks from the Altnabreac area was part of a series describing the work carried out at the Altnabreac research site in Caithness, Scotland as part of a research programme to assess the feasibility of the disposal of high-level radioactive waste in crystalline rock. The work on the site started in 1978 and was completed and reported on by 1981. The laboratory tests were carried out on core samples of Strath Halladale Granite and Moine metasediments (McEwan *et al.* 1980). The geomechanical test results provided data on the 'intact' rock properties that were used with a discontinuity assessment of the drilled core and detailed interpretation of the borehole geophysics in which Dave McCann was the lead scientist. The interpretation of the intact rock and of the discontinuities was used to provide a rock mass assessment.

The borehole cores tested were from the three deep boreholes, which had a terminal depth of 300 m. The properties measured included density, porosity, indirect tensile strength (Brazilian disc), uniaxial compressive strength, triaxial compressive strength, and stress-strain parameters under uniaxial and triaxial conditions varying from 3.5 MPa to 69 MPa. Analysis of the triaxial compressive strength tests included use of the Hoek & Brown (1980) empirical failure criterion.

The test results, along with the mean and standard deviation of most of the parameters, were reported with frequency histograms and depth graphs where appropriate. However, sample depths were not used, sample number being used to differentiate the results.

5.4.2 Mesozoic clays and mudstones from the Harwell Borehole

The research project at Harwell into the feasibility of disposing of low to intermediate waste in argillaceous deposits was carried out at the Atomic Energy Research Establishment site, Harwell, which was the then base of ENPU/FLUPU. The work on site began in 1981 and most of it was completed by 1983. The primary EGU input, that is, the 'basic' geotechnical properties (Horseman *et al.* 1982) was completed at the BGS Exhibition Road office along with the geophysical logging (Horseman *et al.* 1984) but the high load, one dimensional consolidation (McEwan *et al.* 1983) and swelling pressure testing (Hobbs *et al.* 1982) were completed in the new, bespoke engineering geology laboratories in Keyworth, Nottingham. All the major mudstones were tested including the Gault Formation, Kimmeridge Clay Formation, Oxford Clay Formation (the primary target) and the Lower Lias.

The basic testing included standard index tests - water content, bulk, dry and particle density - as well as uniaxial compressive strength and resistivity. The high load consolidation testing used a Denison tensile strength apparatus (Figure 11a and b), which was no longer needed by Imperial College (!). The apparatus was originally used to test metals but was adapted by the BGS to be a compression machine as a one-dimensional consolidation apparatus. The advantage of this equipment was that it provided a constant stress over many days and did not require any electronics other than the data output as an analogue graph. It had a capability to provide a 32 MPa load to a 76.2 mm diameter sample, well over twenty times the stress of a standard oedometer. The electronics for the one-dimensional swell pressure test apparatus were designed by Pete Jackson. This apparatus (see below) was subsequently used on all the swelling pressure research including on the engineering geology of Cyprus and the swell/shrink hazard project from the 1980's until the mid- 2010's.

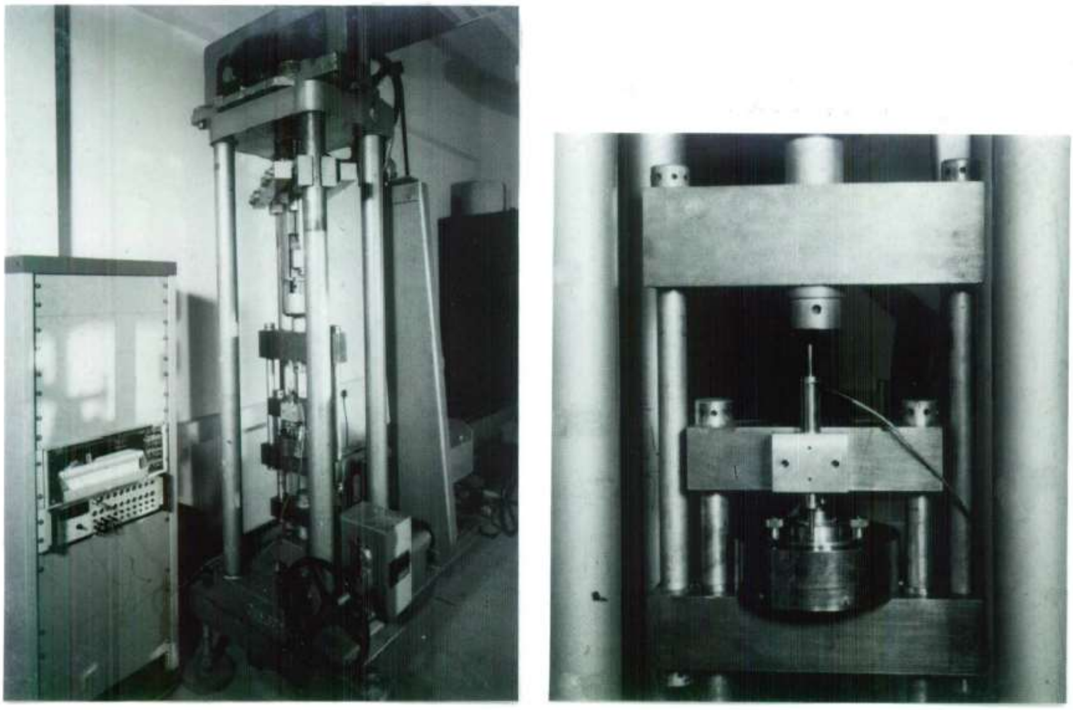


Figure 11 Left: the Denison dead-weight loading system; right: close-up of the oedometer.

The consolidation tests were used to estimate the ‘field virgin compression curve,’ and ‘previous overburden stress,’ which is the yield stress, as well as the rebound curve and standard consolidation parameters including voids ratio and the coefficient of volume change and coefficient of consolidation. An estimate of hydraulic conductivity was calculated from the last two parameters.

5.4.3 Geotechnical characterisation of the Boom Clay

The research testing of the Boom Clay from Belgium used three pieces of equipment unique to the EGU. The ‘soil cannon,’ the high load oedometer and the swell pressure apparatus (that was designed by Pete Jackson and Steve Horseman). The results of the testing are given by Horseman *et al.* (1986).

Tests were performed on undisturbed samples of mudstone taken from a location 247 m below ground surface at the SCK/CEN experimental repository at Mol in Belgium. The Boom Clay samples were in excellent condition and were described as extremely weak, grey to dark grey mudstone. Test methods included (a) the one-dimensional consolidation test with consolidation stresses up to 32 MPa, (b) the one-dimensional swelling pressure test, (c) the isotropically-consolidated, undrained (CIU) triaxial test with pore pressure measurement, and (d) the unconsolidated undrained (UU) triaxial test. All triaxial tests were load-controlled. Triaxial tests were performed using the ‘soil cannon’, specially developed for the measurement of the effective stress parameters of weaker rocks. The cell, which was designed for a maximum confining pressure of 35 MPa, incorporates an internal load cell and LVDT's for lateral strain monitoring. Volume changes may also be determined using an instrumented pore water intensifier. An external clip-on heater jacket allows for test temperatures of up to 80°C.

One-dimensional consolidation test results were interpreted in terms of the Terzhagi theory of the rate of consolidation. Graphical procedures are used to obtain the consolidation parameters and other derived quantities. The 'most probable' value for the yield stress was determined to be 6.0 MPa, giving a yield ratio [overconsolidation ratio (OCR)] at the sampling depth of 2.4. Geological evidence was considered to be indicative of a pseudo-overconsolidation effect but is more likely due to the time and the diagenetic and in pore water chemistry changes that have occurred since deposition. The hydraulic conductivity, k, of the mudstones decreased with increasing effective stress with an approximately linear relationship between k and the logarithm of effective stress.

Under *in situ* conditions the mudstone is estimated to have a vertical hydraulic conductivity in the range 1.8 to 2.0 X 10^{-12} m/s.

Swelling pressure (under zero volume change conditions) was determined to be circa 0.9 MPa, which was considered to be in reasonable agreement with the interpolated values from consolidation testing. It can be inferred from this that very large suctions (negative pore pressures) are present in sampled material.

Triaxial test data on deformability and strength were interpreted within the general framework of critical state soil mechanics (Schofield & Wroth 1968). The stress-strain response below the yield stress, that is, below the state boundary surface, was assumed to be elastic with effective stress dependent moduli. Linear elastic theory has applications in problems involving only small changes in effective stress. The state boundary surface is assumed to comprise the Roscoe and Hvorslev surfaces meeting at the critical state line. Approximate values were reported for the parameters of the critical state model, primarily to allow comparison with the results of other laboratories. Other parameters which were quantified included an undrained shear strength of 1.1 MPa and an undrained Young's modulus (secant at 1% strain) of about 198 MPa under *in situ* stress conditions. The stress-dependency of the undrained modulus was presented in the form of plot of the *Eu/pc' ratio* against logarithm of the yield ratio.

The limitation on the number of samples and on testing due to the time required for each test, limited testing of the pore pressure responses during heating under undrained conditions and on the effect of elevated temperature (80°C) on deformability and strength. It was found that significantly large excess pore pressures (approximately 1 MPa under *in situ* stress conditions) were developed during heating from ambient laboratory temperature to 80°C. The effect was due, primarily, to the expansion of the pore fluid in the sample. A simple model suggested that the change in pore pressure for a given temperature rise should be approximately a linear function of the mean effective consolidation stress *pj.* It was tentatively suggested that, provided thermally-induced excess pore pressures were allowed to dissipate, temperature (in the range 20°C to 80°C) had little effect on undrained modulus, shear strength or the position of the Hvorslev surface in *(p', q, e)* space. It was suggested that additional tests were required to substantiate this. The effect of heating on pore pressure development under undrained and partially undrained conditions could have profound implications for the disposal of heat-emitting wastes in mudstone. Excess pore pressures may significantly alter the near-field and, in the longer term, the far-field groundwater flow pattern. The volume changes associated with the effect may result in additional stresses being placed on gallery linings and other support structures. In addition, since an increase in pore pressure is accompanied by a reduction in effective stress, the capacity of the clay to sustain shear stresses would be reduced. Thus, depending on the magnitude of the initial shear stresses, there was a possibility that the thermally induced pore pressures could actually trigger shear failure. The results of this research confirmed that the effects of heating on the geotechnical response of the mudstone were significant. It was suggested that considerably more research on this topic would be required to quantifying these effects.

5.4.4 Nirex off-site core characterisation programme: intact rock properties

In 1987, research into the potential for radioactive waste repository at a site near Sellafield, Cumbria and, shortly after, near Dounreay in Caithness, Scotland were identified for investigation. Both sites were near nuclear power stations and Drigg, near Sellafield, was the main low level radioactive waste repository. The BGS was involved in many different facets of the research including offsite geotechnical and geophysical laboratory testing.

From late 1990 until 1995, when the project was stopped, Pete Hobbs managed the overall EGU input into the project, while David Entwisle oversaw the day to day running of the research and Dave Gunn set up and managed the thermal properties testing and the triaxial P- and S-wave testing. Several new staff on limited short-term contracts were recruited including Tom Busby, Buzz Collins and Darren Jones. The remnant magnetic susceptibility testing was subcontracted to Professor Don Tarling at Plymouth University. As some of the test data were required before Dave Gunn could set up the thermal laboratory and the triaxial P- and S-wave apparatus, the initial testing was carried by a commercial company and by Clive McCann and co-workers at Reading University respectively. The selection for the engineering geology input was by Pete

Hobbs and David Entwisle with the other disciplines. The testing in the EGU laboratories with the number of tests completed during the project are listed in Table 3.

There was a great variety of sample sizes that had to be produced in the rock preparation facility many of them to fine tolerances. The production of so many test samples for the engineering geology and other laboratories required a very efficient system of work and improvements to the sample preparation equipment including input by the BGS Workshops.

At the time, the BGS did not have a thermal testing laboratory and so David Gunn set one up within the Rock Mechanics laboratory. The thermal laboratory facility was within a small 'greenhouse' of double-glazed UPVC and had fine temperature control with heaters, coolers and fans. It did look a little 'Heath-Robinson' but functioned well. Dave Gunn also identified suitable equipment and methods for the three different tests (specific heat capacity, thermal conductivity and thermal expansion). He carried out all the tests, aided by Lee Jones. As some of the triaxial testing was to be at full core diameter, usually 95 to 96 mm, a new Hoek's cell was bought. It had to be moved in and out of the large compression rig efficiently and safely. It weighed nearly 100 kg and required new lifting and moving equipment and, although moving the cell was a little time consuming, it was done with little physical effort.

A requirement for the testing by the clients was rigorous quality assurance. This was much stricter than that already in place. This was complicated by the number of tests undertaken including new tests and others rarely carried out. As this was in the mid 1990's, the quality assurance (QA) was all paper based. All the different test methods were documented, along with all the other methods used by the BGS, in large lever arch files, one in each laboratory area. One aspect that was introduced, but should have been in place previously, was regular calibration of gauges, load cells and measuring instruments. The discipline of QA has extended to the current day.

The geological units at the different sites are listed below:

- Dounreay: Devonian sandstones (Caithness Flagstone Group) and Moine Super Group metasediments.
- Sellafield: Sherwood Sandstone Group (Wilmslow Sandstone Formation, Chester Formation [reported as the St Bees Sandstone Formation], Cumbrian Coast Group (St Bees Shale Formation, St Bees Evaporite Formation), Brockram Formation, Great Scar Limestone Group (various formations), Borrowdale Volcanic Group (various formations).

The reports were produced for tests on each borehole and for each major geological unit, that is, for Sellafield the Permo-Trias, Carboniferous and Borrowdale Volcanic Group.

The reports are stored at BGS Keyworth in the National Geoscience Data Centre and listed with all the BGS reports for Nirex and others in W:\Teams\RM\NDAcuration\Data\Nirex_Listings\.

Other than the reports, listed below in Appendix 13, two papers were written and presented at the Engineering Group of the Geological Society meeting at Newcastle University in and published in 2005 (Entwisle *et al.* 2005, Gunn *et al.* 2005).

Test name	Parameters	Number of tests
Density/porosity by saturation and buoyancy method	Saturated water content, porosity, dry density, saturated density, grain density (particle density)	836
Saturated Uniaxial compressive strength	Uniaxial compressive strength 38 mm diameter	750
	Uniaxial compressive strength - 100 mm diameter	69
Brazilian indirect tensile strength	Indirect tensile strength	450
Saturated drained triaxial compressive strength at 4 or 5 stresses	Compressive strength at each stress.	
	Linear Mohr analysis – Angle of internal friction, shear strength, uniaxial compressive strength, tensile strength	
	Non-linear Hoek-Brown Analysis – m and s, tensile strength	
	38 mm diameter	85
	100 mm diameter	25
Triaxial static elastic moduli	Young’s modulus load and unload	
	Poison’s ratio – load and unload	
	Bulk modulus – load and unload	
	Shear modulus – load and unload	
	38 mm diameter	71
	100 mm diameter	13
Slake durability, 2 and 5 cycles	Slake durability 2 cycles	8
	Slake durability 5 cycles	3
3D swelling strain	3D swelling strain $\%\varepsilon_1$, $\%\varepsilon_2$, $\%\varepsilon_3$	7
Induced magnetic susceptibility	Induced magnetic susceptibility cgs and SI units	463
Ambient pressure P-wave velocity	P-wave velocity	591
Triaxial P wave and S-wave velocity	P-wave and S wave velocity	39
Resistivity	Resistivity: low salinity water (~20 Ohm.m)	491
	Resistivity: low salinity water (~0.22 Ohm.m)	
Specific heat capacity	Specific heat capacity	50
Thermal expansion at different temperatures	Thermal expansion at different temperatures	38
Thermal conductivity	Thermal conductivity	94

Table 4 Laboratory tests completed for the NIREX project.

6 Engineering Geophysics

Geophysical methods have been applied to research in two main areas:

i. Strong rock
ii. Weak rock and soils

Hard rock applications included: work on igneous rocks related to hydroelectric schemes; the detection of cavities in limestones and chalk; rock quality determination ahead of tunnelling machines; the hot dry rock geothermal energy project in Cornwall in collaboration with the Cambourne School of Mines; assessment of the mechanical nature of rock masses for radio-active waste disposal. The particular requirements common to these three types of programme are to determine the rock quality in terms of joint/fissure frequency and openness and the degree of weathering and strength of the rock material. Geophysical methods of assessment have had some success particularly when more than one technique is used, as in geophysical logging of boreholes.

Geophysical assessment of sediments was directed towards determining dynamic moduli values *in situ* from seismic velocity determinations, as well as *in situ* porosity and density from resistivity and seismic velocity data. Research was carried out at a number of test-bed sites in the UK and comparisons made between *in situ* tests, such as pressuremeter and plate loading tests in boreholes, and the geophysically-derived moduli. A particularly interesting comparison made between the value for rigidity modulus, G, calculated by back analysis from building performance at a power station site, and its value determined by geophysical and direct mechanical means. In this instance, the geophysically-determined value gives the best agreement with the back analysis, both of which are at comparable strain amplitude levels (Cratchley et al., 1982).

In the early days of EGU, Dave McCann was almost the only engineering geophysicist in the Unit (though there were many geophysicists elsewhere in the BGS). Various junior staff were trained and used on geophysical surveys but not until 1976 was another engineering geophysicist (Pete Jackson) recruited. He specialized in resistivity both in the field and in the laboratory. Dave McCann's main early field of research was in inter-hole acoustic scanning. He discussed this and related research in several papers (for example, McCann *et al.* 1975) and another written with his brother, Clive McCann Reading University) (McCann & McCann 1976). The paper showed how the techniques allowed an examination of:

- the determination of the dynamic elastic moduli in a rock mass;
- the variation in lithology with depth and associated changes in the engineering properties;
- the continuity of strata between boreholes.

This was an important time for the development and application of engineering geophysical techniques as there was a considerable amount of resistance by geotechnical engineers to their use in site investigation. It would take several decades before engineering geophysics became accepted as a valuable technique.

By the early 1980s things were changing in the world outside the BGS (then the IGS). Dave McCann attended the 42nd Annual Meeting of the European Association of Geoscientists and Engineers in Istanbul in the middle of 1980. In a field notebook now archived in box files relating to the Newborough Warren project, McCann wrote that *"… several outstanding papers from American, British and German authors were presented and these characterized the rapid progress being made in geophysics since the advent of the mini-computer and micro-processor. A typical example of this trend is the very rapid progress being made with the 3D seismic reflection technique, which could well dominate the methods used in exploration in the near future. The basic approach being adopted in the commercial world is now on-line data computation and interpretation, since the availability of mini-computers with large storage capacity means that much of this side of the geophysical survey can be carried out in the field. Increased contact between the field geophysicist and the computing and interpretation part of the survey in the field will eventually open up a whole new approach to geophysical surveying in the 1980s."* McCann went on to express concern about changes in the way geophysical research was to be carried out in the future. Previously, EGU had been part of the Geophysics Division. However, at around this time, EGU was transferred to the Special Services Division and the Marine Geophysics Unit moved to the Continental Shelf Division. This left the Applied Geophysics Unit, Global Seismology Unit and Geomagnetism Unit in the Geophysics Division to which was added the Hydrogeology Unit and the Computing Unit. McCann was very concerned that necessary investment of funds for geophysical equipment was being spread too thinly and the various Units would not be able "*…to compete effectively with modern trends in geophysical surveying and interpretation. It seems almost inevitable that geophysics in the IGS will fall further and further behind unless a decision is taken to concentrate rather than dilute our effort in this field.*" However, in the years that followed, a number of research projects were carried out and their results were, for the most part, published. The major achievement was the recruitment in 1991 of Dave Gunn as a senior geophysicist in EGU. He was highly successful in obtaining external research grants for his geophysical research work. He finally retired from the BGS at the end of June 2021.

6.1 FOYERS SEISMIC AND RESISTIVITY SURVEYS

Lead: Roger Cratchley

A pumped storage scheme was developed at Foyers, located about halfway down the south-west side of Loch Ness, some 25 miles from Inverness, in the Scottish Highlands between 1967 and 1974. The original turbine (dating back to 1895) had a capacity of 5MW and was used until 1971 to power an aluminium smelter. The new development was to create a pumped storage scheme and enhance the existing conventional hydro-electric scheme. The new development was designed with a capacity of 305 MW.

The IGS carried out a series of geophysical surveys (surface seismics, cross-hole seismics and surface resistivity) to locate weak tunnelling ground. Two cored boreholes were drilled to a depth of around 100 m and geologically and engineering geologically logged. The work was funded from the EGU's internal funds ('science budget'), though it is assumed that the cost of drilling the boreholes was borne by the North of Scotland Hydro-Electric Board which was funding the whole construction project.

The research was carried out in collaboration with geologists from the Highlands and Islands Unit of the IGS based in Edinburgh and they provided geological descriptions of the sites of proposed tunnels and shafts. Cratchley *et al.* (1972, 1976) described the geophysical survey work carried out at the site.

6.2 ASSESSMENT OF ROCK MASS CONDITIONS USING GEOPHYSICAL TECHNIQUES

Lead: Dave McCann

Between about 1975 and 1978, the EGU was commissioned by the Department of the Environment to carry out research into the application of geophysical techniques to the assessment of rock mass conditions and, in particular, the detection of cavities. The research was carried out under three main project headings:

i. Surface geophysical techniques; examples are described in Section 6.1 above (the Foyers Hydro-electric Scheme) and 6.4 below (the use of electrical resistivity surveys to detect cavities in limestone near Bridgend).

ii. Power spectral analysis of tunnelling machine noise. This is discussed in Section 6.6 below (tunnelling machine noise at a sewer tunnel in Warrington)

iii. Borehole geophysical techniques. Examples are discussed in Section 6.3 below.

As well as individual project reports, the research is reported in two general reports by Baria *et al.* (1978) and Baria & McCann (1979).

6.3 INTERBOREHOLE ACOUSTIC SCANNING

Lead: Dave McCann

During the 1970s, there was considerable research carried out into the cross-hole acoustic scanning technique. The reason for this was that by measuring compressional and shear wave velocities, along with gamma-gamma logging to measure density, it was possible to calculate Young's Modulus and Poisson's Ratio, important geotechnical parameters.

McCann *et al.* (1975) described the interborehole acoustic scanning technique that is based on the transmission of an acoustic pulse through soil and/or rock between two adjacent boreholes. In the early research, the acoustic source (the 'sparker') and the detector (or receptor) were lowered to the same depth in adjacent boreholes. This had the advantage in near-horizontal sediments of the signal passing through the same material from source to receptor. So, a particular sediment, say, could be characterized in terms of its acoustic properties. Later, the signal might be transmitted at an angle. The development of the technique required a considerable amount of experimental work to evaluate its practical use in field investigations. This took place in three stages (McCann *et al.* 1975):

i. The development of the instrumentation and the construction of reliable sparker probes.

ii. The study of the results obtained at a variety of different sites to evaluate the effectiveness of the system.

iii. The interpretation of the results obtained in relation to the geology of the various sites investigated.

Results from four surveys were described:

i. Barking Creekmouth in connection with the proposed construction of a tidal barrier across the River Roding. Here the geology consists of alluvial material over Thanet Sands over Chalk.

ii. East Fleet, Dorset. The results at this site the highlighted some of the difficulties in measuring acoustic properties *in situ*. It was concluded that the spacing of boreholes is critical to the study of geotechnical properties by acoustic measurements. Close spacings give good resolution while larger spacings are more representative.

iii. Welwyn Garden City. Here, the technique was used to delineate an infilled sinkhole in the Chalk surface overlain by coarse flint, gravel and cobbles with some intermixed sand.

iv. Whatley Quarry, Frome, Somerset. This site was located on fractured Carboniferous Limestone. It was concluded that the site had no large open fractures occurring directly between the boreholes. Grainger et al. (1973) had previously concluded that in highly fissured, partially saturated material where open fissures are air-filled, the velocity of sound is greatly affected, and good correlations can be obtained between velocity and rock quality.

The advantages of the system over conventional surface geophysics is its three dimensional aspect and its advantage over single borehole logging is the larger volume of material observed, hence giving a more representative result rather than point data.

In 1977, EGU were asked to investigate the possible presence of cavities below an area of disturbed ground at Norman Close, Maidstone, Kent. Two houses were so damaged that they had to be demolished but there was further concern that two adjacent houses that showed cracks. A number of boreholes had been drilled around the houses so that interborehole acoustic methods could be used.

The houses were located on Folkestone Beds of the Cretaceous Lower Greensand that consisted of coarse sands and clayey silts with silty fine sand predominating. At a depth of about 17 m a metre thickness of Fullers Earth that consists of pure montmorillonite clay was encountered. The boreholes terminated in ragstones of the Hythe Beds. The acoustic scanning revealed that an acoustic anomaly lay at a depth of between 7 and 13 m. This anomaly was believed to have been caused by a disturbance to the sedimentary structure. It was suggested that the anomaly was caused either by loose packing of the sediment or cavities and that loose packing was the more likely cause. This might have been caused by a) cambering that primarily affects the Hythe Beds but also produces tensional forces in the overlying Folkestone Beds and/or b) gravitational forces acting down the slope below the site.

The survey conclusions confirm that, often, geophysical surveys can provide additional information about ground problems but, not necessarily, the whole answer. The survey and its conclusions are described by Green *et al.* (1977).

Other surveys involving interborehole acoustic scanning were also carried out in the 1970s. One example was at Llyn Peris, Gwynedd, North Wales in connection with the Dinorwic Pumped storage scheme (McCann & Culshaw 1975). Initial borehole studies indicated that the alluvial deposits overlying the Cambrian bedrock in the valley were of considerable thickness and the consultant (Binnie and Partners) did not wish to determine the geological cross section by deep drilling (presumably, because of the cost). The superficial deposits consisted of interbedded sands, gravels and silts with considerable thicknesses of peat in some places. EGU was asked to carry out an interborehole acoustic scanning survey to:

- Determine the depth to bedrock (that is, derive the rockhead profile).
- Determine the continuity of the various layers of alluvial material between the boreholes previously drilled.

The work was carried out in late November and early December 1973 at each end of Llyn Peris. Excellent results were obtained for all the scans carried out at East Peris and Pont-y-Bala and both objectives of the feasibility study were achieved.

As a result of the success of the surveys at Llyn Peris, Binnie and Partners asked EGU to assess the feasibility of interborehole acoustics at another site in North Wales – Marchlyn Mawr Reservoir. Binnie and Partners wanted to know if the method would be able to detect changes in rock strength of the rock mass caused by changes in water level. EGU concluded that the method was not suitable as any change in measured velocity would be small (Culshaw & McCann 1975).

Further research was reported on interborehole acoustic scanning by McCann & McCann (1976) and McCann *et al.* (1982).

6.4 GEOPHYSICAL METHODS TO DETECT SOLUTION FEATURES ON THE PROPOSED M4 NEAR BRIDGEND

Lead: Peter Jackson

In late 1977, in 1977-8, Peter Jackson, Debbie Suddaby and Roy Baria, at the request of the Welsh Office, carried out a series of geophysical surveys over part of the M4 near Bridgend. The road passed over dolomitic conglomerate of Triassic age containing sinkholes and a number of other cavities. This was of particular concern as some of them appeared to be within 10 m of the ground surface. The surveys were intended to identify both the position and the size of any cavities and to assess the potential suitability of electrical surveying for cavity detection. An electromagnetic and an A.C. resistivity surveys were carried out.

The electrical methods located a zone of high resistivity that appeared to correspond with well-drained superficial deposits beneath which lay fractured conglomerate with some voids. It was suggested that resistivity methods might be successfully applied to cavity location in the environment investigated by the location of the secondary effects of relatively dry superficial deposits and the increased resistivity of the lower conglomerate layer possibly caused by the presence of voids (Jackson *et al.* [1978]).

6.5 GEOPHYSICAL METHODS TO DETECT ABANDONED MINEWORKINGS INCLUDING SHAFTS; DALTON-IN-FURNESS

Lead: Peter Jackson

In August 1979, EGU carried out magnetic and electrical conductivity surveys on an area north of Dalton-in-Furness in south Cumbria where iron had been mined for several hundred years. The site was also near to a proposed 6 km by-pass route around Dalton-in-Furness. While many of the mines were positioned on plans, there were many others for which no plans existed. The survey was carried out as a feasibility study for the location abandoned mine shafts and other evidence of mineworkings.

The proposed geophysical survey resulted from the previous failure of the 'Shrimp' geophysical system that had been tried on behalf of the road project geotechnical consultant. This system essentially uses a surface vibratory source that is used to excite a buried cavity or mineshaft at its resonant frequency. Eight 40x40 m squares had been surveyed with the 'Shrimp' system but the success rate for finding shafts had been extremely low and very costly, since drilling of many of the predicted shaft positions had proved to be totally negative. Anomalies seemed to be situated to one side of the actual position of the shaft but in many cases even known shafts were not detected. The consultant regarded that survey as a failure as the cost had been in excess of £150,000. Dave McCann attended a meeting with the consultant to discuss the 'Shrimp' survey and walked over part of the proposed road and observed the extent of the problem. Whilst some of the mineshafts were obvious as were large areas of subsidence, in open field areas all surface expression of mine workings had been lost. As a result, Dave McCann proposed that EGU should carry out a magnetic or electro-magnetic survey in a feasibility study of these methods. This study was to be funded by the BGS.

Both the magnetic and electrical conductivity methods were successful in detecting shafts and other workings known to be filled with debris and ash, the magnetic field and electrical conductivity being normally higher in the vicinity of such areas. Non-contacting instruments were used that detected changes in the properties of near-surface materials with ash and debris providing a marked contrast. However, shafts covered with debris or backfilled with the original overburden generally did not produce significant anomalies. The surveying technique was rapid compared with conventional resistivity surveying with a three-person team being able to cover about 1,000 m^2 per day using a 2 x 1 m grid. The simultaneous use of two different methods provided enhanced results because isolated pieces of metal that would cause prominent magnetic anomalies were not normally detected by the electrical system. The survey is described in detail and a geological description of the area as well as the survey results are provided in a report by Jackson & Suddaby (1979).

6.6 SURFACE GEOPHYSICAL MONITORING OF TUNNELLING NOISE IN WARRINGTON

Lead: Dave McCann

In the late 1970s, the Transport and Road Research Laboratory (TRRL) and the Building Research Establishment (BRE) set up a Working Party on probing ahead of tunnels and proposed the use of tunnelling machine noise as a source of acoustic noise for probing ahead of the tunnel. As a result, EGU set up a feasibility study using the excavation of a sewer tunnel in along the Manchester Ship Canal in Warrington. A field data acquisition system and data transfer system were developed to record the tunnelling machine noise using a geophone spread of either p-wave geophones or three-component geophones on the surface either in front of, or behind, the cutting face.

An attempt was made to produce a mathematical model of the acoustic characteristic of the noise due to the cutting action of the tunnelling machine and the parameters that affect the acoustic radiation. Environmental noise was considerably lower in amplitude and had little effect on the recording of the tunnelling machine noise up to 30 m from the cutting face. Spectrum analysis and cross correlation of the tunnelling machine noise showed that the noise was a stationary random noise with a superimposed periodic component. The power spectra identified the predominant frequencies due to the various pumps (12.4, 15 and 25 Hz) and also showed that the majority of the energy lies below 50 Hz. The value of the attenuation coefficient varied more at low frequency (12.4 Hz) than at higher frequency (36.9 Hz). Two methods were used for determining the acoustic velocities. The first was an analogue method whereby the tunnelling machine transients were played back on a UV recorder and the delay between the transients measured. The second method used the time lag between the peak of a cross correlation and the zero shift. The project and its results are described in EGU Reports EG/76/1, EG/76/1A, EG/77/6 and EG/78/6.

6.7 BOREHOLE GEOPHYSICAL TECHNIQUES FOR THE DETECTION OF CAVITIES IN A ROCK MASS

Lead: Roy Baria and Dave McCann.

Between 1976 and 1978, the UK Department of the Environment commissioned EGU to carry out research to assess the use of geophysical methods for the detection of cavities in the ground. Various methods were considered but the research was focused on the development of an ‘Acoustic Detection and Ranging system’ (ACDER) to operate in a borehole. It was deemed essential that the acoustic source selected should be powerful enough to achieve sufficient penetration of acoustic energy into the rock mass to give the required resolution of any acoustic discontinuity.

The acoustic pulse source was a modified version of the borehole sparker described by McCann *et al.* (1975). Initial laboratory experiments showed that it was possible to detect a cavity by the reflection technique. Baria & McCann (1977) described the requirements and limitations of the sparker source and the hydrophone receivers.

Field trials were carried out in 1976 at a disused railway tunnel about 1.5 km south-west of the village of Cocking located between Midhurst and Chichester in West Sussex. The geology consisted of a fractured chalk bedrock overlain by loamy soil about 0.25 m deep. Four 150 mm diameter boreholes were drilled to a depth of 30 m. Three boreholes were in a line perpendicular to the tunnel axis, with two of the boreholes on either side of the tunnel 30 m apart, while the fourth borehole was offset 14 m from the line of the other boreholes. One of the boreholes was cored, samples logged for fractures and then waxed for the determination of other geophysical properties in the laboratory. The objective of the field trials was to observe the effect of the tunnel (the ‘cavity’) on the acoustic pulse transmitted between two boreholes, one on either side of the tunnel. The way in which the boreholes were sealed (by grouting around a plastic tube lowered into the borehole) was described by Baria & McCann (1977).

The acoustic source was a 75 mm diameter borehole sparker probe and the detector a multi-element hydrophone array. The sparker and receiver were placed into two separate boreholes in 1 m steps. Unfortunately, the field studies were carried out during the summer of 1976 which was unusually dry. The dry summer had caused the grouting to crack and thus loosened the firm bonding needed for the efficient transmission of an acoustic pulse. Three further boreholes were drilled to carry out further field trials in May and September 1977. Considerable efforts were made to improve the drilling techniques used to seal the boreholes adequately. The outcome of this work was described by Baria *et al.* (1978).

The problem of drilling boreholes in fractured materials was largely overcome by using a foam system combined with improvements to the flexible tubing for sealing off the borehole. The problem was that the geological conditions at the Cocking test site were more complex than the 1976/77 work indicated. A surface seismic refraction survey carried out provided information on the degree of fracturing in the rock mass and a reasonable seismic model of the geological conditions at Cocking. The inter-borehole acoustic scanning results also gave some indication of the presence of the ‘cavity’ and were in general agreement with the seismic model predicted by the surface seismic refraction survey.

6.8 SHALLOW MARINE GEOPHYSICS

Part of Peter Jackson's post-doctoral work at Bangor University had involved shallow offshore geophysical scanning using a number of probes (See EG/78/18 and EG/79/21 on resistivity and sparker probes respectively). This work continued after Jackson's transfer to IGS-EGU. One cruise, in the autumn of 1979 consisted of the following:

- Sledge probe – combined acoustic and resistivity measurements over a variety of sediments to prove the method, which seems to have involved the instruments being towed across the sea floor on a sledge. However, this research involved the instruments being stationery on the seafloor at a series of stations. Measurements at each station took about one hour. Water depth was not relevant but stone-free muds and sands were the preferred seabed lithologies.
- Free field investigation – this involved the calibration of borehole tools and an acoustic profiler ('boomer'). Water depth needed to be preferably greater than about 15 m. Each experiment took about 3 hours and there were six different experiments that needed to be carried out at each site.
- Acoustic profiling – this involved a streaming boomer and two long hydrophones all being towed at a speed of two knots. The objective was to investigate layering within seabed sediments to a depth of 10 m below the seabed.

It seems likely that this one-week cruise on the Bangor University research vessel Prince Madoc, was one of a number of cruises that took place around this time.

6.9 GEOPHYSICAL TEST SITE AT NEWBOROUGH WARREN, ANGLESEY, NORTH WALES

Lead: Peter Jackson

From September 1979 to late 1984, geophysical research on a Holocene, marine sands test site at Newborough Warren, Anglesey owned by the Forestry Commission was carried out. The overall aims of the project were:

i. To improve the understanding of how geotechnical variations relate to geophysical properties of sediments with a view to the use of geophysical measurements as an input to civil engineering designs.
ii. To provide a test site for developing new geophysical and geotechnical techniques for use in site investigation.

The research would carry out a range of geophysical measurements both on the ground surface and down and between boreholes to compare the data obtained with the geotechnical properties of the sands. The measurements proposed were:

- surface geophysics – resistivity soundings and seismic refraction;
- borehole geophysics – acoustic scanning between boreholes, laterolog measurements through slotted casing and shear wave logging;
- self-bored measurements – resistivity, permeability, pressuremeter as well as ground water sampling;
- and large-scale permeability – pumping tests.

The data were to be interpreted for:

- 3D mapping of the base of the sands from resistivity soundings;
- determination of saltwater intrusion from the sea;
- acoustic scanning to determine dynamic moduli and attenuation;
- micro-structure from self-bored resistivity measurements;
- laboratory measurements of free field, pore fluid, porosity and density and permeability;
- estimation of true resistivity from slotted casing values;
- and calibration of test of resistivity measurements – permeameter, free field, slotted casing.

It was intended that the measurements would enable:

- comparison of permeability and attenuation studies;
- determination of dynamic moduli with static values from pressuremeter tests;
- free field/porosity/grain size/permeability relationships for ‘dirty soils’;
- and effects of strain on strength measurements.

Boreholes were to be drilled using the EGU’s own Bedford truck-mounted drilling machine and tube sampling down hollow-stem augers (Figure 12). In total, 14 boreholes were drilled. Self-boring pressuremeter testing was carried out by PM InSitu Techniques Ltd. In 1981.

Figure 12 Jon Hallam and the EGU drilling machine at Newborough Warren.

Geotechnical index testing was restricted mainly to particle size determination (PSD) and moisture content measurements. In addition, sand samples were taken on the tide line for PSD for low, middle and high tide levels and for the lower, middle and upper slopes of adjacent sand dunes to compare environments with PSD.

Not all the originally proposed objectives of the project were achieved but a number of papers and reports were produced, for example, Jackson *et al.* (1980, 1986)

6.10 ELECTROKINETICS

Lead: Dave Beamish, early 1990s onwards

Dave Beamish transferred from the BGS Edinburgh office in the early 1990s. It is not clear why this transfer took place and why he ended up in EGU. His research focus at the time of his transfer was electrokinetics. A paper he wrote with Roger Peart appeared in the publication Terra Nova (Beamish & Peart 1992). The abstract of this paper is copied here to give a brief idea of what electrokinetics is about.

"Electrokinetic phenomena occur in porous rocks and include streaming potential, electro-osmotic and electrophoretic effects. Geophysical techniques can generate acoustic body waves that stimulate electrokinetic coupling at subsurface boundaries. The electromagnetic effects generated are observed using surface electric field sensors. Improved methodologies, aided by recent modelling of the coupled acoustic and electromagnetic wave equations, are re-exploring electrokinetic behaviour in the near surface. The methodologies are aimed at providing geophysical tools that may characterize environmentally sensitive parameters such as the fluid content, the fluid geochemistry and the microstructural fabric of the subsurface."

Beamish & Peart (1996) also discussed the latest state of electrokinetic research at the BGS in 1995.

6.11 DETECTION OF FAULTS USING SURFACE GEOPHYSICAL METHODS

Lead: Dave Beamish EGU

BGS, through EGU, collaborated on a CEC par- funded project to determine the most efficient combination of surface geophysical techniques, in combination with airborne optical scanning data for the routine detection of faults, particularly in areas of abandoned mineworkings (Beamish *et al.* [1995]). An extensive range of geophysical techniques were used from conventional galvanic resistivity through a novel application of natural gamma surface mapping to state-of-the-art ground probing radar (GPR) and RESCAN microprocessor-controlled resistivity mapping. Fourteen test sites were used, all believed to be traversed by faults. The faults had a variety of styles and throw and variable overburden conditions. Only GPR and, to a lesser extent, RESCAN and very low frequency electromagnetics (VLF), were successful in the direct location of faults. With the exception of seismic refraction, all of the techniques applied were successful to varying degrees in the indirect detection. Only GPR and VLF were successful in being efficient in operation and capable of both direct and indirect mapping. GPR yielded high detail of shallow (<6 m) stratigraphy and structure while VLF allowed rapid mapping of resistivity variation down to about 30 m. Magnetometry may also sometimes be applicable if weakly magnetic horizons exist.

6.12 SEISMIC PROPERTIES OF SEA FLOOR SEDIMENTS AND ROCKS (STRATEGIC PROGRAMME FROM 1992-1998)

Lead: Dr. Samantha Marks, Defence Research Agency, Professor Clive McCann; Postgraduate Research Institute of Sedimentology, Reading University, Dr. David McCann (EGU, BGS).

Work at the BGS formed part of an ongoing programme, part strategic and part commissioned by the Ministry of Defence and delivered via the Defence Research Agency (DRA). The first objective was to map the sub-seabed geology beneath the seas surrounding the UK. The second objective was to gather representative samples of sediments and rocks from seabed sediment-coring and rock-drilling sorties. The third objective was to undertake laboratory measurements on these samples of the geotechnical and physical properties affecting sound transmission. The fourth objective was to collate all these data into a properties database that could be associated (tagged) to the mapped geology. The strategic aims of this research included the creation of both geological and associated geotechnical-geophysical property models representing type-sequences of various subsea locations around the UK, such as the Southern and Northern North Sea, the Irish Sea including the North-West Platform and Continental Slope and the English Channel where both friendly and hostile submarines might be operating. Submarine reconnaissance utilised sound echo-recordings that were subsequently evaluated to infer the presence of a submarine based upon their characteristics (that is, echo strength spectrum) deviating from those of echoes anticipated from the expected sub-seabed environment, such as created using the models associated with the type-sections.

Sound propagates through seawater, sediments and rocks as a longitudinal wave, where it can be reflected and refracted when it encounters changes along its raypath in the acoustic impedance of the host medium. The primary properties affecting the acoustic impedance are the density and elastic moduli of materials including sediments and rocks. Density can be calculated via mass and volume measurements and the elastic moduli calculated via speed of sound measurements through samples, such as those gathered from the seabed sorties. These sorties occurred throughout the late 1980s to early 1990s, with the recovered samples stored at the BGS and Reading University. Gravity coring methods were used to collect saturated sediments, down to circa 8 m from the seabed, that were recovered in sealed plastic pipes (approximately 400 mm long by 80 mm diameter). Rotary drilling methods were used to collect rock samples but, while few drill sites were based in the project areas, samples were mainly supplied from other sites that were considered suitable geological analogues.

The laboratory testing programme was undertaken at both the BGS and Reading University facilities. The geotechnical and seismic properties of saturated sediments were tested using standard geotechnical tests and an instrumented seismic-oedometer at the BGS laboratory. Test frequencies were circa 10 kHz for shear waves and 750 kHz for compressional waves. The testing of sediment dispersive (frequency dependent) seismic properties was undertaken at Reading University using a pulse tube cell. These tests covered a 1 kHz - 50 kHz frequency range but did not include sediment sample consolidation. The geotechnical and seismic properties of saturated rocks were tested using standard geotechnical tests and seismic property testing in an instrumented isostatic pressure cell at Reading University. Test frequencies were circa 800 kHz for shear and compressional waves. The test suite included:

- BGS
    - Sediment geotechnical properties (density, moisture content, consistency [plastic limit, liquid limit] and mineralogy).
    - Seismic properties of saturated sediment undergoing consolidation (compressional wave attenuation and velocity, shear wave attenuation and velocity [as a function of density]).
- University of Reading (Postgraduate Research Institute of Sedimentology)
    - Rock geotechnical properties (density, porosity and mineralogy).
    - Seismic properties of saturated rock under isostatic pressures to 70 MPa (compressional wave attenuation and velocity, shear wave attenuation and velocity).

Analyses of the laboratory property data were undertaken to derive algorithms enabling estimation of dependence of seismic properties, that is, shear and compressional wave attenuation and velocity on frequency, density and pressure, where pressure dependence was also a proxy for burial depth dependence. These algorithms and tabulated data tables were collated into the GEOSEIS database presented to the DRA, intended for use in their seismic (acoustic) property modelling of UK marine type-environments. The GEOSEIS database was also extended to the terrestrial environment and provided generic seismic property-dependence information applicable to cohesive marine sediments and cohesive and non-cohesive soils and rocks. The project generated several technical reports describing the laboratory methods and results (McCann *et al.* 1996, Assefa *et al.* 1997, Gunn *et al.* 1998), hard-copy outputs from the GEOSEIS database and academic publications.

6.13 NON-INVASIVE MOISTURE MONITORING WITHIN AN EARTH EMBANKMENT USING RESISTIVITY SCANNING (RESCAN)

Lead: Peter Jackson (EGU, BGS)

An experimental monitoring system using electrical resistivity as a proxy for imaging changing moisture content distribution in engineered earthworks was carried out between April 1993 - March 1995 for the Overseas Development Administration (ODA) in western Kenya on a road embankment constructed of tropical red soil. Tropical red soils have highly variable properties, governed by their soil fabric and mineralogy (see above). As earthworks materials, their geotechnical behaviour is extremely sensitive to changes in moisture content and compaction. The relationship between moisture content and electrical resistivity was established in the laboratory on core obtained using a monitored drilling and sampling technique. The non-invasive nature of electrical resistivity surveys was exploited in the design of a monitoring system placed below the pavement in the topmost layers of compacted soil. Monitoring over a period of 18 months was carried out, starting prior to the construction of the pavement following the completion of soil compaction. Initially, substantial variability in moisture content was inferred from surface monitoring, and even larger changes were seen in corresponding downhole measurements. The moisture content within the body of the embankment stabilised after six months, while a moist layer 'trapped' beneath the pavement dissipated over the following ten months. Two surveys were undertaken during the 'December rains'; they showed large changes in moisture content had occurred quickly in the surface layers on one side of the embankment. This area subsequently failed as a small landslide and was remediated by additional drainage (Jackson *et al.* 2000).

6.14 ELECTRICAL RESISTIVITY METHODS FOR FRACTURE DETECTION AND CHARACTERISATION

Lead: Peter Jackson, BGS. Commissioned by Nirex Ltd.

In the early 1990s, the UK reviewed potential locations for the underground storage of contaminated waste from its nuclear power stations (such as, Sellafield, Dounray and Sizewell etc.) Generally, very low permeability formations were considered suitable for host repositories, as they would best limit the migration of fluids charged with nuclear contaminants, from the stored materials into the formation, with the possibility of entering groundwater systems. However, their sealing integrity could be compromised by flow along joints, faults, bedding planes and so on, collectively called fractures (for example, within the rock continuum). Nirex Ltd. were the agent appointed by the UK government to investigate suitable locations for the underground storage of nuclear waste. Nirex Ltd. commissioned the BGS to advise on potential host rocks around mainland UK, firstly based upon geological criteria, that is, low permeability formations. Thereafter, Nirex and the BGS were required to develop a host selection scheme based upon hierarchical assessment of the *in situ* rock mass and, hence, its suitability against critical characteristics. This included the evaluation and selection of suitable field investigations that could be deployed from the ground surface and also between boreholes. This project focused upon the detection of fractures, indication of fracture aperture and, most importantly, assessment of their potential transmissibility, that related to the hydraulic conductivity and connectivity of the fracture matrix.

Formation imaging using electrical resistivity tomography (ERT) formed part of the investigation, that included a review of ERT field methods and an evaluation of field array configurations optimised for fracture characterisation in specific formations. Rocks comprising lithified, fine-grained ash tuffs of the Borrowdale Volcanic Group (BVG), beneath west Cumbria, were considered a potential host and were the focus of this study (where investigations had already been initiated). A review of recent literature indicated array design, data collection, modelling and inversion methods affected the resulting survey images. A general methodology was advised to ensure sound practice, including:

- A data handling sequence involving: i. field data acquisition forming the field apparent resistivity section; ii. construction of a forward model incorporating an estimate of the geological structure scaled using dimensions and array configurations similar to the field survey; and iii. inversion of an optimum solution for the field resistivity structure based on the minimum sum of the differences between the field apparent resistivity section and the apparent resistivity section generated by the forward modelling.

- Use of 3D rather than 2D finite element or finite difference grids to better represent actual (3D) current flow *in situ* and reduce the 'side-error' artefacts generated in sections, caused by the inability of the 2D solution to accommodate current flow outside the modelled plane.
- Use of electrode array configurations that encouraged current flow through the fracture system to improve the match between the qualitative structure featured in the inverted resistivity images relative to the *in situ* resistivity structure, (that is, image fidelity). This was a consequence of increased uncertainty in the reconstructed image (hence greater error) increasing with distance away from the array electrodes and that the distribution of the current flow pattern into the formation can be optimised by the electrode configuration.

The challenges of ERT surveys in fractured rocks related to the very high resistivity of the intact rock medium and the unknown nature of the fracture matrix (geometry, morphology, connectivity) and its location. The review postulated predominant current flow within fractured, low porosity formations would be through the fluid infilling the fracture networks, increasing with increased fracture aperture (width) and connectivity of the fracture matrix throughout the rock mass. Experiments by Brown (1989) confirmed that the electrical conductance of a single fluid-filled fracture was proportional to fracture aperture, while hydraulic conductance was proportional to the cube of fracture aperture. Consequently, in cases limited to a single, conducting fracture, the Formation Factor, that is the ratio of the formation resistivity to the fluid resistivity, provides an index of fracture aperture.

Recommended fracture aperture assessment schemes included the integration of downhole resistivity logs from multiple tools, especially those current focusing capability (such as Schlumberger's Formation Microscanner, Micro-Spherically-Focussed Logger, Array-Resistivity Imager), with increasing depths of investigation into the formation about the borehole. Integrated interpretation of log suites would form the basis for evaluating fracture aperture, persistence away (up to 3 m) from the borehole and potential connectivity. (Although, the review conceded that further research using the logging tools within scaled physical models simulating controlled borehole environments was still required to better understand the performance of respective tools). Incorporation of this information to constrain the geological model about the boreholes bounding the ground under investigation would better constrain (reduce the uncertainty) the geological interpretation within the central zone. Injection of highly electrically conductive tracer fluids into the borehole was also recommended as a means of improving fracture detection, especially where borehole packers were used to target intervals where relatively wide aperture, well-connected fractures were identified from downhole log interpretations.

Execution of a crosshole ERT tomography survey between two boreholes through the Borrowdale Volcanics Group in west Cumbria was considered feasible. This conclusion was partly based upon a favourable aspect ratio between the boreholes; that is, the distance between the boreholes being far smaller than the depth interval of investigation, better encouraging sub-horizontal current flow into the formation (and, hence, through fractures) between them. Also, it was based upon the formation of interest lying at burial depths below 400 m and saturated with low resistivity fluids, hence providing favourable background conditions for detecting electrically conducting fractures. (For example, the resistivity of intact rocks in the upper BVG was estimated at over 10,000 ohm.m from downhole Dual Laterolog (LLD) measurements and the sampled formation fluids measured to be 0.2 ohm.m). It also advised that further resistivity logs using focused tools such as the azimuthal Laterolog be gathered and integrated with the existing LLD data to improve the fracture assessments within the geological interpretations about both boreholes. A numerical feasibility study was also recommended. This would entail the construction of parameterised ground models and numerical simulation of the forward problem, providing the apparent resistivity benchmark sections (across the zone of interest) for evaluating the inverted field interpretations. Electrode array field configurations, (including field measurement schemes) would then be optimised based upon model simulations producing the most favourable outcomes. Finally, following satisfactory modelling outcomes, the undertaking of crosshole ERT tomographic surveys and subsequent interpretations were recommended only where satisfactory signal-to-noise levels could be obtained from suitable field equipment and set-ups. (Cost estimates were indicated for the field and interpretation aspects of potential survey operations).

6.15 3D RESCAN RESISTIVITY MAPPING OF QUATERNARY GEOLOGY, SELLAFIELD, CUMBRIA

Lead: Richard Ogilvy (EGU). August 1995 for UK Nirex Ltd at Sellafield.

3D RESCAN resistivity surveys were carried out at seven sites in the Sellafield district to map the Quaternary sediments in the top 36 m. These datasets were processed and interpreted using advanced 2D and 3D numerical modelling techniques to give the true subsurface resistivity distribution. Use was made of interactive volume modelling software to assist the visualisation of these geoelectric images and to delineate the volumetric geometry of the three main drift lithologies (clays, sands/silts and gravel/boulder beds).

The results confirmed that 3D resistive imaging is a valuable diagnostic tool for mapping the Quaternary succession and for assessing the spatial heterogeneity of these deposits in both lateral and vertical dimensions. As expected a high level of glacitectonic disturbance was evident at three sites in the GLO Domain (Glacially Overridden) but the drift appeared to be stratiform and one-dimensional at three other sites in the ALV-T Domain (Alluvial Deposits) (see Merritt *et al.* 1995 with regard to the classification of the onshore Quaternary deposits). The dominant drift lithologies were characterised by true resistivities ranging from 10 ohm.m for clays to 10,000 ohrn.m for gravel /boulder beds. However, composite sediments (for example, sandy clays, boulder clays) and even sandstone bedrock appear to exhibit overlapping resistivity values and could not be distinguished without local borehole control.

The resistivity images failed to resolve or detect bedrock at any site. This may have been because of the absence of any distinct bedrock at any site. This may be attributed to the absence of any distinct geoelectric contrast between drift and bedrock or, alternatively, to the drift thickness being in excess of 36 m. It was suggested that these interpretational uncertainties could be resolved with local stratigraphic and hydrological control from boreholes and geophysical logs. With local borehole calibration more realistic iso-volume limits could also be set that, in turn, would have allowed more accurate 3D drift models to be constructed.

The project report describes the work in full (Ogilvy *et al.* 1995).

6.16 GEOPHYSICAL AND GEOTECHNICAL PROPERTY RELATIONSHIPS FOR MARINE SEDIMENTS

Lead: Peter Jackson, EGU, working with BGS Marine Geologists: David Long, Peter Holmes and Martin Stoker. Funded by the Western Frontiers Association, 1995-99.

The Western Frontiers Association included a consortium of oil companies, related service companies, the HSE and the BGS. All parties had a stake in understanding the geology and engineering performance of the whole sequence, from the basement up to modern seabed sediments covering the north-west UK continental slope into the Atlantic. The project coincided with the release of exploration licence blocks west of the Hebrides and oil companies were interested in the hydrocarbons potential of the deeper geology and the stability of the seabed with respect to anchoring drilling platforms. The BGS provided a unified geological interpretation across several licence blocks using deep well and marine seismic data commissioned by the oil companies. An associated engineering geological model was produced by applying a series of simplified geotechnical properties to the lithostratigraphy within the geological interpretation. This model formed the basis for various seabed stability assessments, investigating the risk of seabed consolidation and slipping. This included an assessment of the susceptibility of the upper 10 m within the seabed zone to seismically triggered landslide failures caused by localised, low magnitude seismic events (Ml < 2), which was undertaken by the EGU. Some of the research was published (Jackson *et al.* 2004).

6.17 DEVELOPMENT OF GEOPHYSICAL GROUND MODELS

Lead: Dave Gunn, EGU. Funded by the BGS Science Budget, 1997-2004.

A procedure was established for estimating geophysical properties via an engineering geology hierarchy of lithostratigraphy (clay, sand, chalk), grain size (fine, coarse) and strength (consistency, packing density). The work for the Western Frontiers Association (see section 6.16 above) was followed up with a wider review of associated geophysical and geotechnical property data, especially pertaining to UK stratigraphy. This review enabled the development of relationships to model ground properties important for assessing dynamic loading of road and rail infrastructure, such as shear modulus or stiffness. Such models were applied to scope the shear modulus of the formations or subgrade along rail network routes. The shear modulus of the formation beneath the rail track bed was to become a key aspect when studying the susceptibility of the ground to potentially damaging ground motions triggered by high-speed trains generating Rayleigh waves. Gunn *et al.* (2003) discussed some of the research carried out.

6.18 CROSS-HOLE SEISMIC SURVEYING FOR SINKHOLES

Lead: Peter Jackson, CEG; collaborated with First Ground Investigations (Geotechnical Engineers) and Broad & Gloyens (Consulting Engineers). Commissioned 1998-99.

The Old Vicarage, in the village of Lane End, north of High Wycombe, was a large residence founded on loose to medium dense sand of the former Reading Beds that were underlain by rocks of the Chalk. The rear wall of the house exhibited oblique vertical cracks and was pitching away from the property. This was due to undermining from subsidence of around 1.5 m across a roughly 10 m diameter circular area in the rear garden. The subsidence appeared to relate to slumping of the Reading Beds into a sinkhole in the Chalk around 5-10 m below the ground surface. A crosshole seismic survey was commissioned from twelve 20 m deep, sealed plastic lined, water-filled boreholes located across the garden and about the house to determine the competency of the Reading Beds underlying the property. Survey procedure involved transmission of sound waves generated by a sparker source in one borehole and received by a hydrophones in separate boreholes. The amplitudes of the received pulses provided a proxy to the competency of the Reading Beds and using multiple transmitter-receiver locations, a disturbed zone (or zone of relatively poor competence) was mapped out beneath the rear of the property, extending to around 8 m deep. The sound velocity distribution within the Reading Beds and the underlying Chalk was also mapped via the time delays between the sparker excitation and detection of the received signals. Subsurface intervals of competent Chalk were interpreted as corresponding to higher velocity zones. These were considered excessively deep and variable that inhibited a cost-effective piled solution to remedy the failing foundations. Unfortunately, the consulting engineers (Broad & Gloyens) indicated that the property would be condemned. The project was described by Jackson *et al.* (2001).

6.19 DEVELOPMENT OF A SEABED RESISTIVITY IMAGER

Lead: Peter Jackson working with Kevin Briggs (US Navy, 1998-1999).

The US Navy supported research and development of portable technologies to evaluate the physical properties of seabed sediments that influenced the backscatter of ultrasound. Ultrasound forms the basis for communication and evaluation of the subsea environment and the sediment grainsize distribution and porosity both affect how sound reflects from the seabed. A submersible resistivity scanning system was developed to investigate the porosity of the coarse seabed sediments. It incorporated 256 6 mm electrodes in a 150 mm square grid (16 by 16) capable of imaging the upper 50 mm of the sea floor. A low power, logic counter controlled current switching to 16 electrodes within the grid, while two multiplexed counters controlled the switching of all electrodes on the grid to the voltage measuring amplifiers. The submersible was connected to shipboard, battery power and PC-micro-computer control via a 40 m marine-compatible cable. Scanning cycles incorporating variable pole-dipole electrode configurations, enabled resistivity measurement of the seawater and the seabed about a 100 mm square cuboid 50 mm deep. Seabed Formation Factor images were generated by normalising the seabed to sea water resistivity. The Formation Factor images were interpreted into equivalent estimated porosity distributions using different values of Archie's cementation factor (based on the grain shape).

These porosity distributions contributed to estimations of seabed reflectivity incorporated into US Navy sonar studies.

The research was described by Jackson *et al.* (2000).

6.20 ENGINEERING PERFORMANCE OF UK SOILS AND ROCKS – AUTOMATED TESTS FOR SHRINKAGE; BRICKEARTH COLLAPSE FIELD EXPERIMENTS

Lead: Kevin Northmore working with Neil Dixon (Loughborough University), Chris Rogers and Ian Jefferson (Birmingham University) and Ian Smalley (Nottingham Trent University). NERC grant and SB 2000-02.

Superficial loess or brickearth deposits cover large swathes of China, Eastern Europe and also England south of the Anglian ice margin. They predominantly comprise wind-blown, silt-sized particles that were deposited under periglacial conditions, and can be several 10s of metres deep. Because they settled in cold, dry conditions, within 3 m of the earth's surface where they are poorly consolidated, they often exhibit a very loose packing structure, characterised by point-to-point grain contacts. Where these deposits are under load, this structure is prone to collapse in response to the introduction of water into the pore space, a condition called 'metastability'. This can lead to subsidence damage of buildings founded on brickearth associated with broken drains or flooding. Brickearth metastability was investigated at field and laboratory scale as part of the BGS programme to characterise UK soils.

A field collapse experiment was undertaken near Ospringe, Kent on brickearth within 0.5 m of the earth's surface that was freshly exposed via soil scraping using a long reach digger. It involved loading a 1 m by 2 m plate (to circa 10 tonnes), which was centred in a 5 m by 5 m brickearth island block that was isolated from the surrounding formation by a 2.5 m deep by 0.25 m wide ditch. Initial loading was applied to the brickearth at its natural moisture content, after which, water poured into the ditch was maintained level with the upper surface (of the island block) where the load was applied. Levelling surveys at key points on the load plate and the surrounding block were regularly repeated throughout the dry and wet load cycles. Geophysical property changes of the material within the block were also monitored throughout these load cycles. Resistivity changes were monitored over an array comprising 256 electrodes spaced at 0.25 m evenly distributed over the upper surface of the block. Also, shear wave velocity was monitored between probes located within loaded and unloaded zones of the block. Regular resistivity and shear wave velocity measurements were made throughout the dry and wet load cycles. The site was excavated post-testing, with 'undisturbed' samples taken over different depth intervals within the block, including zones where geophysical measurements were undertaken. Laboratory testing included moisture content, density, consolidation and SEM images.

Brickearth field samples from the unloaded zones were placed into a laboratory oedometer. Relatively low levels of consolidation occurred as samples at their natural moisture content were loaded. However, when saturated while under load, several samples exhibited rapid consolidation, which was attributed as metastability. Evidence of metastable collapse in the field included additional consolidation of an increased rate of the brickearth beneath the load plate. SEM investigations of samples retrieved from this zone indicated collapse in the form of shear scraping of adjacent silt grains as evidenced by curled, scroll-structures in the clay films coating them. Reduced resistivity and increased shear wave velocity measurements recorded within the brickearth suffering metastable collapse were attributed to increased mechanical stiffness and electrical conductance of the soil fabric, arising from its relatively rapid consolidation (or collapse). The research is described by Gunn *et al.* (2001), Gunn *et al.* (2006), Jackson *et al.* (2006) and Zourmpakis *et al*. (2006).

6.21 6.21 PROTECT (PREDICTION OF THE EROSION OF CLIFFED TERRAINS)

Lead: Jon Busby (EGU, BGS) with the University of Brighton (UoB), Bureau de Recherche Géologiques et Minières (BRGM), Geological Survey of Denmark and Greenland (GEUS) and the Institut National de l'Environnement Industriel et des Risques (INERIS).

PROTECT was an EU 5th Framework project led by BGS which ran for 3 years from 2001. Its objective was to research geophysical techniques that might indicate physical property changes within a hard rock coastal cliff that are pre-cursors to an impending cliff collapse. The two geophysical techniques researched were azimuthal resistivity and acoustic crack emissions. As well as research organisations, the consortium also included end users, comprising the Isle of Wight Centre for the Coastal Environment (IWCCE), Direction Departementale de L'equipement de la Seine Maritime (DDE76), Urzad Morski w Gdyni (PMA) and Consorzio Ferrara Ricerche (CFR). Field research sites were established on chalk coastal cliffs in Britain, France and Denmark and positive results prior to cliff collapses were obtained from the French and British sites. A number of papers were published including Busby *et al.* (2004) and Busby & Jackson (2006).

6.22 GAS HYDRATES RESEARCH

Lead: Peter Jackson working with Mike Lovell (Leicester University) and incorporating the work of Chris Rochelle/Keith Bateman in the BGS Hydrates Laboratory. NERC Grant 2001-03.

Gas hydrates research involved experimental and modelling activities focused on understanding the stability of hydrate-bearing seabed sediments in a changing climate. Instrumented laboratory test cells were used to measure the velocity of compressional and shear waves through sand samples, within which CO_2 hydrates were grown. CO_2 hydrate formation within the pore space and subsequent cementation of sand grains increased the stiffness of the sediment and the velocity of shear waves propagating through it. Hydrate formation was accompanied by a drift of aqueous phase ions into the remaining pore liquid. While this increased the salinity of the pore liquid, sediment bulk resistivity decreased significantly because of the decreased mobility of these charge carrying ions as the connectivity of the liquid phase was reduced. The modelling studies focused upon the loss of stiffness in hydrate bearing sediments when hydrate dissociates, for example caused by increased seabed temperature. A two-step modelling approach was undertaken. Firstly, using effective-stress estimators with differing friction components, the depth-dependent shear strengths for non-bearing and hydrate-bearing sediments were estimated. Then, the resistances to seismic accelerations at differing depths within the sediment column were evaluated using these shear strength values in an infinite slope, factor of safety assessment. The research is described by Gunn *et al.* (2002).

6.23 BEACH THICKNESS IN COASTAL SEDIMENT TRANSPORT

Lead: David Gunn working with Richard Tinsley and William Tinsley (Surface Wave Surveys Ltd.). Science Budget 2003-04.

Combined non-invasive geophysical methods for assessing the thickness of beach sediments were evaluated at Easington, Holderness, UK. Galvanic and non-galvanic electrical resistivity, electromagnetic conductivity, shear wave refraction and continuous surface wave methods were tested. The bulk of the beach sediment comprised medium to coarse SAND but incorporated planar lags of well-rounded coarse gravel and cobbles, including a basal lag resting on the top of the underlying till foreshore platform. Trials involved depth sounding at single locations and profiling along both 48 m cross-shore and 24 m long-shore sections arranged in a rectangular grid that was exposed about the low tide. Non-galvanic electrical resistivity was effective over dry, unsaturated sand, but was unreliable over saturated sand. Galvanic resistivity surveys were very reliable over dry and saturated sands and effectively differentiated the unsaturated dry and underlying saturated zone within the beach sediments, from which the phreatic surface could be mapped. However, the base of the beach could not be distinguished due to a very low contrast between the resistivity of the seawater-saturated beach sediments and underlying till. EM conductivity surveys involved the use of separate tools for shallow and deeper depth investigations to circa 6 m deep. These were also effective at distinguishing between the dry and saturated beach sediments but not between the beach and underlying platform. Shear wave refraction surveys utilised a plank source with basal fins to improve shear coupling to the loose sand of the beach. However, with little energy above 30 Hz, difficulties in identifying the refracted arrival over the direct arrival restricted the interpretation of a low velocity beach sediment layer over the higher velocity foreshore platform. However, a frequency range from 5 to 200 Hz available to the continuous surface wave method, enabled the generation of shear wave velocity-depth profiles (circa 15 - 20 m deep) through the beach sediment and several metres into the underlying till. When combined with invasive, dynamic cone penetration resistance-depth profiles, it was possible to interpret both sandy and gravelly intervals within the beach, as well as the weathered and unweathered intervals in the underlying till platform below. These methods were considered suitable for sandy beach sediments up to around 4 m thick. The results are presented and discussed by Gunn *et al.* (2006).

6.24 GEOPHYSICAL MINESHAFT DETECTION

Lead: Richard Ogilvy, together with Simon Caunt - Coal Authority. Science Budget and Coal Authority 2004-05.

The Coal Authority commissioned the BGS to evaluate the performance of the then current geophysical technologies in relation to the detection of unknown or unlocated mineshafts and also the characterisation of the mineshaft and surrounding rock mass where its location was known. Firstly, the latest academic and practitioner reports on the current state of the art in both detection and characterisation across a spectrum of geophysical methods were reviewed. A bibliography and a report were compiled that classified the methods and provided selection specification tables on the basis of technique and performance against different mineshaft configurations (lined-unlined, backfilled, flooded, air-filled etc.) and rock mass conditions (bedrock, superficials, lithology, saturation etc.) Secondly, trials of the detection capability of multiple geophysical field instruments were undertaken over a 50 m square grid beneath which, a soil-infilled and an air-filled mineshaft existed at unknown locations. The grid was within the Coal Measures (mudstones and sandstones) that were overlain with glacial till on a former colliery that had been returned to farmland, near Pewfall, Wigan, UK. This detection programme included trials of the following techniques (inter alia): electrical resistivity and chargeability, spontaneous potential: continuous profiling with electromagnetic and ground penetrating radar tools; infrared thermography. Summaries of the methods and resulting findings from each technique were collated into a single document, which also included a further selection table on the basis of the detection performance. The final, characterisation, phase involved several cross-hole tomography surveys utilising multiple geophysical transmitter-receiver systems deployed down a circular arrangement of eight boreholes drilled in the host rock (of *circa* 15 m diameter to *circa* 30 m deep) surrounding both mineshafts. Hole preparation included deployment of calliper, natural gamma, full sonic and resistivity downhole logging tools prior to sealing the boreholes using slotted plastic casing set in a bentonite-cement grout, which retained water and was electrically conductive. The cross-hole programme included a succession of cross-hole surveys performed about both the infilled and air-filled mineshafts using different techniques including: electrical resistivity, ground penetrating radar and seismic tomography. Again, summaries of the methods and resulting findings from each technique were collated into a single document, which also included a further selection table on the basis of the characterisation performance. Wilkinson *et al.* (2005) discussed the research.

6.25 GEOPHYSICAL MINESHAFT DETECTION - ANNEX 1 DETECTION USING THERMAL INFRARED

Lead: David Gunn working with Mike Deakin of Proviso Systems (who provided/operated the thermal infrared camera used in the surveys). Science Budget 2005-06.

The mineshaft detection survey involved contouring multiple measurements of the average surface temperature of a 1 m^2 of ground taken at 2 m centres over the 50 m by 50 m grid. Non-contact, ground temperature measurements were made from chest height using a hand-held infrared camera capable of providing a 320 x 240 pixelated temperature image to -20^{o}C. A single surface temperature measurement recorded at each location was the average taken from all the pixel values (76,800) in the infrared temperature image. Monitoring of the temperature and barometric pressure measurements of the air 1 m above the surface at locations within the grid allowed the survey to be undertaken under optimal environmental conditions. The survey was undertaken during an early February (2005) morning after several evenings of sub-zero temperatures and while the air pressure was falling. These conditions reduced the influence of solar-reflectance and increased the possibility of ground heating from oxidised gases escaping from the mineshafts. Lowest temperatures occurred over ground covered with long (0.2 - 0.4 m) wispy grass and non-vegetated areas covered with coarse natural or artificial soil with good drainage. Higher temperatures were recorded over poorly drained, muddy or flooded ground, due to the latency of water holding up the ground temperature in these areas. The highest temperatures localised about the air-filled mineshaft, even though it was capped with treated wood and buried under *circa* 0.75 m of soil cover. Traces of methane (0.1%) and with the combined O_2-CO_2 comprising only CO_2 (22%) in soil gas testing indicated oxidisation of methane as the cause of the highest temperatures over the air-filled mineshaft. It was considered that the soil-infilled shaft was not detected on the basis that no temperature anomalies were observed in the ground immediately around it. The research is discussed in a paper by Gunn *et al.* (2009a).

6.26 GEOPHYSICAL MINESHAFT DETECTION - ANNEX 2 CHARACTERISATION USING CROSS-HOLE SEISMIC TOMOGRAPHY

Lead: David Gunn, working with Mike Raines, David Morgan and Lavinia Nelder.

Two cross-hole seismic tomography surveys were undertaken, each from eight boreholes equi-spaced around the circumference of a 15 m diameter circle centred about the axis of an air-filled mineshaft, in the first case, and a soil-filled shaft in the second. Both shafts were *circa* 3 m diameter, brick-lined, capped with treated wooden logs and soil-covered to around 0.75 m deep. The host geology included around 5 - 8 m of glacial till overlying Coal Measures mudstone; the till comprised firm to stiff, sandy clay; the mudstone was weak with thin bands of flaggy sandstone. The survey procedure involved firing a sound pulse from a transmitter fixed at different depths in one borehole and detecting the time of arrival of the sound waves propagating about the mineshaft and surrounding rock mass to receivers at different levels within all the other boreholes. A 3D (volumetric) velocity model incorporating the mine within the rock mass structure was constructed with a 2 m^3 voxel resolution. The transmitter and receiver locations were added and the velocity of sound through individual voxels was calculated using a Simultaneous Iterative Regression Transform (SIRT) to optimise the model to best match the travel times along the ray-paths between all the field transmitter-receiver combinations. This required optimisation of all the time delays through individual blocks, such that the cumulative delay modelled along all the ray paths though the velocity model that best matched the equivalent field delay times. This process involved two iterations, with the first velocity model resulting from the solutions assuming direct straight-line propagation from the transmitter to the receiver. Subsequent models were then generated using ray paths that were refracted at the interfaces between successive voxels encountered along their length. The best optimised model, that produced the minimum cumulative differences between the modelled and field measured delay times, was then investigated for velocity patterns that could be attributed to geological and mineshaft structures. The subsequent interpretation differentiated the till and the mudstone into different velocity ranges, with further interpretation of the presence of the mineshaft by how it perturbed the velocity structure associated with the geological strata. No clear perturbations were observed in the case of the soil-filled mineshaft but the air-filled shaft could be inferred from low-velocity pipe artefacts in the centre of the velocity model within the mudstone. The research is discussed in a paper by Gunn *et al.* (2009b).

6.27 BIOLOGICALLY INSPIRED ACOUSTIC SYSTEMS (BIAS)

Lead: John Rees; EPSRC programme grant with: Gordon Hayward (Strathclyde University), Robert Allen (ISVR - Southampton University); Dean Waters (Leeds University), Mike Lovell (Leicester University), Steve McLaughlin (Edinburgh University), Alba Ultrasound Ltd. (spin-out from Strathclyde University). Laurie Linnett (Fortkey Ltd., industry specialist - ex Heriot Watt University) and Leicester University Post-doctoral Researchers: Said Assous and Claire Hopper. Science Budget and EPSRC Grant 2005-10.

The BIAS project aimed to develop acoustic systems capable of interrogating our material and spatial environment with the same performance achieved by bats and cetaceans. It brought together a multidisciplinary team to develop instrumentation to deliver and detect new acoustic signals inspired by those used to characterise (and communicate within) natural environments, (airborne-bats; marine-cetaceans). Several laboratories were established as demonstrators of the improved NDT technologies in biological, medical, electronic and geological research areas. The ultrasound research laboratory commissioned at the BGS incorporated the absolute movement of multiple piezocomposite transceivers (with a 40 to 200 kHz frequency range) within a 1.5 x 1 x 1 m deep water tank with a 5 micron reposition accuracy. The water tank was of excellent design and construction. This facility supported experimentation and development of more precise ultrasound time delay and distance ranging and, also, improved measurement of acoustic properties of the materials forming layered media. Precise measurement of the phase differences between four frequencies in an echo-reflected signal, enabled time delay estimation that when combined with accurate knowledge of the water velocity, provided improved distance ranging resolution beyond the half-wavelength resolution capable from simple pulse-echo systems. Detection of back-scattered ultrasound over near-decadal bandwidths enabled improved estimation of the velocity and attenuation of ultrasound through single layer plates. This same capability also led to improved discrimination of the materials and thicknesses of individual layers within composite layered systems. Downstream applications arising from the improved resolution distance ranging include more precise submarine vehicle positioning and geodetic movement monitoring. Downstream applications arising from improved characterisation of layered media included condition monitoring of submarine structures. In particular, WINSPEC was a follow-on project that led to the translation of this improved characterisation capability onto an underwater vehicle for inspecting the condition of offshore wind turbine foundations. The research was described by Assous *et al.* (2008, 2011), Hopper *et al.* (2012).

6.28 ELECTRICAL EARTHING FOR ELECTRICAL TRANSFORMER INSTALLATION IN GREAT BRITAIN

Lead: Jon Busby. Funded by Western Power Distribution and UK Power Networks.

Values of ground resistivity, strength and excavatability were combined at 1:50,000 scale for a project for Western Power Distribution and UK Power Networks to determine the most appropriate method of earthing for electrical transformers. This work was undertaken between 2008 and 2010.

Both companies have many 11 kV transformers, mostly on wooden posts in rural areas. For safe use, each transformer is earthed in the ground with a design resistance of 10 Ω or less. This is usually done in one of two ways, either by earthing with copper wires attached to a steel stake that is driven into the ground or by digging a trench in which copper wire is placed and then the trench backfilled. The most efficient method is the driven stake method as it uses less copper and, as the stake is driven several metres into the ground, the earthing is much less likely to be affected by increases of ground resistivity due to the near-surface ground drying out. The driven stake method is suitable mostly where soils and weaker rocks occur in the top 5 to 10 m and the trench method is used where the ground is too strong to enable penetration that far.

The two companies were responsible for different geographical areas that have different types of ground. UK Power Networks responsibilities included East Anglia and the southeast of England where the driven stake method is used. Western Power Distribution was responsible for the southern half of Wales and the West Midlands, areas that commonly have stronger rock near-surface and so the trench method was used. There are two main mechanical and physical properties relevant to this, the geotechnical strength and the resistivity of the ground. The strength is important as it determines the most likely type of installation whether it is a metal spike with a copper wire or a trench into which a copper wire is placed.

A reduction of water content, most notably in coarser materials, greatly increases the resistivity of the ground. The strength, for most engineering rocks, was then reworked as excavatability so that the contractors could take the most suitable kit on site for the work. The resistivity values were based on the effective medium model (Berg 2007) and checked against BGS electrical surveys (Barker *et al.* 1996). The equation used by Berk required that the porosity, saturation, water resistivity and clay content had been measured in the field. Combining the different properties of the ground resulted not only in a likely method of suitable installation but also the depth of earthing and the amount of copper to be used.

The different aspects of the work - expected resistivity, excavatability and probable installation details - were put together in a GIS and this was provided to the clients. The GIS was designed to be used by the clients and smaller, less detailed versions to be used by the installers. Both power networks applied this work to inform the installers of the most likely suitable installation.

The resistivity GIS was extended to the whole of Great Britain and was reported by Busby *et al.* (2012).

6.29 ALERT-ME DEVELOPMENT OF GEOTECHNICAL PROPERTY GROUND MODELS USING GEOPHYSICAL IMAGING

Lead: David Gunn and Jon Chambers - supported by the East Midlands Development Agency, 2009-11.

The East Midlands Development Agency supported the automated 3D resistivity monitoring of a railway embankment along the Great Central Railway near East Leake, Nottinghamshire, UK. Its aim was to demonstrate that by informing more timely interventions, proactive remote condition monitoring could bring about more effective management of a geotechnical asset and, hence, reduce the risk of instability to transportation infrastructure. Poor drainage through and about embankments often leaves them susceptible to heave within their core and slips around their base and flanks. An automated, time-lapse, electrical resistivity tomography (ALERT) system was installed, which incorporated eight 32-electrode transects. Using daily measurements over this array, the volumetric moisture conditions throughout a 21 m section of embankment and the underlying geological formation were monitored. This continued for two years or more, to assess how the embankment condition was affected by seasonal weather patterns and extreme rain events.

Invasive investigations revealed the embankment to comprise coarse grained materials overlying an end tipped fill of siltstone (local Blue Anchor Formation - Mercia Mudstone Group) and mudstone (Westbury Mudstone Formation - Penarth Group) lithoclasts ranging in size from coarse gravel to large cobbles. Time-lapse imaging showed water drained downwards, through the upper coarse materials and into the finer fill, where it appeared to perch before flowing laterally about the core and out at the toe of the embankment. Drainage from the embankment appeared to combine with run off from the prevailing sloping formation to flood the drainage ditch (with water to 350 mm deep) at the toe of the east flank of the embankment. Some superficial slumps due to localised creep were observed over the lower half of the east slope that was in good overall condition. The research was described by Chambers *et al.* (2011a & b) and Wilkinson *et al.* (2011).

Both the research facility and the arising expertise were applied to several follow on projects including iSMART funded by the Engineering and Physical Science Research Council and CALYX-PRIME funded by the Rail Safety and Standards Board. iSMART led to an improved understanding of the geotechnical controls on the resistivity of re-worked, fill materials to encourage the use of field-monitored geophysical proxies to be integrated into more preventative asset management practice. By developing near real-time delivery of 3D resistivity images, CALYX-PRIME focused on developing information systems to support more interactive asset management.

6.30 GEOTECHNICAL-GEOPHYSICAL PROPERTY INTER-RELATIONSHIPS – LABORATORY PROGRAMME

Lead: David Gunn. Science Budget 2011-14

The development of EGU into the Urban Geoscience and Geological Hazards Programme (UGGHP) in 2000-2005 coincided with a period of significant advances in computing and Geographic Information Systems. In part, these advances provided the catalyst for increasing use of digitised map data and the transition from 2D cartographic maps to 3D polygonal models. Geological models of urban centres such as Thames Gateway, Glasgow-Clyde and Greater Manchester were constructed, capturing bedrock, superficial and artificial (made ground) geology at the 1:10k scale suited to district and town planning. New insights into the engineering performance of the ground followed directly from our improved models and visualisation. Also, as part of the Engineering Performance of UK Soils and Rocks programme that was publicly funded via the BGS Science Programme (Science Budget, SB), the UGGHP continued to sample and test the geotechnical properties that provided an index to the engineering behaviour of formations key to UK strategic development. This work continued for a decade and focused especially on UK mudrocks, such as the Gault Clay, Lias Mudstone, Mercia Mudstone and the London Clay where there were significant hazards such as shrink-swell and landslides and also much construction of national infrastructure. This programme of Geotechnical-Geophysical Property Inter-relationships included the combined laboratory testing of geophysical and geotechnical properties on engineering soils comprising these target geological formations and groups. The test procedure resulted in the production of resistivity vs moisture content relationships that defined the drying and wetting of control samples taken from different moisture/density combinations from reworked soil that had undergone standard compaction. Resistivity was then used as a proxy index to characterise the moisture content of samples both dry and wet of optimum density. Also, when combined with the soil Atterberg Limits (plastic limit, liquid limit), moisture content derived from resistivity surveys offered a non-invasive means of assessing consistency and strength. Interestingly, organisational changes within the BGS post-2005 coincided with a gradual (year on year) decrease in the Science Programme funding, which led to the increasing practice of using the Geotechnical-geophysical Property Inter-relationships Programme to co-support the Commissioned Research (CR) programme. Indeed, this programme of testing established the laboratory capability and developed the science base that supported later commissioned projects, such as ALERT-ME and iSMART.

6.31 FUTURE RESILIENT TRANSPORT NETWORKS. FUTURENET - INSTIGATION OF RESILIENCE OF TRANSPORT NETWORKS TO CLIMATE CHANGE

Lead: Chris Baker (Head of Birmingham Centre for Railway Research and Education, School of Engineering, Birmingham University). Consortium including Robert Dingwall (Social Sciences, Nottingham Trent University), Neil Dixon, Tom Dijkstra and Tim Ryley (Civil & Building Engineering, Loughborough University), Phil Sivell (Transport Research Laboratory), David Gunn, Russell Lawley (BGS, Engineering Geology Directorate and Geotechnical & Geophysical Properties & Processes Team). EPSRC EP/G060355/1 and Science Budget 2009-13.

The FUTURENET project aimed to develop solutions to the deleterious climate-impact on transportation networks (mainly road & rail), by addressing: i) the interaction between weather events and the physical network, and ii) passenger behaviour regarding how transport demand changed in response to their perception of network performance. The first work strand involved creating modular models of major transport networks that were used to test how road and rail capacity (defined by journey density and time) responded to different ‘extreme’ weather sequences (where ‘extreme’ could relate to severe drought, temperatures or rainfall). The second strand involved assessing the behaviour of road and rail users from a range of commercial sectors (haulage, tourist, professions etc.) and social demographics (age, sex, activity). The assessment captured both the immediate actions taken to overcome journey interruptions (following diversions or changing transport modes) and also how these issues affected the options considered when planning future travel (different route, departure time or transport mode). Weather sequences were constructed by varying combinations of extreme ‘wet’, ‘dry’, ‘hot’, ‘cold’ annual cycles generated by the 2009 UK Climate Panel prediction algorithms. Decadal sequences (10, 20, 30 years) were used to stress road and rail network models comprising links and junctions (nodes), each ascribed a resilience index (ranging from 0-no resilience to 1-complete resilience) to different weather parameters. In this manner, how the capacity, routing alternatives (or redundancy) and journey times were affected by the anticipated climate-induced weather changes were evaluated. Similarly, the network users’ behaviour study assessed the impact of capacity, route alternatives and journey times on travel considerations that could be integrated with the network climate modelling to forecast how changing passenger demand might affect the likely formats of future transportation networks. The study included exemplar assessments of the cumulated time delays from interrupted train connections along the West Coast Mainline Railway network caused by a landslide in Cumbria and the loss of capacity and congestion caused along the M4 corridor due to extreme rainfall.

The project outcomes were discussed by Jaroszweski (2010), Bouch *et al.* (2011), Bouch *et al.* (2012), Jarosweski (2012) and Dijkstra *et al.* (2014).

6.32 PRIME - DEVELOPMENT OF REMOTELY MONITORED ELECTRICAL RESISTIVITY IMAGING SYSTEM

Lead: Jonathan Chambers with David Gunn. Science Budget 2011-14 and various external funders: NERC Innovation B award and NERC Innovation A award 2014-18)

Background: A significant proportion of the UK's aged geotechnical assets comprising engineered cuttings and embankments along rail and canal routes and dams providing water containment are in an unknown condition. However, understanding their condition is becoming increasingly critical as more and more assets that appear in serviceable condition seem to fail, often due to a loss of internal integrity. Asset owners, the Canal & River Trust, Scottish Canals, Network Rail etc., have devised condition classifications based upon defects detectable via visual inspections, such as fissures, seeps, deformation and slips. While there's no universal classification protocol across all asset owners, they share similar classes such as, good, serviceable, marginal and poor, based upon the prevalence of morphological features that impact mainly on the infrastructure geometry and hence its operability. The dominance of deformation or displacement-based technologies in condition monitoring (certainly until *circa* 2015) served to reinforce responsive asset management practice. Deformations (in all morphological guises) are 'effects' of processes that change the strength of the engineered soil comprising the asset; essentially, surface manifestations of subsurface 'causes'. Recent shifts towards preventative (or predictive) asset management have followed the development of technologies capable of monitoring underlying causes of soil strength changes, such as variable moisture content. This change in approach provided the catalyst for the use technologies, such as PRIME, capable of imaging these earlier causes of distress deeper within the asset.

PRIME Resistivity Monitoring System: Improvement of resistivity monitoring systems supported much of the geotechnical-geophysical inter-property research at the BGS from 2005 through to 2020. Scientific outputs from the ALERT-ME (Section 6 29) and iSMART (section 6 33) projects demonstrated that dynamic soil moisture monitoring offered a basis for preventative asset management. However, the ALERT system cost and data accessibility, or more importantly, access to information directly supporting asset management decisions and remedial solutions, were still barriers to uptake. A NERC Innovation B award supported the commission of CIRIA (Construction Industry Research and Information Association) to undertake research into the geotechnical asset owner community's remote condition monitoring needs. A market for monitoring services and data offering time-lapsed, 3D images of the asset interior and underlying formation was confirmed but with the preferred service provision via a third-party, as this reduced asset owner liability. A further NERC Innovation A award supported the design of a resistivity scanning system based on high volume components to address the high costs of the ALERT forerunner and with GSM connectivity to stream data via an internet portal enabling near-real time access.

The resulting PRIME (**PR**oactive **I**nfrastructure **M**onitoring and **E**valuation) system was modular with highly flexible physical configurations and monitoring programmes capable of satisfying bespoke applications. Field deployment involves connecting the PRIME system to a grid of electrodes configured to optimise current flow throughout the body of the geotechnical asset. These field systems incorporate two switching networks, the first to direct a constant current between selected source-sink electrode pairs and the second to measure the potential differences between different electrode-pairs across the grid, from which the resistivity distribution throughout the asset can be constructed. Remotely programmable switching control allows monitoring optimised for low-cost reconnaissance or focused semi-quantitative imaging of dynamic soil moisture movement driving asset deterioration, that is, a flexible platform for novel, preventative practice. Longer term, adaptive monitoring is now possible, where the progressive changes within the asset can be detected and less intrusive management methods applied. Many academic-stakeholder research collaborations, such as iSMART led by Newcastle University and Geotecs led by University College, Dublin, are now exploring proactive asset management practices using these technologies and approaches. Gunn (2015a) and Gunn & Chambers (2015) describe the use of the PRIME system.

6.33 ISMART - INFRASTRUCTURE SLOPES: SUSTAINABLE MANAGEMENT AND RESILIENCE ASSESSMENT

BGS Role: integrated laboratory and field studies looking at the control of porosity and moisture content on other properties and slope stability.

Lead: EPSRC Programme Grant Principal Investigator - Stephanie Glendinning (Newcastle University); academic consortium included: Neil Dixon (Loughborough University), Joel Smethurst (Southampton University), David Toll (Durham University), David Hughes (Queen's University, Belfast), David Gunn and Jon Chambers. EPSRC Grant 2013-17.

Asset owner/agent consortium: Highways Agency (England), Network Rail, Canal and River Trust, London Underground, Mott MacDonald.

The iSMART consortium integrated laboratory and field monitoring with geomechanical modelling into a new approach (or paradigm) for forecasting the deterioration of geotechnical assets (engineered cuttings and embankments). The project involved several academic and network owner partners, all keen to move from responsive to more predictive, risk-based asset management practices. Laboratory research within the BGS included complimentary measurement of resistivity, pore suction (matric potential) and moisture content on remoulded samples of fill materials taken from earthworks located on major road, rail and flood defence networks. The nature of the changing geotechnical-geophysical property relationships was investigated as sample batches were dried out and re-wetted in repeated cycles. The different inter-property relationships were then applied to proxy field resistivity data streams to track the condition of the monitored sites and assess any subsequent deterioration. Condition was defined in terms of geotechnical properties relative to specific thresholds that defined soil behaviour and deterioration as a change in condition that was deleterious to the function or performance of the geotechnical asset. Hence, applying the laboratory relationships to remotely monitored resistivity data streams provided real time moisture content data that could be converted into estimates of consistency relative to the plastic and liquid limits of the earthworks fill. Continuous, regular monitoring of assets offered data streams that could be evaluated, for example, to differentiate patterns of deterioration from seasonal trends. It was envisaged that, through long-term observations, any anomalous patterns away from established seasonally normal trends could be indicative signatures, or pre-cursors of deterioration. This offered the prospect of early warning systems that could also better define the affected zone and hence support more timely, focused and cost-effective remedial action. Chambers *et al.* (2014) and Gunn *et al.* (2014) described the research.

6.34 ASSESSING THE UNDERWORLD - AN INTEGRATED PERFORMANCE MODEL OF CITY INFRASTRUCTURES

Lead: Chris Roger (School of Engineering, Birmingham University). Consortium including Stephanie Glendinning (Newcastle University), Antony Cohn, Barry Clarke (Leeds University), Joby Boxall, Richard Collins (Sheffield University), Steven Swingler (Southampton University), Helen Reeves (BGS, Engineering Geology Directorate). (ATU geotechnical properties for urban areas via geophysical proxy) (EPSRC EP/K021699/12013-18) (2013-18).

The pipes and cables that deliver utility services to homes are usually buried beneath our urban streets below the surface transport infrastructure (roads and paved pedestrian areas). Streetworks to install, replace or maintain these services using traditional trench excavations disrupt traffic and people movement and will often significantly damage the surface transport infrastructure and the ground on which it bears. The ground and physical infrastructures (that is, utility service and surface transport) coexist symbiotically - intervene physically in one and the others are almost inevitably affected in some way, either immediately or in the future. Moreover, the physical condition of the pipes and cables, of the ground and of the overlying road structure is crucially important in determining the nature and severity of the impacts that streetworks cause. Assessing the Underworld (ATU) aimed at more effective use of geophysical sensors deployed both on the surface and in contact with utility infrastructure to determine remotely (without excavation) the condition of these urban assets.

Modern utility survey methods such as Ground Penetrating Radar (GPR) and electromagnetic locators (for example, CAT & Genny), specialise in utility positioning and identification and provide little quantitative information about the ground conditions and potential disturbances caused, for example, by damaged utilities and associated discharges. Common geotechnical monitoring approaches use sensors in small boreholes to directly monitor soil properties such as moisture content and pore water pressure. This is not always an efficient/effective means of relating the degree and spatial distribution of water saturation to possible water flow from a nearby leaking pipe. Approaches, including the expense of intrusive works, only monitor a small volume of soil around the sensor from which subsurface property changes might not be fully quantified. Individual point sensors cannot provide continuous volumetric images of dynamic subsurface processes and a variety of different conclusions can be drawn about the cause of the ground disturbance, depending upon where the sensors are located. However, non-invasive imaging over surface-based arrays either buried just beneath the pavement or towed along the surface, offer the potential not only to provide early warning of leaks but also to provide accurate location and condition monitoring of leak-affected ground.

To this end, the ATU project used exemplar deployments of geophysical sensors to investigate different target anomalies associated with faulty utility infrastructure. These included detection of degradation (or failure) in either the buried pipes and cables, the road structure (for example, cracking, delamination or wetting) or the supporting ground, associated with property changes caused by faulty services or works, such as wetter and looser soil. For example, the zone of trenching was detected via difference imaging of electrical resistivity and thermal infrared surveys over ground, undertaken before and after excavation, backfilling and repair of the road pavement. 3D, time-lapse electrical resistivity imaging successfully tracked the water ingress into the formation (that comprised clayey silt) from the point of a leak on a 32 mm OD HDPE pipe, while the reduction in stiffness throughout the inundation zone could be monitored using repeated surface wave surveying. Geophysical imaging of both the water infiltration and the loss of strength in the host soil provided early warning of a faulty water pipe before any surface manifestation of leak waters traditionally used to signal a fault. More so, geophysical images provided semi-quantitative information firstly on the change in saturation (via resistivity) and in strength (via shear wave velocity and small strain stiffness) throughout the zone infiltrated by leak water. Water saturation of the formation about the leaking pipe caused a 35 % reduction in soil stiffness from 13 MPa to 8 MPa.

Taking the information provided by the geophysical sensors and combining it with records for the pipes, cables and roads and introducing deterioration models for these physical infrastructures knowing their age and recorded condition (where this information is available), offers a means of predicting how services would be affected if a trench is dug in a particular road. In some cases, alternative construction techniques could avert serious damage (for example, water pipe bursts, road structural failure requiring complete reconstruction) or injury (gas pipe busts). To this end, databases from multiple stakeholders responsible for the integrity of the urban subsurface were combined to develop a prototype Streetworks Decision Support System (SDSS). For example, data and sources included soil conditions and geohazard susceptibility (shrink-swell, running sand, slip, dissolution) from the BGS, flood susceptibility from the EA, water utility networks from local water authorities, gas and electric networks from National Grid and urban roads and wastewater networks from local authorities (for example, Greater Manchester Council). By encouraging use of a common SDSS by multiple stakeholders the ATU project promoted the development of more holistic (joined-up) streetworks management. While this case was built on the premise of overall long-term reduction in the cost of streetworks management, the loss of potential revenue streams held within corporate databases led to resistance against the 'data-sharing' concept behind a common SDSS, especially amongst de-regulated service providers who depended upon both grant and commercial income streams.

The research was described by Chapman *et al.* (2015a & b), Cohn *et al.* (2017), Wei *et al.* (2018) and Dashwood *et al.* (2020).

6.35 WIND-TURBINE FOUNDATION: ULTRASONIC SPECTRAL CHARACTERISATION - WINSPEC – LOW FREQUENCY ULTRASOUND TECHNIQUES TO INVESTIGATE OFFSHORE FOUNDATION CONDITIONS

Lead: David Gunn and Paul Wilkinson. Part of the work was funded by a NERC grant re: Improved Infrastructure Resilience to a Changing Climate; Supported by E.On Technology and New Build Centre - Colin Brett. NERC and E.On 2014-15.

The rapid growth in the construction of renewable energy generators, particularly offshore wind turbines, has brought a variety of issues that will impact on the lifetime of such assets. Non-destructive testing (NDT) is being increasingly called upon to underwrite the future, safe operation of wind turbines by determining the presence, size and type of defects in components such as the tower, nacelle, gearbox, blades and foundations. However, novel materials of construction, difficult access and the sheer size of many components makes this a difficult task, especially in a sector having low margins. Of particular concern is the monopile foundation of some offshore wind turbines.

The foundation of the early generation offshore wind turbines consists of concentric, overlapping cylinders comprising a 5 m diameter, 50 mm thick inner steel monopile (that rises from the seabed), a 5 m high, 70 mm thick annulus of concrete grout and an outer steel transition piece (that has a flanged mounting for the turbine mast). This foundation design is especially susceptible to cracking of the grout at either interface with the steel substructures and even complete loss of concrete from the annulus.

The NERC supported the WINSPEC project and utilised the ultrasound laboratory and numerical modelling capability developed on the BIAS project (see section 6.27) to evaluate the feasibility of using ultrasound to assess the condition of monopile wind turbine foundations. The study was two-phase, firstly, a proof of principle using numerical modelling, and secondly, proof of concept via measurement of ultrasound reflected from physical models in the laboratory. The modelling study compared the reflected ultrasound backscattered from a benchmark layered structure representing monopile foundations in good condition, with that from models modified to simulate the addition of defects, such as cracks and loss of concrete. The laboratory study was undertaken on physical models constructed firstly to half thickness scale, in order to utilise existing transducers (and commensurate bandwidth), and secondly after the acquisition of a bespoke transducer, at full thickness scale. Physical models in both cases comprised concrete grout slabs sandwiched between rolled steel plate, where the grout and steel were respectively 35 mm and 25 mm in the half-scale and 70 mm and 50 mm at full scale. The concrete grout was bonded to the steel plates in the models representing good condition, then various gaps were maintained between the concrete and steel using different thickness shims. The feasibility assessment was then based upon the goodness of fit between corresponding modelled and laboratory reflection spectra, for example from good and defected structures. The modelled and experimental reflection spectra incorporated notches that related to missing energy at a pattern of frequencies specific to each structure. Statistically, significant matches between the modelled and laboratory results proved the feasibility and offered a basis for monopile foundation condition monitoring using backscattered ultrasound. This part of the research was described by Wilkinson *et al.* (2018).

E.On then supported further development and field trials of an ROV-deployed inspection system at the Robin Rigg windfarm in the Solway Firth, UK. This involved the miniaturisation of the laboratory instrumentation and ultrasound transducer into a battery powered, portable system mounted onto an unmanned, underwater vehicle. This field system was operated from the entry deck of the wind turbine and connected via a 30 m long underwater cable to the ultrasound transducer mounted onto an ROV deployed into the seawater filled centre of the monopile. The foundation condition inspection included a succession of echo tests at 15^0 azimuthal intervals about the inner circumference on the monopile over the area of the overlap of the concrete grout. Inspections began about the base and were repeated at 0.5 m depth intervals, with the final scan about the top of the grout annulus. Each scan pixel (approximately 0.5 x 0.5 m) was attributed a condition classification on the basis of a comparison of the echo reflection with signal standards representing either a good condition, crack at the monopile, crack at the transition piece or missing grout. Each inspection took between three and four hours to scan and classify the foundation over an area of *circa* 100 m^2. The trials verified the efficacy of the inspection system to technology readiness level 6 (effective in an operational environment). With regularly repeated inspections, it was intended to use successive foundation condition scans to guide further interventions to manage the operational serviceability of each turbine within the Robin Rigg wind farm. The second part of the research was discussed by Brett *et al.* (2018) and Gunn *et al.* (2019).

6.36 CALYX-PRIME – INTERFACING AND DELIVERY OF PRIME SYSTEM TIME LAPSE 3D ELECTRICAL IMAGES

Lead: David Gunn (with Geotechnical & Geophysical Properties & Processes Team) and Nick Slater, Monitoring Services Director, SOCOTEC Monitoring UK Ltd. Science Budget 2014-15; Rail Research Group Grant.

SOCOTEC, (formerly ITM Monitoring), provide bespoke condition monitoring services to geotechnical asset owners. Services include CCTV, surface probes to monitor soil temperature, moisture and pH, site weather, deformation (using contact sensors such as extensometers, tiltmeters etc.), non-contact laser-scanning and internal inspection utilising geophysical methods such as ground penetrating radar. Data gathered on all sensors are streamed through a web portal accessible via any device that can connect to the internet. CALYX, SOCOTEC’s proprietary platform, configured to suit each asset owners’ needs, is used to visualise all monitored data. Typically, visualisation includes sensor data time series, images of critical locations (slopes, drainage ditches etc.) on the asset and possibly, geophysical sections across the asset’s interior. Alarm states, which can be set on any data are often used to trigger action notifications requiring follow-up site visits or works.

The Rail Research Group supported a collaboration between the BGS and SOCOTEC (then ITM Monitoring) to incorporate the visualisation of resistivity images created from PRIME systems from within the CALYX platform. Hardware and software developments to the CALYX platform included increased memory to the data engine and new code for registering higher order data arrays used to create time-sequenced 3D images. Delivery and manipulation of time-lapse 3D resistivity images from an embankment along the Great Central Railway provided a successful beta-test of the enhanced CALYX platform. SOCOTEC and the BGS went on to establish a business partnership covering the delivery of PRIME data via the CALYX platform to 3rd party asset owners. With increasing use of time-lapse resistivity-monitoring of water movement through seeps in aged infrastructure, early service uptake came from water companies and private owners of earthwork dams. Also, increased uptake of these imaging technologies is changing the owners’ approach towards asset management. Most importantly, these technologies are enabling increasing influence of internal condition monitoring on asset management decisions, which, because deleterious changes in the internal condition are earlier indicators of asset deterioration, this represents a shift towards preventative maintenance. The sudden collapse of the dam at Whaley Bridge (Derbyshire) in August 2020 provided a good example of failure of an asset that was considered in serviceable condition based upon visual inspections. Repeated scour of the downstream slope, while missed by visual inspections could have been detected using resistivity imaging of the earthworks and the flooding of the local village possibly avoided. A detailed description of CALYX-PRIME is provided by Gunn *et al.* (2015b).

7 Geohazard Studies

7.1 LANDSLIDES

7.1.1 General landslide studies

The first slope stability studies concentrated in the early years on landslide mapping and classification, particularly on the Dorset coast in the Jurassic strata of the famous coastal section. Major landslide and mudflow complexes had caused a high rate of recession of the cliff top with damage to property, particularly in the Lyme Regis to Charmouth area. In the late 1970's, landslide mapping in the South Wales Coalfield produced a series of maps at 1:50,000 scale, locating and classifying 579 individual landslides on base maps, which show topography, geology and slope (Conway *et al.*, 1980). The landslides comprise a range of six types from deep-seated rotational ones involving Coal Measures strata to shallow transitional slides involving superficial deposits only, and combinations of the six. More detailed examinations of the most common type (transitional) were completed at two specific sites.

EGU also used traditional slope stability analyses including the infinite slope method and the simplified Bishop and Janbu methods of slices, all non-rigorous methods, on a microcomputer in London. In addition, using a computer in Edinburgh a sophisticated rigorous method due to Sarma at Imperial College was used, which could take into account lateral loading, including earthquake loading.

The Dorset Coast landslides studies began in 1968 under the supervision of Bernard Conway However, work on landslides began in earnest with the arrival of Bruce Denness in the EGU. Initially, he carried out a number of visits to active or dormant landslides around the UK, some in response to enquiries by local authorities and others. It seems likely that many of these enquiries came to EGU via the Land Survey. Examples included, Sheinton, Cressage, Shropshire, rock falls at Loch Sloy Dam, Scotland, mudflows on the Antrim coast, Northern Ireland, Sandgate, Folkestone, Kent, Maryport, Cumberland, Durlston Cliff, Swanage, Dorset, Cayton Bay and between Filey and Saltburn, East Riding of Yorkshire, Hampstead Cliff and Blackgang, Isle of Wight, cliffs at Barton-on-Sea, Hampshire, and many more.

Almost as a culmination of these local studies, Bruce Denness wrote a slightly controversial article for New Scientist magazine entitled "End of the landslide menace?" (Denness 1972). Denness had not obtained formal permission to publish the article prior to publication, a serious 'offence' in the IGS at that time. He excused himself by suggesting that the magazine had published an early draft of the article without referring back to the author!

The Dorset Coast studies more-or-less ended in the mid-1970s, though staff visited occasionally to note changes. Further landslide studies were carried out in Cyprus (major problems in Western Cyprus), Jamaica, South Wales, Telford and elsewhere.

7.1.2 Landslide studies in Ironbridge, Shropshire

In February 1970, Roger Cratchley and Bruce Denness carried out an assessment of a landslide beneath a Church of England school in Ironbridge (Denness & Cratchley 1970) for the Telford Development Corporation (TDC). In his covering letter of 5 March 1970 to Brian Coppack, one of two field mapping geologists resident in Telford at the time (the other was Richard Hamblin), asking Coppack to forward copies of the report to the TDC, Cratchley suggested that the EGU should carry out further investigations to "elucidate the causes of failure and give a guide to general stability conditions at Ironbridge." In the event, EGU sent outputs from the Milton Keynes work (map and table of engineering properties and characteristics). These were favourably received by TDC but, towards the end of 1970, they rejected having similar work done in Telford.

In October/November 1971 Coppack and Hamblin prompted TDC to commission a 400ft borehole from the top of the Ironbridge Gorge and stability assessments of the north side of the Ironbridge Gorge. This was discussed with the TDC in January 1971. A preliminary landslide survey was carried out by Martin Culshaw in early February 1972 covering the Lloyds Coppice, Jockey Bank and Ironbridge areas of the north side of the Gorge (Culshaw 1972). In April 1972, a full proposal was made to the TDC. The Terms of Reference proposed were:

i. To assess the stability of the North Bank of the Severn in the Ironbridge Gorge between Lincoln Hill and the railway line, east of Lloyds Coppice area, and to delineate areas of a) definite stability b) definite instability and c) uncertain.
ii. More detailed investigations of two particular localities are required. The Jockey Bank – Madeley Green area is of immediate priority for possible development. The area immediately below the school above the Municipal Buildings in Ironbridge has slipped within the last two years and also requires investigation, as development is contemplated here also.
iii. The large area of Lloyd's Coppice is actively eroding and decreasing the amount of land above it which is suitable for development. Survey and investigation in order to recommend suitable remedial drainage works are required here.
iv. In the case of Jockey Bank – Madeley Green area assessment of stability is required. In the case of the school site and Lloyd's Coppice, where slipping is known to have occurred, suggestion on suitable remedial measures are required.

Subsequently, in 1973, the work was extended to include Lee Dingle which lies at the eastern end of Lloyd's Coppice. A number of deep and shallow boreholes were sunk in Ironbridge, at Jockey Bank and at Lee Dingle; two deep boreholes were sunk above Ironbridge (Lodge Farm borehole) and above Lloyd's Coppice (Lees Farm borehole). Figure 13 is a copy of an article in a local newspaper written in the spring of 1973 whilst the Lees Farm borehole was being drilled. Geotechnical index tests were carried out on samples from most holes, while *in situ* permeability tests were carried out in the Lees Farm borehole. A number of reports were produced which discussed instability and its causes and recommended remedial measures. Investigations around the school in Ironbridge where the 1970 landslide had occurred were the subject of a published paper (Denness 1977). A number of 'drivers' for the instability were identified and discussed: lithostratigraphy, geological structure (folding and faults), steepness of slope (caused by rapid downcutting by the River Severn and tributaries) and groundwater conditions; the area was known to be extensively under-mined for coal, ironstone and for clay. However, little seems to have been made of the effect of abandoned mineworkings on groundwater conditions and, in particular, groundwater flow to the ground surface. Many areas have been observed to be extremely wet and the role of mining on the instability has not been adequately investigated or assessed.

Tests check land stability

Gorge landslip danger fades

Dangers of landslips in the Ironbridge Gorge are probably less than was once feared, say geologists.

Telford Development Corporation, concerned about the stability of the gorge and how much development could be allowed there, ordered a geological survey. The field survey with drilling rigs is now in its final phase and the results of a preliminary study are expected to be published this week.

But yesterday, Mr Mervyn Whitcut, Telford Development Corporation's land reclamation engineer, said: "We think now the gorge is probably a lot safer than we might have thought at first."

Drilling teams will have sunk between 20 and 30 shallow boreholes in the Ironbridge area, and two deep boreholes behind The Beeches Hospital and at Lees Farm to give a general picture of the strata from the top of the gorge to below the river bed.

Yesterday they started on the 350ft hole at Lees Farm, where they will stay for about a month.

The cores of rock brought up will be later studied in detail and tests made with the boreholes on how much water sinks through the various layers of rock—an important factor in landslip.

Slip areas

The instability of the gorge has been known at least since soon after Abraham Darby built the iron bridge in 1777, when it was noticed in 1784 that the abutment on the Benthall side was moving.

The corporation's survey is to discover the exact stability of the north side of the gorge, particularly in the three main possible slip areas, Lloyds Coppice, Jockey Bank, and the area below Ironbridge C of E School.

Mr Whitcut said the survey had found several old clay, coal and ironstone workings in Ironbridge abandoned before proper records were started at the turn othe century.

The survey could determine how much development can take place in the gorge for recreational use as well as housing, and whether it is worth modernising existing old houses.

Mr Martin Culshaw ~~(left)~~ (right) and Mr Bob Andrews, engineering geologists at the drilling site at Lees Farm, Madeley.

Hassan promises Morocco elections

King Hassan of Morocco has promised elections within the next few months to help lift his country out of its current crisis.

Looking strained but confident after two attempts in 13 months by rebel armed forces officers to kill him, the 43-year-old monarch said he had political remedies to cure Morocco's ills.

But he warned that if the political parties — which have been out of power for a decade and refused recently to join him in a government — continued to make excessive demands, he would not talk with them.

Indications that the parties still intended to drive a hard bargain came shortly before the king spoke to about 100 reporters in the royal guest palace in Rabat last night.

The old-guard nationalist movement, the Istiqlal Party, issued a statement saying the collapse of the situation was the result of the king's "anti-democratic" policies in the last nine years.

To solve the grave crisis, the Istiqlal said the king must "allow the people effective exercise of power."

Car crash split pole

A man standing in a telephone kiosk in Southall Road, Dawley, saw a car going towards Bridgnorth crash.

He thought that the car was travelling too fast, and saw it mount the nearside pavement, collide with a wall and telegraph pole, breaking the pole in two, and swing back across the road.

A5 driver fined £15

A student overtook a line of vehicles in his car on the A5 at Redhill, St Georges, and almost caused an accident, Inspector K. Collins told The Wrekin magistrates.

Peter Alan Day, of Penally, Tenby, Pembrokeshire, admitted driving without due care and was fined £15 yesterday.

Salop rider fined £10

Figure 13 Newspaper article (spring 1973) on landslides in the Ironbridge Gorge with a photograph of Bob Andrews and Martin Culshaw.

More recently, Pennington *et al*. (2008) summarised BGS's knowledge of landsliding in the Ironbridge Gorge.

7.1.3 Landslide studies on the Dorset Coast

A field visit in April 1968 identified sites of “well-developed landslides” and sites to obtain representative samples of the Jurassic System for geotechnical and geophysical testing. The reasoning behind this was that the Jurassic occupies about 15% of the land area of England and that considerable engineering activity was taking place in new towns and the construction of motorways and other trunk roads. In 1969 Bernard Conway proposed that the landslide investigations should be in three stages:

i. Regional distribution study of the Jurassic exposure, which have been subject to slipping on the coast from Pinhay Bay (Lyme Regis) to Swanage, including Portland. Presentation of the distribution of the several types of slip and associated features to be in map (scale 1:25,000) and photographic form. 1:10,560/10,000 scale geological maps and complete stereo air photo coverage was required of the coastline.

ii. Detailed morphological investigation of one or two selected areas of slipping; including mapping, infra-red photography, sampling, tracing of groundwater etc. Presentation of results in map (scale 1:12,500), photographic, physical properties and structure diagram form. 25” maps and air photo cover required.

iii. Geophysical investigation to quantify the various factors likely to be involved in causing slipping, for example, microseisms, weather and sea conditions, groundwater etc. Also rates of movement of currently active slides to be measured.

In a lecture presented to an unrecorded audience in the early-mid 1970s, Bernard Conway described the regional study as taking place on the coast of West Dorset, from Bridport to Lyme Regis. The cliffs are composed of Lower and lower Middle Jurassic sands, clays, marls and limestones, overlain unconformably by Cretaceous clays and sands. The area is situated on the southern flank of the Marshwood pericline. The Jurassic rocks have a low regional dip of 2-3° to the south-east, locally modified by shallow folding. The unconformable Gault and Upper Greensand above show dips of 1-2° to the south. The height of the unconformity varies from 90 to 150 m OD. The present landscape is the result of extensive and intensive erosion during the Tertiary and Quaternary Periods by the Char and Brit river systems which has removed most of the Cretaceous rocks. Outliers of the Gault and Upper Greensand remain only on the highest hills.

It was found that the landslide movement was of four broad types:

i. Shallow depth translational movements involving failure at a relatively planar surface approximately parallel to the ground surface.

ii. Deep-seated rotational movements involving failure at a curved surface.

iii. Free-fall under gravity.

iv. Various forms of mud/sand flow.

The stages 1 and 2 were completed during the spring, summer and autumn of 1969 and Stage 3 begun by Bernard Conway, Pete Collins, Pete Grainger, Dave McCann and others and with the help of voluntary workers. This work continued into the mid-1970s.

The work even made the local press (Pulman's Weekly News, Tuesday 30 September 1969 and Bridport, Lyme Regis & Axminster News, Friday 26 September 1969. It was decided to use John Hutchinson's classification of mass movement published in the Encyclopedia of Geomorphology (Hutchinson 1968).

A marine survey of the western part of Lyme Bay (to about 3 km offshore) was also carried out to establish some of the factors controlling sediment movement along the coast, to ascertain the seaward continuation of geological structures and to attempt to map boulder arcs and other relict evidence of many of the movement. Echo sounding, side scan sonar, sparker and pinger profiles and sea-floor sampling were all carried out in collaboration with the Marine Geophysics Unit.

In 1970 further work was carried out on Stage 3. It was decided that light cable percussion boring was required in the Black Ven area as hand augering had not produced satisfactory samples, together with a deep borehole on the hilltop at Penn Cross. Eventually, the light cable percussion holes were drilled in 1971 and 1972 and the deep borehole in 1973. The research was published both in internal BGS publications and the scientific literature (see Appendices 5a and 7a). The various regional and local maps were not published till around 1977.

From 1976 to 1979, Bernard Conway several times proposed broadening the research to develop a "Coastal terrain evaluation and slope stability map of the Charmouth/Lyme Regis area." This evolved into "Coastal instability and engineering planning maps of the Charmouth/Lyme Regis area of West Dorset." Bernard Conway also drafted part of a possible key for a table for the Engineering Planning Map. This listed three stability categories:

i. Head.

ii. Proven landslips.

iii. Potential instability.

For each of these categories the a) engineering implications and b) site investigation requirements were described This approach was develop and used for the South Essex Geological and Geotechnical Survey for the then Department of the Environment that began in 1975 and occupied engineering geological staff for several years (see above) (Culshaw & Northmore 2002).

7.1.4 Thames Valley subsidence

In late 1973 Bernard Conway submitted a proposal to investigate subsidence in the Thames Valley. It was to consist of two parts:

i. A study of the origin, nature, extent and stratigraphic record of land/sea level changes.

ii. An assessment of the engineering significance of the structures and deposits resulting from these changes.

It is not clear how this project was meant to relate to the EGU's scientific strategy of the time, which still focused on geotechnical and geophysical properties of the Jurassic, engineering geophysical research, landslide studies and geotechnical (engineering geological) mapping of new town and new development areas. The project ran into territorial disputes with the South-East England Field Unit who regarded the geological aspects of the project as falling under their remit.

The main geographical locations were work was meant to be focused were Cooling Marshes, Barking Creekmouth and Foulness, though later work extended to Tilbury. Considerable work had been carried out at Cooling Marshes from about 1970/71. This was continued in the mid-1970s in association with a research student, Nick O'Riordan of King's College London from October 1974 till about September 1977. This work focused on consolidation and surface subsidence of the Thames Alluvium at Cooling Marshes and at Tilbury. O'Riordan carried out a pumping test at Cooling and monitored level changes in a number of boreholes. Resistivity surveys were carried out at Cooling to determine the Alluvium thickness and boreholes were drilled and instrumented with extensometers and piezometers. Additional work at Tilbury docks was carried out involving Delft sampling and Dutch cone probing and piezometer and extensometer instrumentation.

The results and interpretations of the various investigations are contained in EGU reports and in Nick O'Riordan's PhD thesis. However, there appear to be no external publications produced by O'Riordan, or by EGU.

7.1.5 Rock falls on St Helena

St Helena is located in the South Atlantic roughly halfway between South America and Africa, about 5° west of the Greenwich Meridian and about 15° south of the equator. The island has been controlled by the British since 1657. The resident population is around 4,500. The capital, Jamestown, lies in the bottom of the James Valley which is some 400 m at its deepest.

Geologically, the island consists mainly of basalts and other igneous rocks. The basalts are interbedded with ash bands of various thicknesses which tend to erode rather faster than the strong basalts. As a result, the basalts become unsupported and rock falls occur. Vegetation on the valley slopes was removed fairly quickly by goats after the island became inhabited in the early 16th century.

In 1975, Martin Culshaw was sent to the island to carry out an investigation of the rock falls following concern expressed by the island's Council. He discovered newspaper records of rock falls from the middle of the 19th century, though they probably occurred from at least the time of the removal of the vegetation. The worst recorded rock fall occurred in 1890 when 9 people were killed by a fall from Pierie's Revenge (a large rock outcrop). At the turn of the 20th century, the UK military constructed pillars to support overhanging basalt lava flows. This followed a significant number of deaths from rock falls. Two people were killed by a rock fall after Culshaw left the island. The main output of the investigation was a detailed report and a map showing those parts of the valley sides that were the most likely sources of future rock falls. A paper was published about the rock falls by Culshaw & Bell (1992).

Early in the 21st century, Culshaw's investigation was repeated by a consultant and the valley sides around the Wharf were grouted to reduce the rock fall hazard. In 2010/11 some more of the valley sides were extensively netted to catch falling rocks.

As a result of the interest of an academic from the University of Witwatersrand, the two field notebooks (one simply a listing of all photographs taken) were digitised and the field maps scanned. The photographs themselves are held in the BGS's 'Imagebase.' However, the photos are not available to the public though can be viewed by making arrangements with the Survey.

7.1.6 South Wales landslide mapping and databasing

In April 1977, at the invitation of the Welsh Office, a two-year contract was let by the UK Department of the Environment (DoE) for a limited regional survey of the landslides in two areas (the east central coalfield and the north eastern coalfield) of the South Wales Coalfield. Subsequently, the survey was extended to cover the entire Coalfield area on a second DoE contract let between April 1979 and March 1981. The boundary of the South Wales Coalfield was taken as the junction between the Lower Coal Measures and the millstone Grit Series. The Coalfield covers an area of around 2 200 km^2, extending over much of the then counties of West and Mid Glamorgan and parts of Dyfed, Powys and Gwent. The Coalfield was divided into twenty-one valley areas, the boundaries largely following the line of the watershed.

The first part of the project was led by Paul Gostelow and the second part by Bernard Conway and the principal engineering geologists involved on the first part were Kevin Northmore and Stuart Duncan and the second part involved Kevin Northmore and Alan Forster. Pete Jackson and Pete Hobbs assisted at various times, together with voluntary workers and temporary staff. Bill Barclay and D I Jackson of the South Wales and Welsh Marches Unit provided advice and assistance throughout the project.

The objectives of the first part of the survey were to:

- Compare and classify landslide types.
- Relate landslides to particular stratigraphic horizons.
- Identify spring lines and investigate patterns of groundwater flow.
- Assess the effects of mining subsidence on slope stability.
- Indicate areas of present instability.
- Carry out stability analyses.
- Prepare an interim report outlining the results of the initial survey.

The second part of the survey's objectives were modifications of the earlier ones:

- To identify and classify landslide types.
- To map the distribution of landslides in relation to slopes, bedrock and superficial deposits.
- To indicate areas of present instability.
- To prepare a report with data presented as a series of landslide distribution maps and a catalogue of all mapped landslides in the coalfield area.

The survey was in two parts:

i. A desk study of all available map and aerial photograph information.

ii. A walk-over field examination and assessment.

Mapping was carried out at a scale of 1:10,560 or 1:10,000 depending upon the availability of topographic maps. 211 landslides were identified in the first part of the survey and 368 in the second, making a total of 579. The morphological features of each landslide were recorded in as much detail as the base map scale allowed. Also, photographs were taken. Valley side profiles were surveyed on selected stable and unstable slopes. Rock and soil samples were also taken for laboratory testing of geotechnical properties. Data collection was formalized by the use of a field data sheet system that ensured the systematic collection of information. These data sheets formed the basis of the information entered into the landslide database some 20+ years later. The report consisted of three parts: text (geology, physical features, hydrology and engineering geology, classification and distribution of landslides the landslide catalogue arranged in valley area order from west to east; the descriptions are accompanied by 35 photographs illustrating selected landslides) and maps (showing landslide distribution in relation to topography, bedrock geology, superficial geology and slope categories).

The data and findings of the research are contained in BGS report EG/80/4. The landslide catalogue information has been entered into the National Landslide Database (see above).

7.1.7 Dunbar Castle Rock, Scotland

On 21 January 1980, a fairly major rock fall blocked the harbour entrance. The EGU's Scottish office was commissioned by Lothian Regional Council in the summer of 1980 to:

- Establish the current safety of the north-east facing rock slope of Dunbar Harbour entrance.
- Summarise long-term stabilization options with recommendations.

Paul Gostelow and John Smellie carried out the work.

A 70-foot-high tower was built close to the north-east edge of Castle Rock. The tower and parts of a wall were removed prior to 1842 (the date of harbour completion) to create the new harbour entrance. Marine erosion and weathering over the next 140 years resulted in a gradual deterioration of the artificial slope and a major rock fall blocked the harbour entrance. A further failure would have endangered shipping, the castle and the public.

Rocks on both sides of the harbour entrance are volcanic in origin. Red, greenish grey lapilli tuff forms part of an intrusive volcanic neck surrounded by a yellowish white sandstone. Tuffs have been intruded by a dark purplish grey basaltic dyke.

A structural survey was carried out to determine rock strengths and the frequency and orientation of the discontinuities in the tuffs and basalt. Because of access problems, the survey was carried out using terrestrial photogrammetry (then a newish technique). Strength was measured using a Schmidt hammer. A series of slope sections were prepared. It was concluded that the wedge type failures were most likely triggered by marine erosion and undercutting. Three methods of stabilization were considered:

i. rock bolting;

ii. reducing the angle of the slope;

iii. construction of a retaining structure.

Option 3. Was recommended or possibly 1. and 3. depending on what more detailed investigation showed. The work was described by Gostelow & Smellie (1980).

7.1.8 Landslide risk to gas pipelines

7.1.8.1 HOLLY HILL LANDSLIDE, KENT

During the 1990's and 2000's a number of projects on landslide hazard in relation to commercial gas pipeline projects were carried out by the engineering geology team at BGS, usually in collaboration with the field geology team. One of the first of these was in 1989/90 at Holly Hill (6079E, 1610N), near Dargate in Kent, part of a wooded and hilly area known as 'The Blean.' Here, a significant landslide event had occurred in the mid-1960s on a north-facing, unwooded slope, upslope of a major gas main running cross-slope, the toe of which had already infringed on the corridor of the Faversham to Monkton 450 mm gas main that had been constructed in 1967.

The geology consists of up to 5 m of superficial Head Gravels overlying the London Clay Formation. The initial work, consisting of a desk study and ground investigation, was commissioned by British Gas Plc. (South Eastern) following several earlier investigations and studies. The ground investigation involved seven cored boreholes and seven trial pits. One borehole was drilled to a depth of 33 m reaching the Oldhaven Member of the Harwich Formation which underlies the London Clay Formation. During the planning stage, the presence of a line of WWII bomb craters on the slope, visible on historical aerial photographs, had to be taken into account to avoid potentially unexploded items (Hobbs 1988).

The EGU staff involved were Peter Hobbs, Phillip Waine, Jon Hallam, Michael Raines and Buzz Collins. The initial work had two follow-up tasks: a smaller ground investigation in woods to the east (Blean Wood), on the line of a proposed pipeline re-route (Hobbs et al. 1990), and a geophysical investigation of a legacy sheet-pile wall immediately upslope of the pipeline at the Holly Hill site (Hobbs & Raines 1993).

The landslides were of compound type exhibiting rotation, translation and flow modes. The investigation revealed multiple landslide shear planes, typically with slickensided and ‘blue’ gleyed surfaces. These suggested that the landslide was pre-existing and attempts were made during the site investigation to find material suitable for carbon dating (see below). Evidence pointed to many episodes of active landsliding. Aerial photographic evidence, assembled for the initial desk study, indicated that the most recent landslide had occurred between 1965 and 1967, *prior* to construction of the gas pipeline in the summer of 1967. This contradicted a commonly held view at the time (particularly within the ‘Dove’ public house at nearby Dargate!) that the pipeline installation had caused the (re-activation) landslide event. Over the following 20 years the landslide had widened and retrogressed, until by 1989 the toes of two flow lobes were close to crossing the pipeline corridor (Figure 14). The ground was found to contain a wide variety of discontinuities, particularly at shallow depth and, notably, not confined to areas of recent or mappable landsliding (Figure 15).

Figure 14 Central part of Holly Hill landslide complex (pipeline crosses left to right, foreground, at approximately 1.5 m depth).

The “Holly Hill” landslide was first described in a list of inland landslides compiled by Hutchinson (1967) as being of “undulating” type, with a footnote to the effect that ploughing may have reduced slope inclination. Hutchinson (1967) suggested two possible initiating factors for many inland slides: a) progressive reduction in shear strength due to weathering, and b) increases in pore water pressure possibly due to early medieval de-forestation or the ‘little ice age’ between 1550 and 1850.

The gas pipeline was installed during the summer of 1967. Site investigations at Holly Hill, to investigate the developing landslide, had been carried out in 1976 by Ground Explorations Ltd.

and in 1985 by Soil Instruments Ltd. Amongst other investigations were a topographic survey in 1984 and studies by drainage engineers and a water diviner. In 1971 a sheet-pile wall was installed parallel with, and immediately upslope of, the pipeline to protect it from the landslide. In addition, the area was graded and new field drains installed. In 1986 Stress Engineering Ltd. installed strain gauges directly onto the pipeline.

Figure 15 A variety of blue-gleyed and slickensided surfaces in Head and brown London Clay.

A subsequent investigation in Blean Wood, a short distance to the east of Holly Hill (Hobbs & Raines 1993), consisted of three trial pits, from which a sample of a sharply-bounded, horizontal peat band, situated within the London Clay, was taken for carbon dating. A pre-requisite was to make an estimate of the age. This was judged to be 11,000 years BP at the end of the last ice age. The actual date emerged as 11,157 years BP (+/- 50); not a bad guess! The peat was believed to have been the remains of a pond situated within the back-tilted zone of a former landslide, which had occurred entirely within weathered London Clay Formation. Geophysical and geotechnical measurements were also made in the trial pit walls but no drilling was carried out. At both the Holly Hill and the Blean Wood sites, a complex pattern of pervasive joints and shear planes was recorded. At Holly Hill these were found both within and without the presently active landslide, which appeared to have utilised these to form the main parts of its shear surfaces. Many of these features were found to be blue-gleyed and some slickensided (Figure 15 and 16). The pattern closely resembled that at three reported studies elsewhere on the London Clay Formation (Skempton & Petley 1967, Weeks 1969, Spink 1989). Block samples containing identifiable shear planes were obtained from the floor of trial pits for large-scale shear box tests to determine 'residual' shear strength on the planes (Figure 17). The trial pit walls themselves were found to be highly unstable, these tending to fail almost immediately (along the pre-existing blue-gleyed/slickensided shear planes) on removal of the temporary hydraulic props.

Following publication of BGS's findings, the section of pipeline at risk from the landslide was successfully re-routed over a length of about 1.2 km in 1994. Whilst it proved impossible to avoid landslipped ground altogether, the new route was selected to minimise its sidelong slope profile and hence its susceptibility to renewed landslide activity. As part of the Holly Hill survey, an aerial photogrammetric orthophoto map was produced. Subsequently, comparisons were made between this model and an aerial LiDAR survey carried out in 2003 (Ager *et al*. 2004). This produced displacement data which matched exactly observations made of the landslide in 2001, following some re-activation, and also in 2003.

Figure 16 Major slip plane (translational, slickensided/un-gleyed) in brown London Clay.

Figure 17 Preparation of undisturbed block sample (300 mm) in brown London Clay for large

7.1.8.2 OTHER PIPELINE INVESTIGATIONS & FEASIBILITY PROJECTS

During the late 1990's and early 2000's several commercial gas pipeline projects were carried out for British Gas, National Grid, Transco, PIE and their consultants, by the engineering geology team at BGS. The work was often, but not always, in connection with slope instability issues on either existing gas mains or proposed gas main routes, and usually in collaboration with the field geology team. One of the first of these was in 1989/90 at Holly Hill in Kent (see Section 7.1.8.1 above). Those major projects that qualified as ground investigations included Ben Rhydding (West Yorkshire) in 2001-2002 (Figure 17) (Gibson *et al.* 2001, Waters *et al.* 2001), Wormington to Sapperton (Cotswolds) in 2007-2010 (Figure 18) (Barron *et al.* 2007, Gibson *et al.* 2007, Hobbs *et al.* 2007) and Aislaby (North Yorkshire) in 2015 (Hobbs 2015). These tended to be spread over two or three years, involved close collaboration with the client organisations and featured several phases of work from desk study through geotechnical assessment and slope stability analysis to 3D modelling. Others, considered more as feasibility studies for proposed pipeline routes, were carried out between 1999 and 2002 and included Wooler to Moffat and St. Fergus to Haddington (Dumfriesshire), Chalgrove to Nuffield (Oxfordshire), Hatton to Silk Willoughby (Lincolnshire) (Sumbler *et al.* 1999) and Ilchester to Boddington (Northamptonshire). These had significant geological, geographical, geohazard and risk content and led to the development of semiautomated route assessments (Ager *et al*., 2004). BGS staff Involved in most of these projects included: Mark Barron, Colin Waters, Holger Kessler, Peter Hobbs, Andrew Gibson, Vanessa Banks, Anthony Morigi, Steven Booth, Michael Sumbler and Gisella Ager.

Figure 18 High pressure gas main investigation at Ben Rhydding, W. Yorkshire (2001).

Figure 19 Horizontal directional drilling at Hailes Bank, Wormington to Sapperton pipeline route (2010).

7.1.8.3 HAZARD ASSESSMENT FOR THE NATIONAL GAS AND ETHYLENE PIPELINE NETWORKS

Two generic projects were commissioned by Advantica for Transco in relation to the national gas pipeline network in 2003. The projects were concerned not only with landslide hazard but also with that posed by the dissolution of more soluble rocks. The research involved collating available information regarding landsliding and dissolution across Great Britain and presenting it in a way meaningful to pipeline operators (Cooper *et al.* 2003, Forster *et al.* 2003). Six hazard zones were developed separately for both landsliding and dissolution. These ranged from Class 0 in which the hazard was not likely under present conditions through to Class 5 were the hazard was almost certainly present and may be active. In 2005, a further report was commissioned to investigate in more detail the nature, scale and spatial distribution of recorded landslides that may affect the pipeline network – specifically the location, length, width, landslide type and incremental movement rate of landslides affecting the network (Gibson *et al.* 2005).

In 2005, Huntsman Petrochemicals commissioned two reports, similar to those commissioned for Transco in 2003, to assess landslide and dissolution hazards in relation to the national ethylene pipeline network (Cooper *et al.* 2005, Forster *et al.* 2005).

7.1.9 Landslide at St Dogmaels, Pembrokeshire, South Wales

In 1993, a significant landslide took place near St Dogmaels in Pembrokeshire, South Wales. Preseli Pembrokeshire District Council asked EGU to carry out preliminary investigations of the landslide. This took place in February 1994 and the investigation consisted of a desk study, engineering geomorphological mapping and an electrical resistivity geophysical survey. The purpose was to identify surface features relating to the landslide, to provide an indication of the depth to rockhead, to characterize the electrical properties of the soils and rocks and to identify any existing documents relevant to the landslide. The report (Hobbs *et al.* 1994) contributed to the design of the sub-surface investigation and interpretation of the causes of the landslide and to the design of remedial measures to stabilize it.

A 1:1,250 scale engineering geomorphological map was produced. The mapping showed that the landslide was probably a complex, multiple regressive debris/earth slide with several components, comprising rotational, translational and flow movements. Movements had been in one direction only. The main landslide probably took place at the end of the last glaciation. Circumstantial evidence indicated that there had been little movement for at least 200 years. Causative factors that may have contributed to the landslide were:

- large volumes of surface and, maybe, subsurface water entering the landslide due to climate and drainage changes and to inadequate artificial drainage;
- the placement of fill material at the top of the landslide at Pencnwc Farm;
- removal of trees from the landslide;
- removal and/or redistribution of natural material from the lower part of the landslide;
- absence of piped drainage from the houses built on the landslide.

Electrical soundings showed possible superficial deposit thickness in the range 50-60 m. Further investigations were recommended.

7.1.10 Rapid methods of landslide hazard mapping based on work in Papua New Guinea, Fiji, Jamaica and Slovakia

The background to the research is given in the section on overseas work below. The work was based on the hypothesis that a map showing the distribution of landslide hazards can help planners to prepare for, and/or mitigate against, the effects of landsliding on communities and infrastructure, and also avoid or minimize the risks associated with new developments.

The approach combined the use of remote sensing and a geographic information system (GIS). Remote sensing methods and GIS software were both developing fast in the 1990s when the project took place (1993-5 and 1998-2000). The underlying principle was that the relationships between past landsliding events, interpreted from remote sensing, the geology, relief, soils etc. provided the basis for modelling where future landslides are most likely to occur. This was achieved using a GIS by weighting each class of each variable (for example, each lithology ‘class’ of the variable ‘geology’) according to the proportion of landslides occurring within it compared to the regional average. Combinations of variables, produced by summing the weights in individual classes, provided ‘models’ of landslide probability. The approach was empirical but had the advantage of potentially being able to provide regional scale hazard maps over large areas quickly and cheaply. The production of particular landslide hazard zonation maps was regarded as an incidental product rather than the main objective. The main purpose of the case studies was to identify a practical methodology and to define both benefits and limitations.

Research was carried out in Papua New Guinea and Fiji and included ground checking visits to sites in the two countries. It was concluded that the methods were capable of providing provisional hazard maps at the regional scale, cost effectively and in a realisable time frame. It was recommended that further consideration was given to implementing such techniques and checking them in other geological and environmental situations.

As the first part of the project was focused on geologically very young and active terrains, the second part, in Jamaica and Slovakia, was aimed at extending the methodology to other regions to develop a generic approach that could be applied more generally to developing countries worldwide. It would be interesting to revisit the methodology proposed in 2000 in the light of the rapid development of remote sensing and digital mapping methods over the last twenty years.

It is worth noting that the two-phase project described above was regarded as a BGS Overseas Division one. Whilst the knowledge of remote sensing techniques undoubtedly was found in the Overseas Division, the knowledge and understanding of landslides was a main strength of EGU and Kevin Northmore provided this to the project.

The various project reports (Greenbaum 1995, Greenbaum *et al.* 1995a, b, Greenbaum *et al.* 2000, Marsh 2000, Northmore *et al.* 2000, O'Connor *et al,* 2000) can be found in the references as they are not EGU project reports and so are not listed in the Appendices.

7.1.11 Fault reactivation and landslides

The EGU (Laurance Donnelly) investigated the mining-induced reactivation of faults and how this varied across the coalfields in the United Kingdom. These were observed to cause damage to land, houses, roads, railways, engineered structures (bridges, tunnels, dams) and utilities (sewers, pipelines, cables). Disputed cases of fault reactivation have resulted in Land Tribunals and claims for compensation for damage to land and property, often incurring significant financial losses. In other cases, investigated flooding and gas emissions were recorded. The research concluded that several phases of fault reactivation are possible during multi-seam (3+) mining operations, separated by periods of relative stability. In some circumstances, such as minewater rebound or residual mining subsidence, further movements along a previously reactivated fault are possible. Several papers and BGS internal documents were produced to offer guidance on the management and mitigation of hazards associated with faulted ground in the engineering and insurance industries (Donnelly *et al.* 2019a).

In particular, Laurance Donnelly investigated the mechanisms of fault reactivation during mining subsidence. The consequence is the generation of fault scarps on the ground surface and complex fissure networks that caused damage to engineered structures and land by the appearance of fault scarps (also known as 'steps' by subsidence engineers). However, in the South Wales Coalfield fault scarps and ground fissures occur on the moorland plateaux and valley interfluves. These differed significantly from other cases of mining-induced fault reactivation recorded in the coalfields of the UK due to their magnitude and extent, being up to 4 m high and 3-4 km long. It was observed that large, rotational-slip landslides developed in association with the fault scarps, where the faults and grabens intersected the valley crests. It was possible that the reactivated faults might have played an important role in the initiation of first-time slope movements and the reactivation of existing landslides. However, extensive mining has taken place in the Welsh valleys in the past couple of hundreds of years. The geological evidence suggests that mining subsidence also reactivated the faults. The fault scarps probably represent several phases of reactivation during the deglaciation of the valley sides causing lateral spreading of the valley interfluves and graben generation.

References include: Donnelly *et al.* 2000, 2009a, 2010a, b, Donnelly & Fuks 2010

7.1.12 Engineering geology of historical heritage sites in Scotland

'Historic Scotland' is a Government Agency with an aim to understand, protect and provide access to Scotland's heritage that includes prehistoric and historic monuments. The BGS EGU investigated three high-profile sites for Historic Scotland at Edinburgh Castle, Dumbarton Castle and Smailholme Tower. Each of the structures were built on igneous rock masses that had become weathered and unstable in places. The instability generated small to moderate rock falls and, in the case of Edinburgh Castle, there was a landslide back-scarp developing in the made ground and superficial deposits between Johnstone Terrance and the Esplanade, on the south side of the castle (Donnelly *et al.* 1998). The rock and slope instability of these three sites were potential hazards for the visiting public and also negatively impacted on the instability of the historical site, causing damage to parts of the buildings and ancient monuments. Detailed field mapping of the rock mass discontinuities and the determination of the relative strength of the rock mass enabled likely failure mechanisms to be determined. The rock mass was subsequently zoned into categories of areas of low, moderate and high risk, depending on the proximity of a potential rock fall failure to an area where the public may visit or where this impinged on part of the historical structures. The modes of failure were complex and included toppling failure, wedge failure, translational sliding failure and rotational slip failure where there were soils or superficial deposits (Donnelly *et al.* 2005)

At Edinburgh Castle it was necessary to engage the services of a roped access specialist sub-contractor for the safe access to the unstable slope. Once a safe operating system had been established this enabled the digging of trial pits into the slope and the implementation of geophysical surveys using 2D resistivity. The trial pit logs and results of the resistivity traverses permitted the failure mechanisms to be determined. These were controlled by the steep slope angle, weak engineering properties of the loose, uncompact made ground on the 'tail' part of the 'crag and tail' structure, and areas of increased porosity and permeability with zones of saturation in the made ground. Collaboration with geotechnical slope stability consultancies enabled the slope at Edinburgh Castle, Dumbarton Castle and Smailholme Tower to become stabilised using a combination of rock bolts and mesh, and soil nails (Donnelly *et al.* 1997*a*, b). These protective methods ensured the protection and integrity of the historical sites and the safety of the visiting public.

7.1.13 Northern Ireland, Antrim coast landslide hazard zoning

In 1997/8, the Northern Ireland Geological Survey asked EGU (then called the Coastal and Engineering Geology Group) to carry out a landslide hazard assessment for land-use planners of a part of the Antrim Coast. The purpose was to show politicians and administrators that apparently hazardous areas were not necessarily ‘blighted’ by landslides, or other geohazards, and that actions (such as walk-over survey through to a full ground investigation) could be used to ensure that safe use of the land could be made.

The Antrim Coast was chosen for the study because it is heavily landslipped but also because few people live there. This may seem odd but one of the objectives of the study was not to alarm politicians and administrators by showing landslide hazard in populated areas in the first instance. It was hoped that having seen that little land was likely to be blighted, they might go on to commission further work in the north Belfast area, where the geological conditions are similar to Antrim. However, this never happened.

Six coloured maps were produced that combined to produce the final Ground Classification map:

- Topographic base map
- Geological base map
- Aerial photographic interpretation
- Slope angle
- Hydrogeological factors
- Ground classification

The maps produced were in colour. A report was produced (Forster 1998) and, later, a paper was published that included the Antrim coast work (Cripps *et al.* 2002).

7.1.14 Beachy Head cliff stability surveys

Slope stability and geophysical field surveys were carried out for Trinity House Lighthouse Service, initially during 1999 and 2000 following a major, nationally reported, rock slide of the 125m chalk cliff immediately behind the unmanned Beachy Head lighthouse, which severed the electricity supply to the light on 12 January 1999. The cables were suspended from a concrete bunker on the cliff top, which was situated at the easternmost end of the rock slide. Loss of power necessitated in the installation of emergency staff and generators. The debris from the rock slide, estimated at 260,000 tonnes, reached to within 40 m of the base of the lighthouse. An unstable block remaining attached to the cliff for a few weeks after the main slide delayed engineering works (Figure 20) and finally failed on 8 April 1999. Tension crack development was found to be a key stability factor. Further visits to the site to check on stability continued every one to two years until about 2007.

Figure 20 Pre- and post- rock slide of 8 April 1999 at Beachy Head.

7.1.15 Slope dynamics project

The 'Slope Dynamics Project' was initiated in 1999 and funded by the BGS's Science Budget/Core Programme. The project was seen as a linking contribution to the activities of the newly created Coastal and Engineering Geology Group. The project's purpose was to examine, in detail, the processes of coastal landsliding on natural cliffs over extended periods, using state-of-the-art geomatics and geotechnical methods, and to determine its contribution to coastal erosion. Initially, 12 test sites around the English coast were selected and monitored for a trial period to cover a wide range of stratigraphies, lithologies, scales and landslide modes. These sites are summarized in Table 5. The project team consisted of Peter Hobbs, Lee Jones, Matthew Kirkham and Catherine Pennington with many other colleagues and students contributing. As the project developed it became clear that regular monitoring of so many, widely separated sites was impractical and the number was reduced to four: the three North Norfolk sites plus Aldbrough. Subsequently, this was reduced to one, Aldbrough, on the Holderness coast of the East Riding of Yorkshire.

The Aldbrough site, dubbed BGS's 'Coastal Landslide Observatory' (CLO), has been monitored at three monthly intervals from 2000 to 2020, with only a few interruptions. The principal method was ground surface modelling using Terrestrial LiDAR (TLS). At the turn of the century this method was in its infancy and the BGS was amongst the first in the UK to use it for engineering geological applications; initially by buying in the expertise from a start-up company, 3D Laser Mapping Ltd., and then by acquiring the systems in-house. Since then, a wealth of expertise and continual upgrading of both TLS and GPS/GNSS equipment and software has taken place in BGS under the banner 'Geomatics' led by Lee Jones and assisted by Matthew Kirkham (Jones & Hobbs 2021). As a direct result of the development of these capabilities, several commercial contracts were obtained between 2004 and 2019, principally concerned with slope instability, both in the UK (coastal and inland) and overseas, but also including surveys of caves, tunnels, estuaries, quarries and geological type-sections.

The aim of the monitoring was to make accurate 3D models of the ground surface of the cliff, beach and hinterland and to compare with the results from previous visits to the same area) thus giving a series of 'change models' showing the geomorphological processes occurring and providing the basis for 'volume lost' calculations and slope stability analyses. In 2012 and 2015 this was augmented by two phases of borehole installation, landward of the clifftop, that were fitted with instrumentation (inclinometer casing and piezometers), and also a weather station nearby. Aerial photogrammetry from a drone platform was successfully trialled. This tended to be used to provide a general overview and to fill in gaps where sections of cliff were not visible from the ground. A major advantage was that these drone data could be added to the TLS data, as indeed could Aerial LiDAR (from full-sized aircraft), with minimal post-processing.

Site	Geology	Easting	Northing	Width (m)	Monitoring period
Ware Cliff (Lyme Regis, Dorset)	Blue Lias, Jurassic	332747	90954	850	2000 - 2004
Black Ven (Lyme Regis, Dorset)	Charmouth mudstone, Jura	334823	93021	1,200	2000 - 2004
Stonebarrow Hill (Charmouth, Dorset)	Gault, Dyrham, Lias	337167	93017	1,000	2000 - 2004
Beachy Head (Sussex)	Chalk, Cretaceous	558400	95120	350	2000 – 2004#
Folkestone Warren (Capel-le-Ferne, Kent)	Chalk, Cretaceous	625788	138446	200	2000 - 2004
Warden Point (Isle of Sheppey, Kent)	London Clay, Ypresian	601776	172644	425	2000 - 2004
Weybourne (N. Norfolk)	Glacial Deposits	611367	343672	100	2000 - 2006
Sidestrand (N. Norfolk)	Glacial Deposits	626500	339797	600	2000 – 2017*
Happisburgh (N. Norfolk)	Glacial Deposits	638600	330896	350	2000 – 2017*
Aldbrough (East Riding of Yorkshire)	Glacial Deposits	525730	439735	300	2001 - 2020
Robin Hood's Bay (N. Yorkshire)	Glacial Deposits	495378	504787	320	2000 - 2005
Speeton Sands (N. Yorkshire)	Speeton Clay, Cretaceous	514337	476198	520	2000 - 2005

*Irregular intervals after 2006

Coincided with period of monitoring for Trinity House at Beachy Head lighthouse

Table 5 Slope Dynamics Project test and monitoring locations.

The results showed that the cycle of major landslide initiation at Aldbrough was between 6 and 7 years based on three major landslide events at the site. Results from the highly accurate digital inclinometer probe notably 'predicted' the last of these in February 2017 (Figure 21) with a classic S-shaped displacement curve beginning about 15 months prior to the event and with the event itself occurring at the steepest portion of the curve (Figure 22). As the borehole containing the inclinometer was, at the time, several metres landward of the landslide the results were interpreted as the sequence: increase, *failure* and decrease of lateral stresses behind the cliff face. Overall seaward displacements recorded by the inclinometer were of the order of hundreds of millimetres. The majority of data recorded was non-telemetric, that is, the site had to be visited to take measurements or to download data logged on site.

Relationships between storm, wave and rainfall with volumetric loss from the cliff were demonstrated over a period of years. It was more difficult to provide causal links. This was probably due to a temporal disconnect between coastal erosion, its effect on stress relief and finally the onset of landsliding. It was demonstrated that displacements consistently originated at a depth of 12 m, that they had a nett seaward (ENE) direction overall and that they increased proportionately with proximity to the cliff and to the ground surface. It was shown that landslide embayments remained intact over the monitoring period that each major rotational event occupied all, or nearly all, of the embayment and that each embayment migrated westward rather than along the coast as had been suggested. The key role of the thin and weak Dimlington Bed (silt and silty clay susceptible to liquefaction) in determining the mode and morphology of the landslides was clearly shown and was backed up by geotechnical laboratory testing.

Figure 21 Backscarp of fresh landslide event (14th February 2017).

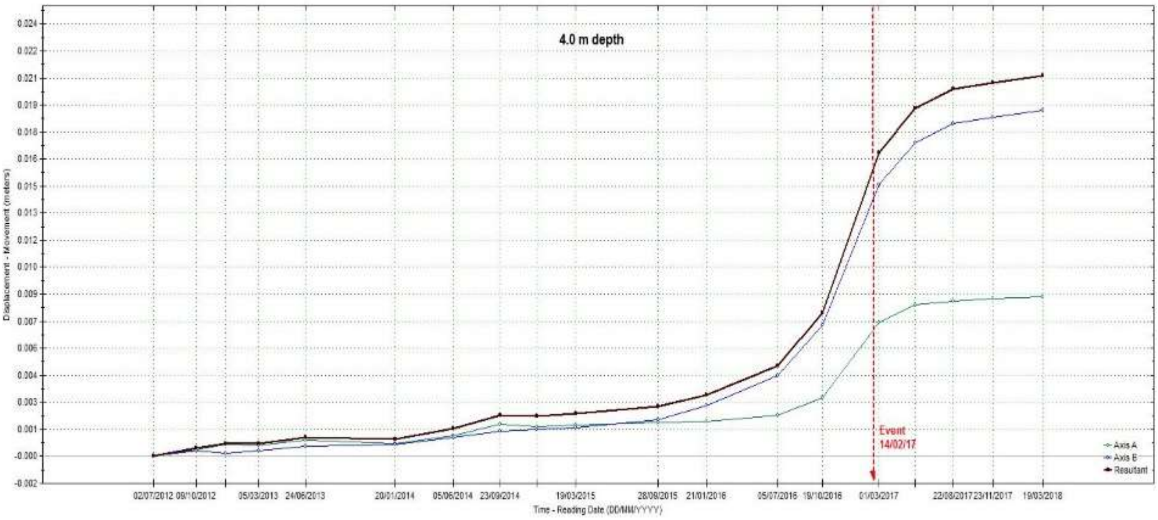


Figure 22 Plot of inclinometer displacements between 2012 and 2018 showing the landslide event of 14 February 2017.

Due to the site visit timings, the methodology employed did not allow every detail of geomorphic processes on the cliff to be measured but was able to elucidate the long-term cycles of landslide activity and to study their relationship to extreme rainfall events, storms and wave data. Several papers and reports were published between 2001 to 2018. In 2021 the project was suspended to allow a re-appraisal to take place and to introduce new technologies and a revised team.

7.1.16 Coastal landslide at Nefyn, Gwynedd

0n 2 January 2001, a landslide occurred in part of the sea cliff at Nefyn, Gwynedd, North Wales. Tragically, a man was killed and his wife seriously injured. A road runs down from above the cliff to sea level. The lower part runs parallel to the coast and on this part cars are parked pointing towards the sea. The debris flow occurred above the road in two phases. The first of these pushed several cars right to the very edge of the road. One of the cars was occupied by two people and a dog. However, they could not get out of the car because the doors were blocked by the debris flow. Passers-by suggested that the two people climb out of the car windows with their help. The two people did not feel capable of this but passed the dog out. Shortly afterwards, a second debris flow occurred that swept the car over the edge, killing one passenger and seriously injuring the other.

The cliffs that make up the bay run south westwards between two rock headlands, Penryn Bodeilas, to the north east, and Penryn Nefn, to the south west. The small town of Nefyn lies close to the south west end of the bay. The cliffs are mainly made up of three suites of material of glacio-fluvial origin (Gibson & Humpage 2001, 2002; Gibson *et al.* 2002). These were probably deposited at the margin of a retreating ice-front towards the end of the Devensian glaciation. Three separate 'Sediment Suites' were identified. The debris flows originated from the third of these. Sediment Suite III contains a heterogeneous mix of glacial, glacio-fluvial, glacio-lacustrine, periglacial and aeolian deposits. The various lithological units are as follows:

- Soft to firm, brown, sandy silt
- Impersistent beds of soft, grey, laminated clay and soft grey massive silt
- Cobble–gravel bed bound by calcareous cement and almost impermeable
- Lower sand and gravel unit (mainly fine to coarse grained sand with localized lenses of gravel)
- Grey till

A number of isolated bodies of grey silt were also identified and these steep-sided, bowl-shaped features are thought to be infilled kettle holes. Thin deposits of head and yellow silt (probably loess) are found on the cliff top. Gibson and Humpage (2002) carried out a hazard zonation of the coast of the Bay with the Nefyn area falling into a very high hazard zone.

In the summer of 2001, Martin Culshaw was summoned to the magistrate's court in Pwllheli to give evidence at the inquest into the death of the man at the site of the landslide.

In the spring of 2021 a further landslide occurred about 2-300 m north east of the 2001 landslide. The toe of the slip plane was located just above the relatively impermeable, cemented cobble-gravel referred to above. The backscarp of the landslide ended up around 10 m from the rear wall of a bungalow built before the 2001 landslide.

7.1.17 Scottish road network landslide study

In August 2004 a period of unusually high rainfall triggered some major debris flows that blocked the A83 between Glen Kinglas and to the north of Cairndow, the A9 to the north of Dunkeld and the A85 at Glen Ogle (Winter *et al.* 2006). The Scottish Executive commissioned a major study of the problem (Winter *et al.* 2005). As part of this study, the EGU was asked by Transport Scotland to address the following: "Development of a debris flow hazard and exposure assessment system based on existing digital datasets to provide a preliminary hazard ranking of 'at-risk' areas of the road network." Three data sources were used for the study as they covered the entire study area:

i. BGS DiGMap. GIS layers of geology at 1:50,000 scale showing bedrock and superficial deposits.

ii. NEXTMap Britain. A high-resolution digital terrain model generated from a 2005 airborne survey in Scotland and derived from the INTERMAP Digital Terrain Model product.

iii. Centre of Ecology and Hydrology land use data, a digital map that gives a comprehensive picture of the UK Broad Habitat.

Five main components were considered to be required to determine the hazard potential of debris flows affecting the road network:

i. Availability of debris material.
ii. Hydrogeological conditions.
iii. Land use.
iv. Proximity of stream channels.
v. Slope angle.

Five classes of debris flow hazard were determined and mapped against the Scottish Trunk Road Network. This then allowed priority areas to be identified (Harrison *et al.* 2006).

7.1.18 Landslide hazard assessment for forestry

The Forestry Commission (FC) is a non-ministerial government department responsible for publicly-owned forest in Great Britain. The organisation has separate, but linked, management units for England, Scotland and Wales; 60% of its land is in Scotland, 26% in England and 14% in Wales. The FC in Scotland and Wales asked the British Geological Survey (with the Transport Research Laboratory, [TRL in Scotland]) to carry out a study to identify and quantify landslide hazards that had the potential to affect third party assets such as infrastructure, property and communities. This was carried out between 2008 and 2011 (Foster *et al.* 2012) as a desk-based investigation designed to analyse a range of information, including the BGS National Landslide Database, National Digital Geological Mapping (DiGMap50), landslide potential maps ('GeoSure' and 'DebrisFlow') and information from published literature. These resources were used to 'score' key landslide characteristics and, where necessary, estimate the magnitude and extent of the hazard, using a custom geographical information system (GIS) combined with an established algorithm used to assess the susceptibility to landslide hazard and the likelihood of its impact on third party assets. These data were then interrogated by expert geologists to determine those areas of known landslides or known landslide susceptibility that may impinge upon, or affect, managed Forestry Commission land and assets. For areas in which a high landslide potential was identified, pro-formas were completed that gave detailed information on the geological and geomorphological conditions, any known and recorded landslides, assets at risk and a scoring of the landslide hazard (Figure 23a) and likelihood (Figure 23b). The outputs from this study consisted of an attributed GIS and an accompanying set of aforementioned detailed pro-formas.

The study results are now contributing to the management and maintenance of Forestry Commission assets in Scotland and Wales. Table 6 shows the elements of the rating system used for slope instability in GeoSure. Tables 7 and 8 show how the different scores were determined.

The project was led by Claire Dashwood (nee Foster). The work was subsequently extended, using similar methodology, to locations in England on behalf of Forestry Commission England.

Rating	GeoSure Slope Instability Layer
A	No indicators for slope instability identified.
B	Slope instability problems are unlikely to be present.
C	Slope instability problems may be present or anticipated.
D	Slope instability problems are probably present or have occurred in the past.
E	Slope instability problems almost certainly present.

Table 6 Descriptions for the five ratings of slope instability within GeoSure.

Score	Run-out (L)
1	Outside likely run-out distance
2	Outside of distance for any new slides but within run-out distance for reactivations
3	Within run-out distance (extremes/first time failures)
4	Within run-out distance (most cases)
5	0m to asset

Table 7 Rating system for likelihood incorporating runout.

Score	Impediment Factor	Example
1	Landslide must cross a river	
2	Adverse topography	Slide needs to go up hill to reach asset.
3	Slide path goes against topography	Generally down slope but asset may be out of the direct path of a landslide or obstacles intervene.
4	Way is clear but slope is shallow	Low slope angles between landslide and asset.
5	Way is clear but slope is steep	Steep slope, run out more likely to reach asset.

Table 8 Impediment factor for inclusion in likelihood score.

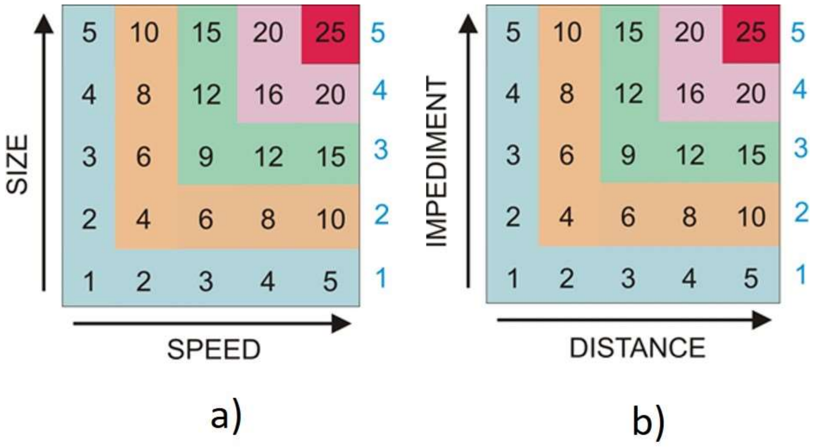


Figure 23 Score matrix for 'hazard (a) and ‘likelihood’ (b).' The overall score (1-5), given as the first number in pro-formas, is shown on the right of the diagram.

7.1.19 North York Moors landslide mapping

The BGS developed a multi-stage methodology for landslide mapping by augmenting traditional mapping techniques with new geospatial technologies (Jordan *et al*. 2016). This used traditional field mapping techniques combined with 3-D aerial photograph interpretation, variable-perspective 3-D topographic visualisation and digital data capture, applied through a series of strategic (national and regional-scale), repeat (recurring local) and responsive (rapid-deployment, site specific) surveys. This method allowed better characterisation and understanding of the country's landslides: an essential requirement for landslide susceptibility modelling, risk assessment and resilient infrastructure planning. In 2012 the BGS methodology was applied to the North York Moors National Park in northern England, UK: an area with steep slopes, landslide-prone lithologies and an exposed coastal section but few recorded landslide events. Over 550 landslides were identified (Figure 24) and data on the characteristics and mechanisms of these were used to inform the National Landslide Database, the National Landslide Domains Map and the National Geohazard Assessment (Jordan *et al*. 2018). A detailed investigation of a characteristic large-scale relict landslide was undertaken utilising high resolution airborne LiDAR, boreholes, geomorphological mapping and geophysical techniques to investigate the mode of failure and the potential for reactivation under future climatic conditions (Boon *et al*. 2015).

In terms of landslide activity, two main forms of failure are evident: large-scale, deep-seated failures (often slides) (for example, Figure 25) and smaller-scale, shallow failures (typically earth flows and/or slides). The degree of degradation and geomorphology of the large-scale features suggested development under Pleistocene periglacial conditions. Very fresh, shallow features show that the processes responsible for triggering the smaller-magnitude landslides are still active.

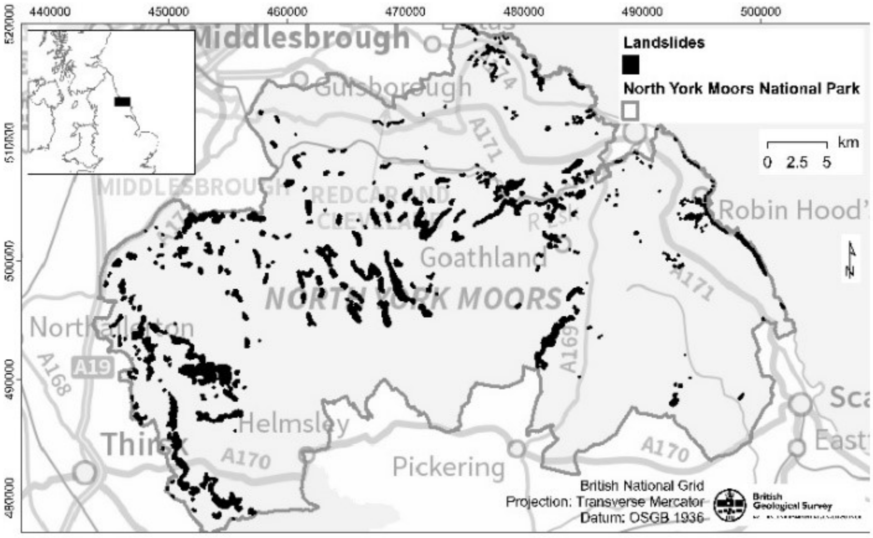


Figure 24 Landslide distribution in the North York Moors National Park. Contains Ordnance Survey data © Crown Copyright and database rights 2015.

Figure 25 The Mark Nab landslide in the North York Moors National Park (Great Fryup Dale, NGR 471368, 502842. Photo: A. Cooper.

7.1.20 Miscellaneous BGS-funded projects 2012 – 2015

- BGS landslide database analysis,
- Landslide impact inventory establishment,
- Modelling the trigger effects of weather event sequences on shallow translational landslides,' £50k

This suite of research projects considered the effects of antecedent precipitation on landslide incidence in the UK. During 2012-2013 an extraordinary amount of precipitation resulted in an increase in the number of landslides reported in the UK, highlighting the importance of hydrogeological triggering. Slope failures (landslides on engineered slopes), in particular, caused widespread disruption to transport services and damage to property. South-West England and South Wales were most affected. Easy-to-use and accessible indicators of potential landslide activity are required for planning, preparedness and response and, therefore, analyses have been carried out to determine whether antecedent effective precipitation can be used as a proxy for landslide incidence. It was shown that for all landslides long-term antecedent precipitation provides an important preparatory factor and that relatively small landslides, such as slope failures, occur within a short period of time following subsequent heavy precipitation. Deep-seated, rotational landslides have a longer response time as their pathway to instability follows a much more complex hydrogeological response. Statistical analyses of the BGS landslide database and of weather records enabled determination of the probability of at least one landslide occurring based on antecedent precipitation signals for South-West England and South Wales. This research was part of a suite of analyses to provide tools to identify the likelihood of regional landslides occurrence in the UK (Pennington *et al.* 2014).

7.1.21 Landslides and Climate: Scottish Government funded projects (2016)

- Complexities and delays in the precipitation-runoff-soil water-groundwater-deformation cascade
- Early warning systems for landslides
- Workshop with Norwegian landslide experts from NVE, Oslo
- Triggering conditions for landslide early warning

The Scottish Government National Centre for Resilience (NCR) was launched towards the end of March 2016. Devolved UK Government means that resilience management issues are prioritised in different ways. Scottish interests are in wind, flooding and landslides, particularly because of the catastrophic impacts on road and rail infrastructure.

Following discussions with the Scottish NCR, the Health and Safety Laboratory (HSL) was awarded a grant for a project in connection with further development of the Hazard Impact Framework (HIF). The HIF work involved developing guidelines, quality standards and a consistent approach to underpin the development of current and future natural hazards capabilities. This funding supported three tasks led by the BGS.

- Task 1: Establish case studies of deep-seated rotational landslides to evaluate the complexities and delays in the precipitation-runoff-soil water-groundwater-deformation cascade.
- Task 2: A workshop with Norwegian colleagues to compare and learn about the methodologies used in Norway for early warning
- Task 3: Analysis of Scottish landslides (2004-2015) to identify triggering conditions to aid the development of a landslide early warning system for Scotland.

The British Geological Survey (BGS) has a long track record of landslide-related research. This has resulted in products such as the National Landslides Database (NLD) containing more than 17,000 landslide events and GeoSure that captures knowledge on the spatial variation of landslide susceptibility. BGS, a member of the Natural Hazards Partnership (NHP), was responsible for the issuing of Daily Landslide Hazard Assessments (DLHA) that were communicated to the wider responder communities (category 1 and 2 responders) through the Hazard Manager portal operated by the Met Office (MO).

The Norwegian Water Resources and Energy Directorate (Norges vassdrags-og energidirektorat or NVE) was responsible for the management of Norway's water and energy resources. NVE's mandate was to ensure an integrated and environmentally sound management of the country's water resources, promote efficient energy markets and cost-effective energy systems and contribute to efficient energy use. The Directorate plays a central role in the national flood contingency planning and bears overall responsibility for maintaining national power supplies. NVE was involved in research and development in its fields and was the national centre of expertise for hydrology in Norway. From 2009 NVE were assigned greater responsibility for the prevention of damage caused by landslides. As part of this responsibility, NVE issued daily landslide hazard assessments and has developed a broad range of communication tools.

Both NVE and BGS were developing their capabilities for the daily assessment of landslide hazard across their respective countries. Great Britain (GB) and coastal Norway share a common humid oceanic climate and annually receive precipitation in the form of cyclonic low-pressure systems or as extra-tropical storms that travel across the Atlantic. Extreme meteorological events capable of triggering floods and landslides were becoming more frequent, with both GB and Norway being affected by a sequence of record-breaking precipitation events in the past decade. BGS and NVE have similar interests, particularly focused on communications and weather assessments for hazard reporting. BGS was interested in the workflow systems, landslide modelling approaches and communication channels at NVE. NVE expressed an interest in BGS experience with landslide event analysis, National Landslide Database analysis, weather types and information sharing as part of the Natural Hazard Partnership and the analysis of impacts on transport infrastructure.

These projects resulted in an improved insight into the precipitation response mechanisms of unstable slopes across Scotland. In the absence of reliable data, the method developed involved characterisation of the dominant surface materials on a 1km^2 grid (informed by the BGS surface lithology base layer) and apply a 1D soil moisture balance using three classes of voids (macro, meso and micro, with boundary conditions governed by free drainage [33 kPa suction] and permanent wilting [1,500 kPa suction]). The potential for triggering landslides was governed by a comparison of the antecedent soil moisture status and the forecasted next day precipitation. The model was normalised against long-term seasonal precipitation (with lower thresholds in the drier east and north-east of the country, for example). This provided a dynamic and regionally specific assessment of landslide triggering that could be used to inform the daily landslide hazard assessments as part of the suite of forecasts of the Natural Hazards Partnership (Dijkstra *et al.* 2014 and 2016a).

7.1.22 Landslide Risk Assessment: ESA/World Bank funded project (2014 – 2015)

Caribbean Earth Observation multi-temporal landslide risk assessment project, £84k

The primary objective of this ESA project was to raise awareness within the World Bank (WB) of the capabilities of Earth Observation (EO) data and specialist service providers to supply information customised to the specific needs of individual projects. This project was set up within the ESA/WB geoworld initiative to contribute to the WB Caribbean Risk Information Program that was operating under a grant from the ACP-EU Natural Risk Reduction Program.

The Caribbean is heavily affected by natural (and geo-) hazards with over US$5 billion in losses in the last 20 years (source: CRED database). A specific example of the environmental, social, economic and political issues that the project was addressing was highlighted by the effects of Hurricane Tomas on St Lucia in October 2010. The hurricane resulted in seven deaths with 5,952 people severely affected, while the cost of the damage was estimated at US$336.2 million, representing 43.4% of gross domestic product (ECLAC, 2011). Understanding and mitigating these 'geo-environmental disasters' (as they are termed in ECLAC, 2011) is a primary concern in the region. The ITC-led Caribbean Handbook for Disaster Information Management (CHARIM) operates in five Caribbean countries (Belize, Dominica, Saint Lucia, St Vincent & the Grenadines and Grenada). CHARIM has several objectives including developing a structure for landslide and flood hazard and risk assessment. This ESA project is focused on "risk information services for disaster risk management in the Caribbean" a title that has been abbreviated to EO-RISC (Earth Observation for Risk Information Services in the Caribbean) internally by BGS. EO-RISC deliverables directly contributed to the CHARIM objectives, for example, by providing data and services that enabled certain hazards, such as landslides, to be identified directly.

EO-RISC was addressing various issues in the Caribbean. In broad terms, the Latin America and Caribbean Regional Urban and Disaster Risk Management Unit (GPSURR), with funding from the ACP-EU Natural Disaster Risk Reduction Program, managed by the Global Facility for Disaster Reduction Recovery (GFDRR) has begun the "Caribbean Risk Information Programme to support the Integration of Disaster Risk Management Strategies in Critical Sectors" project. This has been initiated to strengthen the regional and national capacity to create and use hazard and risk information for planning and development processes, and consists of four components:

i. creation of a geospatial information basis, focusing on the collation, quality control and adequate storing, management and sharing of existing geospatial data in a spatial data infrastructure;

ii. development of a methodological framework for the development of hazard and risk information for development and planning processes;

iii. implementation of five national pilot hazard studies aimed at implementing the methodological framework in partnership with Caribbean countries, and

iv. integrating institutional strengthening as a cross-cutting activity to all components.

The Caribbean Risk Information Programme formed part of the Probabilistic Risk Assessment (CAPRA) Program whose objective was to enhance the capacity of targeted sectors in Latin America and the Caribbean Region to develop and mainstream disaster risk information into development programs and policies by providing knowledge products and services. Counterpart agencies were the Ministries of Works and Physical Planning in the following countries: Belize, Dominica, Grenada St. Lucia and St. Vincent and the Grenadines. With a focus on national-level landslide and flood hazard assessments, country-wide baseline data and information are required. They span a broad range such as: Land Use/Land Cover, updating of river and stream courses, extent of lakes, water bodies, and watersheds, basic road network, landslide inventory, digital elevation models, geology including fault lines, geomorphology, soil maps, etc. (Jordan *et al.* 2015).

7.1.23 National Capability landslide projects

Response to SAGE/COBR request to assess landslide impact following the 2015 Nepal Earthquake. Collaboration with Durham University, UEA, Cardiff University and NASA, USGS, ICIMOD, etc.

Following the M7.8 Gorkha earthquake in Nepal on 25th April 2015, the UK played a leading role building an inventory of landslides and advising on the associated hazards. BGS and partners at Durham University used satellite imagery to map and characterise over 3,000 landslides triggered by the earthquake. They used various types of satellite data (obtained via the International Charter Space and Major Disasters and directly from data suppliers) including WorldView, UK-DMC2, SPOT, Pleiades and RADARSAT-2 to create maps of landslides active since the earthquake. These maps help relief efforts by showing where roads or rivers are blocked and where villages have been affected by landslide debris.

The UK team also worked alongside, and compiled the landslide maps from, other agencies such as NASA, NGA, MDA and ICIMOD to produce a comprehensive map of the post-earthquake landslides. The maps have been posted in several locations including the Charter website, UNOSAT, Nepal Earthquake Support and Earthquakes Without Frontiers, and are being used on the ground by several relief agencies [see: https://www.bgs.ac.uk/news/nepal-earthquake-response-2015/ and Williams et al. 2018.]

7.1.24 Other landslide projects

- Rapid response to requests for information from the UK Foreign and Commonwealth Office regarding a fatal co-seismic landslide in the Langtang Valley, Nepal, involving a British national.
- Response to a SAGE/COBR request to assess landslide impact following the 2016 Ecuador Earthquake:
    - The BGS has played a leading role in building an inventory of landslides and advising on the associated hazards following the M7.8 Ecuador earthquake on 16th April 2016. A landslide situation analysis has been produced for a number of areas in Ecuador, providing valuable advice to the UK government and international agencies. A variety of satellite imagery (obtained via the International Charter, Space and Major Disasters) was used to create maps of landslides active since the earthquake.
    - These maps have now been disseminated through the Space Charter, UNOSAT, UK Government Departments and MapAction. These are helping the relief efforts by showing where the population has been affected by landslide debris, including where roads or rivers were blocked. The maps have been posted in several locations including the Charter website, UNOSAT and MapAction and are being used on the ground by several relief agencies. [see https://www.bgs.ac.uk/news/ecuador-earthquake-disaster-response-2016-2/].
- Natural Hazards Partnership – developing a water balance model capable of assessing/forecasting landslide hazards for the GB. This has been operational since 2017. See above under **Scottish Government funded projects.**

7.2 SWELL-SHRINK

Research into the swelling and shrinkage characteristics of clay soils in Britain began in the early 1990s. The first geological formation to be investigated was the Gault Clay. This was followed by the Mercia Mudstone Group, Lambeth Group, Lias Group and the London Clay Formation. The research was triggered by work to develop the GHASP geohazard information system for insurance (see below). It was realised that, apart from a number of papers published in Géotechnique in 1983, very little had been published on this geohazard in the UK.

However, knowledge of the geohazard, its consequences, and how to deal with it was available. On 21 February 1973, Roger Cratchley wrote to a Mr A J Timms, Chief Engineer of Croudace Holmes of Caterham, Surrey, following an enquiry in relation to a residential development at Cliffe Wood, Kent. He quoted comments by Martin Culshaw:

“With reference to your letter of the 9th February 1973 and our telephone conversation of the 16th February 1973, I hope the following comments will be of use to you.

“It is known that weathered London Clay, exposed at ground surface, will suffer vertical movement due to seasonal variations in soil moisture content which is accentuated by the presence of trees with high transpiration rates. Small unwooded areas close to tree covered ground will probably behave similarly.

“If trees or thick undergrowth are removed from a site shortly before development, swelling of the ground, over a prolonged period, may result due to cessation of the transpiration. This swelling will occur irregularly and light structures on conventional strip footings are often subject to damaging strain. This appears to be the situation at your site.

“One satisfactory way of tackling this problem is as follows. All tree roots should be completely removed and the resulting holes refilled with compacted clay fill. The whole site should be allowed to 'weather' for at least one winter. As swelling will probably not have ceased, short bored pile foundations to a depth of about 20ft should be used.

“If the area is unstable or potentially so (i.e. susceptible to landslipping) it may be necessary to put in deep (15 to 25 ft) and extensive drainage to lower water table levels and hence reduce pore pressures and hopefully increase the soil's shear strength.

“The land on which you have experienced trouble seems to be of the former type (i.e. swelling ground) but overconsolidated clay slopes (e.g. in London or Wealden Clay) often show instability. On future sites of this type, it may be advisable to employ a soil mechanic or engineering geology consultant to carry out a brief site investigation to determine the nature of the ground and make suitable recommendations.”

Figure 26 shows and example of a terrace of houses built on London Clay in Essex. However, the terrace runs across the line of a hedge which, because of the drainage and the removal of water by the hedge vegetation, meant there were different responses to the placing of the load of the houses on wetter and drier London Clay. As a result the terrace subsided more on either side of the trench.

Figure 26 Terrace of houses on London Clay in Essex showing the differential settlement as the terrace crosses a hedge line.

7.2.1 Swelling properties of mudrocks at Harwell

In 1982 Hobbs *et al.* reported on research carried out in 1980 and 1981 as part of the radioactive waste disposal project. The report assesses the results of a preliminary study on the swelling properties of mudrock core from two boreholes from Harwell. The main laboratory test was the one-dimensional swelling pressure test using specially developed apparatus. Additional index tests included the free-swell test and determinations of dry density, natural moisture content, linear shrinkage and Atterberg limits. Mineralogical details were also obtained of the test materials. The main overconsolidated clays tested were Gault Clay, Kimmeridge Clay, Corallian (clay), Oxford Clay and Lower Lias (clay). It was concluded that swelling problems could be anticipated particularly from the Gault Clay and Corallian mudrocks. It was concluded that swelling was important in repository engineering as it could adversely affect shaft sinking and tunnelling operations.

7.2.2 Formation studies

A series of reports were prepared over a number of years into the geotechnical properties of some of the swell/shrink susceptible clays referred to above. The shrinkage and swelling of clay materials, either natural or engineered, costs millions of pounds every year in the UK (Figure 27a and b). To address this problem the British Geological Survey (BGS) developed a ground-breaking, internally funded study of the engineering geology of British mudrock formations during the 1990's and 2000's. Following this, a parallel study of the shrink/swell properties of these clay-rich materials was set up employing the same samples collected for the 'engineering geology' study. The initial work in the early to mid-1990s involved carrying out literature studies of swelling and shrinkage geotechnical properties of clay-rich materials (Hobbs & Jones 1995) and the related geological aspects (Gostelow 1995). The research then focused on specific geological formations and their swell-shrink properties. Formations covered in the studies were: Gault Formation (Hobbs & Jones 1998), Mercia Mudstone Group (Jones & Hobbs 1998), Lias Group (Hobbs *et al*. 2007) and Lambeth Group (Jones & Hobbs 2004). In addition, the shrink/swell study covered the London Clay Formation. This led to a seminal study of the 3D volume change potential of the London Clay based on borehole records, geotechnical laboratory tests, mineralogical tests and data from the National Geotechnical Database using robust statistical techniques (Jones & Terrington 2011).

These studies, and the reports generated, have resulted in wide interest from industry and academia, evidenced in the many tens of thousands of downloads of the geological formation studies. They have also led to laboratory testing contracts for BGS from major engineering projects such as HS2 and further studies related to climate change (Harrison *et al.* 2012). The skills and expertise built up by BGS staff, in particular Lee Jones, Peter Hobbs, Matthew Kirkham, Katy Freeborough, Ricky Terrington, David Entwisle and Stephen Horseman, over many years has been solidly based on field and laboratory experience and the development of innovative sampling, testing equipment and state-of-the-art 3D modelling and visualisation (Jones *et al.* 2017, Hobbs *et al.* 2019). The expertise gained resulted in Lee Jones and Ian Jefferson of Birmingham University contributing the chapter on 'Expansive Soils' for the 2012 edition of the Institution of Civil Engineers (ICE) Manual on Geotechnical Engineering (Jones & Jefferson 2012)

Figure 27 a (left) shrinkage cracks in Lambeth Group clay; b (right) subsidence caused by shrink/swell.

7.2.3 SHRINKiT

Shrinkage of clay soils, resulting from a reduction in water content, is a costly geohazard recognised worldwide that affects foundations, shallow infrastructure and many other engineering activities. The purpose of the 'SHRINKiT Project', initiated in 1998 and funded by Science Budget (SB), was to replace traditional methods of laboratory testing for the geotechnical index parameter, shrinkage limit. The shrinkage limit is one of three Atterberg limits that serve to characterise the response of clay soils to changes in water content, the other two being liquid limit and plastic limit. It is described as the water content below which little or no volume change occurs and is defined by graphical construction using the water content vs volume plot.

Traditionally, the shrinkage limit has been determined by immersion in mercury, utilising Archimedes' Principle to measure the change in volume on drying. As such, the test, and hence the parameter itself, has tended to be overlooked in western countries. Standard test procedures worldwide still use this method, including British Standards. Mercury, both in liquid and vapour form, is extremely hazardous to health. In addition, there are many problems with the immersion tests, particularly when testing specimens that are undisturbed, for example, containing voids and fissures, that have a significant silt content or that are particularly sensitive to handling.

During the 2000's, methods other than mercury immersion have been developed and published. These have included wax immersion, whereby irregularly-shaped sub-specimens, with different water contents, are wax coated so that they remain impervious to water during submerged weighing. However, the SHRINKiT method remains relevant, particularly due to its relative accuracy and the large number of plot points with which to determine the hockey-stick shaped shrinkage curve (Figure 28) and hence, by graphical construction, the shrinkage limit. The SHRINKiT test equipment utilises a range-finding laser to measure the volume and a digital balance to measure the weight of a cylindrical specimen of remoulded, compacted or undisturbed soil (Figure 29) (Hobbs *et al.* 2010, 2012, 2014). As such, it can be considered an expensive option in its present form, particularly when compared with the apparatus required for the other Atterberg limits. However, the method was developed as a research tool rather than a commercial product. In this regard, it has been successful in generating a large number of tests on a wide variety of clay soils from the UK and overseas, the shrinkage limits of which have ranged from 9% to 34% (Hobbs *et al.* 2019).

The range of soil types tested enabled a shrinkage limit classification to be proposed (Table 9) and confirmed a previously noted relationship between shrinkage limit and peak bulk density during shrinkage for most, but not all, soil types. In addition, the relationship between the shrinkage limit of matched undisturbed and remoulded samples (that is, the 'shrinkage sensitivity') was investigated. Unlike the mercury immersion, and most other methods, SHRINKiT requires only one test specimen, typically a section of core trimmed (or remoulded) to a regular 100 x 100 mm cylinder and is fully automated with the exception of the final stage where oven drying at 105°C is required. This minimises handling of the specimen, an important factor with sensitive, metastable or extremely weak materials.

w_s (%)	Class description
<10	Low
10 - 15	Medium
15 - 20	High
20 - 30	Very high
>30	Extremely high

Table 9 Proposed classification for shrinkage limit, w_s (remoulded specimens only).

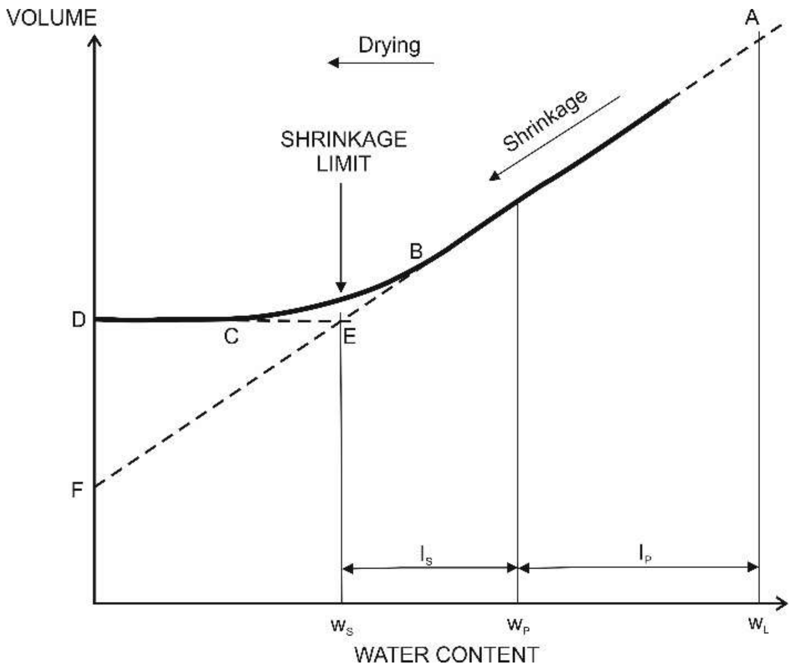


Figure 28 The shrinkage curve showing the graphical shrinkage limit construction.

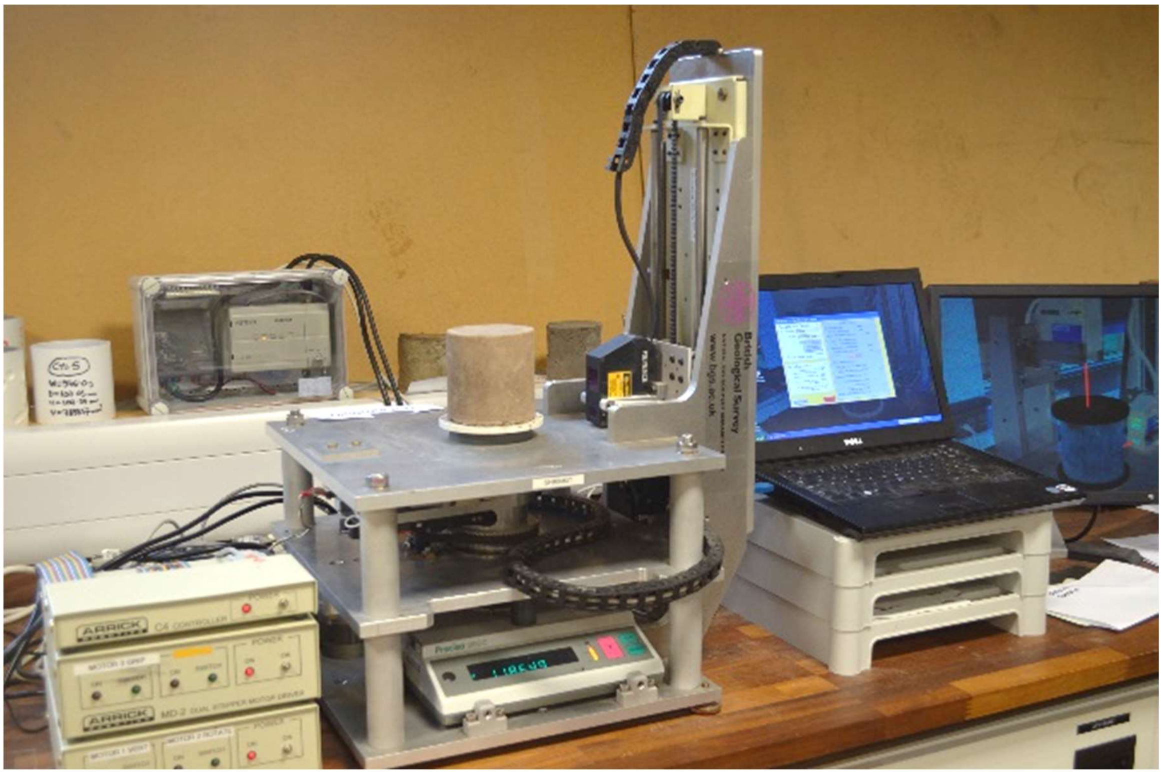


Figure 29 SHRINKiT apparatus.

7.2.4 3D swelling strain apparatus

The 3D swelling strain apparatus for stiff clay and weaker rocks was designed by Steve Horseman with the assistance of Dave Entwisle. The test is described in the International Society for Rock Mechanics suggested methods (1981, 2007). The test measures the swelling strain developed by a sample when unconfined and immersed in water. Orthogonal measurements were made on a cube sample, one measurement usually being made perpendicular to bedding. However, the apparatus was expensive as it required low friction waterproof glands through which rods attached to micrometer gauges that measure the swelling strain, were inserted.

The BGS apparatus tilted the sample on to the corner of the cube and the apparatus was large enough to take 60 mm samples flooded to a reasonable depth, so that it did not need to be regularly topped up with water. It did not require leak-proof seals for the strain gauge armatures. The original BGS apparatus had standard dial gauges and readings were taken at suitable intervals. A more recent version (Figure 30) used digital micrometers monitored by a computer. Tests took several days to complete.

The apparatus was occasionally used for BGS and commercial project but was in regularly used on the swell-shrink tests for the UK Rocks and Soils projects. A number of geological formations had their swell-shrink characteristics reported on by Lee Jones and Pete Hobbs. An example of a test on a sample of the London Clay Formation from Stanwell showing typical plots of the strain measured on each axis and of volumetric strain are shown in Figure 31a and b.

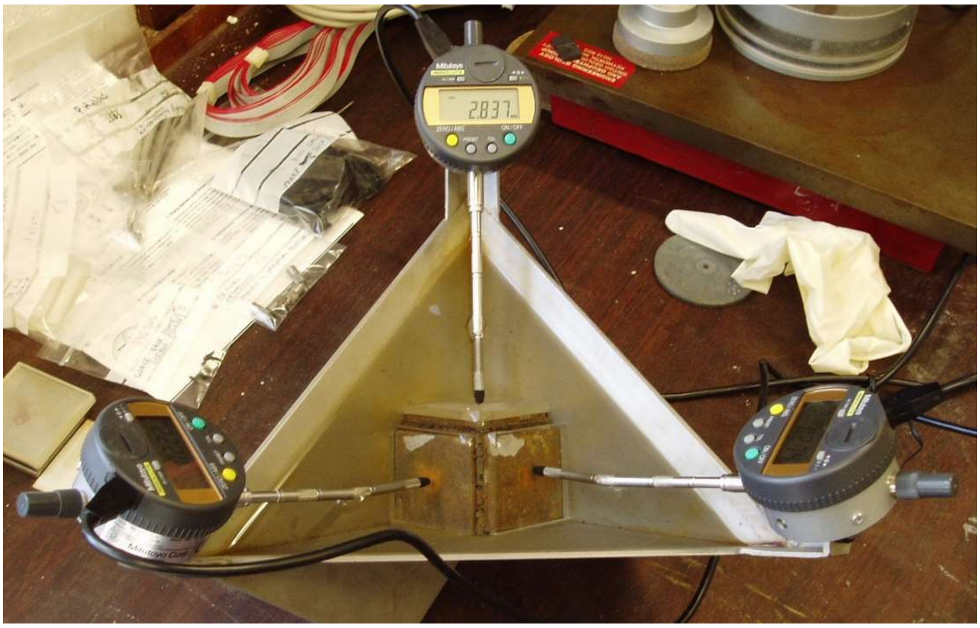


Figure 30 *3D swelling strain apparatus with digital micrometers*.

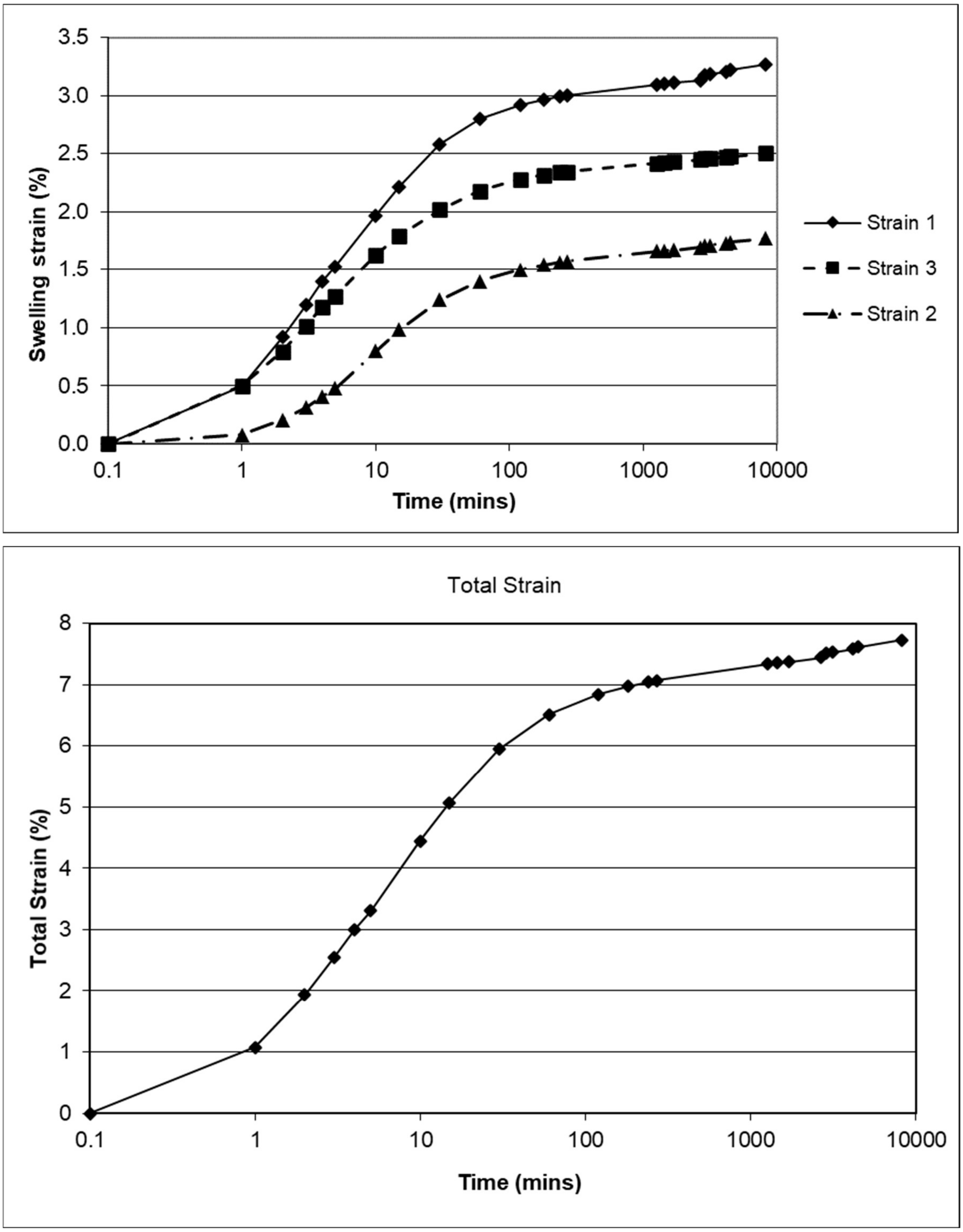


Figure 31 top (a) plots of the strain measured on each axis*; bottom (b) p*lot of volumetric strain

7.3 SINKHOLES AND KARST

From the mid 1980's until about 1990 most of the BGS study of sinkholes was *ad hoc* undertaken in conjunction with the geological field mapping programme, aided by the help and guidance and knowledge of Martin Culshaw (Culshaw & Waltham 1987). In these years Tony Cooper progressed the understanding of gypsum karst and sinkholes in eastern England, especially around Ripon with field mapping and airborne multispectral remote sensing (Cooper, 1986, 1988a, 1988b, 1989). The recognition of a serious subsidence problem in the area led to the commissioning of site reports and the utilisation of geophysics to help to map and understand the boundaries of the sinkholes. The earliest combined study was undertaken for the proposed Ripon by-pass for which Tony Cooper had raised alarm about the susceptibility to sinkhole development affecting the road and proposed bridge. He produced a technical report on the mapped sinkholes in the area (Cooper, 1992 –WN/92/8/C part 1) which was accompanied by a geophysical assessment report by Dave McCann, Jon Busby and Pete Jackson (McCann *et al.* 1992 – WN/92/8/C part 2). A subsequent survey looked at parts of the Ure Bridge site utilising EM31 and EM34 electromagnetic surveys with microgravity and galvanic resistivity (McCann *et al.* 1992 – WN/92/17C). Further reports on the bridge site included the recognition of a subsidence pipe beneath the north abutment of the bridge (Cooper 1994 – WN/94/86/C). The design of the bridge involved making it a much stronger structure that could lose any one support and not collapse, though it would not be usable until remediation was carried out (Cooper & Calow 1998, Cooper & Saunders 1999, 2002). Numerous other investigations and reports were undertaken that utilised geophysics including a sinkhole that badly damaged a house at Hutton Conyers (Cooper *et al.* 1993 - WN/93/01C) and the redevelopment of Ripon tax office site (Patterson *et al.* 1995). Reports on numerous other sites in Ripon were also produced around this time (Cooper 1993a - WN/93/17C, 1993b - WN/93/32C, 1994 - WN/94/5C) and summaries of Ripon subsidence (Cooper 1995a, 1995b). A proposed supermarket site on Magdalens Road, Ripon was also investigated using geophysics (Meldrum *et al.* 1996 - WN/96/5C) and chippings from boreholes examined, identified and interpreted (Cooper 1996a - WA/96/008C). At the same time active subsidence was recognised at Ure Bank in Ripon and the first report for the site indicated the extent of the sinkhole (Cooper 1996b - WA/96/72R) while a subsequent report detailed the major collapse (Cooper 1997a - WA/97/61R). Later reports detailed possible mitigation measures for the sinkhole (Cooper 1999 -WA/99/09R, Cooper 2005b). The weekend of 17-19th May 1996 saw an Engineering Group of the Geological Society field group, led by Tony Cooper, visit this sinkhole and others in the Ripon area and the dissolving gypsum cliff at Ripon Parks (James *et al.* 1981); the following day was a visit to landslides and mining problems in the Bradford region. Other studies of gypsum outside of Ripon included a study of caves and breccia pipes in the Permian gypsum of the Vale of Eden, Cumbria (Ryder & Cooper 1993).

The subsidence problems at Ripon were a major concern to the BGS and Harrogate Borough Council was informed about the problems while Tony Cooper was preparing his first paper on the subject for a conference in 1982 (Cooper 1986). In 1993 he produced a report for the Planning Department and addressed the Planning Committee at Harrogate. Following this representation Harrogate BC with the Department of the Environment advertised a project in 1994 to investigate the subsidence at Ripon and formulate planning uidance. Unfortunately, the BGS bid failed and Dr Alan Thompson of Travers Morgan (later Symonds Travers Morgan) won the bid. BGS did however get a contract to update the geological maps for Ripon, which although mapped in 1979-80 were shown to be incorrect due to more borehole information and more subsidence events. Tony Cooper produced revised maps and showed Dr Alan Thompson the geology of the Ripon area. The guidance was subsequently published by Thompson *et al.* (1996, 1998). It is worth noting that at the end of the project the BGS bid would have been cheaper; the big lesson learnt from this experience was that it is better to go in cheap and increase the value with contract variations. It is also worth making projects modular so the work can be more easily fitted to the expected budget and additional items can be added as contract variations.

In the early 1990's Tony Cooper was also involved with subsidence problems due to gypsum dissolution at Darlington. These affected the southern part of the town around Parkside and numerous places to the east of the town. Working with Darlington Borough Council initial reports (Cooper 1994 - WA/94/52Cm, 1995c – WA95/11/C and 1995d - WA/95/3C) led to an extensive investigation with boreholes (Cooper 1997b - WA/97/65R) funded by the European Union and Darlington Borough Council as the ROSES project (Risk of Subsidence due to Evaporite Solution). This ran from 1998 to 2001 led by Paul Younger and John Lamont-Black of Newcastle University with contributions from Richard Forth and Colin Jones. Partners included Darlington Borough Council, notably led by Jim Gordon the Borough Engineer, Zaragoza University in Spain (Francisco Gutierrez and Mateo Gutierrez), Alexander Klimchouk (Ukraine National Academy of Sciences) and Rudolph Liedl, George Teutsch, Martin Sauter and Steffen Birk of Tübingen University in Germany. Publications relating to this work in the UK included revised maps and borehole interpretations for Darlington (Cooper & Gordon 2000) and studies of the hydrogeology of the Darlington area (Lamont-Black *et al.* 1999, 2002, Lamont-Black *et al.* 2005) and building damage mapping in Spain (Gutierrez *et al.* 2000, Gutierrez & Cooper 2002) plus a paper on geotextile use at Ripon to protect roads from sinkhole development (Jones & Cooper 2005). The collaboration with Alexander Klimchouk from 1995 onwards also led to the publication of a special volume detailing the gypsum karst of the world (Klimchouk *et al.* 1997a) that included chapters on Great Britain (Cooper 1997c), China (Lu Yarou & Cooper 1997) and an overview of the world (Klimchouk *et al.* 1997b) plus chapters describing individual countries and the processes of gypsum karstification. 1997 also saw Tony Cooper co-leading the International Association of Hydrogeologists XXVII Congress field trip to Yorkshire, Northumbria and Eastern Scotland with Paul Younger and Nick Robins.

In 1996 another project looking at sinkholes over gypsum karst was funded by the Department for International Development (DFID) with Tony Cooper from BGS working with Bernardas Paukštys and Jurga Arustiene of the Lithuanian Geological Survey and Lu Yaoru of the Chinese Institute of Hydrogeology and Engineering Geology at Zhengding, Hebei. Studies were made in the respective countries and numerous papers about gypsum karst geohazards, some involving planning and aquifer protection, were published (Lu Yaoru & Cooper 1997a, 1997b, Paukštys *et al.* 1997, 1999), The final project reports were by Cooper & Calow (1997, 1998) and a more complete overview was presented by Cooper (1998). Tony Waltham kindly took the party to Cheshire to look at salt subsidence problems. Collaboration between Tony Waltham and Tony Cooper resulted in papers on gypsum karst in Ripon (Cooper & Waltham 1999) and a comparison with gypsum caves in Pinega, Russia (Waltham & Cooper 1998).

Subsequent to his visit to Cheshire with Tony Waltham, Tony Cooper investigated salt subsidence in Cheshire as part of the National Karst Database studies (see section 4.4 above). Areas of natural salt dissolution subsidence and anthropogenic subsidence due to brine extraction were recognised based on the previous work of many BGS geological surveyors and PhD studies, but this was the first time that the information had been collated (Cooper 2001a, b, 2002a, b). This work informed the GeoSure study for salt subsidence and further information about salt subsidence in Stafford and Droitwich was also included.

On 14 September 1999 Tony Cooper presented a lecture entitled “My house fell in a hole: problems with soluble rocks (and the inspiration for Alice in Wonderland)” to The British Association for the Advancement of Science Meeting in Sheffield. This story made most of the National press and media around the world even reaching Tasmania (Cooper 2001c) and also being used as a quiz question on Canadian radio. Later on in July 2013 the topic featured on the BBC “One Show” with Gyles Brandreth and Tony Cooper visiting sinkholes around Ripon.

In the early 2000s it was decided to create a new National Karst Database (see above), in part based on information obtained from new geological mapping on the Chalk of southern England and from newly available LiDAR (Light Detection And Ranging) data. At this time BGS was becoming more multidisciplinary and engineering geologists were more involved with the field surveying, especially of landslides, while field geologists became more involved with some aspects of engineering geology such as karst. From early 2003 Tony Cooper was part of the Shallow Geohazards Team then from 2007 until March 2012 spent half his time as Team Leader for Shallow Geohazards and Risks and the remainder as the Regional Geologist for Yorkshire. Andrew (Andy) Farrant was similarly involved with his time split between field surveying and karst geohazards where he brought his expertise of the Carboniferous limestone karst and Chalk karst into the Engineering Group (Cooper *et al.* 2001, Forster *et al.* 2003, Waltham *et al.* 1997, Maurice *et al.* 2006). Resultant papers included work on geohazards, building damage classification and planning (Farrant & Cooper 2008, Cooper 2008a, 2008b, Cooper *et al*. 2010, 2011), plus work on the karst database and GeoSure (see sections 4.4 and 7.20.2). Utilising this work also permitted soluble rocks to be considered as a hazard relevant to the national gas pipeline system (Cooper *et al*. 2003 - CR/03/217N; Gibson *et al*. 2005). Martin Culshaw oversaw all this karst-related work and published a textbook on sinkholes and subsidence with Tony Waltham and Fred Bell (Waltham *et al*. 2005). During this time Tony Cooper led an International Association of Engineering Geology and the Environment (IAEG) trip to Ripon as part of a conference in 2006 (Cooper 2009). Further collaboration with Zaragoza University and the Geological Survey of Oklahoma saw more publications about the identification, prediction and mitigation of sinkholes over evaporite karst (Gutierrez *et al*. 2008a, 2008b).

University collaboration featured heavily from 2010 to 2013. In March 2012 Tony Cooper partially retired and Vanessa Banks took over as Team Leader for Shallow Geohazards and Risks. An early study involved overseeing a 3-month long Masters thesis study undertaken by Andrea

Columbo of Bologna University looking at Tufa deposits at Via Gellia, Cromford, Derbyshire (Columbu *et al*. 2013). Tony Cooper co-supervised 3 student project studies in gypsum karst hydrogeology at Leeds University with 3 students culminating with a paper on sulphate-rich springs and gypsum karstification (Cooper *et al*. 2013). Further collaboration with Francisco Gutierrez of Zaragoza University produced three more papers (Gutierrez & Cooper 2013, Cooper & Gutierrez 2013, Gutierrezz *et al*. 2018). Tony Cooper retired fully in March 2014, but remained attached to BGS and Engineering Geology as an Honorary Research Associate (HRA). Subsequent papers included entries for the Encyclopedia of Engineering Geology (Cooper 2016, 2018, Culshaw & Cooper 2017). Other papers including some from the Geological Society Geological Hazards Working Group (that first met in 2006 and reported in 2014) took many years to be edited, but were finally published in 2020 (Cooper 2020a, 2020b).

From 2012 onwards Vanessa Banks as Team Leader oversaw the research at Ripon with numerous enquiries and commercial work related to problematical sites in the city that were investigated with geophysics. Work on geological hazards also involved collaboration (aided by Tony Cooper) with the Fire and Rescue Service following concerns raised by the well-publicised February 2014 sinkhole and house collapse in Ripon. Vanessa Banks also supervised a student study involving BGS geophysics and elevation monitoring that was undertaken by G Williams culminating in a paper (Williams *et al*. 2020). Ongoing work in Ripon involving Hannah Cullen-Gow includes the development of a 3D geological model of the ground beneath the city.

7.4 COLLAPSIBLE SOILS

With the exception of one major research project, collapsible soils were never a major interest of EGU, probably because they were mostly restricted to south-east England as they resulted from the deposition of wind-blown silts in the form of loess (known as brickearth in the UK). They were first encountered by EGU staff during the extensive 'South East Essex Project' (see Section 3.2 above). Because, at the time, relatively little was known about the geotechnical properties of collapsible soils and the consequences of their ability to collapse, when they were found in south Essex it resulted in research to characterise them engineering geologically and geotechnically. The results of that research are found in the 12-part South Essex Report. However, eventually, the research was properly written up for publication by Northmore *et al*. (1996).

Some years later, further research was carried out into the nature of gull-fill material found in widened fissures (probably caused by cambering) in the Hythe Beds at Allington Quarry in Kent. Four samples of the material were tested and because the silt content was so high (greater than 75%) the material was interpreted as being loess deposited during the late Devensian in a periglacial environment. Three of the samples were collapsible (Bell *et al*. 2003).

The publication of the two papers led to a research proposal to NERC, in collaboration with Ian Jefferson and colleagues from Birmingham University's Civil Engineering Department. Very few engineering geological research proposals were ever funded by NERC but, on this occasion, Martin Culshaw was a member of the NERC Earth Sciences Peer Review Committee. The proposal was submitted towards the end of his term of office and by then he had learned how to get proposals funded. The proposal was accepted and the three-year research project resulted in a significant number of publications.

The research was based around a large-scale loess collapse field trial at a brick pit in brickearth at Ospringe in Kent (Zourmpakis *et al*. 2006). The purpose was to better understand the relationship between wetting and volume reduction in loess. The in situ loess 'sample' was laterally 5.0 by 5.0 m and 1.5 m deep. The sample was isolated, flooded in a controlled manner and subjected to surface stress of up to 210 kPa for ten days. The sample was geotechnically and geophysically instrumented using piezometers, rod extensometers, resistivity arrays, a resistivity probe and shear wave transducers (Zourmpakis *et al*. [2006], Jackson *et al*. [2006], Gunn *et al*. [2006]). The research concluded that by combining the various monitoring techniques it was possible to greatly improve the interpretation of geotechnical measurements in loess.

Despite the relatively limited extent of collapsible soils in Britain, they were included in the GHASP and GeoSure geohazard information systems (see below Section 7.8).

7.5 SECONDARY SEISMIC HAZARDS

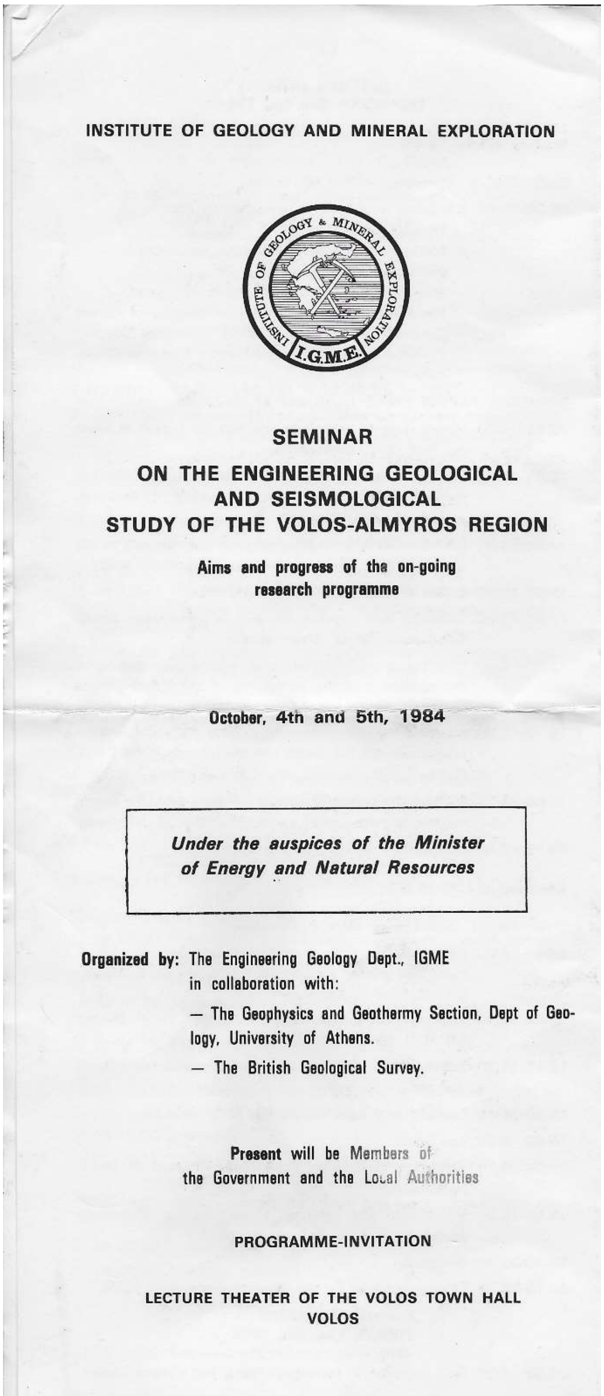
7.5.1 Engineering geology and seismic hazard studies in Volos, Greece

The research programme aimed to combine the two approaches of engineering geological mapping and geophysical studies with a third – seismic risk assessment, also in collaboration with the IGS's Global Seismology Unit, as well as with IGS International and the Regional Geophysics Unit. The general objectives were to carry out an integrated survey, including geology, geotechnics, seismo-tectonics and seismicity, to guide development planning and engineering decisions in the region, and to act as a pilot study within the context of Council of Europe proposals for Earthquake Research. The project was intended as a model for similar studies elsewhere. The dynamic response of the ground surface to earthquake energy is dependent on the geology in a number of different ways. The tectonic framework for the region controls the types and depths of earthquakes most likely to occur and the propagation of energy; local attenuation of energy is determined by the lithological types and their geotechnical and geophysical properties; and the shape of individual sedimentary or alluvial basins that can affect where the energy is concentrated. However, the local, shallow geological conditions are also important in determining the location and magnitude of secondary seismic hazards such as liquefaction, ground motion amplification, landsliding, ground rupture and tsunamis.

The project involved setting up a seismometer network across Eastern Greece (which was managed by Mike Raines who was resident in Greece), carrying out a mainly desk study assessment of major structures and faults across this region (Dave Greenbaum), carrying out surface resistivity and magnetic surveys in the Volos and Almiros basins, partly to determine the depth to bedrock in the two basins and partly to determine seismic characteristics of shallow sediments in the two basins to enable susceptibility to ground motion amplification to be determined (Peter Jackson), carrying out detailed engineering geological mapping of the Volos basin (Martin Culshaw and Alan Forster) and drilling and logging various boreholes mainly in the Volos basin (Martin Culshaw). Samples from the boreholes were tested geotechnically and to measure seismic resonance. All the data gathering was completed by March 1985. All the field work was reported on and the geotechnical laboratory testing of 76 disturbed samples was completed (Entwisle & Brooks 1984).

A seminar on "The engineering geological and seismological study of the Volos-Almyros Region – aims and progress of the on-going research programme" on the 4 and 5 October 1984 at the Lecture Theatre of Volos Town Hall. The first day consisted of a series of presentations and the second was a field excursion in the region (Figure 32a and b). The two days were attended by Malcolm Brown, the Director of BGS, the Director of the Greek Geological Survey – the Institute of Geology and Mineral Exploration (IGME), the Head of the Geology Department at Athens University and the Minister of Energy and Natural Resources, as well as the Prefector of Magnesia, the Mayor of Volos and the President of the Magnesia District Technical Chamber. From EGU, Roger Cratchley, Peter Jackson and Martin Culshaw all spoke.

Only one interpretative report was completed (Culshaw 1985). This was because of financial difficulties at the IGS; the budget was cut to 20% and, as a result, the preparation of final reports and academic papers was only partly completed. It is disappointing that the research could not be completed because the research was in a new field (secondary seismic hazards) and would have placed EGU in a leading position. In 1989, Martin Culshaw visited Athens to review the possibility of completing the work with George Koukis, EGU's main counterpart at IGME. Unfortunately, nothing could be achieved due to lack of funding.



INSTITUTE OF GEOLOGY AND MINERAL EXPLORATION

SEMINAR
ON THE ENGINEERING GEOLOGICAL AND SEISMOLOGICAL STUDY OF THE VOLOS-ALMYROS REGION

Aims and progress of the on-going research programme

October, 4th and 5th, 1984

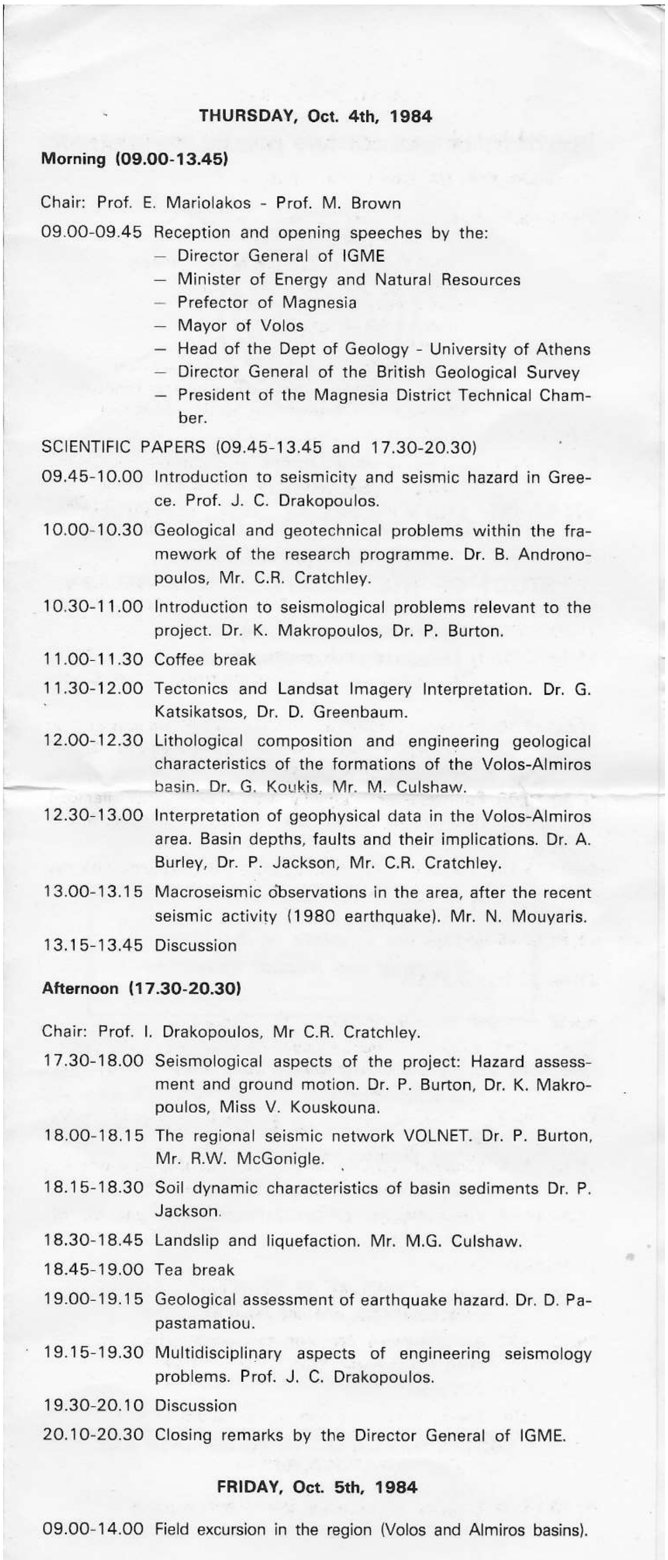
Under the auspices of the Minister of Energy and Natural Resources

Organized by: The Engineering Geology Dept., IGME in collaboration with:
- The Geophysics and Geothermy Section, Dept of Geology, University of Athens.
- The British Geological Survey.

Present will be Members of
the Government and the Local Authorities

PROGRAMME-INVITATION

LECTURE THEATER OF THE VOLOS TOWN HALL
VOLOS



THURSDAY, Oct. 4th, 1984

Morning (09.00-13.45)

Chair: Prof. E. Mariolakos - Prof. M. Brown

09.00-09.45	Reception and opening speeches by the: — Director General of IGME — Minister of Energy and Natural Resources — Prefector of Magnesia — Mayor of Volos — Head of the Dept of Geology - University of Athens — Director General of the British Geological Survey — President of the Magnesia District Technical Chamber.

SCIENTIFIC PAPERS (09.45-13.45 and 17.30-20.30)

09.45-10.00	Introduction to seismicity and seismic hazard in Greece. Prof. J. C. Drakopoulos.
10.00-10.30	Geological and geotechnical problems within the framework of the research programme. Dr. B. Andronopoulos, Mr. C.R. Cratchley.
10.30-11.00	Introduction to seismological problems relevant to the project. Dr. K. Makropoulos, Dr. P. Burton.
11.00-11.30	Coffee break
11.30-12.00	Tectonics and Landsat Imagery Interpretation. Dr. G. Katsikatsos, Dr. D. Greenbaum.
12.00-12.30	Lithological composition and engineering geological characteristics of the formations of the Volos-Almiros basin. Dr. G. Koukis, Mr. M. Culshaw.
12.30-13.00	Interpretation of geophysical data in the Volos-Almiros area. Basin depths, faults and their implications. Dr. A. Burley, Dr. P. Jackson, Mr. C.R. Cratchley.
13.00-13.15	Macroseismic observations in the area, after the recent seismic activity (1980 earthquake). Mr. N. Mouyaris.
13.15-13.45	Discussion

Afternoon (17.30-20.30)

Chair: Prof. I. Drakopoulos, Mr C.R. Cratchley.

17.30-18.00	Seismological aspects of the project: Hazard assessment and ground motion. Dr. P. Burton, Dr. K. Makropoulos, Miss V. Kouskouna.
18.00-18.15	The regional seismic network VOLNET. Dr. P. Burton, Mr. R.W. McGonigle.
18.15-18.30	Soil dynamic characteristics of basin sediments Dr. P. Jackson.
18.30-18.45	Landslip and liquefaction. Mr. M.G. Culshaw.
18.45-19.00	Tea break
19.00-19.15	Geological assessment of earthquake hazard. Dr. D. Papastamatiou.
19.15-19.30	Multidisciplinary aspects of engineering seismology problems. Prof. J. C. Drakopoulos.
19.30-20.10	Discussion
20.10-20.30	Closing remarks by the Director General of IGME.

FRIDAY, Oct. 5th, 1984

09.00-14.00	Field excursion in the region (Volos and Almiros basins).

Figure 32 a and b Programme for the seminar on the engineering geological and seismological study of the Volos-Almyros region.

7.5.2 Assessment of secondary seismic hazards for urban planning (in China and Costa Rica)

Between 1992 and 1995, Martin Culshaw, Dave Gunn, Alan Forster and Peter Jackson worked on an applied research project funded by the UK's Overseas Development Administration (ODA). The objectives of the project were to:

i. develop a simple integrated geoscience methodology based on existing data to identify areas of secondary seismic hazard;

ii. apply this methodology to two cities located on Quaternary sediments in earthquake-prone areas and to verify using published earthquake data;

iii. produce the data in a form suitable for incorporation into local planning procedures and utilisation by National Geological Surveys and other related organisations.

These broad objectives were intended to result in urban planners being able to plan while accounting for the likely effect of earthquakes on cities without needing to be concerned, at a basic planning level, with the uncertainties associated with prediction of the location, size and date of the next earthquake. Hence, the overall project aim can be described as being:

> *To develop a methodology that allows a planner to consider secondary seismic hazards (geo-hazards) during the planning process and to publish the methodology in the form of a reference manual for use by planners (the 'user's guide').*

Two countries were chosen as locations for the research to be carried out: Costa Rica and China. Visits were paid to the two countries and collaboration in Costa Rica was established quickly. China was much more difficult as the research institutes approached for collaboration were suspicious of the BGS motives and establishing links was a very slow process. Although the original intention was to produce maps for a city in each country showing the likely extent of secondary seismic hazards in the event of a damaging earthquake, the time and resources available to the project made this impossible. San Jose, the capital of Costa Rica and Tangshan in eastern China were tentatively identified and a paper was eventually published with regard to Tangshan (Forster *et al*. 2009). However, the proposed maps were never produced. The two reports were only ever completed in draft, one describing the nature of the hazards and the second how land-use planners could deal with them from a planning perspective.

A number of lessons were learned from this failed project:

i. It was misguided to try to work in a country like China without pre-existing contacts at a time that the country was only just beginning to 'open-up.'

ii. Contacts need to be established and work programmes agreed with the collaborating countries before any visits take place.

iii. Although obvious, the project outputs and the time needed to deliver them should be compatible with the budget; juggling the outputs and the budget with other projects was not acceptable.

7.6 VOLCANIC HAZARDS

7.6.1 Engineering geology of the Soufriere Hills Volcano, Montserrat (1996)

The small island of Montserrat is a British dependent territory located in the West Indies. The Soufriere Hills volcano dominates the southern part of the island overshadowing the now abandoned capital town of Plymouth. In 1996, the volcano erupted having been dormant for over 400 years. Laurance Donnelly was assigned to Montserrat. The objectives were to assist with the establishment of the Montserrat Volcano Observatory (MVO). Daily routine tasks included, ground deformation (establishment of a GPS and precise levelling network across the volcano), geophysics (establishment geophysical monitoring stations including a seismic network and microgravity), geochemistry (the sampling of hydrothermal springs and gas plume measurements using COSPEC and FTIR), petrology (the collection of rock samples for petrographic analysis), geotechnical stability investigations of the extrusive dome and the potential for pyroclastic flow generation, primary and secondary geohazards zonation for tsunamis, landslides and rock-falls, ground rupture, flooding, liquefaction, lahars and ash plumes.

The effective communication of the geological hazards was important. Associated levels of risks, potential impact and consequences were reported to the public and media. There was regular communication with the Police and Military and advice given to assist with evacuation planning. The design and implementation of a reconnaissance mineral exploration survey to assist the UK Task Force locate a rock mass with suitable engineering properties to provide a raw material for engineering construction was also carried out. Perhaps one of the most notable events occurred on Sunday morning, 26 May 1996, when all of the geologists and volcanologists were based in the volcano observatory. An ash plume travelled from the summit of the volcano; it covered most of the south-western part of the island, turning bright Caribbean sunlight to instant darkness. It was not known if the ash plume was generated by instability of the extrusive dome or from a pyroclastic flow.

The Director of the observatory asked for a volunteer to try to locate the helicopter, instruct the pilot to fly to the volcano and report back on the activity. Laurance Donnelly volunteered. The information was necessary to determine whether an evacuation was necessary. The hot lapilli ash fall burned through clothing causing mild burns/irritation to the skin. In total darkness, using the road kerb-side as a guide, it was possible to walk northwards several hundreds of metres beyond the ash plume, where the helicopter was waiting. On route to the volcano, the pilot was instructed to divert and pick up the MVO camera person and video person, to capture the events, whist geological observations were made. On approach to the Tar River Valley, draining the east flank of the volcano into the Atlantic Ocean, the deposits from a pyroclastic flow were evident, complete with a debris deposit and delta of exploding sediments as the deposit cooled and expanded in the ocean. The low cloud covering the summit of the volcano was suddenly broken by an instantaneous heat flux, felt in the helicopter, as a second pyroclastic flow was generated, flowing with an eerie silence and high speed along the Tar River Valley. Upon entering the Atlantic Ocean the plume expanded and increased in speed as it flowed across the surface of the ocean. For the first time, a pyroclastic flow had been observed entering the ocean from the land, perhaps giving an indication of the pyroclastic flows that devastated the near-by island of Martinique in 1909, killing 25,000 residents with one survivor who was located in an underground prison where the temperature was cooler. Importantly, these observations of the terrestrial to marine pyroclastic flow were captured on film. The images were subsequently transmitted around the world via news channels and provided an insight into the mechanisms of pyroclastic flow generation from unstable dacite-andesite domes, by comparison to the collapse of an eruption column.

Approximately nine years later, in 2005, Laurance Donnelly was invited to collaborate with the BGS EGU and went back to Montserrat where he designed a ground investigation in the Balham Valley that drains the south-eastern flank of the volcano into the Caribbean Sea. The once deeply-incised valley had been infilled and choked with lahar deposits, burying the main bridge that crossed the valley. The ground investigation located the original bridge within the lahar deposits. A series of trial pits provided preliminary observations and geotechnical parameters for the design of a replacement bridge. During this visit to the island, the MVO invited Laurance Donnelly to investigate the causes of a landslide that had started to undermine the edges of the helicopter landing pad. The geomorphology of this landslide was mapped, the failure mechanisms determined and stabilisation and mitigation options provided. The University of South Wales invited Laurance to publish a paper on the pyroclastic flows that transgressed from the land to the sea on the Soufriere Hills Volcano. These were considered as an analogue for pyroclastic flows that also transgressed from south to north, from the terrestrial to the marine environment, in the Caradoc (Ordovician), located at present day in the area around Tryfan, and the Glyders in Snowdonia, North Wales. A number of papers were published on the Montserrat eruptions (Donnelly *et al.* 2006, Donnelly 2007a, b, 2008, 2009a).

7.7 7.7 ABANDONED MINEWORKINGS

7.7.1 7.7.1 Stability assessment and roof-fall monitoring at Castlefield Limestone Mine, Dudley

The mining of limestone at Castlefield Mine near Dudley, which started in the 18th century, resulted in a long and continued history of mine collapse and crown-hole formation above the area mined including land adjacent to Dudley Zoo. The limestone extracted came from the Upper Wenlock Limestone (now the Much Wenlock Limestone Formation) that lies beneath approximately 22 m of the Lower Ludlow Shale Group that included 1.5 m of Passage Beds. The land above the mine was occupied by the Dudley Sports Centre (cricket and football) and the formation of crown-holes was a danger. In 1983, after a crown-hole opened up and halted sporting activities, a major study of the abandoned limestone mines was begun.

The EGU project on the mines related to the assessment, monitoring and stability of the abandoned limestone workings and was part of the BGS West Midlands Microseismicity Project. The objective was to develop and test remotely monitored acoustic events (roof-falls) in abandoned mines and the discrimination of roof-falls from surface events, using routine computer-based data analysis to provide advance warning of any rock falls. The engineering geological component was to provide an engineering geological basis for the microseismic project and to identify and evaluate the main sources of instability in the workings. A record of roof-falls was made and an assessment of the causes carried out to establish a geotechnical basis for the development of the monitoring net and interpretation of the acoustic events.

The mine survey, led by Jon Hallam (Hallam & Mitchell 1984) was carried out as the existing mine plans were not detailed enough for the needs of the project. This included a system of 24 underground survey stations. The accessible part of the mine was 215 m NW-SE and up to 120 m NE-SW with an area of 13 400 m^2 (Figure 33). The pillar corners and other significant features on the mine boundary were numbered and their co-ordinates established by angle and distance measurement using a theodolite and a tape and, occasionally, by compass bearing and tape measurement. The underground survey was correlated with the National Grid. Numerous roof spot heights were taken using a ‘sonic tape.’ Each pillar was numbered with a plastic number plate attached to its NW face. The average height of the roof above the sand surface of the floor of the mine was 4.8 m. The mine was partly filled with a sand/silt mix (about 2 to 3 m thick) that had been pumped into part of the mine behind a bund and had leaked into the surveyed part of the mine.

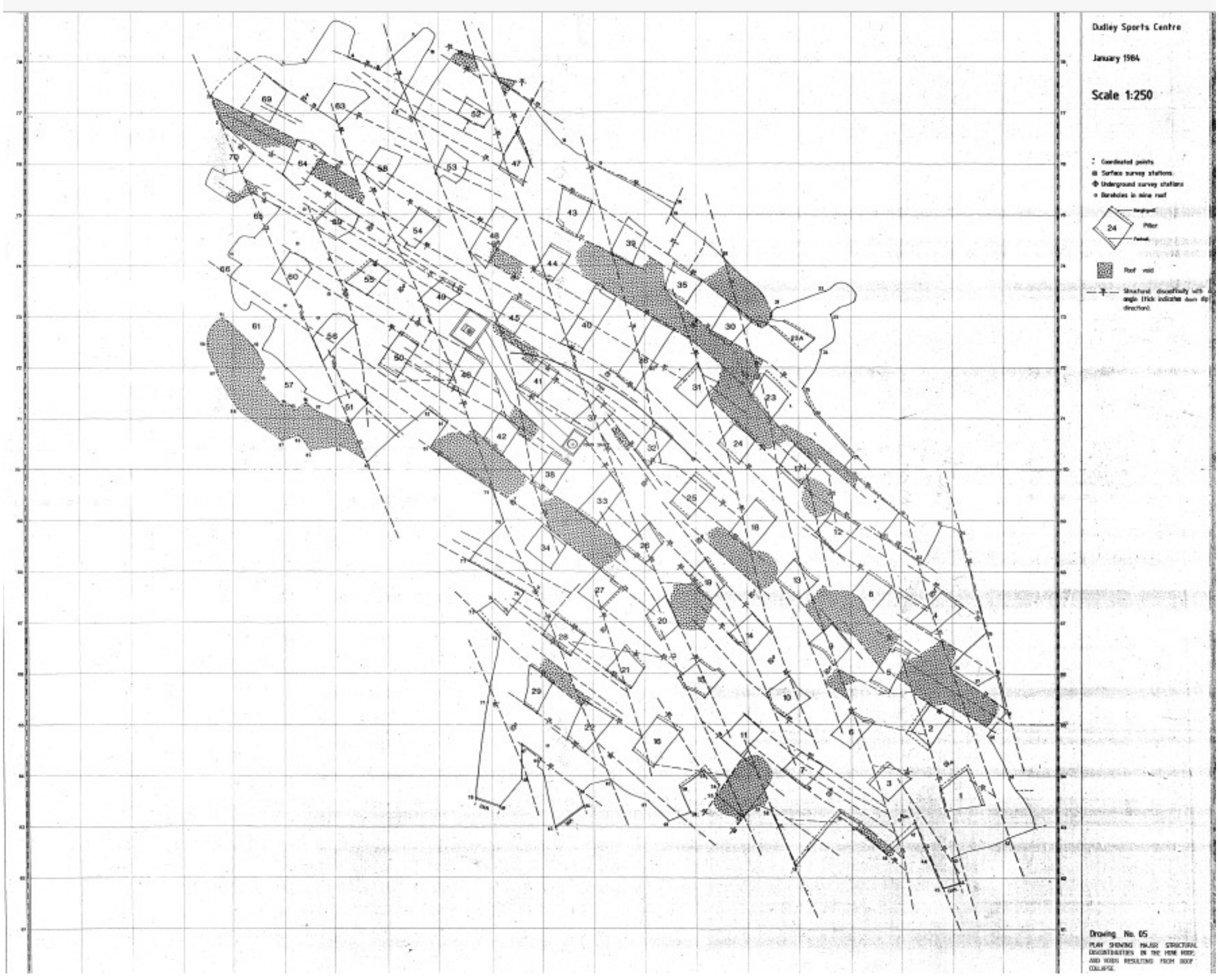


Figure 33 Plan of the Castlefield Mine with the pillars, structural discontinuities and the location of roof voids (shaded areas) from Hallam & Mitchell, 1984.

The pillars were fairly regular and their shape generally followed the jointing pattern of the rock. The roof was irregular and its condition was considered to be exceedingly poor and often comprised in the Passage Beds, the limestone having been mined. The instability of the roof was, in part, due to the jointing and the clay joint infill that swelled when near the damp mine atmosphere. The clay joint infill had a tendency to fall out removing support to the roof rock. Some very large roof voids were measured from less than 1 m above the roof to 14 m above the roof level.

The engineering geological aspects were led by Steve Horsemen (Horseman *et al.* 1984) and included:

- Mine Survey.
- Pillar numbering.
- Description of the accessible workings.
- Structural geology including bedding plane and joint survey (as suggested in ISRM methods).
- Inspection of fall zone.
- Netting and roof-fall monitoring.
- Assessment of roof stability.

The bedding plane was mostly at an angle of 10° – 12° but this increased to the northeast to 34° due to down warping associated with faulting. The joints surveyed were presented on a lower hemisphere, equal area stereographic projection net. The joint sets were identified and described in detail. Three main joint sets were identified with two minor joint sets.

To assess the microseismic results there were regular inspections of the mine to assess the location and size of any rock fall. After each rock fall was located and its mass (in kg) estimated, it was then covered in agricultural netting so that it would not be confused with future rock falls in the area. Enabling factors in roof instability included:

- jointing, joint set 1 provided a boundary surface for all major rock falls;
- water and its interaction with clay joint fill;
- bedding in the Passage Beds;
- and some major rock falls may have been affected by faulting or localized folding.

The microseismicity aspects of the work were led by the Global Seismicity Research Group based in Edinburgh, together with Dave McCann and Pete Jackson of EGU, who were involved in the calibration of the system. The seismic experiments (Jackson *et al.* 1986) were designed to investigate the propagation paths and energy produced by roof falls, so that the arrival times recorded could be used to calculate the location and possible size of the rock falls. A series of calibration surveys were carried out on the corners of selected pillars using seismic reflection. Initially, the energy for both experiments was supplied by a sledgehammer, but some experiments included jacking of pieces of rock from the roof, that had an estimated energy, to mimic the real roof fall case. The properties of the sand depended on its saturation and its properties appeared to control the propagation times and amplitudes of the seismic waves generated by roof-falls. From the experiments it was concluded that accurate location of roof-falls and estimation of the size of the rock fall required a detailed survey of the fill.

The main source of microseismic acoustic events was the impact of roof-fall debris on the mine floor, which occurred at detectable magnitudes at frequent intervals. Based on the knowledge accumulated during this project it was shown that the acoustic emission records provided a measure of the positions and rates of rock-fall and, therefore, deterioration of the mine roof.

In 1987-88 much of the Castlefield Mine was infilled with a paste containing water, colliery spoil, pulverised fuel ash and cement.

7.7.2 Abandoned coal mine research

Until Laurance Donnelly joined the BGS in 1995, EGU did little work on problems related to abandoned coal mineworkings. In part, this was because the National Coal Board and its successors dealt with problems related to the abandonment of coal mines. However, in the mid-1980s the closure of coal mines accelerated and so by the 1990s problems were becoming much more apparent. Laurance's doctoral research was concerned with the reactivation of faults during mining and so he was well aware of most of the issues relating to coal mine abandonment.

However, the research into the use of relatively new geophysical methods, such as interborehole acoustics, did find some application with regard to mineworkings in the 1970s and 80s. Perhaps one of the most important geophysical studies was completed in 1982 for the Department of the Environment (McCann *et al.* [1982]). This carried out an overview of the use of geophysical methods to detect natural cavities, mineshafts and anomalous ground conditions (see below).

Donnelly's first report, in 1996, was on an investigation of fault reactivation and mining subsidence ground deformations in the Leicestershire Coalfield (Donnelly 1996). He carried out a number of similar investigations in the UK as well as in Colombia, South America (see below).

The EGU investigated mining hazards in the UK and provide research and practicable guidance on the occurrence, investigation, management and mitigation of the associated risks. Many UK urban environments are located in regions where past mining has occurred. As such, abandoned mineworkings left a legacy of hazards. Site investigation techniques and methodologies were proposed that were appropriate to past mining areas, with particular emphasis on geophysical and new thermal methods to delineate old workings. The mining hazards investigated included: crown-hole development from shallow, abandoned, partial extraction, longwall subsidence, faults and fissures, gas emissions, flooding and minewater rebound, infilled ground from quarrying, mining waste and dereliction. The development of digital information systems was also advanced so geological and mining data and information could inform investigations at the desk study stage. The EGU also supported the Land Survey and field mapping for the investigation of geological hazards and mining hazards. Research was also conducted to investigate a realistic and definable zone of influence around a collapsed mine shaft, considering the geology and engineering properties and geotechnical behaviour of the superficial deposits, for construction and insurance purposes. Investigations included; collaboration with the Environment Agency for the determination of minewater rebound at Whittle Colliery in Northumberland, support for Glasgow City Council to assess mining subsidence at Bellahouston Park, in Glasgow (see below), fault reactivation and subsidence investigations at Easington Colliery in County Durham, and mining subsidence assessments for the UK insurance industry and loss adjusters. Ultimately, these investigations and research assisted significantly and influenced the rewrite of the CIRIA guidance on mineworkings and the production of a new manual on abandoned mineworkings commissioned by the Coal Authority and CIRIA, published in 2019, as well as other publications (see, for example, Mason *et al.* 2019 and Donnelly *et al.* 2019a). Other publications included Bell & Donnelly 2006, Bell *et al.* 2005, Donnelly 2009, Donnelly *et al.* 1998a, b, 2003, 2019b, 2020a, b.

7.7.3 Geophysical methods to detect natural cavities, mineshafts and anomalous ground conditions

Because cavities of various sorts are relevant to site investigation, the potential use of geophysical methods is important. As a result, the Department of the Environment commissioned a review to examine the use of geophysical methods. The report (McCann *et al.* 1982) described the application of a wide range of geophysical methods. The practical use of each method was illustrated by a number of case histories and a comprehensive bibliography was provided up to the report date.

For ‘standard’ geophysical methods, it was suggested that in favourable circumstances it was possible to detect a cavity whose depth of burial was less than twice its effective diameter. No one geophysical method would provide the answers to all problems in the location of cavities and mineshafts. Whilst the main trend in geophysical research at the time was directed towards improvement of the standard methods, at the same time new methods were being introduced. However, more research was recommended on the application of seismic reflection systems, particularly in the development of a high frequency seismic source coupled with the use of digital stacking techniques by computer. Electromagnetic methods had provided useful results and radar, in particular, appeared to be an exciting possibility. Application of advanced computer modelling techniques to electrical resistivity surveys had also proved very successful but more field-based case histories were required. Also, the use of inter-borehole and surface to borehole seismic and electromagnetic methods was a welcome development as the surveys could be carried out alongside the site investigation borehole programme. The final report was an impressive document being some 273 pages long!

7.7.4 Abandoned mine investigations

In 1997, the EGU was commissioned by the National Trust to conduct an investigation of Force Crag Mine in Cumbria, the last operational metalliferous mine in the Lake District until it was abandoned in 1991. The mine was located at the head of the Coledale Valley, approximately 7 km to the west of Keswick, adjacent to Lake Braithwaite, in an area of outstanding natural beauty. The mine primarily produced zinc and barytes starting in the 19th century. The mine, mill and associated infrastructure had since become a geological site of special scientific interest (SSSI) and a Scheduled Ancient Monument. The Force Crag mine was complex, with several levels, inclines and stopes sunk into the hillsides. Some of the adit entrances had collapsed generating distinct and impressive subsidence depressions. The National Trust were concerned the mine entrance collapses could be impounding huge volumes of acid mine waters containing high amounts of metals and suspended minerals. If the mine entrances became breached, these could flow into local streams, rivers and lakes causing contamination and discoloration. The BGS investigation consisted of the surface mapping and characterisation of subsidence associated with the mine. Where necessary, advice was given for the establishment of a safety fence to prevent walkers passing in the vicinity of the areas of collapse and subsidence. The underground mine complex was then surveyed and mapped noting, in particular, areas of failure or potential future instability. Finally, samples of mine water and surface waters were collected for analysis at the BGS to provide a base line for the future comparison and monitoring of the chemistry and potential metal pollutants (Dumpleton *et al.* 1996). In the years that followed the BGS report produced acted as a reference for the future mitigation of the mining hazards at Force Crag mine. The Coal Authority, Environment Agency and Newcastle University developed a minewater treatment scheme to reduce the level of metal pollution.

Following the geological investigations at Force Crag Mine, the National Trust commissioned an underground survey of Coniston Mine. The copper mines were located above Lake Coniston in Cumbria and mined copper minerals from the 16th Century until the 1950s. Levers Water is a small reservoir located above part of the copper mines, built in 1717 to extend a small natural lake (tarn). During the construction of the reservoir some of the abandoned mines were breached and exposed. These were subsequently plugged by the engineers. In the 1990s, there was an attempt to destroy the plug and to flood the mine. This could have caused an environmental disaster if the mine waters had flowed into Lake Coniston. The BGS EGU mapped the geology, geometry and stability of part of the mine before the mine was accessed by civil engineers to seal the plug and prevent further access (Donnelly & Dumpleton 1997).

Milldam Mine, extracts fluorspar from the Hucklow Edge vein system, a significant east-west trending mineral deposit in Derbyshire, hosted by the Carboniferous Limestone. The mine was reopened in 1985 and led to the reopening of the nearby Glebe Lead Mine at Eyam. A new mine access adit was granted planning permission in 1987 and production commenced in 1991, until the mine went into care and maintenance in 1999 due to high operating costs. During the driving of the mine roadways and adits, the roof of the otherwise strong limestone was susceptible to collapse due to the presence of old, abandoned workings or zones of soft mudrock associated with faults (fault gouge). The BGS EGU, working with Leeds University, were invited by Laporte Minerals to conduct an underground geophysical survey in an attempt to locate the old mine workings and faults in advance of roadway construction. P-wave seismic surveys were performed between mine roadways located at different stratigraphical levels. Delays in the arrival of the first P-wave, facilitated by the use of tomographic modelling software, permitted the potential zones of instability to be located thereby reducing time lost in roof failures, improving efficiency of the mine construction and, importantly, reducing the health and safety risks of the mining engineers (Donnelly & Pearce 1996).

7.7.5 Fault reactivation near Houghton-le-Spring and Seaham, County Durham

Serious cracking to the wearing surface of the A690 Sunderland-Durham road at Houghton Cut was reported in the Sunderland Echo (April 14, 2000). This report included unsubstantiated suggestions that the damage might be related to reactivation of faults by rising minewaters in the Coal Measures that here underlie the Magnesian Limestone. A subsequent article in the Sunderland Echo (April 17, 2000) drew attention to the apparently rapid development of the cracking and commented on the possible implications for proposals for disposal of hazardous waste in the Houghton Quarry landfill site that lay close to the damaged road. A brief examination of the damaged road and immediately adjoining ground, prior to repair work in April 2000, revealed extensive fissuring in the limestone over a strike length of at least 1 km centred upon the site of damage to the road (Young & Culshaw 2001). A field survey on either side of the road was carried out in June 2000. Particular attention was paid during the investigation to evidence of fissuring or other damage in the vicinity of known faults. The field investigation of this area revealed widespread evidence of fissuring and structural damage that may have resulted from reactivation of faults within the Magnesian Limestone and underlying Coal Measures rocks. The extent of former coal mining beneath the area was reviewed briefly. The investigation was commissioned by the Environment Department, Sunderland City Council and was co-funded by the British Geological Survey as part of its Urban Geology and Geohazards Programme (formerly EGU).

A second field survey was conducted during June 2001 to examine the effects of renewed ground movements in the Magnesian Limestone outcrop. The features described in the second report (Young & Lawrence 2001) appeared suddenly during May 2001, causing further damage to land and structures and causing minor injuries to a member of the public.

To ascertain the extent and position of any voids associated with the fissures that cut the A690 road, the BGS was commissioned by Sunderland City Council to undertake ground penetrating radar and ground conductivity surveys across parts of the road during May 2002. Although the surveys clearly revealed the position of several fissures beneath the road no significant voids were detected beneath the road at the time of the survey (Cuss & Beamish 2002). Further fault movements adjacent to the road in April and May 2003 indicated that the now called Houghton Cut Fault was still active (Young 2003).

A desk study and field survey were carried out during August and October 2004 to examine the occurrence, effects and likely causative mechanisms of surface collapse features within parts of the town of Seaham, County Durham. Seaham is located close to the east coast and lies above the continuation of faults found at Houghton-le Spring. Surface collapses had been a feature of the area for many years and during the era of underground coal mining were regarded as one of the inevitable consequences of this industry. Despite the abandonment of mining beneath the area between about 35 and 50 years before the 2004 survey, such surface instability remained troublesome within parts of the area, resulting in damage to buildings and structures. The study was commissioned by the District of Easington and undertaken by BGS's Physical Hazards Programme (formerly EGU).

The collapse features recorded in the Seaham study exhibited considerable similarities to surface fissuring reported from nearby locations elsewhere on the Magnesian Limestone outcrop, notably in the Coxhoe, Houghton-le-Spring and Sunderland areas (Goulty & Kragh 1989, Wigham 2000, Young & Culshaw 2001, Cuss & Beamish 2002, Young & Lawrence 2002, Young 2003). These authors demonstrated a close spatial relationship between surface disturbance and individual faults or areas of faulted ground within the underlying Magnesian Limestone. Most of the disturbance reported from these areas appears to lie in the hangingwall, or downthrow side, of the associated faults.

The collapse features at Seaham are also concentrated within comparatively narrow belts within the hangingwall zones of known faults. At Houghton-le-Spring, Young & Culshaw (2001) demonstrated that surface fissures developed by widening of joints within the limestone, mainly within the hangingwall zones of faults. Although most records for the Seaham area give little or no information on the nature of the limestone exposed in any collapse features, where such information is available, fissuring of the underlying Magnesian Limestone, resulting from dilation of joints appears to be involved.

It was concluded that at Seaham, as at Houghton-le Spring, collapse features are concentrated in belts up to 300 m wide along known zones of faulting. Renewed or continuing subsidence of underlying coal mine workings may be causative factors in the formation of collapse features and the reactivation of known faults may be a causative factor in the formation of collapse features. It was also suggested that rising minewater levels also may be a causative factor in renewed subsidence or fault reactivation (Young *et al.* 2006). Though minewater pumping was being carried out by the Coal Authority in the early 2000s in the Durham Coalfield to prevent groundwater levels rising, it is not known for how long that policy continued.

7.7.6 Thermal imaging techniques to detect abandoned mineshafts

At the turn of the twenty first century, an estimated 10,000 coal mine shafts were thought to exist and many of their locations were either unknown or inaccurate. They represented a significant environmental hazard, posing the danger of collapse as well as the potential to leak noxious gases and acid mine waters. The benefits of detecting mineshafts before they are disturbed by construction or on development of a site are twofold; safety is increased and costs are reduced. No definitive technique existed that could reliably detect such mineshafts. The need for a rapid, cheap and non-intrusive technique was clear so in 2000 it was decided to carry out research using thermal imaging techniques. The project was led by Dave Gunn and funded by the BGS.

The research was carried out on Baildon Moor in West Yorkshire where both bell pits and shafts into pillar and stall coal workings were known to exist. Previous studies in some non-coal mining areas suggested that appropriate interpretation of airborne thermal images was likely to provide a useful means of detecting thermal anomalies over abandoned mineshafts. The specific objectives of the study were to:

- detect thermal anomalies over known mineshafts with a surface expression;
- detect such anomalies over known mineshaft locations without a surface expression;
- detect unknown mineshafts;
- determine whether known mineshafts are missed by the technique;
- investigate the physical basis of any anomalies recorded by use of geophysics;
- calibrate the thermal and geophysical responses over known mineshafts using geophysics;
- and ,make recommendations on the implementation of the technique over development sites.

The study demonstrated that successful data acquisition for mineshaft detection must take into account seasonal and meteorological conditions. Mineshaft detection performance of a thermal image is significantly influenced by precipitation receipt, temperature and barometric pressure conditions in the period leading up to and during data acquisition. The study confirmed that thermal data acquisition for shaft detection should be conducted during a period of dry weather. In particular, the study highlighted the significance of temperature in the period leading up to data acquisition. Colder conditions in the period leading up to data acquisition appeared to result in the greatest contrast between mineshaft and surroundings in a thermal image. Therefore, it was preferable to conduct thermal data acquisition in winter or spring, not summer or autumn. Precipitation, temperature and pressure should be monitored in the field prior to and during thermal data acquisition and significant weight given to meteorological conditions in the timing of data acquisition (Gunn *et al.* 2001).

In 2002, a multidisciplinary team conducted a study at Chilwell Dam Farm (a former coal mining area) in Nottinghamshire to develop further the British Geological Survey's capability to detect abandoned mineshafts. To this end, an airborne thermal survey of the site was commissioned. The thermal data were analysed in conjunction with site visits, geophysical surveys, soil stripping of the top layer of soil from the site and analysis of aerial photography, geological field slips and mine plans. The BGS had previously applied the technique with success on Baildon Moor where mineshafts had obvious surface expression (see above). The Chilwell Dam Farm project took place at a site where the mineshafts did not have a clear surface expression (Ager *et al.* 2002).

The Chilwell Dam Farm research further demonstrated the potential for rapid detection of abandoned mineshafts using the airborne thermal surveying technique. In particular, the study confirmed that shafts without an obvious surface expression on the ground can be detected from an airborne thermal sensor. Almost two thirds of the mapped shafts at the site were detected by the thermal survey and the remaining third were not detected due to their close proximity to either trees or damp ground or due to their occurrence within a zone of rock that had a dark appearance in the thermal image. In addition, several thermal anomalies were identified that had potential to relate to a mineshaft. Only one previously undetected mineshaft was indicated by the study, as a result of the geophysical investigations. At all other locations where a thermal anomaly was detected and had the potential to relate to an unmapped mineshaft the outcome was inconclusive due to the failure of the soil-stripping process to verify the location of mineshafts across the site.

7.7.7 Mining subsidence at Bellahouston Park, Glasgow

Bellahouston Park is located near the centre of Glasgow. It is one of the main areas of open-space in this urban area and forms a focal point for leisure and recreation. Furthermore, the Park is frequently the venue for major public events. Mining subsidence within the Park has resulted in ground deformation, shaft collapse and the demolition of severely damaged property. On the 3rd March 1998, Glasgow City Council (GCC) expressed concern to the British Geological Survey (BGS) that mining subsidence is a threat to the safety of Park visitors and to the long-term future of the site as a public park. It was agreed that a phased approached would be best suited to determining the likely hazard from mining subsidence. Phase 1 was carried out between the 6 and 7 April 1998 involving an assessment of the existing data and information held by GCC. The information held by the BGS was also examined (Donnelly 1998).

In 1999, following on from the work of Laurance Donnelly, Steve Rogers and Alison Sowerbutts carried out a desk study review of the available borehole and site investigation data from the vicinity of Bellahouston Park to achieve a number of objectives:

i. Map the distribution of coal seams and faults encountered within the Park.

ii. Map the distribution of drift thickness and also the depth to rockhead.

iii. To identify those coal seams that had been worked and to characterise the nature of those workings.

iv. To attempt to characterise the nature of the existing collapse events to help identify other areas of higher risk.

v. To identify areas of the Park where there was little geological reason for the presence of mining related hazards.

vi. To recommend a future strategy of study and investigation to help restore Bellahouston Park to its former role as the City's premier outdoor event area.

The solid geology consists of rocks of the Upper Carboniferous Limestone Coal Formation with a stratigraphic thickness of approximately 100 m. This succession can be divided into two parts by a thick development of mudstones known as the Black Metals. Below this there have been no coals worked within the Park area although there was some evidence that ironstones have been taken. Above the Black Metals, seven significant coal seams have been identified, although workings are largely confined to the Knightswood Gas coal seam and minor workings in the Pollok Stone seam. The distribution of superficial deposits thickness is broadly a thin cover (approximately 5 m or less) around the eastern and western margins of the Park, with the superficial deposits thickening significantly across the middle of the Park, to a maximum thickness of approximately 25 m. The two main lithologies present within these superficial deposits are a non-cohesive silty clay or clay, sitting on top of a more cohesive glacial till.

There are principally two types of mining subsidence-related hazards within the Park area. The first is the formation of surface penetrating crown holes with an unknown depth to the base of the cavity. The second subsidence-related hazard is as a result of the collapse of deeper workings and the migration of this void towards the surface. The presence of abandoned mine workings under the Park does restrict the activities that can be undertaken within the Park boundary. However, these restrictions vary spatially within the park, with some areas having a relatively low risk and others having a much higher risk. The site was provisionally classified as one of four hazard types. Hazard classes I & II represent the areas most at risk from further crown hole development. It was recommended that a geophysical survey capable of detecting any voids in the subsurface be carried out across this area. It was recommended that heavy equipment not be installed in these zones without further investigation or ground reinforcement. To determine the nature of the mining-related risk and to plan appropriate remedial measures, further site investigation work was recommended (Rogers & Sowerbutts, 2000).

To further constrain the geological interpretation of the Park and the resultant mining hazard, three sets of boreholes were drilled for GCC: 13 in April 2003, 3 in October 2003 and 10 in March 2005. The boreholes were open-holed to just below rockhead.

The conclusions arising from all the investigations were as follows:

i. There have been extensive mine workings in the vicinity of Bellahouston Park, namely the Ibroxhill Ironstone mine along with coal workings in the Knightswood Gas and Pollok Stone coal seams. However, in the main Park area along the southern margin, only the Knightswood Gas seam has been extensively worked. Boreholes that intersect the Pollok Stone seam are only found in the southeast corner outside the Park boundary.

ii. Borehole data indicated that the Knightswood Gas seam has been worked extensively across the whole of the park where the coal is present.

iii. The geological and hazard model is consistent with the position of crown holes and other subsidence features developing in areas with a thin superficial deposits cover and where the Knightswood Gas Coal is close to the rockhead surface.

iv. The detection of voids and solid coal during drilling of the Knightswood Gas Coal confirms that coal was extracted beneath the Park using partial extraction (stoop and room) rather than total extraction methods.

v. The presence of abandoned mineworkings under Bellahouston Park does restrict the activities that can be undertaken in the Park.

vi. Evidence suggests that areas designated hazard classes 1 and 2 represent those at risk from crown hole development from collapse of mineworkings in the Knightswood Gas Coal.

The area designated hazard class 4 was enlarged as a result of the borehole drilling programme. None of the new or pre-existing boreholes in this area showed evidence for mineworkings and, from the geological modelling, the area was assumed not to be undermined.

7.8 GEOHAZARD INFORMATION FOR INSURERS AND OTHER USERS

7.8.1 GHASP – geohazard information for insurers

1989-90 was a very dry period in the UK - two hot dry summers and a dry winter in between. The result was that the Mesozoic and Tertiary mudstones and clays of Central and SE England (where rainfall is lower anyway) suffered from excessive shrinkage. In the early 1970s, the UK insurance industry had decided to include 'subsidence' in the risks covered by house insurance policies. 'Subsidence' essentially meant any ground movement except that arising from mining subsidence caused by coal extraction, which was the responsibility of the Coal Authority. The insurance companies had suffered small losses following the hot summer of 1976 but nothing like what happened in 1990-1991. During that period, 'subsidence' claims increased to £500m a year over the two years - over £1 bn in total. Losses in 1989 and 1992 were over £300m in each year. This was a huge loss for which the UK insurance industry was almost totally unprepared.

One day in about 1990/1 Martin Culshaw was telephoned by someone at the Independent Insurance Co (now bankrupt and gone). The person had trained as a geologist and he asked a simple question: "There seems to be a correlation between subsidence claims and geology; is that possible?" The penny dropped and Martin Culshaw offered to go and see his company to explain what was happening and maybe give consultancy advice. In the event, no further contact was made. At about the same time, the Research Unit at Lloyds (insurance underwriters) put an advert in their house journal asking for information on geology in relation to subsidence. Brian Kelk saw the advertisement and offered to meet them at Lloyds in London. He was accompanied by Martin Culshaw, the most senior engineering geologist. So, the two separate contacts were brought together. As a result, BGS asked us to produce a 'trial' GHASP, which was done for the Swindon area (which Brian Kelk knew well as he had worked there for a few years).

The trial was completed and BGS was then approached by one of the underwriters at Lloyds (the current company Hiscox Insurance was involved with the Syndicate at Lloyds that BGS worked with). It was agreed that a partnership would be formed, BGS having a 2/3rds share and the Syndicate a 1/3rd share. BGS set out to produce a national product for Britain that would help insurers understand the risks from 'subsidence'. Brian Kelk did a rough calculation that valued the data and the cost of producing the product (combined) at £600k (in 1992). The Syndicate agreed to put up their third (£200k) to enable BGS to build the product. There was a problem in that almost none of BGS's geological spatial data (maps) were digitised and the data that were digitised were at a scale of 1:250,000, bedrock only. Brian Kelk personally raster scanned the 1:50,000 scale geological maps and used the 1:250,000 scale maps to fill in the gaps where larger scale mapping did not exist. As a result the product required a lot of interpretation (for example, to take account of superficial deposits). It was decided that we would use postcodes as the basis of the hazard assessment. This was because the insurance industry used postcodes and they were available digitally from the Post Office. A 'subsidence' hazard rating for each of 9,233 postcode sectors was worked out manually using a formula that Brian Kelk and Martin Culshaw worked out and a team of retired survey geologists implemented. Britain was divided into seven regions and a geologist allocated to each one: Region 1 SE England (Reg Thurrell), Region 2 Central England (David Mills), Region 3 Lancashire and Yorkshire (Jack Taylor), Region 4 SW

England (Brian Williams), Region 5 N England (??), Region 6 Scotland (Innes Lumsden), Region 7 Wales (Brian Hains). Martin Culshaw was the project leader for this part of the work.

The product was built for only £100k and it was an immediate success. However, many of the UK insurance companies didn't have any computers! So BGS had to first act as IT consultants before the system could be installed. GHASP was purchased by 35% of the whole UK home insurance industry and grossed well over £3m, a third of which went to BGS's partner. While the product was at its peak, the Underwriter sold the holding company for £1m! So, for an investment of £100k (BGS didn't need the other £100k), they made £2m. Not a bad return. The product lingered on for many years, particularly with smaller companies. And income continued in a small way till the early part of the 2000s. One problem was that the fee charged, whilst related to the size of the individual insurance companies, only applied for each of the first five years. After that the annual payment tailed off to about £5k per year.

Some organisations tried to produce rival products. For example, the Royal Insurance paid for a product to be developed by John Doornkamp *et al*. that sampled the geology from BGS's maps on a grid (to get round BGS's copyright - they thought that BGS only 'owned' the linework). However, there was a court ruling and it was judged that BGS owned copyright on the lines and what was between the lines. The Soil Survey also produced a product but it is thought that they only sold one copy.

The geohazards covered were:

i. Shrinking and swelling clays
ii. Landslides, including cambering
iii. Dissolution
iv. Shallow undermining
v. Compressible soils

GHASP (GeoHazard Susceptibility Package) was the forerunner of GeoSure. The main difference was that rather than attributing the postcode sectors, as was done with GHASP (because of the lack of digital geological data) GeoSure attributed the geology in terms of geohazard susceptibility. GeoSure would not have been developed if GHASP had not been developed first. Luck also played a part for GeoSure in that in the early 2000s BGS received a local tax refund of over £2m. It was decided to use it mostly to digitise the 1:50,000 geological maps. With those, GeoSure became feasible.

A 'son-of-GHASP' product for Greater London was produced around 1994/5, mainly by Poul Strange. This was at a scale of 1:10,000 (GHASP10). It was not successful because GHASP50 itself worked so well. The insurance industry gained huge value from GHASP50 and the extra value from GHASP10 was not worth the extra cost! GHASP10 had additional hazards – collapsible soils and running sands, both of which later were included in GeoSure.

Two short papers in relatively obscure conferences proceedings (Culshaw 1993, Culshaw and Kelk 1994) were written and a very brief news item appeared in Mercian Geologist (Anon. 1993). This was done to establish BGS's 'ownership' of GHASP but not in a way that would give much away. Keith Turner (then Colorado School of Mines) made a presentation on behalf of Brian Kelk to the 1997 European Science Foundation Conference: “Virtual environments for the Geosciences: Space-time modelling of bounded natural domains” held in Rolduc, The Netherlands. The talk was entitled: “Systems, data, information or solutions? Addressing the needs of the UK financial services sector.”

It is sad to note that the BGS refused to invest any of their £2m+ profit at all in improving knowledge and understanding of the geohazards themselves. At the time, the budget for swell-shrink was £10k per year. It was not until 2000 that it was possible to start developing geohazard databases and develop some serious research into processes.

7.8.2 GEOSURE – geohazard information for all

Strictly, GeoSure (National Ground Stability dataset) was not produced directly by engineering geologists, though they, particularly Alan Forster, were heavily involved in its development. This product achieved what the GHASP developers always intended: a digital geological map of Britain attributed with information on geohazard susceptibility. The main differences compared with GHASP were that the data used were (mostly) at an original scale of 1:50,000, giving a ground resolution of 50 m, the data were vectorised (rather than rasterised) and the geology was attributed rather than the postcode sectors. Also, GeoSure mostly covers ground stability related to natural geological hazards (compressible ground includes artificial deposits). The dataset on non-coal was not included but exists separately. However, what is clear is that without the (financial) success of GHASP, the geological data would not have been digitised and GeoSure would not have been created. Since it was developed, GeoSure has been supplied to tens of thousands of users and BGS has earned millions of pounds from its data.

The GeoSure dataset comprises six different Geographical Information System (GIS) layers, with each layer representing a different natural ground stability hazard that occurs in Great Britain (Lee & Diaz Doce 2018). The GeoSure datasets are polygon (area) layers, which are described using a simple A to E potential hazard classification (A = Low, E = High). The six datasets cover:

i. Shrink-swell
ii. Landslides (slope instability)
iii. Soluble rocks
iv. Compressible ground
v. Collapsible deposits
vi. Running sand.

A number of additional relevant datasets also have been created:

- superficial Deposit Thickness Model;
- scans of onshore borehole logs for Great Britain;
- scans of geology and historic topography maps;
- ground permeability data (sustainable urban drainage, SUDS);
- susceptibility to groundwater flooding data;
- geological indicators of past flooding data;
- environmental sensitivity data;
- GIS data identifying potential radon hazard;
- soil Parent Material Model;
- and non-coal mining hazards data.

Of these, the non-coal mining hazards dataset was produced as part of the GHASP datasets. Coal was not included because the Coal Authority held the national dataset relating to coal mining and was best placed to provide relevant information.

GeoSure has a separate insurance product that gives an index-level assessment of the potential for a geological deposit to create financial insurance loss due to natural ground movement. It incorporates the combined effects of the six BGS GeoSure hazards on (low-rise) buildings and links these to a postcode database (the derived postcode database). This database contains a normalised hazard rating for each of the six BGS GeoSure themes hazards (i.e. each BGS GeoSure theme has been balanced against each other) and a combined unified hazard rating for each postcode in Great Britain. This product is similar in concept to the original GHASP product.

GeoSure was financially successful. For example, figures for the period 2004 to 2009 showed income ranging from just over £700k in 2004-5 to £1,200k in 2007-8 and just under £1,100k in 2008-9.

7.8.3 Assessment of hazard and risk – guides for users

In 2002 a general guide to geohazard and risk was written (Forster *et al.* 2002). It was intended for users of geohazard information but who were not experts in the subject. It set out to explain the following:

- the concepts of hazard, vulnerability and risk;
- the idea of primary and secondary geohazards;
- and hazard assessment methodologies in urban planning.

Particular attention was also paid to:

- volcanological hazards and associated risk;
- hazard and risk associated with earthquakes;
- hazard and risk associated with contaminated land;
- a hydrogeological view of geohazard and risk;
- and various insurance industry views of geohazard and risk.

A national assessment of the main geological hazards that affect Great Britain were discussed by Forster *et al.* (2003). The geohazards included were:

- landslides;
- running sand;
- compressible soils;
- collapsible soils;
- dissolution;
- and shrinkable clay soils.

The report describes the reasons for using a deterministic approach for the assessment of these geological hazards rather than a probabilistic approach. It then describes how a deterministic method was devised and applied to each of the above geohazards. It also discusses how the results may be explained for different types of user groups.

In 2006 a third general guide was produced on the communication of geohazards information to the public (Forster & Freeborough 2006). The report main aims were:

- to collect examples of ways in which a variety of organisations have tried to convey the nature and significance of geohazards to non-geological audiences;
- to determine which have been the most effective in their intentions and which have failed;
- to provide guidance on the (then) current best practice for achieving effective communication of geohazards to relevant groups in Great Britain;
- and to compile a specification, or range of specifications, for publication (paper, digital, web) to inform the British public about geohazards around them and their implications.

7.9 GEOHAZARD MAPPING IN THE UAE (2002-2006)

In addition to the geological mapping of the UAE, a general overview of geohazards with respect to broad physiographic zones found in the UAE was carried out. This is shown on the accompanying 1:500K scale ‘Geohazard Overview Map’. The Geohazard Overview Map is not a ‘geohazard ’map in the true sense in that it does not identify zones of hazard *susceptibility* (or *potential*). The preparation of such hazard susceptibility/potential maps requires detailed field survey, data acquisition and analyses that were beyond the scope and funding of this study.

The engineering geohazards are described in relation to four main physiographic zones, namely: I - Mountains, II - Alluvial Fans and Wadi Deposits, III – Desert Area, and IV – Coastal Zone and Inland Sabkhas.

In general terms, the UAE is an area where geological hazards are those typically found in the hot dry lands of the desert environment. The main geohazards have been described and salient points are summarised below. These geohazards can influence or, in some instances, constrain engineering development in the UAE. However, it should be pointed out that the presence and nature of these hazards are generally well- documented in the engineering geological literature and/or engineering standards, and should be appreciated, understood and accounted for by experienced and competent professionals working in the UAE.

The bulk of the work on geohazards (other than seismicity and tsunamis) was carried out by Kevin Northmore and Dave Boon.

7.9.1 Landslides

Landslide hazards of any significance are relatively infrequent in the UAE and are restricted to the Mountain Zones IA and IB. Rock falls form the most common type of failures from jointed rock masses within both the bedded Permian to Lower Cretaceous limestones of Zone IA in the Musandam Peninsula and the ophiolite-dominated areas of Zone IB. In addition to rock falls, large toppling failures (and incipient toppling failures) are particularly evident in the Tertiary limestones of Jebal Hafit in Zone IA. Large to medium-scale rock slides appear to be restricted to the steeply-dipping western slopes of the limestones in Zone IA, with failures occurring where steeply-dipping bedding planes ‘daylight ’on over-steepened slopes.

The most widespread cause of slope instability appears to be that associated with road construction, where virtually every road cutting is prone to ongoing minor rock falls, slides and wedge failures. In many of the major road cuttings, stabilisation measures have been put in place to mitigate the effects of the cut slope instability, to varying degrees of success.

Even though the UAE has a generally low level of seismic hazard, ground accelerations and minor fault movements resulting from even low intensity earthquakes have the potential to cause movement of already unstable rock masses, leading to falls and topples.

7.9.2 Karstic ground conditions

Sinkholes, dissolution pipes, dissolution cavities and widened joints and fissures at or near the ground surface are characteristic features of karstic areas and may pose a hazard in parts of the mountainous limestone areas in the UAE (Mountain Zone IA). Examples of such features can be readily seen in the limestones of Jebal Hafit but appear to be less frequently developed in the well-bedded Permian and Cretaceous limestones forming the northern part of the mountain zone of the Musandam Peninsula. Dissolution cavities, pipes and widened joints and fissures (which may be in-filled with sediment and detritus washed in over time) can lead to instability of steep road cuttings and other excavations. Near-surface dissolution cavities present a particular hazard when the roofing strata can no longer support their own weight or the added weight of construction loads, leading to sudden collapse. Pre-construction walk-over surveys and site investigations in the limestone terrain of Mountain Zone IA should be directed to ascertaining the presence, extent and dimensions of such features.

7.9.3 Flash floods

Flash floods may occur after torrential rainstorms in the mountain wadis and on the often complex drainage systems of the Alluvial Fans in Zone II. Recognition of the risks posed by wadi and sheet flood hazards, resulting from intense intermittent rainstorms in the mountain zone, is a pre-requisite for successful planning and engineering development in the alluvial fan terrain, particularly for the construction of roads and other infrastructure. Where necessary or possible to do so, avoidance of those areas thought, or known from previous events, to be areas of high flood risk can be achieved by sensible, informed land-use planning. If avoidance is not an option, road routes, etc. should be located in such a way that the number of channel crossings are minimised. A general principle that should be appreciated in planning and development on alluvial fans is that the established natural drainage lines are the most efficient (and cheapest) means of dealing with surface water flows. Roads and other structures likely to disturb this natural equilibrium should, as far as possible, be designed to minimise disturbance to the natural drainage regime.

7.9.4 Sand and dust movement

Sand and dust movements are a significant geohazard associated with the Desert Area of Zone III. The effects of these hazards can also extend beyond the desert area to impinge on roads, population centres and agricultural areas beyond the desert margins. The removal of sand and dust by wind from desert surfaces (deflation), and its subsequent transport and deposition can lead to soil impoverishment and scouring of support from engineering structures, abrasion of building materials and destruction of agricultural areas. Problems associated with dust storms include the spread of disease, suffocation of livestock, development of static electricity, interruption of telecommunications, disruption of transport, property damage, and harm to human health through bronchial complaints. Visibility reduction due to blowing dust is also a major problem, particularly to the transport industry.

Mitigation measures may include removal of sand deposits (where economical and effective to do so), stabilisation techniques and creating barriers to arrest or slow sand movement by such means as vegetation windbreaks or shelter belts. All such measures have advantages and disadvantages, and often a combination of different techniques is needed to obtain optimum results.

It is recommended that any stabilisation and control measures are monitored before, during and after their implementation, so that data on the wind-sand-dust system and its response to the implemented measures can be used to inform and advise planners on the likely effectiveness of similar projects in other areas. An understanding and appreciation of deflation (erosion), transportation and deposition processes of wind-blown sand and dust is essential for effective land management. This can best be achieved by adopting sensible land surface management programmes that include measures to limit destabilisation and dust-generating activities by human interference (including removal of vegetation by overgrazing and uncontrolled excavation and construction activities) and promote, wherever possible, natural stabilisation processes.

7.9.5 Aggressive ground conditions

Aggressive ground conditions associated with saline soil and groundwater conditions are not restricted to the coastal zone (Zones IVA) and inland sabkhas (Zone IVB), but are most intense in these areas and of particular concern in the coastal zone because of rapidly expanding engineering developments. Such conditions can seriously affect the durability and longevity of construction materials, particularly steel and concrete.

The high surface temperatures of the UAE promote evaporation of surface and near surface moisture resulting in a process called ‘capillary rise’. Removing near-surface water from the soil causes more salt water to be drawn up from below, which subsequently evaporates, leaving an accumulation of salts such as gypsum, dolomite and halite behind in the soil. This also has implications for buildings founded on fill placed on top of the natural ground surface. In such locations the capillary rise can extend into the placed fill (i.e. above the original ground surface), resulting in salt deposition and subsequent aggressive chemical and physical attack on the foundations and other associated structures after construction.

Structures in the coastal zone, particularly those built on offshore islands, are also exposed to airborne chlorides in addition to saline ground water, so in addition to the foundations, the above-ground structure is also susceptible to corrosion by wind-borne salts, and requires careful choice of materials to ensure longevity.

The problems of aggressive ground conditions in the Middle East are well documented and generally widely understood by competent engineers and developers, and adherence to relevant standards and guides should be a prerequisite to help mitigate their effects.

7.9.6 Variable bearing strengths

The mechanical behaviour and density of the coastal (Zone IVA) and inland sabkha (Zone IVB) sediments can vary both laterally and vertically, depending on the sediment types, moisture content, and development of a surface crust. Variation in the vertical and horizontal compressibility of sabkha deposits, particularly in uncemented layers, can cause severe differential settlements of building foundations if not adequately identified and accounted for in design. The presence of low density layers can similarly lead to settlement problems if not adequately identified during site investigations.

Care is needed in attempting to increase the density of near-surface load bearing layers by mechanical compaction as this may result in breaking up weakly cemented underlying layers, resulting in lower overall bearing capacities. Gypsum within the soil sequence can also undergo alternate hydration and dehydration under hot and humid conditions, resulting in volume changes that may cause heave or subsidence leading to the distress of foundations and structures.

Because sediment properties in Zone IV can vary greatly over short distances, ground investigations need to be directed to carefully establishing these variations within the boundaries of each development site. In addition to ascertaining the nature and properties of the local lithological sequence (including the extent, depth and bearing properties of weak low-density layers, which may also be susceptible to liquefaction), ground investigations should also include an appraisal of the ground and groundwater chemistry, the results of which should be accounted for in engineering design and development.

7.9.7 Liquefaction

Liquefaction is a phenomenon marked by a rapid and dramatic loss of soil strength that can occur in saturated cohesionless (sandy and silty) soils subjected to earthquake motions. The onset of liquefaction is usually sudden and dramatic, and under appropriate conditions can result in large deformations and settlement of the ground surface and hence foundations of structures.

For liquefaction to occur, soil types susceptible to liquefaction must be present in areas where a shallow water table results in saturated ground conditions. Geologically younger (Quaternary) sandy soils are most susceptible, with the most recent Holocene soils (less than 10,000 – 11,000 years old) being most prone to liquefaction. In addition to natural soils, artificial soil (fill) deposits, particularly those created by the process of hydraulic filling, may also be susceptible to liquefaction. Based on these broad geological criteria, it is likely that Quaternary beach sands, sabkha deposits and some artificial marine sand fills of the UAE coastal zone (Zone IVA) are potentially susceptible to liquefaction to a greater or lesser degree, depending on local lithological and density characteristics.

Critically, for liquefaction to occur, these soils also need to occur in areas likely to suffer strong seismic shaking due to earthquake-induced ground motions. Because of the generally low seismicity of most of the UAE, it is likely that over the majority of the coastal zone south and west of Dubai the liquefaction hazard is also likely to be low, although this should be confirmed from selected site-specific evaluations. As with the seismic hazard, the potential liquefaction hazard tends to increase towards the north.

The procedure for assessment of liquefaction hazard highlights the need for site-specific evaluations. These are essential for a realistic appraisal of liquefaction hazard in the UAE and were beyond the scope of the present report. For each site-specific study the following steps are required to be checked:

i. Susceptibility, that is, whether or not the soil at any particular site is prone to liquefaction (e.g. clay soils or dense sandy soils with corrected SPT blow counts greater than 30 will not liquefy).

ii. Hazard, that is, whether or not liquefaction can occur under the ‘design ’earthquake (e.g. the soil may be prone to liquefaction but the shear stresses generated by the design earthquake may not be severe enough to trigger liquefaction).

iii. Risk, that is, the possibility that, should liquefaction occur, engineering foundations suffer damage, and the extent of such damage.

7.10 MULTI-HAZARD PROJECTS

7.10.1 FUTURENET (Future resilient transport networks – an inter- disciplinary approach), £1.5m (2009 – 2013)

EPSRC funded project. Much current discussion about transport and climate change focuses on the impact of transport on climate change. Indeed, many mitigation measures are focussed upon the transport change, and many mitigation measures are focussed upon the transport sector. FUTURENET brought together a wide variety of academic expertise spanning the engineering, environmental and social sciences, together with a diverse group of stakeholders in the transport industry. The project recognized that climate change impact has two dimensions:

i. an engineering dimension derived from the interaction between climate design, weather events;

ii. and the physical network, and a socio-economic dimension derived from the interaction between weather and climate and the patterns of transport demand.

FUTURENET integrated both in assessing the future resilience of the UK transport system. This interdisciplinary approach assisted stakeholders in adapting the transport network and increasing resilience of critical transport infrastructure. FUTURENET developed scenarios for how the transport system in the UK might look in 2050. An overarching model framework was developed that combines transport models with climate change scenarios and transport scenarios to enable the resilience of different types of transport network to be evaluated.

7.10.2 iSMART (Infrastructure Slopes: Sustainable Management and Resilience Assessment), £1.7m (2013 – 2017)

iSMART followed on from FUTURENET. It focused on the UK's transport infrastructure as one of the most heavily used in the world. The rail network takes 50% more daily traffic than the French network; the M25 between junctions 15 and 14 carries 165,000 vehicles daily; London Underground is Europe's largest subway. The performance of these networks is critically dependent on the performance of cutting and embankment slopes that make up £20bn of the £60bn asset value of major highway infrastructure alone. Many of these slopes are old and suffering high incidents of instability (increasing with time). iSMART created a visualised model of transient water movement in infrastructure slopes under a range of current and future environmental scenarios, based on a fundamental understanding of earthwork material and system behaviour. This can be used to create a more reliable, cost effective, safer and more sustainable transport system. The impact of the improved slope management will be highly significant in both direct economic and indirect social and economic terms: planned maintenance costs ten times less and reduces delays caused by slope failure. This project offered a unique opportunity to unite six academic institutions and coalesce their field, laboratory and computing facilities.

7.10.3 Safer Self-Recovery (multi-disciplinary research into post disaster self-recovery in Nepal and Philippines), £300k (2017)

Following a disaster, the majority of families rebuild their homes themselves. This British Academy-funded research project considered how the physical environment influences such ‘self-recovery’ by investigating disasters in the Philippines (typhoons Haiyan in 2013 and Haima in 2016) and Nepal (the 2015 Gorkha earthquake). Despite the many differences in the disaster contexts, there are some common barriers to self-recovery (and building back better) in a substantially changed and dynamic multi-hazard, post-disaster environment. These are related to changes in water supply (shortage or surplus), impacts of post-disaster geohazard events on infrastructure (particularly affecting transport) and the availability of technical advice. People face a broad spectrum of challenges as they recover and tackling these ‘geo-barriers’ may help to create a more enabling environment for self-recovery. The findings point to what needs to be in place to support self-recovery in dynamic physical environments, including geoscience information and advice and restoration of infrastructure damaged by natural hazard events. Further research is necessary to understand the issues this raises for the shelter and geoscience communities, particularly around availability of geoscience expertise, capacity and information at a local scale.

7.10.4 Hydrology, Earth Observations and Modelling Exploration. HydEOMEx, £10k (2016)

NERC funded project: NEC05868: the Hydrological Earth Observation modelling exploration (HydEOmex) project was a small-scale (£25k), short-term pilot project (running January to May 2016) designed to demonstrate the potential of Earth Observations in hydrological applications for a range of stakeholders. The project was funded by NERC, following a funding 'sandpit' aimed at developing proof-of-concept 'climate services' applications. Evaluation of the relevance of EO of soil moisture was performed by comparing it with a near surface soil water balance developed by the BGS. The goal of the pilot study was to use EO products (in particular, soil moisture and vegetation condition) and integrate these with existing hydrometeorological monitoring programmes, to evaluate the potential benefits of more integrated monitoring and forecasting systems in future. The focus is on situation monitoring ('nowcasting') and forecasting over the monthly-to-seasonal timescale, and not short-term (that is, 1–5 day) flood forecasting. However, the potential benefits are clearly not just for drought but also for early warning of persistent wet periods.

7.10.5 Landslide hazard and risk assessment for Africa (2016 – 2017)

NERC/GCRF-funded project and World Bank/GFDRR-funded project. Ove Arup & Partners International Ltd (Arup) and the British Geological Survey (BGS) were appointed by the World Bank's Global Facility for Disaster Reduction and Recovery (GFDRR) to characterise landslide risk for five countries in Sub-Saharan Africa: Ethiopia, Kenya, Uganda, Niger and Senegal. (This was later extended to cover further countries across the continent). This study formed part of a wider initiative by the GFDRR to characterise multi-hazard risk in Sub-Saharan Africa. As part of this initiative, this study made use of data provided by the following consortia, also commissioned by the GFDRR, to investigate some other aspects of multi-hazard risk in Sub-Saharan Africa:

- Exposure development – ImageCat Inc., CIESIN, University of Colorado and SecondMuse. Referred to in this report as the SSA (Sub-Saharan Africa) Exposure Consortium.
- Flood and drought risk characterisation – CIMA. Referred to in this report as the SSA Flood and Drought Consortium.
- Earthquake risk characterisation – Risk Engineering and Design (RED) and Evaluacion de Riesgos Naturales (ERN). Referred to in this report as the SSA Earthquake Risk Consortium.
- Volcanic risk characterisation – Global Volcano Model, British Geological Survey and University of Bristol. Referred to in this report as the SSA Volcanic Risk Consortium.

The annual rate of fatalities resulting from landslides worldwide is, generally speaking, increasing (Petley 2011). Notwithstanding the influence of external factors (for example, the advent of the Internet to aid disaster reporting or the widespread utilization of remote sensing for landslide mapping), a broad increase in worldwide estimated annual fatality rate moving through the 20th Century and into the 21st Century is apparent. Nadim *et al.* (2006) attributed the increasing frequency of landslide disasters to greater susceptibility of surface soil to instability due to over-exploitation (mining and deforestation), growing urbanization, uncontrolled land use and unregulated population growth into previously undeveloped areas. Petley *et al.* (2005) also indicated that there appears to be a close correlation between global climate change and the number of fatalities caused by landslide events. Of particular note for this study was the observation by Petley *et al.* (2005) that "the majority of fatalities occur in less developed countries". It is for this reason that landslide risk analysis in sub-Saharan Africa is vital to managing the annual fatality rate due to natural disasters (Redshaw *et al.* 2016 and Dijkstra *et al.* 2016b).

8 TRAINING COURSES

8.1 ENGINEERING GEOLOGY

In around 1993 it was decided that many scientific staff in the BGS lacked any knowledge of engineering geology. The aim of this course was to explain what the subject areas that relate to engineering geology and engineering geologists. It was also to show how engineering geologists can provide useful input to the work of others in the BGS. Each course lasted for 4.5 days and evolved over the years and in 1997, the last year it was run, contained:

- Introduction to engineering geology (general concepts)
- Site investigation
- Classification in engineering geology
- Core logging for engineering geology purposes
- Borehole geophysics
- Engineering geophysics
- Core logging practical
- Geomechanics I – soils
- Geomechanics II – rocks
- Geohazards
- Groundwater in engineering geology
- Laboratory visit with some practical
- Engineering geology mapping
- Engineering geology problems – classwork
- Field visit the Nottingham and Grantham areas

As can be seen, this is a lot to cover in such a short time. Initially overseen by Martin Culshaw and later by David Entwisle, over the years it involved many of the engineering geology group staff (Martin Culshaw, David Entwisle, Alan Forster, John Hallam, Peter Hobbs, Peter Jackson, Dave McCann, Kevin Northmore, Steve Shedlock and, in a guest role, Gary Wealthall). There were copious notes to go with this course that was tagged “an engineering degree in less than a week,” well, without the project work. The presenters use photographic slides and overheads.

It was presented several times at Keyworth and once in Edinburgh. After 1997 it was decided that the course was too unwieldy and contained too much information for sensible ingestion by many on the course other than in a superficial way, which might have been enough. As it was considered that the course was far too concentrated it was decided that a number of separate courses could be run, perhaps a day or a few days long, based on engineering geological subjects.

One spin off from this course was BGS involvement in the Nottingham Trent University MSc in contaminated land management to provide some geological and engineering geology background. This course, presented in 1999 and led by Alan Forster, included:

- Environmental geology – processes
- Structural geology
- Maps
- Geology of the UK – Pre-Quaternary and Quaternary
- Environmental geological maps – Wigan
- Soil and rock description
- Engineering geological classification
- Soil mechanics
- Rock mechanics

As well as Alan Forster, the staff involved were Laurance Donnelly and Pete Hobbs.

8.2 DESCRIPTION AND CLASSIFICATION

The first of the engineering geology courses for the BGS, after the main course was stopped, was on "Description and Classification in Engineering Geology." This course was led by David Entwisle and ran for many years being presented once or twice a year, mostly in Keyworth but also at Wallingford and Edinburgh offices when there were enough willing volunteers. The course was also run for overseas guests at the BGS and a couple of times at Scott Wilson Ltd. (now AECOM) in their Chilwell office. Initially, the course was for field geologists so they could understand differences between geological description for mapping geologists and that required of engineering geologists, mostly for ground engineering. However, this was broadened to anyone whom it was thought could find it useful including hydrogeologists, 3D geology modellers and the enquiries team.

In the original Engineering Geology course "Description and Classification" was covered in about 3 to 4 hours. This course lasted 2 days covering soils on Day 1 and rocks on Day 2 with copious notes based on the most up to date version of BS 5930 and latterly David Norbury's book "Soil and Rock Description." It was primarily class taught with an hour or so in the laboratories with a tour and teaching of simple laboratory techniques relevant to soil description, that is, liquid limit and plastic limit. Day 2 included a visit to the National Geoscience Data Centre (NGDC) to look at and describe examples of soil and rock core followed by a class problem.

8.3 LANDSLIDE MAPPING

Following on from the "Description and Classification" training course, a "Landslide Mapping" training course was proposed and was initially led by Alan Forster and Andy Gibson. The first course was run in 2002 and several times after that with an update in 2005. It was later organized and run by Pete Hobbs and Claire Dashwood. The course objectives were to provide training in the identification, description and recording of landslides in the field and health and safety aspects. It was hoped that the course would promote the importance of slope processes in different regions of Great Britain. It was aimed at field geology mappers and those working in geohazards.

The initial courses were field based in two modules.

- Module 1: Landslides in lowland and coastal periglacial areas.
- Module 2: Landslides in upland glaciated terrains.

Module 1 lasted 4 days, based in Lyme Regis and comprised:

- An introduction to different styles of landslides and their features in fresh coastal exposures (Black Venn, Hooken Cliff, Bindon, Portland) and degraded inland slopes at Stonebarrow/A35 bypass, Wellington District or the Cotswolds.
- Recognition and assessment in urban areas and the built environment - Lyme Regis, East Cliffe, A 35 Charmouth By-pass.
- Influence of discontinuities and structure.
- Introduction of landslide domains.

Module 2, lasted 2 days, based in the Peak District and comprised:

- Identification components in a degraded terrain (Edale).
- Identification and description of degraded large features and debris flows including mapping (Rowlee Bridge, Alport Castle, Longdale).
- Assessment of landslide maps in mapping areas.

Over the years, various other one-off courses were run for specific groups, for example, staff from the Cyprus Geological Survey and part-time civil engineering students at Nottingham Trent University.

9 OVERSEAS WORK – A SUMMARY

Roger Cratchley had spent the majority of his early career years working for the Overseas Geological Survey (which became the Overseas Division of the BGS) as a geophysicist. He worked mainly in Southeast Asia and Africa. When he became Head of the EGU this experience made him keen to take on overseas work in engineering geology.

Over the years, EGU was funded mainly by the British Government (through the Overseas Development Ministry [ODM], the Overseas Development Administration [ODA] and the Department for International Development [DFID]) to carry out a range of projects mainly in developing countries. For some of the projects listed below more detailed information is provided above under one of the scientific classifications.

9.1 COLOMBIA AND ECUADOR (1972)

A proposal was submitted to carry out "geotechnical research into slope stability, largely in tropical conditions" by Bruce Denness in the middle of 1972. The proposal envisaged a joint research and development project with the Transport and Road Research Laboratory. Initially, work would be carried out in Colombia. The objectives were to:

i. engage in research and development (with regard to slope stability) in tropical climatic conditions;

ii. cooperate with (or instruct) foreign engineers and geologists;

iii. undertake troubleshooting in the event of potential or actual disasters;

iv. and foster good relations with developing countries based on an understanding of local problems.

However, despite Bruce Denness paying visits to both Colombia and Ecuador, the project did not develop further than the two short visits. However, further aid work was carried out in Ecuador in the late 1970s and in Colombia in the late 1990s (see below).

9.2 CHILE (1973)

In 1973 a request from the Chilean Government to kit out the geotechnical laboratory at the Chilean Geological Survey was received and agreed. Martin Culshaw was scheduled to go out to Chile to advise on the setting up of the laboratory. However, in 1973 a coup overthrew the government and while the equipment was sent to Chile the supporting visit was cancelled.

9.3 ST HELENA, SOUTH ATLANTIC (1975)

In February 1975, EGU was asked to carry out a rock fall investigation in the James Valley of St Helena an island in the mid-Atlantic Ocean. The work was funded by British Government Overseas Development Administration. The field work lasted three weeks but as the island was only accessible by sea another two weeks were required for travel to and from the island. The work was carried out by Martin Culshaw (apparently, a young engineering geologist was requested because of the steepness of the slopes!) and is described above.

9.4 INDONESIA (1976 TO 1978)

Martin Culshaw carried out engineering geological mapping of the Banda Aceh basin on the northern tip of Sumatra, Indonesia. The project was part of a British Government Overseas Development Administration funded Technical Cooperation project involving the geological mapping of Sumatra north of the equator. The Banda Aceh project was scheduled for 20 months from November 1976. The project's main aim was to train Geological Survey of Indonesia engineering geologists in engineering geological mapping. Martin Culshaw was based at the Geological Survey of Indonesia in Bandung, West Java and spent a total of 16 weeks in the field in three separate visits. The project is described above.

9.5 FIJI (1977 – 1979?)

Andy Green who joined EGU in 1976 went on an Overseas Development Agency contract to Fiji during 1977. It is not clear how long the contract lasted (probably two years but he left the BGS shortly after returning from Fiji in early 1981). The work was advisory and involved training but much of it seemed to consist of a range of groundwater studies rather than engineering geological activities.

9.6 JAMAICA (1978 – 1981)

In the latter part of 1978, Martin O'Hara, an engineering geologist, was recruited to work on a three (?) year contract in Jamaica. According to his mid-tour report dated November 1979, his letter of appointment described the work as follows:

"During your appointment you will be responsible for all field and laboratory engineering geology investigations, projects and reports, and you will provide consultancy and liaison services on the geological aspects of engineering problems for the Government sector: this will include the giving of advice on measures to combat earthquake risks in building projects; the geo-technical investigation of small dam-sites for irrigation purposes and geological investigations for hydroelectric studies and installations. You will also be required to undertake on-the-job training of two or three Jamaican Engineering Geologists." This type of work was expected to continue for the remainder of the contract.

9.7 ECUADOR (1978 – 1980)

In February 1978, Richard I. Johnson began a two-year technical cooperation project in the Engineering Geology Section of the Ecuadorian Directorate of Geology and Mining. Johnson never worked in the EGU and it is assumed that he was recruited by ODA. Work included 'geotechnical' mapping for "Slope Angle studies, geology, Terrain Evaluation, Soils Mapping, and finally Geotechnical interpretation." Other work included smaller site investigation projects, advising on aggregate extraction and setting up and operating the geotechnical laboratory funded by the UK.

The information summarized here is taken from a preliminary progress report dated August 1979.

9.8 SRI LANKA (1980 – 1981)

In early 1980, Martin Culshaw went to Sri Lanka for an 18-month Overseas Development Agency Technical Cooperation contract in the Irrigation Department following a scoping visit with Roger Cratchley in 1979. The UK Government was in the process of funding the construction of the Victoria Dam on the Mahaweli River in central Sri Lanka. As part of the funding it was decided to provide comprehensive rock and soil mechanics laboratory equipment and two rotary coring drilling rigs. The work essentially broke down into two areas:

i. ensuring that the equipment provided by the British Government arrived safely at the Irrigation Department;

ii. and providing training in site investigation for small dam sites the building of which was the main activity of the Department.

The work covered much of southern and central Sri Lanka but was brought to a premature end in April 1981 when the UK Government decided to cut back on various aid projects.

9.9 CYPRUS (1981 – 1986)

Collaborative research between EGU and the Geological Survey Department of Cyprus (GSD) began in 1981 with the geotechnical mapping and data assessment of the greater Nicosia area south of the UN 'Green Line' established in 1974 to separate Greek Cyprus from Turkish Cyprus. Peter Hobbs and Ian Moore provided the EGU input. The output of this work was a geotechnical map (that would now be referred to as an engineering geological map) of Nicosia and a detailed report. The EGU's contribution to this work was funded by the UK's Overseas Development Administration (ODA). The results of the mapping are presented in a report (number EG/82/10 by

Hobbs & Loucaides, 1982) and on a 1:25,000 scale engineering geological map based on field mapping at 1:10,000 scale.

The collaborative research in Cyprus continued in 1982-6 with a study of the engineering geology of cohesive soils associated with ophiolites. Cohesive soil formations are found close to the Troodos Ophiolite. The soils are largely bentonitic and very susceptible to shrinkage (when dried) and swelling (when wetted). The geotechnical investigation focused on the Pliocene marls in the Nicosia area (1982-3), followed, in 1983-4, by a geotechnical study of the Pliocene marls of the Polis region of northwest Cyprus and the 'tectonised' bentonitic clays of the Moni Formation in the Pendakomo area of southern Cyprus.

In 1984, the research was broadened to include a detailed engineering geological investigation of two adjacent areas in the Paphos region of southwest Cyprus where extensive outcrops of Kannaviou Formation bentonitic clays, 'Melange' and other cohesive deposits derived from allochthonous Mammonia Complex rock are involved in widespread mass movements. The investigation was divided into two study areas, one of around 40 km^2 centred on the village of Phiti and the second of around 63 km^2 centred on the village of Statos. The two study areas form a continuous survey area located adjacent to the western margin of the updomed Troodos Massif. Both areas are characterized by widespread slope instabilities. These were mapped at large scale (1:10,000) and utilized the experience gained in the South Wales Coalfield a few years earlier in 1977-81 (see above).

The final part of the project involved collecting and geotechnically and mineralogically testing supplementary samples from the main cohesive soil formations elsewhere in Cyprus. Testing was carried out in the Geological Survey Department of Cyprus.

The main EGU staff involved in the work were Pete Hobbs, Kevin Northmore and Paul Gostelow. Six reports Nos EGARP-KW/86/1-6 and two landslide maps provide the main outputs of the research (Hobbs *et al.* 1986, Gostelow & Loucaides 1986, Hobbs 1986, Northmore *et al.* 1986, Charalambous *et al.* 1986 and Northmore 1986). The laboratory testing data were retained by the Geological Survey of Cyprus. It is not clear whether the data were ever entered into a digital database.

Early in the project (1981) Paul Gostelow carried out a short study of the slope stability of waste tips of the Amiandos asbestos mine waste tips. The opencast mine had been operating since 1904 but since closed (Gostelow & Loucaides, 1981). The mine was located in the Troodos Mountains some 1,400 m above sea level. A total of 75 slip surfaces in six tips were analysed for stability. It was concluded that the likelihood of a deep-seated mass failure was "remote." The most likely mode of failure was suggested to be by non-circular slip during conditions of high pore water pressures generated by either rainfall or earthquake loading. It was recommended that slopes should be 30° or less but that this figure could be increased if natural groundwater conditions were found to be more favourable, or decreased if the reverse was true.

9.10 GREECE (1981 – 1984)

In 1981, IGS (now BGS) and the Greek Geological Survey submitted a joint 3-year project proposal to the Commission of the European Communities (CEC) sector of Environment for 50% funding of a project "to provide at a regional level an assessment of the engineering geology and seismic hazards of areas scheduled for future development within the general region of Eastern Greece which extends from Volos in the north to Atalandi in the south." This was within the context of Council of Europe proposals for seismic risk and prediction and hazard assessment. The research proposal was for the period April 1981 to March 1984 and had four elements:

i. geology and tectonics;
ii. seismology;
iii. engineering geology/geotechnics;
iv. and environmental geology – hazard assessment, seismic risk.

The proposal was unsuccessful but in 1984 a similar proposal was submitted to the CEC in the sector of 'Raw materials.'

In reality, the project was begun in financial year 1982-3 and continued in 1983-4 and 1984-5. The project was funded by IGS and IGME themselves and the second CEC proposal for 50% funding was obviously intended to defray some of the costs. In the case of the IGS, a new Executive Director (Malcolm Brown) had been appointed in 1979 and he introduced a cross-disciplinary research programme. As the 1981 CEC proposal was already submitted, Brown agreed that the project should be funded from core IGS funds as one of the cross-disciplinary projects. The project was carried out with the Institute of Geology and Mineral Exploration (IGME) and the Seismological Institute of Athens University in the more limited Volos and Almiros area of central Greece. Alan Forster, Peter Jackson and Martin Culshaw were the main EGU staff involved in the project, together with some voluntary workers. The scientific elements of the work are described above.

9.11 COSTA RICA AND CHINA (1992 – 1995)

Between 1992 and 1995 ODA funded a project to develop a methodology for land-use planners to deal with secondary seismic hazards as part of the planning process. Costa Rica and China were selected as countries to develop an advisory system. The project was not very successful as the reports were not completed because of delays in finding collaborators in China and the project being inadequately funded. The project involved Martin Culshaw, Dave Gunn, Alan Forster and Peter Jackson.

9.12 PAPUA NEW GUINEA, FIJI, SLOVAKIA AND JAMAICA (1993 – 1995 AND 1998 – 2000)

The project was concerned with developing a generic approach to rapid landslide hazard mapping and modelling that could be applied and adapted in developing (as well as developed) countries worldwide. The approach developed provided a rapid and cost-effective solution to the problem of providing regional landslide hazard information. The ultimate aim was to prevent or minimize loss of life and damage to property. The project was seen as a contribution to the United Nations' International Decade for Natural Disaster Reduction (IDNDR).

The first part of the research between 1993 and 1995 was carried out in Papua New Guinea and Fiji and focused on geologically very young and active terrains. Parallel work was also carried out in Colombia by the Cali office of Ingeominas (the national geological survey of Colombia). The second part of the work, between 1998 and 2000 was aimed at extending the methodology to other regions to develop a generic approach that could be adapted. The countries chosen were Jamaica, which has a more mature geology but a very active climate, and Slovakia, which has an even more mature geology and a temperate climate.

The research was intended to show how regional landslide hazard maps could be produced at a reasonable cost to provide information useful at the detailed (site-specific) level. They provide a useful starting point for initial pre-development planning (for example, new road routes or pipelines), identifying areas where conventional ground investigations may be required and for developing disaster response plans. The research resulted in a series of reports – Greenbaum 1995, Greenbaum *et al.* 1995a, b, Greenbaum *et al.* 2000, Marsh 2000, Northmore *et al.* 2000, O'Connor *et al,* 2000.

9.13 COLOMBIA GEOLOGICAL HAZARDS (1995 – 1999)

Intermittently from 1995 to 1999, Laurance Donnelly was involved in investigating geomorphological hazards, volcanic hazards and mining hazards in Colombia with the Colombian Geological Survey (CGS) (Servicio Geológico Colombiano; formerly known as INGEOMINAS) and the University of Medellin (Bell *et al.* 2005, Donnelly *et al.* 2001a, b, 2010c, Ojeda & Donnelly 2009). In Antioquia, this included the environmental impact of small-scale and artisanal coal mines in the areas of Amaga, Angelopolis, Venecia and Bolombolo, located in the Central Cordillera of the Colombian Andes. Historically, mining was poorly mechanised and restricted to shallow room and pillar workings. However, semi-mechanisation using the longwall mining method at some mines generated subsidence, fault reactivation, fissures and ground compression. In this region of high relief, incised river and stream valleys and thick, residual soils, the subsidence also generated landslides. These mining hazards negatively impacted on homes, roads and agricultural land. British developed subsidence prediction software (for example, Subsidence With Influence Function Techniques, also known as SWIFT) was applied to predict subsidence in Colombia and modified based on the local geology comprising thick, strong, igneous intrusive and extrusive deposits and lateritic soils that differed from the geology of the British coalfields. The mapping of geological faults and rock mass discontinuities took place at the Industrial Hullera mine in Colombia to assist mining engineers with geotechnical investigations for strata control and subsidence predictions. In Bogota and Medellin, investigations focused on the geohazards zonation of the cities to foresee the possibility for the occurrence and impact of micro-seismicity, flooding and landslides. These geohazards were a particular concern on the outskirts of the cities, where rural to urban migration resulted in the unplanned and dense colonisation of the lower and middle mountain slopes. The resultant maps and hazards zonation plans facilitated the design and planning for infrastructure to mitigate against the impact of these geohazards. Volcanic hazards zonation was also undertaken for Galeras and Nevado del Ruiz volcanoes. This included field visits to Nevado del Ruiz.

On 13 November 1985, a plinian eruption occurred on the Nevado del Ruiz Volcano, located in the Andean Cordillera of Colombia approximately 100 km southwest of Bogota. A series of pyroclastic flows interacted with snow and ice, forming the summit ice cap that covered an area of 25 km^2. The rapid transfer of heat from the eruption, combined with the seismic shaking, generated lahars (mud flows) and avalanches of saturated snow, ice and rock debris. These flowed along the principal drainage channels (the Chinchina, Guali and Langunillas drainage basins) and within four hours these had travelled over 105 km, descending 5,100 m, leaving a wake of catastrophic destruction and obliterating everything in their path. These were the deadliest lahars in recorded history. The town of Armero was buried beneath the blanket of mud. During a field visit close to the summit, a small explosion generated a lahar that was sampled and petrographically analysed at the BGS in Keyworth. General advice was also provided for the extraction of pumice on the lower slopes of Galeras Volcano for use as a civil engineering raw material.

9.14 HIMALAYAS AND KARAKORAM GEOLOGICAL INVESTIGATIONS (1996)

Previously, Laurance Donnelly had observed landslides in the Nepal Himalaya in the vicinity of Mt. Everest base camp. Following these experiences of conducting geological investigations at moderate to high altitude and in challenging conditions, Laurance Donnelly was asked by the EGU on behalf of the then Department for International Development (DFID) and Aga Khan Rural Support Program (AKRSP) to implement a geological investigation in Kashmir and the northwest Pakistan and Afghanistan frontier. The region is one of the most remote, inaccessible and inhospitable parts of the Himalayan orogenic belt. Here, two of the world’s largest and most distinct mountain belts intersect: the Karakoram Himalaya in Pakistan and the Hindu Kush in Afghanistan.

The investigation was primarily aimed at the provision of advice on mineral exploration, mining geology and the assessment of geological hazards. Tribal villagers had sunk a series of adits into the mountain sides to extract carbonaceous shale-coal as a source of fuel. The coal provided a vital, alternative source of fuel for the villagers. Traditional fuel supply was wood, that had become severely depleted, and imports of kerosene from neighbouring China and Afghanistan were too expensive. The mining methods used were rudimentary with poor understanding of the geology and basic strata control and mine ventilation. Due to the highly complex deformation of the Jurassic limestones that hosted the mineral resource, the mining engineers were unable to follow the seam underground because it was often lost due to faulting, thrusting and folding. The valuable coal was located in lenses or pockets, up to several tens of metres in size. The first part of the investigation was to determine the location of the coal 'seams' and by mapping at the surface and in underground adits, with the support from the Pakistan Geological Survey, who had sent a small team of geologists from Islamabad. Once the structural geology had been determined and the complex faulting history understood, this permitted the interpolation of the geology between points of observations. This information was conveyed to the mining engineers to help relocate the seams in underground workings. Advice was also provided for the support of mine entries, as some had collapsed when sunk through the talus and accumulated scree that covered the mountain slopes. Above the mine, on the upper mountain slopes, were glaciers and meltwaters that posed a significant risk to the mine. General advice was provided on the management and mitigation of landslides and flooding from these glaciers. The international aid provided enabled the villagers to better extract the important coal supplies as a local source of fuel. The research carried out was later published (Donnelly 2004).

9.15 MOZAMBIQUE SLOPE INSTABILITY AND BUILDING DAMAGE (2001)

In April 2001, Alan Forster visited Maputo, the capital of Mozambique, to carry out a scoping study there to determine the nature of problems of slope instability and building damage. It was also hoped to strengthen links with the Laboratorio de Engenharia de Mocambique and the Mozambique Geological Survey, particularly with reference to engineering geology and geohazards. It was hoped that the visit would result in the preparation of proposals for future joint activities. Unfortunately, no further collaboration appears to have been achieved.

Maputo is built on a Pliocene Formation that, in its upper part consists of poorly cemented ferruginous red sandstones and silty sand which gradually changes to a yellow sand with depth (Forster 2009). The sands are remarkably uniform consisting of 5% coarse sand, 75% fine to medium sand and 20% clay and silt. Five buildings were observed, for one of which tilting was judged to have been the result of inadequate foundation design. The other four were judged to have been affected by removal of finer silty material by internal erosion due to the flow of water through the intergranular pore space.

Landslides were identified on the south and eastern margins of Maputo. They are associated with the abandoned marine and estuarine coastal slopes. The slopes show different angles and different stages of maturity. Hence the potential for landsliding varies. It was proposed that land-use planners in Maputo should commission the development of a slope instability potential map for the more landslide susceptible areas and, perhaps an engineering geological map for the whole of the city.

9.16 UAE GEOLOGICAL MAPPING (2002 – 2006)

In 2002, the British Geological Survey (BGS) was commissioned by the UAE Federal Government, Ministry of Energy, to produce 1:50,000 scale geological maps of the bedrock and superficial geology of the northern part of the United Arab Emirates (UAE). In addition, a general overview of geological hazards present in the whole of the Emirates was also provided. It is divided into two parts: 1) seismic and tsunami hazards, including seismic hazard maps; and 2) other geological hazards. The research is contained in Volume 4 of the main report (Musson *et al.* 2006*)*.

9.17 ABU DHABI 3D SUPERFICIAL AND BEDROCK GEOLOGICAL MODEL (2011 – 2012)

The twelve-month project took place between 2011 and 2012. The main objectives of the project were to:

- create a combined geological and geotechnical database for the Abu Dhabi urban area for the purposes of providing data for 3D geological modelling;
- and create a 3D geological model showing the distribution, thickness and elevation of lithological units beneath the Abu Dhabi urban area using existing downhole borehole data.

According to the project report (Price *et al*. 2012), a digital database was created to store index level and downhole and geotechnical data. 10,636 borehole records, supplied by the Abu Dhabi Municipality and private and public sector organisations, were collected and processed using a standardized lithological coding system compliant with BS5930. 2,400 of these boreholes were used to create the geological model. This was developed by construction and correlation of 76 cross sections across the project area, followed by digitization of envelopes defining the surface and sub-surface distribution of each lithological unit. The model included eight natural and artificial superficial units and fourteen bedrock lithological units.

The thickness of the Quaternary superficial deposits ranges up to 30 m though they are absent in some areas. A major unconformity exists separating Miocene bedrock and younger Quaternary deposits. It cuts progressively downwards into progressively older parts of the Miocene succession from east to west.

Dissolution cavities were recorded in over 500 borehole records within the project database. Cavities are coincident with areas of gypsum beds that are either at rockhead or where it is overlain beneath the Baynunah Formation in the west of the project area. In some areas Quaternary sediments are absent where cavities are found but elsewhere they are covered by sand-rich younger Quaternary sediments.

9.18 SINGAPORE URBAN MAPPING (2013 – 2022)

A succession of projects, funded by the Building and Construction Authority of Singapore (BCA), delivered a substantially revised and up-to-date interpretation of the bedrock geology, including a new ICS compliant stratigraphy and structural framework. This work is presented in a series of peer reviewed journal articles and a 3D geological model of Singapore. Details of the engineering geology and geophysics contributions are given above.

This revised understanding of the geology of has important implications for current and future urban development. The additional complexity identified within the bedrock and superficial geology means that highly variable ground conditions should be anticipated horizontally and vertically at all scales and in all geological units. However, a better understanding of possible geometrical arrangements of geological units will also allow for better prediction of the nature and distribution of lithologies, discontinuities, alteration, and groundwater and, therefore, of the properties of the subsurface and the potential for geological hazards and resources. Application of this new geological understanding to the engineering of buildings and infrastructure, at all stages of urban development, will result in an overall reduction of both risk and cost.

To facilitate the adoption of the new stratigraphy, BCA also commissioned the BGS to produce digital and printed maps (bedrock, superficial, combine sand engineering geology) and memoir for Singapore. This is accompanied by a Practitioner’s Guide, which was developed specifically to assist those working in the civil engineering industry with the identification of geological features of interest and interpretation of stratigraphical units.

The initial project between 2013 and 2014—which involved reviewing existing documentation, undertaking a limited amount of fieldwork, and producing a 3D geological model—was led by Simon Price. Those that followed were led by Marcus Dobbs and included a wide-range of activities such as:

- third-party review of geophysical investigations;
- detailed core logging and fieldwork studies;
- geotechnical and geochemical laboratory testing;
- formal publications;
- and extensive training, seminars and workshops with stakeholders in Singapore.

9.19 INDIA – LANDSLIDE HAZARD (2016 – 2022)

An international research team has co-developed a prototype, regional-scale landslide forecasting system in two hazard-prone districts of India, helping authorities to improve early warning and build resilience to rainfall-triggered landslides. The prototype, managed by the Geological Survey of India (GSI), enabled authorities in the hazard-prone districts of Nilgiris and Darjeeling to receive experimental daily landslide forecast bulletins for rainfall-triggered landslides during the 2020 and 2021 summer monsoons. Over twelve per cent of the Indian landmass is prone to landslides, with the Himalaya and Western Ghats regions particularly prone due to the specific climatic, geomorphological and geological factors found there.

The project was developed by a multidisciplinary team consisting of physical scientists, engineers, social scientists and practitioners from nine organisations in the UK, Italy and India, under a five-year funded research grant from UK Research and Innovation (UKRI) called LANDSLIP. The BGS contributed a team of engineering geologists and geomorphologists.

The research team came from:

- India: Geological Survey of India, Amrita University, Practical Action-India, SaveTheHills and Keystone
- Italy: Consiglio Nazionale delle Ricerche
- UK: British Geological Survey (EGU), Kings College London, Meterological Office, Practical Action Consulting International, Newcastle University

The project was led by Bruce Malamud of Kings College London and, initially, Helen Reeves and, later, Emma Bee of the BGS. The primary aim of LANDSLIP has been to contribute to better landslide risk assessment and early forecasting for hydrologically controlled landslides at a regional spatial scale, and daily to seasonal temporal scales. (Information from the BGS website 25.02.23).

10 NON-GEOLOGICAL AWARDS

Various geologically-related awards received by engineering geological staff are listed in Appendix 8. However, one award is missing from that list because it had nothing to do with work at the BGS. In December 2004, shortly after he retired, Jon Hallam was awarded the Royal Navy's 2003 Shadwell Prize at the UK Hydrographic Office. This prize is open to anyone who has not been formally trained as a hydrographic surveyor. Jon carried out a survey of the harbour of Acairseid Mhor on Eriskay in the Outer Hebrides. Tides were read from the tidepole in the harbour and chart datum was established by careful comparison with the records for Stornoway. He spent three weeks gathering data followed by meticulous processing to produce a very fine graphic at 1:2,000 scale. The survey has been used to draw a new plan to be added to the chart of the Sound of Barra.

11 ……TO THE FUTURE

As indicated earlier, after the 2019 restructuring engineering geology staff moved to various teams across BGS, with a majority of staff moving into the ‘Multi-hazards and Resilience’ ‘challenge’ under John Rees, within the Geotechnical & Geophysical Properties and Processes (GGPP) and Shallow Geohazards & Risk (SGR) teams. With the departure of the Theme Manager (Helen Reeves) in May 2020, Engineering Geology and Infrastructure (‘Engineering Geology’) was no longer a recognised ‘team’ or ‘group’ within the BGS organisational structure. Also, several long-standing engineering geology staff retired around this time; Jon Busby in May 2021 and Peter Hobbs and Dave Gunn at the end of June 2021. It is interesting to note that Peter Hobbs was the last working BGS member of staff to have worked for IGS in London in the 1970s and early 1980s (he joined the BGS on 22 July 1974). With the retirement of these three, over 100 years of experience had been lost.

This nadir in engineering geology in BGS proved temporary. In March 2021, GGPP and SGR joined the Engineering and Environmental Geophysics and Geodesy and Remote Sensing teams to form a new capability called Shallow Geohazards and Earth Observation (SGEO) with Jon Chambers as the lead. And by August 2021 a new engineering geology strategy had been developed within the Multi-hazards and Resilience Challenge to address the perceived gap left by the removal of Engineering Geology from the organisational structure. One of the main outcomes of this strategy was to formally establish a new ‘Engineering Geology Team’ within the SGEO capability by merging staff from the former GGPP and SGR teams. In early February 2022 Marcus Dobbs was appointed as Head of Engineering Geology and the team formalised within the BGS organisation structure from April 2022.

The focus of the current Engineering Geology Team (as of 2024) is separated into six NC-funded activities:

i. Engineering Geology Laboratories: maintaining and enhancing the capability of the BGS Soil Mechanics Laboratory, the Rock Mechanics and Physics Laboratory, the Engineering Geophysics Laboratory and the new BGS Landslide Laboratory.

ii. Geotechnical Property Data: maintaining, populating and QA’ing data within the BGS National Geotechnical Properties Database (NGPD), and exploring new ways of interrogating and presenting these data for stakholders in industry.

iii. Geotechnical-Geophysical Property Relationships: developing correlations between geotechnical and geophysical properties so that geophysical data can be directly translated into geotechnical properties such as moisture content and shear strength, and for maintaining and enhancing BGS shallow geophysics field surveying capability.

iv. Landslides hazard research: developing a deeper understanding of different landslide processes, both in the UK and globally.

v. Daily Landslide Hazard Assessment and Natural Hazard Partnership: QA’ing and enhance the functionality of the National Landslides Database; identify new landslide events in the UK and updating the National Landslides Database; providing a Daily Landslide Hazard Assessment based on weather forecasts and interpretations of the water balance model (in Scotland); responding to enquiries about landslides received from the public, media and national and local government bodies; and participating in the Natural Hazards Partnership (includes Cabinet Office, DEFRA, EA , MetOffice, OS,..).

vi. Karst Hazard Research: developing a deeper understanding of karst processes in the UK and the maintenance and population of the BGS National Karst Database.

In many respects, it is the new SGEO Capability, rather than the Engineering Geology Team per se, that represents the real legacy of the original ‘Engineering Geology Unit’. By incorporating not only traditional engineering geology competencies (soil mechanics, rock mechanics and shallow geohazard processes), but also modern techniques for imaging and monitoring the surface and subsurface with geophysics and remote sensing, SGEO provides a state-of-the-art capability for characterising and monitoring near surface properties and processes. The capability also continues to expand with the establishment of the Coastal and Estuary Hazards Team, which was introduced in April 2024 with Andres Payo as the lead. The future of engineering geology within BGS, for now, is bright once more.

As the Engineering Geology Unit evolved, so has this report. What had started as a farewell to EGU, and thank you to all the staff for what they achieved over 50+ years, has now also become an endowment for those in SGEO who continue the work of the EGU.

11.1 MAY ENGINEERING GEOLOGY REMAIN IMPORTANT

It is interesting to note that, in the 00s, the number of engineering geological and geophysical papers published in the Quarterly Journal of Engineering Geology and Hydrogeology by BGS staff was as many as five or six a year. However, ‘it’ is not all about published papers. While the NERC NORA system records the number of times BGS published papers are downloaded, it also records downloaded reports. By April 2021 two of EGU’s ‘Engineering geology of British rocks and soils’ reports were in the top five of downloaded items. The report on the Mercia Mudstone Group had been downloaded 50 348 times and topped the list whilst the report on the Lias Group was fourth with 20 946 downloads. The report on the Lambeth Group was nineteenth with 13 598 downloads. As a result, three EGU staff were in the list of top five authors: Dave Entwisle (3rd) with 135 207 downloads, Lee Jones (4th) with 131 127 downloads and Pete Hobbs (5th) with 126 841 downloads. Also, Suzanne Self was 8th, Kevin Northmore 13th Martin Culshaw 37th Jon Busby 43rd and Simon Price 49th. The new generation have a lot to live up to!

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Appendix 1 Applied Research in Milton Keynes, UK

The following text was included with various outputs from the Milton Keynes work placed in the BGS archives in late 2008.

From 1968 to about 1973, the then Engineering Geology Unit (by 2008 it had become the science theme of Land Use and Development) of the then Institute of Geological Sciences (now British Geological Survey) carried out an engineering geological mapping study of the Milton Keynes New Town (MKNT) area in Buckinghamshire, UK. At that time, little engineering geological mapping had been carried out in the UK, one of the earliest being the engineering geological map of Belfast which was begun in 1967 and published by the Geological Survey of Northern Ireland in 1971 (Bazley 1971; Wilson 1972).

The revised terms of reference for the work (after the first ToR had been rejected by the Milton Keynes Development Corporation as too expensive) were to:

i. investigate rock properties (particularly those of engineering significance) and their variations within the Milton Keynes designated area and to show these variations in map form;

ii. and carry out trial geophysical surveys in an attempt to delineate buried channels beneath the wide valley through which the River Ouzel flows.

The main output of the work was a report (EG/69/1) (Cratchley et al. 1969). This was in three volumes, a preliminary report that discussed the engineering geology of the area and summarised some of the geotechnical properties, a second volume that included the borehole logs (and summary geotechnical data) from 30 cable percussion boreholes for the project paid for by the Milton Keynes Development Corporation and a third volume that included borehole logs and summary geotechnical data for a large number of Minuteman auger, 4 inch auger and B40 hollow stem auger boreholes. Numbering of these is inconsistent; Borehole 31 may not exist.

The report is described as ‘preliminary’ and was produced around October 1969. A final report was scheduled for December 1969 but was never produced. The figures are not bound into the Volume 1 of the report. On page 3 of the report reference is made to Figures 1, 2 and 3. Two of the three have been identified and are available separately in Cratchley & Denness (1972):

- Figure 1. Trend of selected engineering index properties in one zone of Oxford Clay at Milton Keynes (Figure 2 of Cratchley & Denness 1972)
- Figure 2. Distribution of selected index parameter ratios showing engineering property trends in Oxford Clay (Lower Middle) at Milton Keynes, Bucks. (On film) (See 15. below) (Figure 3 of Cratchley & Denness 1972)
- Figure 3. Uncertain – may be 16. below.

The same Figures 2 and 3 are also referred to on page 8 of the report and in the report’s Appendix 1 (page 18). A table of selected engineering properties is included in the report’s Appendix 2 (page 20). Though only indirect reference is made to them in the report, it was accompanied by an ‘engineering geological map’ (see 3. below) and a detailed table of engineering characteristics (see 4. below). At first glance, the map looks identical to the geological map (see 2. below). However, it is not quite the same. For example, different river terraces are coloured together on the engineering geological map. Only three copies of the map survive, two water-coloured and one crayoned. Two copies of the table, which is very detailed, survive. It was probably intended to link the map and table into the final report in more detail but, as indicated above, that final report was never completed.

From 1970, the impetus for the original work diminished in the light of other priorities. A member of staff, Jon Hallam, continued to plot new borehole data sent by the Milton Keynes Development Corporation and to carry out some interpretation (see below) but the work was never published.

Further work continued from 1970 focusing mainly on Suggestion 4 of the 1969 preliminary report for further general investigations: "The amplitude of trends of engineering properties in the Lower Oxford Clay." A series of manual plots for various properties were produced on film and paper (mainly concerning the Jurassic strata and focusing, particularly, on the Upper Athleta zone of the Oxford Clay) but these have not been retained because the source of the original data is not known and so the data that the plots rely on are not available. Roger Cratchley and Bruce Denness published a paper on the research at Milton Keynes in 1972 at the 24th International Geological Congress (Cratchley & Denness 1972). That paper is a better written version of the 1969 report. Bruce Denness completed research into the scale of variation of engineering properties in the boulder clay (Denness 1974). The work was extended by Dave Russell (University of Reading) who carried out doctoral research on the effect of weathering on the physical and chemical properties of some Mesozoic clays across southern England (Russell 1977). Some of Russell's research was later published.

At about the same time, the MKNT area was remapped and a special sheet published at a scale of 1:25 000 (see 2. below). This was accompanied by a report (Horton 1974). No other reports or publications were forthcoming.

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OTHER MATERIAL STORED IN BGS ARCHIVES

i. 1. 1967 special 1:25000 scale topographic sheet showing the boundary of MKNY under the "New Towns Act 1965. The North Buckinghamshire (Milton Keynes) New Town (Designation) Order 1967.

ii. 2. Colour printed geological 'Classic areas' map at 1:25 000 scale of Milton Keynes. Ordnance Survey sheet SP83 and parts of SP 73, 74, 84, 93 & 94.

iii. 3. ‘Geology Map of Milton Keynes’. Uncoloured on topographic 1:25 000 scale special sheet for the area. 5 copies.

iv. 4. ‘Engineering Geology Map of Milton Keynes’. Hand coloured on topographic 1:25 000 scale special sheet for the area. 3 copies, 1 mounted on card.

v. 5. Table of engineering geology characteristics to accompany 1:25 000 Engineering Geology Map of Milton Keynes. (On paper). 2 copies, one with colours.

vi. 6. Tunnel Foul Sewer/ Geological sections along possible routes based on borehole and seismic data. Hand coloured at 1:10 000 scale. Provisional draft.

vii. 7. Map of (ground) surface contours (25 feet intervals) for Milton Keynes at 1:25 000 scale. (On film). 2 copies.

viii. 8. Milton Keynes Area 1968 Borehole Project. Map of borehole locations and attributes at 1:25 000 scale. Shows area of Ouzel Valley mapped at 1:10 000 scale (see 10-14 below). (On film).

ix. 9. Map of IGS boreholes within Milton Keynes Designated Area 1968/9 at 1:25 000 scale. (On film).

x. 10. Map of Drift thickness (shaded in intervals <3 m, 3-10 m, >10 m) at 1:25 000 scale. Also shows Drift infilled buried valley. (On film). 2 copies.

xi. 11. Ouzel Valley map of borehole positions at 1:10 000 scale. (On film). Two versions, not identical. 2 copies of one, 1 of the other.

xii. 12. Ouzel Valley map of sand and gravel deposits at 1:10 000 scale with thickness contours. (On film). Two versions, not identical. 3 copies of one and 1 of the other.

xiii. 13. Ouzel Valley map of sand and gravel deposits at 1:10 000 scale. Not contours but shading to show areas of different thicknesses (shaded in intervals <3 m, 3-10 m, >10 m). (On film). 2 copies.

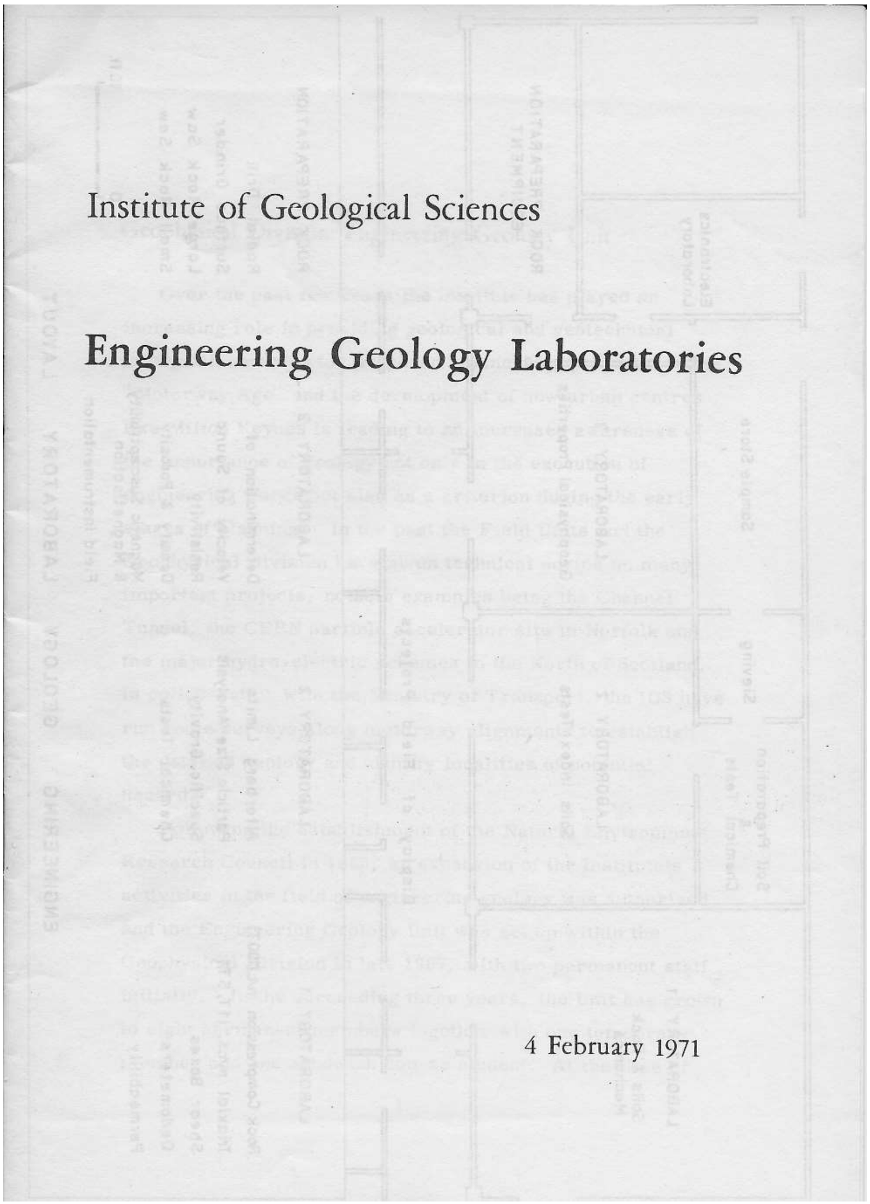
xiv. 14. Ouzel Valley map of Drift thickness at 1:10 000 scale. Not contours but shading to show areas of different thicknesses (shaded in intervals <3 m, 3-10 m, >10 m). (On film). 2 copies.

xv. 15. Ouzel Valley Engineering Geology map at 1:10 000 scale. Colours explained in the Table of Engineering Characteristics (4. above). (On paper).

xvi. 16. Figure 4 of Denness (1974) Distribution of selected index parameters in a vertical trench section in Boulder Clay at Little Woolstone, Bucks at a sample interval of one metre (vertical and horizontal). (On film)

xvii. 17. Engineering indices of Oxford Clay at Milton Keynes (Site 1). (On tracing paper)

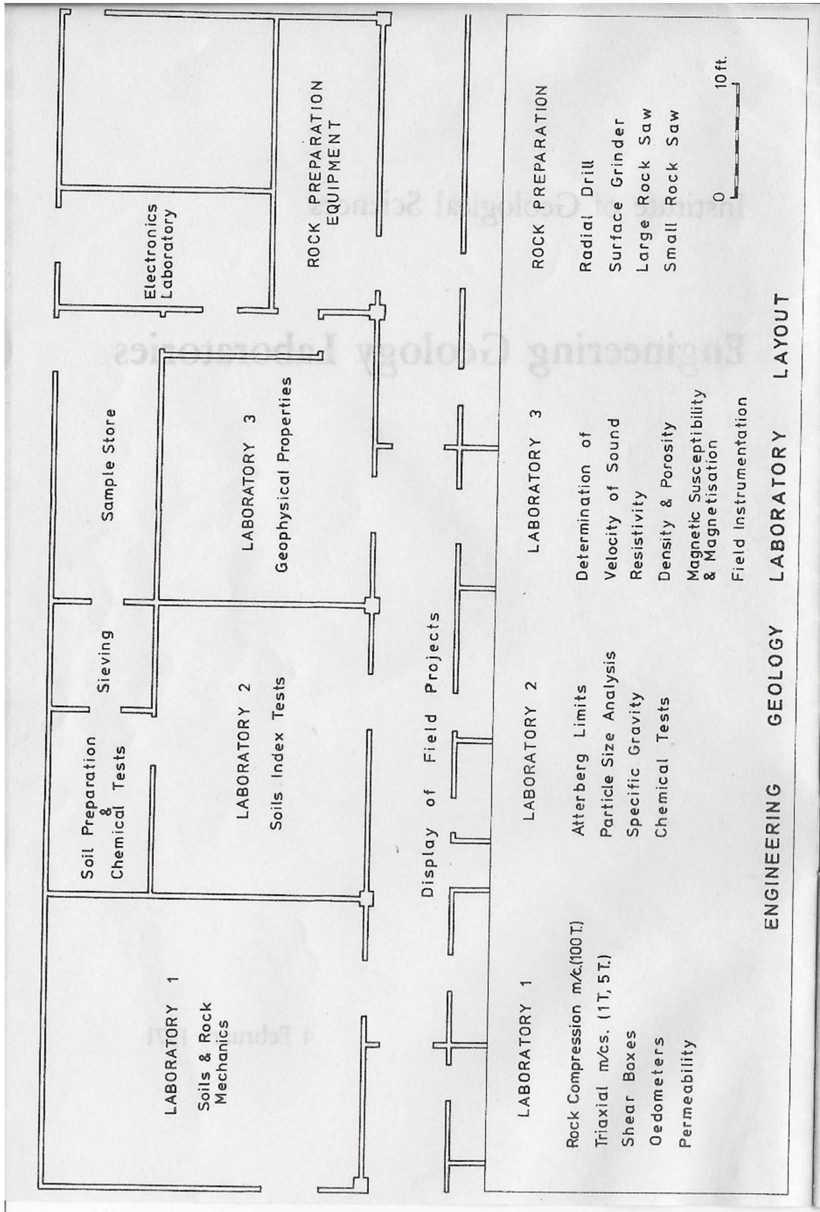
Appendix 2 Booklet describing the opening of the Engineering Geology Laboratories



Institute of Geological Sciences

Engineering Geology Laboratories

4 February 1971



ENGINEERING GEOLOGY LABORATORY LAYOUT

Geophysical Division: Engineering Geology Unit

Over the past few years the Institute has played an increasing role in providing geological and geotechnical information needed for proposed engineering projects. The "Motorway Age" and the development of new urban centres like Milton Keynes is leading to an increased awareness of the importance of geology not only in the execution of engineering works but also as a criterion during the early stages of planning. In the past the Field Units and the Geophysical Division have given technical advice on many important projects, notable examples being the Channel Tunnel, the CERN particle accelerator site in Norfolk and the major hydro-electric schemes in the North of Scotland. In collaboration with the Ministry of Transport, the IGS have run route surveys along motorway alignments to establish the detailed geology and identify localities of potential hazard.

Following the establishment of the Natural Environment Research Council in 1965, an expansion of the Institute's activities in the field of engineering geology was authorized and the Engineering Geology Unit was set up within the Geophysical Division in late 1967, with two permanent staff initially. In the succeeding three years, the Unit has grown to eight permanent members together with one temporary member and one sandwich course student. At the time of opening of the Engineering Geology Laboratories, the staff is as follows:

Head of Unit	Mr. C.R. Cratchley
Geophysical Properties & Field Geophysics	Dr. D.M. McCann Mr. P. Grainger, Mr. P.C. Sharkey
Soils & Rock Mechanics including Engineering Geology Mapping	Dr. B. Denness, Mr. B.W. Conway (i.c. field operation) Mr. A. Harding (i.c. laboratories) Mr. J. Hallam, Mr. P. Collins, Mr. R. Andrews

New laboratories were constructed and equipment installed during 1970 and early 1971. At the same time, the Unit has been conducting its own programme of field investigation, mainly in collaboration with other Units of the IGS, particularly the Field Staff and other Units within the Geophysical Division.

While the main requirements in Engineering Geology are seen to arise from the growing volume and complexity of the information requested from IGS in connection with large-scale civil engineering projects such as establishment of new towns, motorways, dams, barrages, underground tunnels and large-scale underground storage, there are also significant basic information requirements for fundamental studies of the earth's crust, to aid geophysical interpretation and to assist groundwater research.

In the short term, the needs of government for the solving of practical problems must obviously be given special attention and in varying degree this will remain a permanent factor in the detailed research programme.

Another permanent factor is that any fundamental work on the properties of rock types under varying natural conditions can be effective only with a full appreciation of the geology of these rocks, their structural setting and terrain. In this connection it is desirable to develop forms of geotechnical mapping, which give increased attention to engineering characteristics, and to devise data banking schemes which will ensure that the varied kinds of information in IGS departmental files can be correlated by geological formation and locality with engineering studies.

Within this very general framework the current activity of the Engineering Geology Unit can be grouped as follows:

In collaboration with Field Units and the Hydrogeological Department, development of field mapping for engineering purposes and to establish techniques for the production of engineering geology maps, particularly in connection with new urban development and to carry out surveys for such projects at the right time in the planning process.

The development of a catalogue of physical and engineering property data for incorporation into the main IGS data bank. When developed, this could be a valuable repository for data from other organisations.

The setting up of testing laboratories in soil and rock mechanics and for geophysical properties, and to undertake laboratory investigations on properly collected material especially from areas in which associated field engineering or in-situ tests can be effected.

The development of in-situ investigation techniques, especially geophysical, for appraisal of site conditions, determination of geological structure, and evaluation of physical properties.

The investigation of slope stability problems in both soils and rock particularly with regard to:-

a. motorway cuttings
b. coastal erosion processes and cliff falls.

Following on from (b) the possible factors affecting stability and stabilisation of coastal cliffs and harbour installations may be studied in collaboration with the Unit of Coastal Sedimentation.

At some time in the future the nature, causes and prevention of large-scale subsidence may be studied.

Co-operation with University research groups, especially in the field of instrumentation will be continued.

Laboratories: Laboratory facilities now available in the Geological Museum comprise: (1) a rock and triaxial laboratory where standard triaxial (drained and undrained) tests on soils and rocks are to be carried out. Consolidation apparatus and shear boxes have also been installed. (2) Soils laboratory-classification and chemical tests on soils. (3) Geophysical and electronics laboratories where geophysical properties of rocks and soils are to be determined and some instrument development will be done. A plan of the laboratories is given inside the front cover.

Current Field Programmes

Geotechnical Studies of Jurassic Rocks: A pilot engineering geology mapping project has been carried out in the Milton Keynes area in collaboration with IGS field staff and with the Milton Keynes Development Corporation. The investigation included extensive laboratory study of material from a series of boreholes in part financed by the Corporation, and from a later borehole drilled by IGS after an examination of the preliminary results.

Geotechnical data obtained from the Milton Keynes survey has been collated into a series of maps and overlays, based on the 1:25,000 Special Geological Sheet of Milton Keynes, an interpretive property chart and report which were submitted to the Milton Keynes Development Corporation. This work will be published in 1971. A project to relate geotechnical and geophysical properties of the Upper Athleta Zone of the Lower Oxford Clay, started in 1969 in the Milton Keynes area, has been extended on a regional scale by Dr. McCann, Dr. Denness and Mr. Grainger, in conjunction with Dr. C. McCann of the University of Reading, and assisted by Mr. Hallam and Mr. Collins. In support of this study microfaunal analysis of samples from boreholes at five localities between Dorset and Yorkshire has been carried out by the Palaeontological Department. Instrumentation has been developed to measure the variation of the velocity of sound with depth by transmission between adjacent boreholes. This technique was used both in the regional study and on the Charmouth coastal landslip where useful information on the in-situ condition was obtained.

Data banking of engineering and physical properties has been started. The data from the Milton Keynes survey has been used in a pilot scheme, carried out by the Engineering Geology Unit with student assistance.

Landslip Studies: Dr. Denness has concentrated on the general approach to mass movement from two standpoints. From observation in the field of a number of different landslips, a general principle has been outlined whereby many unstable masses are seen to be associated with naturally occurring reservoirs of groundwater. Reports are in preparation for publication illustrating the principle and suggesting generally applicable remedial measures. Mr. Conway has simultaneously developed a special case of this principle relating to secondary reservoirs formed from debris of the Black Ven landslide complex in Dorset. The analytical approach has led to the prediction of the failure locus from the analysis of a self-generating shear failure mechanism. The analysis can be applied generally to slopes in hard and soft rock through a wide range of natural and man-made conditions, including continuous, jointed, and bedded materials.

Mr. Conway has completed a regional field survey of Jurassic coastal landslips of Dorset. Approximately 120km of coastline from Swanage to Lyme Regis have been examined

and the various unstable features mapped at 6" to 1 mile scale. Many of the unstable areas here are clearly associated with groundwater reservoirs. Measurements of thickness and rates of movement of the Black Ven mudflow have continued. The main active flow moved 37.5 metres in seven months.

During 1970 a wide range of slope stability problems in hard and soft rocks has been examined in an advisory capacity for public bodies and local authorities by members of the Unit, particularly Dr. Denness, Mr. Cratchley and Mr. Conway. Examples range from the Stromeferry bypass in Wester Ross - a series of slides in rocks of Lewisian and Moine age, in conjunction with IGS Edinburgh, through motorway cutting stability in Coal Measures rocks on the M62 in Lancashire, in conjunction with IGS Leeds, to coastal cliff stability in Lias Clay at Charmouth, Dorset, in conjunction with IGS Exeter and the Bridport Rural District Council. In the last example, members of the Unit carried out additional velocity scanning and resistivity measurements as well as supervising the contract site investigation. The cliff-top hereabouts appears to be underlain by an ancient mud-flow with a thickness of 3-5 metres and the presence of this hitherto unsuspected feature has undoubtedly contributed to the increased rate of cliff loss in recent years.

Geophysical Studies: A variety of geophysical studies in engineering geology has been carried out during the year.

At the site of the Foyers hydro-electric pumped storage scheme Mr. Cratchley and Mr. Grainger, assisted by Mr. Hallam and student voluntary workers have begun a series of seismic and resistivity measurements over the proposed low pressure tunnel line to attempt to assess rock quality along the route. Preliminary measurements have also been made in the tunnel itself. The project is largely experimental and is aimed at assessing the usefulness of this type of measurement in predicting conditions along tunnel routes.

Dr. McCann and Mr. Grainger completed a seismic refraction survey of the CERN site near Mundford, Norfolk, intended to examine the relationship between the seismic velocities and the degree of fracturing in Chalk. Reasonably good correlations are obtained between velocities and previously established Chalk "grades".

Research into the application of continuous seismic profiling techniques to shallow inland waterways has been continued by Dr. D. M. McCann in collaboration with Dr. C. McCann of Reading University. Experiments were carried out to reduce the noise level caused by multiple reflection in shallow water, using new instrumentation on the Thames between Reading and Goring. Excellent results were obtained.

A detailed offshore sparker and sonar survey was carried out in Lyme Bay by members of the Marine Geophysics Unit; the Engineering Geology Unit representative, Mr. J. Hallam, was responsible for sea-bed sampling.

This survey forms part of an integrated approach to the problems of coastal stability on the Lyme Regis to Bridport section of the coast where mud-flow activity and cliff recession rates are high. Stabilisation of these coastal cliffs can only be achieved by establishing good drainage in the cliffs combined with the establishment of coarse beach material to prevent marine erosion of any slipped material. The subject is therefore one which requires the combined approach of marine and earth sciences.

An experimental assessment of a recently developed borehole logging instrument was carried out at the end of 1970. This "3-D" logger has been developed commercially in the United States to record shear and compressional wave velocities and hence allow Young's modulus to be calculated throughout the depth of this borehole. The instrument was used under contract, together with gamma ray, density and caliper tools in the Leatherhead, Tattenhoe (Milton Keynes) and Wilsey Down (Cornwall) boreholes. Results have yet to be assessed. Laboratory testing of samples from the Tattenhoe borehole has started.

A research contract is in progress with the Marine Science Laboratories at Menai Bridge for the construction of an under-water resistivity and acoustic probe.

Future Study: A theme which the Engineering Geology Unit might develop in the future is the study of subsidence. Subsidence due to salt extraction is already an important problem. Subsidence due to water, oil and gas extraction might become more serious in future. Study of subsidence problems would be done in close consultation with the Hydrogeological Department of IGS, but no firm proposals have yet been developed.

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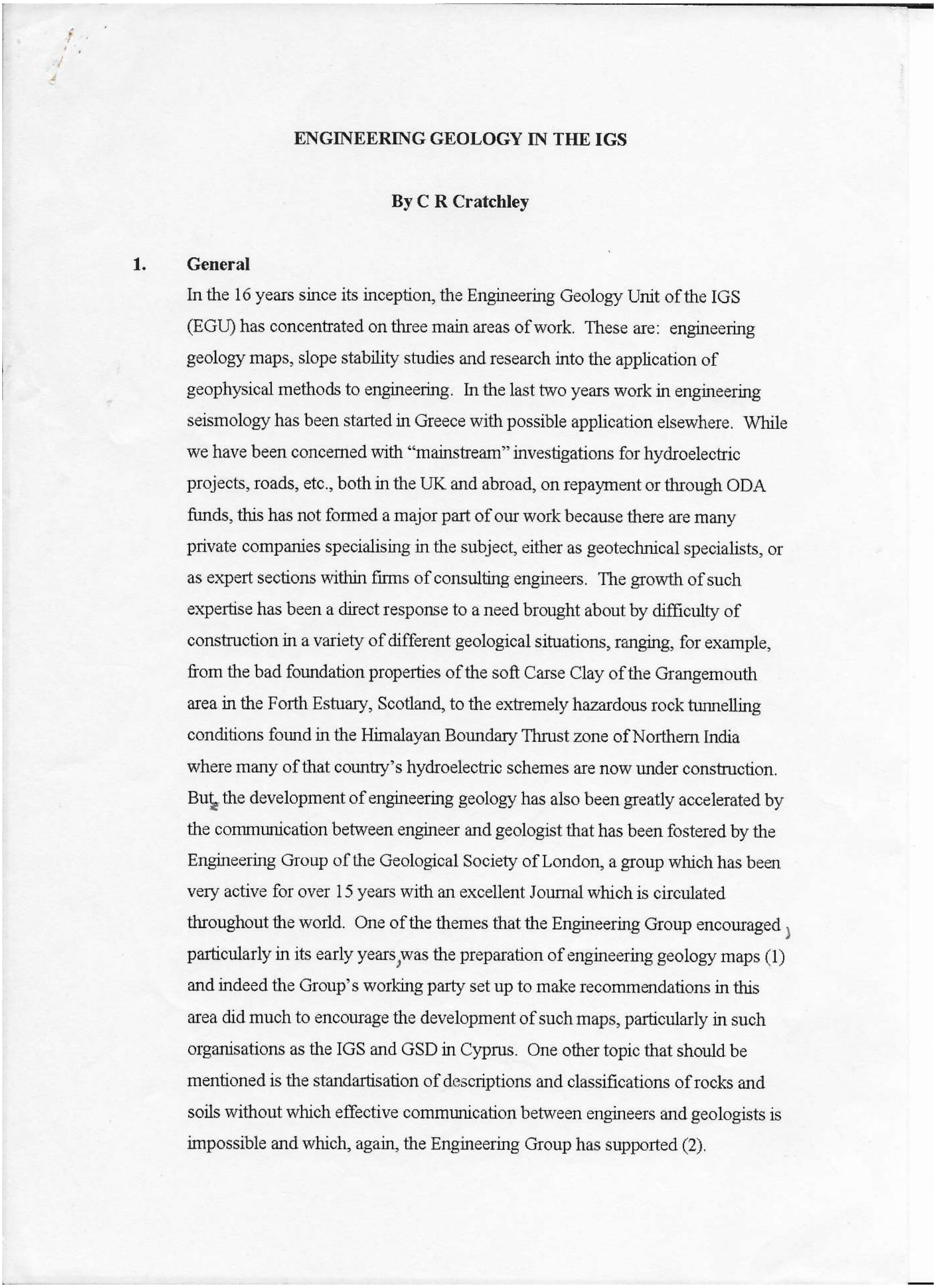
Appendix 3 Engineering Geology in the IGS, 1982, C R Cratchley



ENGINEERING GEOLOGY IN THE IGS

By C R Cratchley

1. General

In the 16 years since its inception, the Engineering Geology Unit of the IGS (EGU) has concentrated on three main areas of work. These are: engineering geology maps, slope stability studies and research into the application of geophysical methods to engineering. In the last two years work in engineering seismology has been started in Greece with possible application elsewhere. While we have been concerned with "mainstream" investigations for hydroelectric projects, roads, etc., both in the UK and abroad, on repayment or through ODA funds, this has not formed a major part of our work because there are many private companies specialising in the subject, either as geotechnical specialists, or as expert sections within firms of consulting engineers. The growth of such expertise has been a direct response to a need brought about by difficulty of construction in a variety of different geological situations, ranging, for example, from the bad foundation properties of the soft Carse Clay of the Grangemouth area in the Forth Estuary, Scotland, to the extremely hazardous rock tunnelling conditions found in the Himalayan Boundary Thrust zone of Northern India where many of that country's hydroelectric schemes are now under construction. But, the development of engineering geology has also been greatly accelerated by the communication between engineer and geologist that has been fostered by the Engineering Group of the Geological Society of London, a group which has been very active for over 15 years with an excellent Journal which is circulated throughout the world. One of the themes that the Engineering Group encouraged, particularly in its early years, was the preparation of engineering geology maps (1) and indeed the Group's working party set up to make recommendations in this area did much to encourage the development of such maps, particularly in such organisations as the IGS and GSD in Cyprus. One other topic that should be mentioned is the standartisation of descriptions and classifications of rocks and soils without which effective communication between engineers and geologists is impossible and which, again, the Engineering Group has supported (2).

Against this background, then, the EGU has tended to concentrate on the strategic approach to regional problems and has been concerned with regional studies of foundation conditions in New Town areas, development and the like, landslip survey and stability analysis, both for panning purposes and to guide the subsequent and necessary site investigation for design. Some examples of this approach are given below. In addition, some parts of the research programme in geophysical methods have relevance to the seismic risk element that has to be considered in earthquake prone areas.

2. Mapping for New Town Projects

An early example of this type of work was in the designated area for the new city of Milton Keynes some 50 miles NW of London. A projected population of 250,000 is to be accommodated in a completely new urban area set in a rural environment. From the geological point of view the disadvantage of this setting was the lack of existing subsurface data in the form of boreholes so that our knowledge of the three dimensional data was limited to the few borehole and geophysical measurements we could make ourselves. However, we were able to give guidance on the best routes for a sewer tunnel, the main drainage line (so as to avoid running sands) and general foundation conditions in the different rock and soil types in the area (3). The study also enabled us to develop the principles on which our current maps are produced.

A second major example was in connection with the third London Airport development at Foulness in South Essex and we were commissioned by the Department of the Environment to undertake a regional engineering geology study of the area designated for urban and industrial development, some 450 sq km around Southend, between the Crouch and Thames estuaries, associated with the proposed new airport. This project gave the opportunity of experimentation with different ways of presenting the three dimensional geology, particularly emphasising the variations in physical, lithological and geotechnical characteristics of the sediments and sedimentary rocks of the area. It also gave us the opportunity to set up a major data bank from existing and new boreholes put down to sample the various strata, which ranged from soft alluvial clays, sands, gravels of Quaternary age to the stiff fissured London Clay. Of particular interest and some engineering significance were the loess-like Pleistocene deposits called "Brickearth" which occurs as terrace deposits in the center of the area, and has the characteristic of collapsing under heavy foundation loads when saturated with water. Determination of the characteristics of these deposits, of the disposition and nature of the alluvial deposits, with their very poor foundation and tunnelling properties, and of the whereabouts of landslip enabled us to produce a suite of maps at 1:25,000 scale illustrating the three dimensional geology, lithology and engineering behaviour, together with an engineering planning map at the same scale. This map subdivides the area into 25 zones each having its own engineering characteristics in terms of foundations, excavation, tunnelling, suitability for fill, drainage, etc. The results of this survey gave significant guidance to planners on the best geological/geotechnical options for the proposed rapid transit route to the airport, areas for heavy industry, etc. The complete data set was also organised in such a way that very rapid appraisals could be made by Civil Engineering Consultants of the feasibility of undertaking certain engineering operations such as bridge/tunnel crossing of buried channels infilled with alluvium. Finally, guidance on site investigation and laboratory testing requirements for deposits such as the usual loessic Bickearth were given (4).

Other surveys overseas include the Geotechnical Map if Nicosia, Cyprus, where particular problems arise with shrinking and swelling clays.

3. Foundation Conditions for Industry

Further ideas were developed by Dr Gostelow in the next major phase of this type of work in the Scottish estuaries. This project was related to the requirements of the Scottish Development Department to plan and offer the most suitable sites for petrochemical development in estuaries such as the Forth and Cromarty on the East Coast of Scotland where it is likely that gas gathering pipelines from the North Sea oilfields will be brought ashore. Whereas in South Essex we were required to present data relevant to a variety of possible engineering operations, in the Forth Estuary for example, specific information on the suitability or otherwise of the subsoil to withstand the heavy foundation pressures (in excess of 200 KN per square metre) associated with petrochemical development was required and necessitated a different approach. Out of this work came the concept of the "geotechnical profile" and the mapping of this area in terms of these profiles which take into account the geological and geotechnical history of the deposits, their resulting consolidation characteristics and hence the overall bearing capacities and settlement that each profile can accommodate. The area is complicated by the presence of past and present mine workings, both for coal and oil shales in the solid rocks beneath the Forth Estuary, leading to the necessity to have two categories of foundation (E & F) at the low end of the scale, A to B already established for the Cromarty Estuary.

4. Seabed Stability Studies

Another type of mapping project has been our collaboration with the Continental Shelf Division of the IGS in providing geological maps with geotechnical interpretations of the seabed of the UK Continental Shelf. This programme is a long term one funded mainly by the Department of Energy and aims to complete coverage of the shelf within a decade. The work is related to the stability in general terms of structures such as oil production platforms founded on the seabed and the ease of excavation and stability of pipeline trenches. Particular hazards which can be encountered on the seabed of the North Sea include soft clay silts which can contain gas which apparently causes "pock mark" features; infilled channel deposits of soft clay that can only be located accurately and economically by the use of specialised geophysical tools like the deep tow boomer; mobile sandwaves and scouring out from beneath pipelines; foundered strata at depth which might lead to subsidence in superficial deposits on the seabed. The major problem with this type of project is the lack of data and the difficulty and cost of acquiring new data. This has had two consequences: it has not been possible to produce the type of engineering geology map that can be produced for land areas, and it has led us to a research programme in collaboration with others such as the Marine Science Laboratory, University College of North Wales, to find methods of indirectly determining properties of rocks and sediments by geophysical methods.

5. Geophysical Studies

Geophysical methods have been applied to research in two main areas:

a) Hard rock and b) Sediments.

a) Hard rock applications currently are: work on igneous rocks related to hydroelectric schemes; the hot dry rock geothermal energy project in Cornwall in collaboration with the Camboume School of Mines; assessment of the mechanical nature of rock masses for radio active waste disposal. The particular requirements common to these three types of programme are to determine the rock quality in terms of joint/fissure frequency and openness and the degree of weathering and strength of the rock material. Geophysical methods of assessment have had some success particularly when more than one technique is used, as in geophysical logging of boreholes.

b) Geophysical assessment of sediments has been directed towards determining dynamic moduli values in situ from seismic velocity determination, as well as in situ porosity and density from resistivity and seismic velocity data. Currently, research is being carried out at a number of test bed sites in the UK and comparisons are made between in situ tests, such as pressuremeter and plate loading tests in boreholes, and the geophysically derived moduli. A particularly interesting comparison has been made between the value for rigidity modulus, G, calculated by back analysis from building performance at a power station site, and its value determined by geophysical and direct mechanical means. In this instance, the geophysically determined value gives the best agreement with the back analysis, both of which are at comparable strain amplitude levels (5).

6. Engineering Geology and Seismic Risk Studies

We are currently running a joint programme with the Institute of Geology and Mineral Exploration (IGME) in the Volos area of Greece. This programme aims to combine the two approaches (engineering geology mapping and geophysical studies) so far mentioned with a third – seismic risk assessment, also in collaboration with the IGB Global Seismology Unit. The general objectives are to carry out an integral survey including geology, geotechnics, seismotectonics and seismicity, to guide development planning and engineering decisions in the region, and to act as a pilot study within the context of Council of Europe proposals for Earthquake Research. We hope that this project will be a model for similar studies elsewhere. The dynamic response of the ground surface to earthquake energy is dependent on the geology in a number of different ways. The tectonic framework for the region controls the types and depths of earthquakes most likely to occur and the propagation of energy; local attenuation of energy is determined by the lithological types and their geotechnical and geophysical properties; and the shape of individual sedimentary or alluvial basins which can affect where the energy is concentrated.

7. Slope Stability Studies

We have been carrying out slope stability studies throughout the life of the EGU, concentrating in the early years on landslip mapping and classification, particularly on the Dorset coast in the Jurassic strata of the famous coastal section. Major landslip and mudflow complexes have caused a high rate of recession of the cliff top with damage to property, particularly in the Lyme Regis – Charmouth area. More recent work in the South Wales Coalfield has produced a series of maps at 1:50,000 scale, locating and classifying the 579 individual slips on base maps, which show topography, geology and slope. The slips comprise a range of six types from deep-seated rotational involving Coal Measures strata to shallow transitional slides involving superficial deposits only, and combinations of the six. Currently, more detailed examinations of the most common type (transitional) have just been completed at two specific sites and there are plans to undertake landslip potential or susceptibility mapping.

We have also been using traditional slope stability analyses including the infinite slope method and the simplified Bishop and Janbu methods of slices, all non-rigorous methods, on a microcomputer in London. In addition, we have available on computer in Edinburgh a sophisticated rigorous method due to Sarma at Imperial College which can take into account lateral loading, including earthquake loading. These techniques have already been applied to landslip problems in Cyprus (major problems in Western Cyprus), Jamaica, S.Wales, Telford. There may be work in the future in Indonesia.

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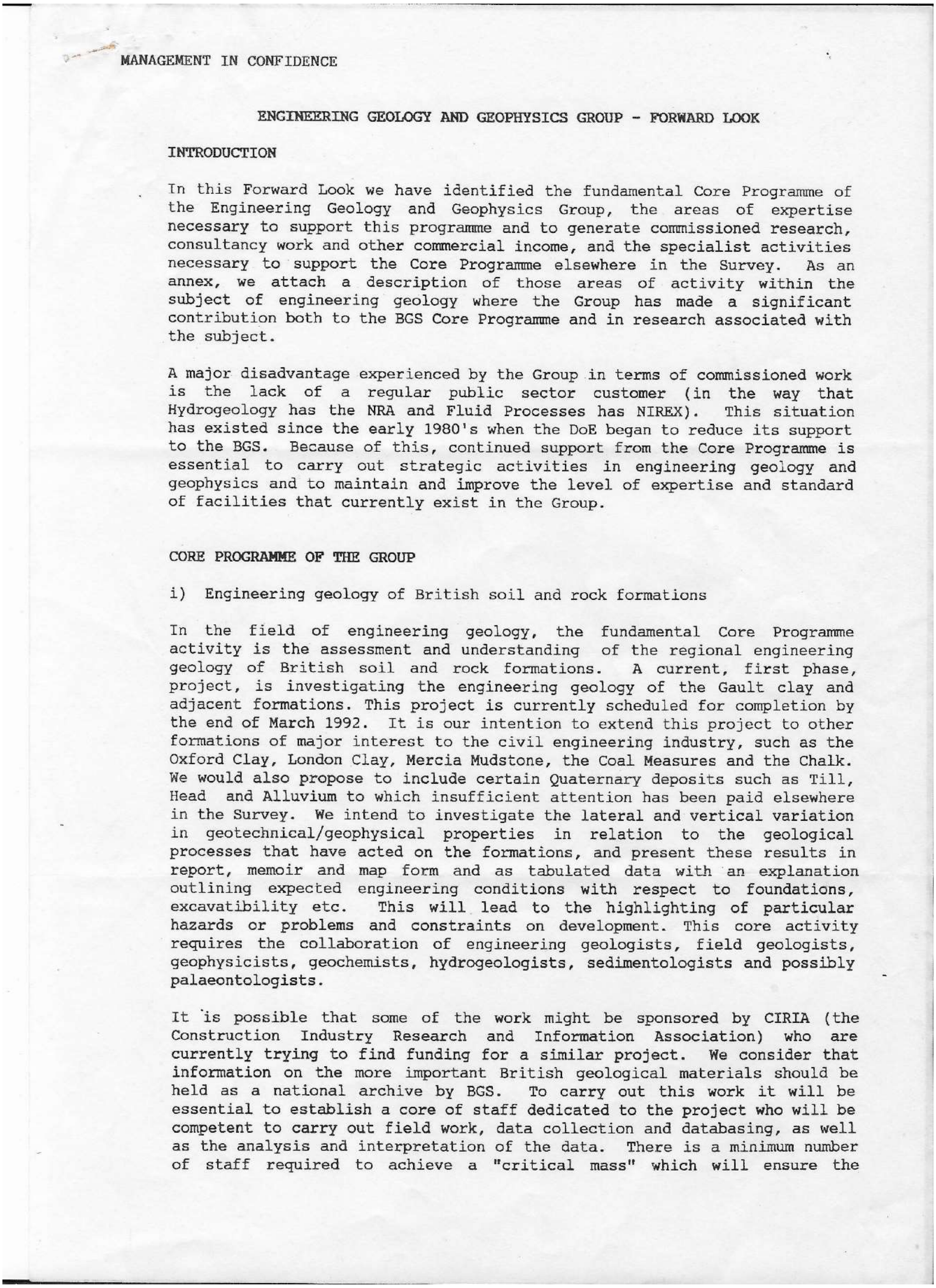
Appendix 4 Engineering Geology and geophysics Group – forward look, 1991 D M McCann and M G Culshaw



MANAGEMENT IN CONFIDENCE

ENGINEERING GEOLOGY AND GEOPHYSICS GROUP - FORWARD LOOK

INTRODUCTION

In this Forward Look we have identified the fundamental Core Programme of the Engineering Geology and Geophysics Group, the areas of expertise necessary to support this programme and to generate commissioned research, consultancy work and other commercial income, and the specialist activities necessary to support the Core Programme elsewhere in the Survey. As an annex, we attach a description of those areas of activity within the subject of engineering geology where the Group has made a significant contribution both to the BGS Core Programme and in research associated with the subject.

A major disadvantage experienced by the Group in terms of commissioned work is the lack of a regular public sector customer (in the way that Hydrogeology has the NRA and Fluid Processes has NIREX). This situation has existed since the early 1980's when the DoE began to reduce its support to the BGS. Because of this, continued support from the Core Programme is essential to carry out strategic activities in engineering geology and geophysics and to maintain and improve the level of expertise and standard of facilities that currently exist in the Group.

CORE PROGRAMME OF THE GROUP

i) Engineering geology of British soil and rock formations

In the field of engineering geology, the fundamental Core Programme activity is the assessment and understanding of the regional engineering geology of British soil and rock formations. A current, first phase, project, is investigating the engineering geology of the Gault clay and adjacent formations. This project is currently scheduled for completion by the end of March 1992. It is our intention to extend this project to other formations of major interest to the civil engineering industry, such as the Oxford Clay, London Clay, Mercia Mudstone, the Coal Measures and the Chalk. We would also propose to include certain Quaternary deposits such as Till, Head and Alluvium to which insufficient attention has been paid elsewhere in the Survey. We intend to investigate the lateral and vertical variation in geotechnical/geophysical properties in relation to the geological processes that have acted on the formations, and present these results in report, memoir and map form and as tabulated data with an explanation outlining expected engineering conditions with respect to foundations, excavatibility etc. This will lead to the highlighting of particular hazards or problems and constraints on development. This core activity requires the collaboration of engineering geologists, field geologists, geophysicists, geochemists, hydrogeologists, sedimentologists and possibly palaeontologists.

It is possible that some of the work might be sponsored by CIRIA (the Construction Industry Research and Information Association) who are currently trying to find funding for a similar project. We consider that information on the more important British geological materials should be held as a national archive by BGS. To carry out this work it will be essential to establish a core of staff dedicated to the project who will be competent to carry out field work, data collection and databasing, as well as the analysis and interpretation of the data. There is a minimum number of staff required to achieve a "critical mass" which will ensure the success of this long term strategic core activity. This is not possible with present staff levels, funds and other commitments. Help in these areas will need to be provided from the Core Programme and sought from outside sources.

ii) Determination of the geomechanical properties of the rock mass by geophysical methods

In the field of engineering geophysics, the Fundamental Core Programme activity is the determination of the geomechanical properties of the rock mass of Britain by means of indirect geophysical methods applied in the field and in the laboratory. This is achieved by:

a) measurement of the geophysical properties of rock and soil materials, both at ambient conditions and at elevated pressures and temperatures that more nearly simulate the in situ state, and determination of their relationship to the geotechnical properties;

b) geophysical borehole logging and cross-hole seismic and electrical surveying to provide data on the physical and mechanical properties of the rock mass, including, for example, the degree of fracturing and in situ dynamic elastic moduli;

c) development of high resolution, surface geophysical methods to determine variations in the structure and geology of the rock mass at a site scale.

iii) Geotechnical/geophysical properties database

The geotechnical/geophysical properties database is one of a number of databases in BGS which are intended to hold geological data of strategic importance. This database also provides fundamental underpining to the Core Programme activities described above and is intimately linked to them. Consequently, as the Group's Core Programme activities proceed, the database will grow as the quantity of data obtained increases. However, it is likely that the type of data held will also need to expand if all the available data are to be databased.

At present, our database can only grow as data become available on a project basis. If the database is to provide a reasonable coverage on both a geographical and a geological basis, then additional data will need to be extracted from the original site investigation (SI) reports to provide the data coverage not available from the Group's Core Programme and commissioned activities. To date only a small proportion of the data held in site investigation reports by BGS has been extracted (probably no more than 10-15%). Vast quantities of further data are available in site investigation reports held by local authorities, engineering consultants, public utilities and others, but this can only be obtained on a targeted basis at the cost of collection.

NGIS funds are currently being used to redesign the database to conform with BGS-wide standards, to fully validate older project databases, to add in-house data and to make the databases more available to potential internal and external users. We intend to include geophysical properties within the database, since this is an area where information is often sought by outside bodies.

The inclusion of new data in the database will require a small, long-term staffing commitment to maintain and upgrade the database (as already happens, for example, in Hydrogeology Group) and to complement the Group's other Core Programme activities which will generate some of these data; some of these staff will need engineering geological/geophysical training and must be supervised by an experienced engineering geologist.

iv) Other core activities

The Group makes a significant contribution to the Core Programme activities of other Groups, particularly those in the Thematic Maps and Onshore Surveys Division. We are utilising geophysical surveying methods to study various geological problems such as the identification of faults, the investigation of the depth and extent of buried valleys and the determination of the boundaries of different lithologies. We are also geophysically logging all boreholes drilled by, or for,the Survey, and also any available boreholes of geological importance in any geological sheet currently being mapped; for example, this year we are logging a number of water wells on the Grantham sheet.

We are continuing the development of new geophysical surveying techniques, including ground probing radar, and the transient electromagnetic and magnetotelluric methods, which are will be available for field use in the present financial year.

A small amount of Core Programme funding is being used to develop the specialist field of geoarchaeology but, in time, we expect that this will become a consultancy service (see below)

Increasingly, the Group is providing engineering geological contributions to sheet memoirs. This is particularly the case in SW England where the Group has contributed to the Exeter and Shaftesbury memoirs and has begun work on the Plymouth memoir. This involvement not only enhances the content of the memoirs, but contributes directly to the Group's main Core Programme activity (see 1. above) and adds to the database (3. above). In time, the benefits will be in both directions as work on individual geological formations is completed.

THE BGS R & D PROGRAMME

The Group is engaged in a number of projects that are wholly, or partly funded by the R & D Programme. These are:

i) a study of the hazard of rainfall-induced landslides around the Mediterranean using GIS, in collaboration with the Institute of Hydrology and three European universities. This is partly funded by the CEC;

ii) collaboration with Regional Geophysics Group in the study of the UK rock stress field. This is partly funded by the CEC;

iii) interpretation of electrical images of borehole core from the Ocean Drilling Project (ODP). This is partly funded by NERC.

Future R & D funding will be sort for projects where the Group's strategic interests coincide with those of the funding programme and to enhance further, our expertise.

COMMERCIAL POTENTIAL

The Group, in common with other parts of BGS, can generate income in at least four separate ways:

i) commissioned/commercial research,
ii) consultancy,
iii) contract services,
iv) data sales.

i) The potential for increased commissioned research has been briefly discussed above; at the present time a new public sector research sponsor is not apparent, though it is expected that research commissioned by the ODA (Subvention Fund) and DoE (Applied Geology Mapping programme) will continue, building upon the successful research carried out over the last ten years. Technical cooperation work from ODA probably will be available irregularly. Other government department contracts are likely to be won from time to time, for example, from the MOD.

Over the last five years, the Group has expanded its commercial research work, winning contracts from organisations such as the LAMDA consortium, BNFL, the former CEGB and Wimpey Environmental. We believe that the potential exists to increase the level of commercial research over the next five years, particularly in relation to seismic tomography, computer-controlled, multiple electrode resistivity surveying (RESCAN) and electrical core scanning (CORSCAN). However, it is also possible that commercial research funding might be obtained for the further development of new geotechnical testing techniques (such as the elastimeter) and soft rock borehole sampling methods .

ii) The Group has acted as engineering geological and geophysical consultants for a range of clients for almost twenty years. The Group is consulted by many outside bodies, including government departments, public utility companies, local authorities and engineering consultants, for a wide range of advice on the solution of problems in engineering geology and geophysics. For example, at the geological end of the spectrum, we advise on problems associated with geological hazards, such as landslips, and provide information on the geotechnical characteristics of UK soil and rock formations. In the geophysical field, we advise on the suitability of various geophysical methods for use in site investigation and to solve particular engineering problems.

Thus, we have a wide range of expertise in the field of engineering geology/geophysics and it would seem sensible to develop the scope of these activities for industry and government organisations in the form of a consultancy service. However, before this can be done, a market assessment should be carried out to evaluate the potential for income generation in this highly competitive market. Also, further investment will have to be made in extending quality assurance, upgrading equipment and establishing more efficient management of a rapid response service.

One example of how such a specialist consultancy service might develop has been demonstrated in the field of geoarchaeology, for which the Group has responsibility. At present, this activity is partly funded from the Core Programme but we are developing micro-geophysical surveying methods for operating in detail over small areas at archaeological excavations. We see considerable potential for this type of specialist work to be included in major engineering site investigations in areas of archaeological importance.

iii) The principal contracted services that can be provided by the Group are geotechnical and geophysical laboratory testing and geophysical borehole logging. In all these areas we would seek to place ourselves in the high quality, high price, lower volume sector of the market with the additional capability to provide some highly specialised tests or techniques. We should not attempt to compete for high volume, low price work. The current NIREX work being carried out by the Group and recent enquiries lead us to believe that there is potential for increased income generation from contracted services of this nature. Such work has additional benefits for the Core Programme and commissioned research in that it allows capital investment in laboratory and logging equipment and keeps a pool of trained staff available.

iv) Until the Group's database is more fully developed, we see only limited potential for the sale of geotechnical and geophysical data.

SUPPORT ACTIVITIES

The Group provides a number of activities which support Core Programme and commercial work within the Group, the Division and the remainder of the Survey; these include:

i) Geotechnical/geophysical laboratory testing

During the 1970's, the Group had a well appointed suite of laboratories, in which a wide range of geotechnical and geophysical testing was carried out in support of the Group's Core Programme, commissioned research and commercial work. After the move to Keyworth in 1982, very little investment was allowed in either equipment or staff and the laboratories slowly ran down until only a small amount of testing was carried out. Over the past year, we have sought to reinstate the laboratory facilities towards full capability, particularly since we obtained a large NIREX contract for testing the core from the boreholes at Sellafield and Dounreay. We intend to continue this programme during 1991/92 and develop the Group laboratories as an efficient, modern facility. In the medium term, additional space may be required to achieve this. Alternatively, laboratories in our original design specification, but subsequently transferred to other Groups, could be returned to their original function.

ii) Instrument development

The Group has always had a strong interest in the development of specialised geophysical and geotechnical testing equipment for both laboratory and field application. Particular examples of past developments are the high pressure test rig for the measurement of compressional and shear wave velocities, the elastimeter for the measurement of static elastic moduli without the use of strain gauges, a triaxial load cell to determine strength parameters of soils and weak rocks at elevated temperatures and the borehole sparker probe. Current developments include a sea-floor shear wave source (in conjunction with UCNW), a multiple electrode, computer-controlled resistivity system (RESCAN) and a resistivity device for examining borehole core for the ODP project (CORSCAN).

Some of these devices have been patented and are being sold through commercial organisations. Staffing levels in our Instrument Development

Laboratories have been built up to a reasonable level over the past two years, and it is intended that further new geophysical/geotechnical devices will be developed over the next few years for commercial exploitation.

A further important aspect of our work in this area is our responsibility for the Survey's Geophysical Equipment Pool, which involves the maintenance and servicing of a wide range of geophysical equipment. This equipment has to be kept at a high level of operational efficiency for geophysical surveys carried out as part of the Core Programme and for commissioned/commercial purposes, both by the Group and by Regional Geophysics Group.

iii) Borehole activities

The Group is currently responsible for both the BGS Drilling Section and the BGS Borehole Geophysical Logging Section. Both sections make a valuable contribution to the Core Programme and we are currently geophysically logging all boreholes drilled by the Drilling Section. It is our intention to continue this practice as long as both activities remain part of the Core Programme.

Although both activities have commissioned research and commercial possibilities in civil engineering, hydrogeological and landfill and pollution studies, the best opportunities lie with the Borehole Geophysical Logging Section. New equipment is currently being purchased through the Hydrogeology Business Opportunity and we hope to put borehole geophysical logging on a firm financial footing during 1991/92. In conjunction with the equipment development, BGS has developed the Wellog borehole logging software package to a high degree of sophistication for the interpretation of the geophysical borehole logs.

In addition, the Group has developed both cross-hole seismic and electrical resistivity instrumentation and is able to produce both seismic and electrical tomograms of the rock mass between adjacent boreholes. Specialised equipment for carrying out cross-hole seismic measurements in a horizontal mode was developed for use in the Channel Tunnel. We have the capability to carry out the field work and the computer modelling of the results and are a recognised contractor in this field.

In the drilling and sampling field, the Group has designed and built a number of specialised core barrels, one of which is in commercial production under licence. Within the BGS we provide a consultancy service on all aspects of drilling and sampling. The centralisation of much of the Survey's drilling activity within the Group has enabled more effective use of available resources and a planned investment programme.

iv) Geophysical surveys

The Group is responsible for all geophysical surveys within the Groundwater and Geotechnical Surveys Division. We have a wide range of comparatively modern digital geophysical surveying equipment and well qualified staff to operate it. We are well placed to carry out a wide range of geophysical surveys in the fields of civil engineering, hydrogeology, landfill and pollution, mineral exploration and geological mapping. It is anticipated that demand for our services will increase both in the UK and overseas. We have been very keen on research applications and have tried to bring in new ideas and methods through our published work, both in BGS reports and scientific journals. One example of this innovation is the RESCAN system referred to above.

CONCLUSIONS

From this assessment of the Group's immediate future, it is clear that there exists a broad expertise and a wide range of capability in the fields of engineering geology and applied geophysics.

We consider that the Group's primary function is to carry out the Core Programme activities identified above.

We have identified two principal Core Programme activities, both supported by, and intimately linked to our database. We also support the Core Programme activities of other Group s.

Increased staffing will be required to achieve the Core Programme objectives.

R & D income will continue to be sought from the Survey's programme and outside sources to enhance expertise and support strategic aims

We believe that our major effort to generate greater income from outside sources should be directed towards increasing the amount of commissioned/commercial research carried out by the Group.

Our consultancy work should continue but any expansion should be carefully assessed by a market survey in view of the highly competitive nature of this type of work.

There seems to be considerable scope for increased income generation form contracted services provided by our laboratories and our geophysical borehole logging set up. Such high quality, but routine, work benefits the Core Programme and commissioned research by providing resources to upgrade equipment and maintain a pool of experienced technical staff.

The support functions should be maintained with adequate BGS support. Much of the cost of this support is likely to be recovered as overheads from commercial income.

D.M. McCann M G. Culshaw

D M McCANN M G CULSHAW

ANNEX

AREAS OF EXPERTISE

i. Geological hazard assessment

This is an area of work in which the Group has been active for some time, both in the UK and overseas. In recent years work has included regional landslide surveys in Cyprus and South Wales, mine stability surveys in the West Midlands and study of secondary seismic hazards in Greece. The Group recently obtained CEC research funding for a landslide study in southern Europe. We see a continuing need to be active in this field both strategically, in carrying out Core Programme and commissioned regional surveys and research, and in carrying out consultancy work for a range of clients including public utility companies and local authorities.

In the last few years the DoE has commissioned a number of databases covering geological hazards, both natural and artificial. These studies have been carried out mostly by engineering/geological consultancies, though BGS is currently working on a contract for DoE on natural contamination, and consist of:

a)	Landslides	(Geomorphological Services Ltd./Rendell Palmer and Tritton)
b)	Natural cavities	(Applied Geology Ltd.)
c)	Foundation conditions	(Wimpey Environmental Ltd.)
d)	Abandoned mineworkings	(Ove Arup)

While these databases are in the public sector, in so far as they were paid for by the tax-payer, they are not necessarily being maintained or updated by their private sector creators. It is essential that all these databases are kept up to date with new information as it becomes available; our present concern is that these databases will fall into disuse if this does not happen. It would seem advisable that all these databases should be brought together at BGS in the national strategic interest as a National Archive, which could be consulted by industry, commerce and the public. We have the expertise to operate and maintain the databases and to interpret the data held in them. However, there would be a cost in maintaining them and it is doubtful if all this cost could be recovered fully from chargeable enquiries. Without DoE's strong support, it is also questionable whether all the database creators would transfer these database resources to BGS.

ii) Engineering/environmental geological mapping

The Group has had a sustained interest in the development and production of engineering geological maps, either in their own right or as part of environmental geological mapping. Indeed, there are good arguments for suggesting that environmental geological maps are better produced under the overall supervision of engineering geologists, with their applied perspective, rather than the Thematic Maps and Onshore Surveys Division. Particular attention would need to be given to the mapping of Quaternary deposits because of their importance in environmental geology.

Major engineering geological surveys have been carried out for the DoE in South Essex, for the former Scottish Development Department in the Firth of Forth and Cromarty Firth and for ODA. More recently, the Group has produced engineering geology maps as part of the Applied Geology mapping programme of the DoE. As a result, the Group has built up a wealth of experience in presenting engineering data in map form. This experience will be utilised to enhance the presentation of the results from our Core Programme activities.

iii) Engineering and hydrogeological geophysics

The Group has been involved in research and development in the field of engineering geophysics for more than twenty years; two staff from the Group worked on the Working Party of the Engineering group of the Geological Society on Engineering Geophysics whose report was published in 1988. We have been particularly involved in the development of new geophysical methods for use in site investigation; these include cross-hole seismic and electrical resistivity surveys, development of seismic tomography and the use of geophysical borehole logging to obtain engineering properties of the rock mass. We have worked on the use of geophysical methods to detect cavities and old mine workings, to assess rock mass conditions such as the degree of fracturing and to study landslides. We have published a wide range of papers in collaboration with engineering geologists in the group and we have worked closely with to provide integrated geotechnical/geophysical studies in several locations.

In the hydrogeological field, the Group has an excellent record working overseas where geophysical methods have been widely used to locate water resources in many areas. At present, we are involved in the use of a number of geophysical techniques, including seismic tomography, to locate aquifers in a fractured, crystalline rock mass in Zimbabwe. We plan to increase our geophysical involvement in UK hydrogeological work following on from new opportunities that have arisen as a result of the recent BGS reorganisation.

Our expertise in these two fields is second to none and, with the continuation of underlying Core Programme support to allow innovation and development, commissioned research income should be capable of being expanded.

iv) Rock physics

The Group has always been associated with research into methods for assessing the engineering properties of the rock mass. We have been particularly interested in the measurement of the fundamental geophysical properties of rocks including studies at high temperatures and pressure and their relationship to the geotechnical properties. In this respect geophysical borehole logging studies and cross hole seismic and electrical surveys have been carried out and the results used to provide an indirect assessment of the engineering properties of the rock mass including degree of fracturing, in-situ elastic moduli, etc. The Group has also been involved with Regional Geophysics Group in the study of the UK in-situ rock stress field and data have been derived from borehole and rock core information and the laboratory measurement of anelastic strain.

v) Other interests

Other areas which the Group has had interests in the past are:

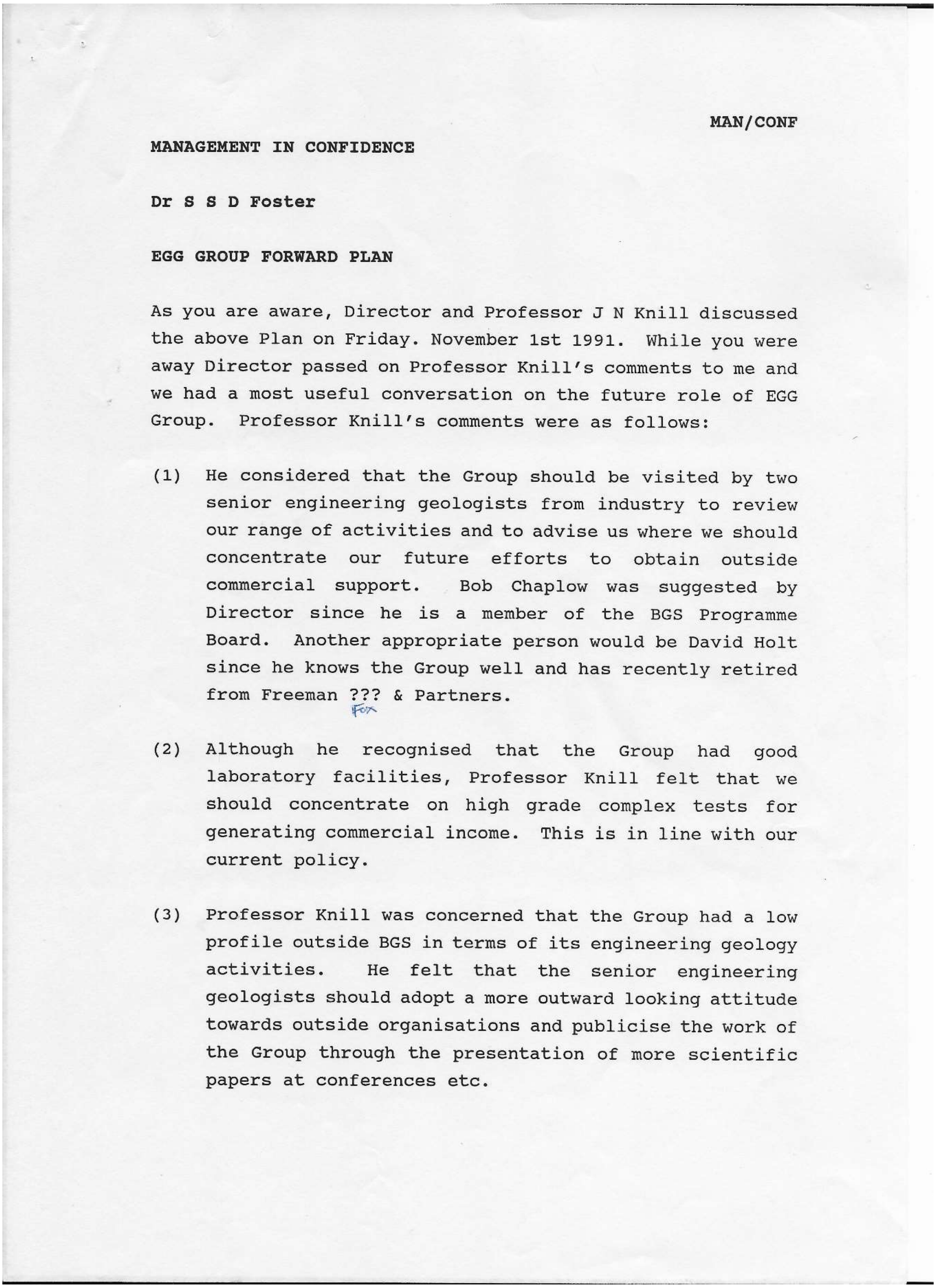
1. Coastal engineering, particularly in the near-shore environment.

2. Marine geotechnical/geophysical studies.

3. Engineering construction materials.

All three of these areas have considerable scope for the Group but activity on them has largely ceased as a result of lack of staff. We would only recommend increased activity if additional resources were available from fully funded commissioned research or consultancy work.

Appendix 5 EEG Group Forward Plan, 1991, D M McCann to S S D Foster



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MANAGEMENT IN CONFIDENCE

Dr S S D Foster

EGG GROUP FORWARD PLAN

As you are aware, Director and Professor J N Knill discussed the above Plan on Friday. November 1st 1991. While you were away Director passed on Professor Knill's comments to me and we had a most useful conversation on the future role of EGG Group. Professor Knill's comments were as follows:

(1) He considered that the Group should be visited by two senior engineering geologists from industry to review our range of activities and to advise us where we should concentrate our future efforts to obtain outside commercial support. Bob Chaplow was suggested by Director since he is a member of the BGS Programme Board. Another appropriate person would be David Holt since he knows the Group well and has recently retired from Freeman ??? & Partners.

Fox

(2) Although he recognised that the Group had good laboratory facilities, Professor Knill felt that we should concentrate on high grade complex tests for generating commercial income. This is in line with our current policy.

(3) Professor Knill was concerned that the Group had a low profile outside BGS in terms of its engineering geology activities. He felt that the senior engineering geologists should adopt a more outward looking attitude towards outside organisations and publicise the work of the Group through the presentation of more scientific papers at conferences etc.

(4) Professor Knill considered that the Group should be called just Engineering Geology Group but Director and I agreed that this would not be a popular move with our geophysicisits.

(5) Professor Knill was very keen on our regional engineering geology studies, such as the Gault Clay project and felt that these activities should be expanded to other geological formations.

Director and I then discussed other matters that concerned the Group as follows:

(1) Director felt that following his discussions with Roy Baria there is considerable potential work for the Group in the field of geothermal energy, particularly in site specific engineering type investigations. We agreed that I would prepare a flier to advertise BGS's expertise in the geothermal field for possible use by Roy Baria in obtaining more CEC sponsored work. We agreed that the decision made by the Career Management Board to transfer Roy Baria from RG Group to EGG Group would be implemented in the near future and I was asked to arrange it.

(2) Director also discussed Wellog and Robin Brereton's rock physics activities. I said that I felt it had been a mistake not to transfer Robin Brereton to EGG Group at the time of the split with EGG Group but that my assessment at the time had been that disruption to the geophysical staff should be kept at as low a level as possible. Director indicated that he had some sympathy with this approach but said that no action could be taken until Brian Stephenson had reviewed the Business Opportunities, including well Log and made appropriate recommendations. In any case, no action could really be taken during the current financial year.

(3) I raised the possibility of a new approach to funding of EGG Group for its work in the Core Programme, whereby funds for engineering geological activities on the Land Survey programme were made available to EGG Group. It would then be our responsibility to allocate these funds to those aspects of the field mapping programme which were of the highest priority. This approach to funding has the advantage that any cuts in funding could be taken on a pro rata basis across our whole programme and not on specific projects. Director said he was not averse to this proposal and asked me to prepare a short paper outlining my proposals.

Dr D M McCann
Manager
Engineering Geology and Geophysics Group

9 December 1991

Appendix 6 Engineering Geology Leaders and Organisational Names

Chief Engineering Geologist (Head of Unit, Group Manager, Programme Manager, Head of Science, Head of Engineering Geology)

C R Cratchley (Roger)	1967 – March 1985
M Price (Mike)	April 1985 – September 1988
M G Culshaw (Martin)	October 1988 – December 1990
D M McCann (Dave)	January 1991 – June 1995
M G Culshaw (Martin)	July 1995 – June 2006
D M Bridge (Dave)	July 2006 – March 2007
A Gibson/H J Reeves/K Royse/ R Shaw (Andy/Helen/Kate/Richard) (Joint leadership)	April – October 2007
A Gibson (Andy)	November 2007 – December 2008
H J Reeves (Helen)	January 2009 – October 2019
M R Dobbs (Marcus)	February 2022 – ongoing

Roger Cratchley retired from the BGS at the end of March 1985

Mike Price left the BGS at the end of September 1988

Dave McCann retired from the BGS at the end of April 1997

Martin Culshaw retired from the BGS at the end of March 2008

Dave Bridge retired from the BGS at the end of March 2007

Andy Gibson moved to Portsmouth University as a Senior Lecturer at the end of December 2008

Kate Royse remained at the BGS as Chief Digital Officer (from October 2019) but left in early 2022.

Helen Reeves continued to work at the BGS after the Engineering Geology and Infrastructure Directorate (see below) closed. She moved to a consultancy job in Leeds in early May 2020.

Operational unit names:

Engineering Geology Unit (EGU)
    1967 – 1983

Engineering Geology and Reservoir Rock Properties Group (EGRRP)
    1983 – 1986

Engineering Geology and Reservoir Properties Group (EGARP)
    1986 – 1988

Engineering Geology Research Group (EGRG)
    1988 – 1991

Engineering Geology and Geophysics Group (EGGG)
    1991-1997

Coastal and Engineering Geology Group (CEG)

1997-1999

Urban Geoscience and Geological Hazards Programme (UGGH)
1999 – 2005

Physical Hazards Programme (PH)
2005 – 2007

Land Use and Development Science Theme (LUD)
2007-2011?

Land Use Planning and Development Science Theme (LUPD)
2011? – 2013

Engineering Geology Directorate (EG)
2013 – 2017

Engineering Geology and Infrastructure Directorate (EGI)
2017 – 2019

Engineering Geology Team
2022 – ongoing

Appendix 7 Staff Lists

STAFF LISTS FROM ANNUAL REPORTS

Annual Report 1967
Engineering Geology Unit
London
Head: C R Cratchley
B W Conway
J R Hallam

Annual Report 1968
Engineering Geology Unit
London
Head: C R Cratchley
B W Conway
P H Collins
J R Hallam
D M McCann

Annual Report 1969
Engineering Geology Unit
London
Head: C R Cratchley
B W Conway
P H Collins
B Denness
P Grainger
J R Hallam
D M McCann

Annual Report 1970
Engineering Geology Unit
London
Head: C R Cratchley
B W Conway
P H Collins
B Denness
P Grainger
J R Hallam
D M McCann

Annual Report 1971
Engineering Geology Unit
London
Head: C R Cratchley
B W Conway
P H Collins
M G Culshaw
B Denness
A Forster
P Grainger
J R Hallam
A D Harding
D M McCann

Annual Report 1972
Engineering Geology Unit
London
Head: C R Cratchley
B W Conway
P H Collins
M G Culshaw
J Darwell
B Denness
A Forster
P Grainger
J R Hallam
A D Harding
D M McCann
K J Northmore
M Sarginson
D M Warrell

Annual Report 1973
Engineering Geology Unit
London
Head: C R Cratchley
B W Conway
M E Collyer (Secretary)
M G Culshaw
J Darwell
N M Dave
B Denness
S V Duncan
A Fairlie
A Forster
R A Godson
P Grainger
J R Hallam
D M McCann
S J Milburn
K J Northmore
S Patel
M Sarginson
D M Warrell
J Wells

Annual Report 1974
Engineering Geology Unit
London
Head: C R Cratchley
R Baria
B W Conway
M G Culshaw
W G Darling
D M Darton
J Darwell
B Denness
S V Duncan
A Forster
R A Godson
J R Hallam
P R N Hobbs

J T Lambert
C B Marshall
D M McCann
S J Milburn
K J Northmore
J Patterson
M Sarginson
E Wilson (Secretary)

Annual Report 1975
Engineering Geology Unit
London
Head: C R Cratchley
R Baria
M Burbidge
B W Conway
M G Culshaw
S V Duncan
A Forster
M Fourniss
J R Hallam
P R N Hobbs
M C Kennedy (Secretary)
J T Lambert
D M McCann
K J Northmore
J Patterson

Annual Report 1976
Engineering Geology Unit
London
Head: C R Cratchley
R Baria
B W Conway
M G Culshaw
S V Duncan
A Forster
M Fourniss
T P Gostelow
A S P Green
J R Hallam
P D Jackson
J T Lambert
D M McCann
K J Northmore

Annual Report 1977
Engineering Geology Unit
London
Head: C R Cratchley
R Baria
B W Conway
M G Culshaw (in Indonesia)
S V Duncan
A Forster
T P Gostelow
A S P Green
J R Hallam

P R N Hobbs
P D Jackson
M C Kennedy (Secretary)
J T Lambert
D M McCann
D D Nalliah
K J Northmore
D Suddaby

Edinburgh
F A Ashton
D Long

Annual Report 1978
Engineering Geology Unit
London
Head: C R Cratchley
R Baria
B W Conway
M G Culshaw
S V Duncan
A Forster
T P Gostelow
A S P Green (in Fiji)
J R Hallam
P R N Hobbs
P D Jackson
M C Kennedy (Secretary)
J T Lambert
D M McCann
T McEwen
K J Northmore
D Suddaby
Z Khawaja

Edinburgh
D Long

Annual Report 1979
Engineering Geology Unit
London
Head: C R Cratchley
R Baria
B W Conway
M G Culshaw
A Forster
J R Hallam
P R N Hobbs
S T Horseman
P D Jackson
D M McCann
M C Nielson (Secretary)
K J Northmore

Edinburgh
T P Gostelow
J T Lambert
D Long

I C Moore
K Tindale

Annual Report 1981 and 1982
Engineering Geology Unit
London
Head: C R Cratchley
B W Conway
M G Culshaw
A Forster
J R Hallam
S P Hassett
P R N Hobbs
S T Horseman
P D Jackson
S R Lees (Secretary)
D M McCann
K J Northmore

Edinburgh
S A Alexander
T P Gostelow
D Long

Minute from H W Haslam, Programme Planning Team to Roger Cratchley (date 8 December 1983) listing staff line managed by Cratchley
Keyworth/London
Head: C R Cratchley
B W Conway
M G Culshaw
A Forster
D Greenbaum
J R Hallam
P R N Hobbs
S T Horseman
K J Northmore

Wallingford
D J Allen
M J Bird
A T Ellis
M Price
R G Spicer
K S Wilson

Edinburgh
S A Alexander
T P Gostelow
D Long

Annual Report 1982/83 (date 1 Jan 1985)
Engineering Geology and Reservoir Rock Properties
London/Keyworth
Head: C R Cratchley
M G Culshaw
S T Horseman
A Forster
J R Hallam

P R N Hobbs
K J Northmore
S P Hassett

Wallingford
M Price
D J Allen
M J Bird
A T Ellis
K S Wilson
R G Spicer

Edinburgh
T P Gostelow
D Long
S A Alexander

Annual Report 1985/86 (date 31 March 1986)
Engineering Geology and Reservoir Rock Properties
Head: M Price

Annual Report 1987/88 (date 31 March 1988)
Engineering Geology and Reservoir Properties
Keyworth
Head: M Price
D Bridger
M G Culshaw
A Forster
T P Gostelow
K J Northmore
J R Hallam
P R N Hobbs
J A Crummy
D C Entwisle
M B Fry

Wallingford
D J Allen
M J Bird
A T Williams
A S Butcher
N E Short

Annual Report 1988/89 (date 31 May 1989)
Engineering Geology
M G Culshaw
D Bridger
A Forster
T P Gostelow
PRN Hobbs
K J Northmore
J R Hallam
D C Entwisle
P J Waine
M B Fry

Annual Report 1989/90 (date 31 March 1990)
Engineering Geology

M G Culshaw
D Bridger
A Forster
T P Gostelow
PRN Hobbs
K J Northmore
J R Hallam
D C Entwisle
P J Waine

Annual Report 1990/91 (date 1 November 1991)
Engineering Geology and Geophysics
Head D M McCann
D Bridger
J H Page
D Beamish
M G Culshaw
P G Greenwood
P D Jackson
R J Peart
J P Busby
A D Evans
A Forster
T P Gostelow
PRN Hobbs
K J Northmore
J R Hallam
S L Shedlock
A C Cripps
D C Entwisle
D A Gunn
S F Kimbell
P I Meldrum
M G Raines
S M Fenwick
S J Self
N Bosworth
B Collins
L D Jones
G E Rippin
A M Barnes
J L Meakin

Annual Report 1991/92 (date 1 December 1992)
Engineering Geology and Geophysics
Head D M McCann
J H Page
C L Silverman
R Baria
D Beamish
M G Culshaw
P G Greenwood
P D Jackson
R J Peart
J P Busby
A D Evans
A Forster
T P Gostelow

PRN Hobbs
K J Northmore
J R Hallam
S L Shedlock
A C Cripps
D C Entwisle
D A Gunn
S F Kimbell
P I Meldrum
M G Raines
S M Fenwick
S J Self
R C Flint
B Collins
L D Jones
G E Rippin
A M Barnes
H Wilson
J L Meakin

Annual Report 1992/93 (date 1 June 1993)
Engineering Geology and Geophysics
Head D M McCann
J H Page
C L Silverman
R Baria
D Beamish
M G Culshaw
P G Greenwood
P D Jackson
R J Peart
J P Busby
A D Evans
A Forster
T P Gostelow
PRN Hobbs
K J Northmore
J R Hallam
S L Shedlock
A C Cripps
D C Entwisle
D A Gunn
S F Kimbell
P I Meldrum
M G Raines
S M Fenwick
S J Self
R C Flint
B Collins
L D Jones
G E Rippin
A M Barnes
H Wilson
J L Meakin

Edinburgh
D Long

Annual Report 1993/94 (date 1 April 1994)
Engineering Geology and Geophysics
Head D M McCann
J H Page
C L Silverman
R Baria
D Beamish
M G Culshaw
P G Greenwood
P D Jackson
R D Ogilvy
R J Peart
J P Busby
A Forster
T P Gostelow
PRN Hobbs
K J Northmore
J R Hallam
S L Shedlock
A C Cripps
D C Entwisle
D A Gunn
S F Kimbell
P I Meldrum
M G Raines
S M Fenwick
S J Self
R C Flint
L D Jones
G E Rippin
A M Barnes
H Wilson
J L Meakin

Edinburgh
D Long

Annual Report 1994/95 (date 1 August 1995)
Engineering Geology and Geophysics
Head M G Culshaw
J H Page
C L Silverman
R Baria
D Beamish
P G Greenwood
P D Jackson
R D Ogilvy
R J Peart
J P Busby
A Forster
T P Gostelow
PRN Hobbs
K J Northmore
J R Hallam
S L Shedlock
A C Cripps
L J Donnelly
D C Entwisle

D A Gunn
P I Meldrum
M G Raines
S J Self
R C Flint
L D Jones
G E Rippin
A M Barnes
H Wilson
J L Meakin

Annual Report 1995/96 (date May 1996)
Engineering Geology and Geophysics
Head M G Culshaw
J H Page
R Baria
D Beamish
P G Greenwood
P D Jackson
R D Ogilvy
R J Peart
J P Busby
A Forster
T P Gostelow
PRN Hobbs
K J Northmore
J R Hallam
S L Shedlock
A C Cripps
L J Donnelly
D C Entwisle
D A Gunn
P I Meldrum
M G Raines
S J Self
R C Flint
L D Jones
G E Rippin
A M Barnes
J L Meakin

Annual Report 1996/97 (date 31 March 1997)
Engineering Geology and Geophysics
Head M G Culshaw
J H Page
R Baria
D Beamish
P G Greenwood
P D Jackson
R D Ogilvy
R J Peart
J P Busby
A Forster
T P Gostelow
PRN Hobbs
K J Northmore
J R Hallam
S L Shedlock

A C Cripps
L J Donnelly
D C Entwisle
D A Gunn
P I Meldrum
M G Raines
S J Self
R C Flint
L D Jones
G E Rippin
A M Barnes
J L Meakin

Annual Report 1997/98 (date March 1998)
Coastal and Engineering Geology
Head M G Culshaw
J H Page
L Ware
R S Arthurton
P Balson
R Baria
C D R Evans
A Forster
B Humphreys
P D Jackson
K J Northmore
J Ridgway
R T R Wingfield
A Crosby
T P Gostelow
D A Gunn
J R Hallam
PRN Hobbs
J G Rees
D S Brew
A C Cripps
L J Donnelly
D C Entwisle
R C Flint
H M Glaves
L D Jones
A M Barnes
R Newsham
K E Outhwaite
M P Slater
J M Woodhead
J L Meakin
P D Gibson

Annual Report 1998/99 (date May 1999)
Coastal and Engineering Geology
Head M G Culshaw
J H Page
L Ware
P Balson
R Baria
C D R Evans
A Forster

B Humphreys
P D Jackson
K J Northmore
J Ridgway
T P Gostelow
D A Gunn
J R Hallam
PRN Hobbs
J G Rees
D S Brew
L J Donnelly
D C Entwisle
H M Glaves
L D Jones
M P Slater
J L Meakin

From the Annual Report for 1999/2000, staff were no longer listed by Unit or Group. However, managers at various levels were listed

Annual Report 1999-2000
No staff mentioned (but Head M G Culshaw)

Annual Report 2000-2001
Urban Geoscience and Geological Hazards
Head M G Culshaw

Annual Report 2001-2002
Urban Geoscience and Geological Hazards
Head M G Culshaw

Annual Report 2002-2003
Urban Geoscience and Geological Hazards
Head M G Culshaw

Annual Report 2003-2004
Urban Geoscience and Geological Hazards
Head M G Culshaw

Annual Report 2004-2005
Physical Hazards Programme
No staff mentioned (but Head M G Culshaw)

Annual Report 2005-2006
Physical Hazards Programme
No staff mentioned (but Head M G Culshaw)

Annual Report 2006-2007
Physical Hazards Programme
No staff mentioned (but Head A Gibson)

Annual Report 2007-2008
Land Use and Development
Head A Gibson
H Reeves Team Leader Geoengineering Properties and Processes
A Cooper Team Leader Shallow Geohazards and Risks
B Rawlins Team Leader Sustainable Soil Management
S Price Team Leader Urban Development

Annual Report 2008-2009
Land Use and Development
Head H Reeves
D A Gunn Team Leader Geoengineering Properties and Processes
A Cooper Team Leader Shallow Geohazards and Risks
B Rawlins Team Leader Sustainable Soil
S Price Team Leader Urban Development

Annual Report 2009-2010
Not published

Annual Report 2010-2011
Land Use Planning and Development
No staff mentioned (but Head H Reeves)

Annual Report (Annual Science Review) 2011-2012
Land Use Planning and Development
No staff mentioned (but Head H Reeves)

Annual Report (Annual Science Review) 2012-2013
Engineering Geology
No staff mentioned (but Head H Reeves)

Annual Report 2013-2014
Not published

Annual Report (Annual Science Review) 2014-2015
Engineering Geology
No staff mentioned (but Head H Reeves)

Annual Report (Annual Science Review) 2015-2016
Engineering Geology
No staff mentioned (but Head H Reeves)

Annual Report (Annual Science Review) 2016-2017
Engineering Geology and Infrastructure
No staff mentioned (but Head H Reeves)

Late 2019: Engineering Geology and Infrastructure Directorate disbanded along with other similar Directorates.

Annual reports

Appendix 8 External Activities

Committee of the Engineering Group of the Geological Society

Member: C R Cratchley
D M McCann
M G Culshaw
A Forster
P R N Hobbs
L J Donnelly
D C Entwisle
H Reeves

Secretary: D M McCann (1976-1980)
A Forster

Vice Chair/Chair: M G Culshaw (1992 – 1994, 1994 – 1996)
D C Entwisle (2008 – 2010, 2010 – 2012)

Engineering Group Working Party on Description of Rock Masses (Geological Society)

Member: D M McCann (1974-1977)

Engineering Group Working Party on Engineering Geophysics (Joint Geological Society/CIRIA)

Member: D M McCann (1995-2001)
M G Culshaw (1995-2001)
P D Jackson (1995-2001)

Committee of the Environmental and Industrial Geophysics Group of the Geological Society

Member: D M McCann (1994-1998)
P D Jackson

Chair: D M McCann (1990-1994)

Engineering Geology Special Publications, Geological Society

Editor: M G Culshaw (1989-1992)

Quarterly Journal of Engineering Geology and Hydrogeology Editorial Board

Editor: A Forster (2000 - 2001)
Member: C R Cratchley (1977 -1980)
Member: M G Culshaw (2002 – 2006)
Member: D C Entwisle (2008 - 2019)
Member D A Gunn (2007 - 2010)
Assistant Editor M G Culshaw (2008 - 2012)

Engineering Geology Editorial Board

Member: M G Culshaw (2001 – 2007)

Georisk Editorial Board

Member: M G Culshaw (2006 - 2009)

Publications Committee of the Geological Society

Member: M G Culshaw (2005-2007)

Council of the Geological Society

Member D M McCann (1985-1988)
Member: M G Culshaw (2005-2009)

East Midlands Regional Group of the Geological Society Committee

Chair: M G Culshaw (1999 – 2002)
Member: D C Entwisle (1997 -2002)
Member: D Boon (2006 – 2012)

Council of the Yorkshire Geological Society

Member: H J Reeves (200? - 200?)

Department of Energy Sea-Bed Stability Committee

Member: D M McCann (1973-1975)

British Standards Institution Site Investigation Committee

Member: D M McCann (1991-1998)

Institution of Civil Engineers Site Investigation Steering Group

Member: D M McCann (1992-1994)

British Standards Institution Ground Investigation and Ground Testing Committee (B526/3)

Member D C Entwisle (2009 to date)

Commission No 1 ‘Engineering Geological Maps’ of the International Association for Engineering geology and the Environment

Member: M G Culshaw (1991-2007)
Chair: M G Culshaw (1993-2007)

Commission No 25 ‘Engineering Geological Models’ of the International Association for Engineering Geology and the Environment

Member: M G Culshaw (2014-2022)

Cogeoenvironment

Member: A Forster

Bulletin of Engineering Geology and the Environment

Editor-in-Chief M G Culshaw (2013-2019)

Association of Geotechnical and Geoenvironmental Specialists (AGS)

Laboratories Working Group

Member	D C Entwisle (2007 to date)

Data Management Working Group

Member	D C Entwisle (2010 to date)

AWARDS AND AFFLILIATIONS

Engineering Group of the Geological Society Award

M G Culshaw (1989)
P D Jackson (1997)
L J Donnelly (2008)

Geological Society Glossop Medal

M G Culshaw (2004)

Geological Society of America, Engineering Geology Division E B Burwell Award

M G Culshaw (2006)
F G Bell (2007)
L J Donnelly (2007)

International Association for Engineering Geology and the Environment Hans Cloos Medal

M G Culshaw (2010)

John Grimwade Medal for contributions to ultrasound research

C R Brett, D A Gunn, B A J Dashwood, S J Holyoake and P B Wilkinson (2018)
The inspection of foundations in offshore wind turbines. Insight – the Journal of the British Institute of NDT, 60(1), 19-27

International Association for Engineering Geology and the Environment Marcel Arnould Medal

M G Culshaw (2020)

Geological Society Coke Medal

H Reeves (2021)

Association of Geotechnical and Geoenvironmental Specialists (AGS) Laboratory Working Group Award

D C Entwisle (2018)

Visiting Professorships

University of Edinburgh:	D M McCann
Nottingham Trent University:	M G Culshaw (2000-2008)
University of Birmingham:	M G Culshaw (2006- present)

Appendix 9 Publications Before 2000 (alphabetical by first author)

Arnaud-Vanneau, A., Camoin, G. F., Haggerty, J. A., Premoli Silva, I., Rack, F., Bergersen, D. D., Bogdanov, Y., Bohrman, H. W., Buchardt, B., Christie, D. M., Dieu, J. J., Enos, P., Erba, E., Fenner, J., Gee, J. S., Head, M. J., Hobbs, P. R. N., Ito, H., Jansa, L., Ladd, J. W., Larson, R. L., Lincoln, J. M., Nakanishi, M., Ogg, J. G., Opdyke, B. N., Pearson, P. N., Quinn, T. M., Watkins, D. K. & Wilson, P. A. 1993. Les Edifices carbonates des atolls et guyots du Pacifique nord-occidental; resultats preliminaires du Leg ODP 144. Comptes Rendus de l'Academie des Sciences, Serie 2, Mecanique, Physique, Chimie, Sciences de l'Univers, Sciences de la Terre, volume 317.

Baria, R., Jackson, P. D. & McCann, D. M. 1989. Further development of a high frequency seismic source for use in boreholes. Geophysical Prospecting 37, No.1, 31 52.

Brereton, N. R., McCann, D. M. & Brightman, M. A. 1982. Geophysical borehole logging results from crystalline and soft rocks in the UK. In: Proceedings of the NEA Workshop on Geophysical Investigations in Connection with Geological Disposal of Radioactive Waste, 8th 10th September, Ottawa, Canada.

Buchan, S., Dewes, F. C. D., McCann, D. M., & Taylor Smith, D. 1967. Measurements of the acoustic and geotechnical properties of marine sediment cores. Marine Geotechnique, Ed. Richards, S. F., University of Illinois Press, Urbana, 327 p.

Buchan, S., McCann, D.M. & Taylor Smith, D. 1972. Relations between the acoustic and geotechnical properties of marine sediments. Quarterly Journal of Engineering Geology, 5, 265 284.

Clark, M. R., Gillespie, R, Kemp, T., McCann, D. M. & Forde, M. C. 1998. Electromagnetic properties of railway ballast. In the Proceeding of the 1st International Conference Railway Engineering, Editor M. C. Forde, Brunel University, London, 10th July 1998, 21-28.

Colla, C., Forde, M.C., McCann, D. M. & Das, P. C. 1995. Investigation of Masonry Arch Bridges using Non-Contacting NDT. In: Proceedings of the Sixth International Conference on Structural Faults and Repairs. Editor M. C. Forde, London, 3rd-5th July, 1995, 1, 235-239.

Colla, C., Das, P. C., McCann, D. M. & Forde, M. C. 1995. Investigation of stone masonry bridges using sonics, electromagnetics and impulse radar. Proceedings of the International Symposium. Non-Destructive Testing in Civil Engineering (NDT, CE), September 26-28, Berlin.

Colla, C., Forde, M. C., McCann, D. M. & Das, P. C. 1995. Investigation of Masonry Arch Bridges using Non-Contacting NDT in Proceedings of the Sixth International Conference on Structural Faults and Repairs. Editor: M.C. Forde, London, 3rd-5th July, 1995, 1, 235-239

Colla, C., McCann, D. M., Forde, M. C., Das, P. C. & Batchelor, A. J. 1997. Radar tomography of masonry arch bridges. In Proceeding of the Seventh International Conference on Structural Faults and Repair, Editor M. C. Forde, Edinburgh, 8th to 10th July 1997, V1, 43-152.

Colla, C., Das, P. C., McCann, D. M. & Forde, M. C. 1997. Sonic, electromagnetic, and impulse radar investigation of stone masonry bridges. NDT & E International, Vol 30, No.4, 249-254.

Cornwell, J. D., Cannell, B. & McCann, D. M. 1989. Application of geophysical methods to sand and gravel deposit assessment. In: Proceedings of the Extractive Industry Geology Conference. Gaskarth, J. W. & Lumsden (Eds). University of Birmingham, UK, 16th 19th April, 1989.

Cornwell, J. D. & McCann, D. M. 1991. The application of geophysical methods to the geological mapping of Quaternary sediments. In: Forster, A., Culshaw, M. G., Cripps J. C., Little J. A., & Moon, C. F. (eds), Quaternary Engineering Geology, Geological Society Special Publication No. 7, 519-526.

Cratchley, C. R. 1976 or later. Geophysical measurements in rock mechanics investigations. 447-456

Cratchley, C. R. 1977. Engineering geology of south Essex. In: Proceedings of a Conference on: “Surface modelling by computer.” London: Institution of Civil Engineers. 43-49.

Cratchley, C. R., Grainger, P., McCann, D. M. & Smith, D. I. 1972. Some applications of geophysical techniques in engineering geology with special reference to the Foyer Hydro Electric scheme. In: Proceedings of the 24th International Geological Congress, Section 13,163 175.

Cratchley, C. R., McCann, D. M. & Ates, M. 1976. Application of geophysical techniques to the location of weak tunnelling ground with an example from the Foyers hydroelectric scheme, Loch Ness. Transactions of the Institution of Mining and Metallurgy, Section A, 85, A127 A13.

Cratchley, C. R., Davies, A. M. & Taylor Smith, D. 1982. Enhancement of the role of geophysics in marine geotechnical investigations. In: Proceedings of the Oceanology International Conference, 2-5 march 1982, Brighton, UK, Paper O182, 4.1.

Cratchley, C. R., Hobbs, P., Petrides, G. & Loucaides, G. 1982. Geotechnical map of Nicosia, scale 1:25000, map, published by: Cyprus Geological Survey.

Cratchley, C. R., Culshaw, M. G., Hallam, J. R., Jackson, P. D. & McCann, D. M. 1984. A test bed site in sand for geotechnical and geophysical studies. In: Proceedings of the 46th Meeting of the European Association for Exploration Geophysics, London.

Cripps, J. C., McCann, D. M., Culshaw, M. G. & Bell, F. G. 1988. The use of geophysical techniques as an aid to the detection of abandoned shallow mineworkings. In: Proceedings of Minescape '88 Symposium on 'Mineral Extraction, Utilisation and the Surface Environment. Institution of Mining Engineers, Harrogate, UK, 281 288.

Culshaw, M. G., Jackson, P. D. & McCann, D. M. 1987. Geophysical mapping techniques in environmental planning. Culshaw, M. G., Bell, F. G., Cripps, J. C. and O'Hara, M. Planning and Engineering Geology, Geological Society Special Publication No.4, 171 77.

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Appendix 10 Publications (2000-2007 and later) (alphabetical by first author)

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Nelder, L. M. 2003. Environmental and Industrial Geophysics Group (EIGG) Work-in-Progress meeting visit report. British Geological Survey Internal Report IR/03/085, 40p.

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O'DONNELL, K. E., FREESTONE, S. E. & BROWN, S. E. 2004. Geochemical baseline data for the urban area of Kingston-upon-Hull. British Geological Survey, Keyworth, UK, IR/02/80.

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Pennington, C. V. L., Culshaw, M. G. & Cooper, A. C. 2008. A geological assessment of the landslides in the Ironbridge Gorge, Shropshire. British Geological Survey Report CR/08/157, 33p.

Price, S. J., Bridge, D., Kessler, H. K. & Terrington, R. 2007. The Manchester and Salford 3-D superficial deposits model: a guide to the model and its applications. British Geological Survey Internal Report IR/07/001.

Price, S. J., Farrant, A. R., Leslie, A. R., Terrington, R. L., Merritt, J., Entwisle, D., Thorpe, S., Horabin, C., Gow, H., Self, S. & McCormick, T. 2012. A 3D superficial and bedrock geological model of the Abu Dhabi urban area, United Arab Emirates. British Geological Survey Commercial Report, CR/11/138. 75p.

Raines, M. G. & Beamish, D. 2003. An electromagnetic survey to locate a buried mineshaft at the Macmerry Business Park, East Lothian. British Geological Survey Commissioned Report CR/03/226.

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RAWLINS, B. G & O'DONNELL, K. E. 2004. Presentation of lead and zinc data from soil geochemical surveys of the urban area of Corby and surrounding rural land. British Geological Survey Internal Report, IR/04/095.

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Reeves, H. J. & Gibson, A. D. 2004. A walkover survey of a rockslide on The Storr, Isle of Skye. British Geological Survey Commissioned Report CR/04/195.

Rowlands, K. A. & Jones, L. D. 2002. Strategy, location and sampling of the Lias Group. British Geological Survey Internal Report IR/02/032. 90p.

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Vane, C. H. & Jones, L. D. 2002. A Drift spectroscopy study of clays. British Geological Survey Internal Report IR/02/033.

Waters, C. N., Hobbs, P. R. N. & Tragheim, D. G. 2001. The mineralogy and geochemistry of samples of the Lias Group of England and Wales. British Geological Survey Commissioned Report CR/01/128.

Waters, C. N., Price, S. J., Hawkins, M.P., Marchant, A.P., Fironi, E., Brown, S.E., Tye, A.M., Flenning, C., Davies, J., Schofield, D., Barclay, W.J. & Garcia-Bajo. 2005. A background to Urban Geoscience studies in the Swansea – Neath – Port Talbot area. Report IR/05/073R

Wilby, P. R., Forster, A. & Booth K. A. 2002. Geology and slope instability survey of Causeway, Cadora and Bigswear Woods, Gloucester. British Geological Survey Commissioned Report CR/02/044, 54p.

Wildman, G. & Forster. A. 2005. Giving landslides the slip. Surveyor 24 November 2005. Coastal and river engineering.

Young, B. 2002. Fracturing in the Permian rocks exposed in Houghton Quarry landfill site, City of Sunderland. British Geological Survey Commissioned Report CR/02/114.

Young, B. 2003. Renewed fissuring in the Magnesian Limestone beneath the A690 road at Houghton-le-Spring, City of Sunderland. British Geological Survey Internal Report IR/03/111. 9p.

Young, B. & Culshaw, M. G. 2001. Fissuring and related ground movements in the Magnesian Limestone and Coal Measures of the Houghton-le-Spring area, City of Sunderland. British Geological Survey Technical Report WA/01/04.

Young, B. & Lawrence, D. J. D. 2001. Recent fissuring in the Magnesian Limestone at Houghton-le-Spring, City of Sunderland. British Geological Survey Research Report RR/02/03.

Young, B. & Lawrence, D. 2006. Surface collapse features in the Magnesian Limestone of the Seaham area, County Durham – an investigation for District of Easington. British Geological Survey Commissioned report CR/06/225

Appendix 13 Presentations (2000 onwards [before 2000, presentations were mostly not recorded])

Auton, C., Arkley, S., Finlayson, M. A., Maurice, L., Hughes, A., Entwisle, D. & Reeves, H. 2011. Moray Ness GSI3D ZOOMing in? GSI3D Consortium Workshop, Nottingham, UK, 1-2 March 2011. Nottingham, UK, British Geological Survey.

Breward, N. 2003. Distribution of Natural Contamination of the Bioaccessibility and Risk Assessment in Contaminated Land Investigation, 3rd June 2003, The REACT Centre, Rotherham.

Bridge, D. McC. 2003. Integrating environmental information with urban planning policy – a decision support tool for planners.

COGEOENVIRONMENT Workshop, Vilnius, Lithuania, September 2003.

Carney, J. D. 2002. Flooding. Presentation to the Parliamentary Committee on Earth Sciences.

Carney, J. D. 2002. Flooding. Presentation to the Geological Society, East Midlands Regional Group.

Carney, J. D. 2003. Flooding. Presentation to the Royal Institution of Chartered Surveyors (2 x cpd days in May)

Cooper, A. H. 2000. My house fell in a hole – problems with soluble rocks and the inspiration for Alice in Wonderland! London, Imperial College, February 2000.

Cooper, A. H. 2000. Environmental problems caused by gypsum karst and salt karst in Great Britain. Turkey, Karst2000 Conference, September 2000.

Cooper, A.H. 2000. My House fell in a hole – problems with soluble rocks. Derby University, December 2000.

Cooper, A. H. 2001. Natural and induced halite karst geohazards in Great Britain. Eighth International Symposium on Sinkholes and Karst, Louisville, Kentucky, USA, March 2001.

Cooper, A. H., Farrant, A. R., Adlam, K. A. M. and Walsby, J. C. 2001. The development of a national geographic information system (GIS) for British karst geohazards and risk assessment. Eighth International Symposium on Sinkholes and Karst, Louisville, Kentucky, USA, March 2001.

Cooper, A. H. 2001. The geology of Hell's Kettles at Croft near Darlington. Darlington. Durham University, March 2001.

Cooper, A. H. 2003. My house fell in a hole – problems with soluble rocks and the inspiration for Alice in Wonderland! Yorkshire Geological Society, Durham, January 2003.

Cooper, A.H. My house fell in a hole – problems with soluble rocks and the inspiration for Alice in Wonderland! Geological hazards meeting, Liverpool University, March 2003.

Cooper, A. H. My house fell in a hole – problems with soluble rocks. Bath Royal Literary and Scientific Institution. October 2006.

Cooper, A. H. The Geology of the Ripon area (including gypsum and subsidence). Ripon Civic Society.

Culshaw, M. G. 2000. Invited lecture: "Environmental information systems for sustainable urban planning, regeneration and management." 1st URGENT Annual Meeting, University of Cardiff, 9-10 April 2000.

Culshaw, M. G. 2000. Lecture: "Impacts of abandoned mineworkings on aspects of urban development." Institution of Mining and Metallurgy and North of England Institute of Mining and Mechanical Engineers Conference on "The legacy of mineral extraction," Neville Hall, Newcastle-upon-Tyne, 18-19 May 2000.

Culshaw, M. G. 2000. Invited Lecture: “The political and economic implications of natural disasters – the impact of geohazards on the health and wealth of the UK.” All-Party Parliamentary Group on Earth Sciences, Houses of Parliament, London, 14 June 2000.

Culshaw, M. G. 2001. Invited Lecture: “From dig-it-all to digital: the rise and fall and rise again of the geological map.” Inaugural Professorial Lecture, The Nottingham Trent University, DICE Building, Tuesday 30 January 2001.

Culshaw, M. G. 2001. Invited lecture: “Environmental information systems for sustainable urban planning, regeneration and management.” 2nd URGENT Annual Meeting, University of Birmingham, 4-6 April 2001.

Culshaw, M. G. 2001. Invited keynote lecture: “Bridging the gap between geoscience providers and the user community.” EuroConference on the Characterisation of the Shallow Subsurface: Implications for Urban Infrastructure and Environmental Assessment: “New Paradigms for the Prediction of Subsurface Conditions,” Spa, Belgium, 7-12 July 2001.

Culshaw, M. G. 2001. Invited lecture: “The impact of geohazards on the health and wealth of the UK.” Loughborough Advanced Technology Initiative, BGS Keyworth, 16 October 2001.

Culshaw, M. G. 2001. Invited introductory lecture: “Problem soils: an introduction from a British perspective.” East Midlands Geotechnical Group of the Institution of Civil Engineers Symposium on ‘Problematic Soils,’ The Nottingham Trent University, School of Property and Construction, 8 November 2001.

Culshaw, M. G. 2002. Convenor and Rapporteur, Workshop on Environmental Information Systems for Sustainable Urban Planning, 3rd URGENT Annual Meeting, University of Birmingham, 8-9 April 2002.

Culshaw, M. G. 2002. Invited lecture: “Geological hazards in Britain and beyond.” Derby Natural History Society, Allestree, Derby, 12 April 2002.

Culshaw, M. G. 2002. Invited Lecture: “PSInSAR, ground movements and their geological interpretation.” All-Party Parliamentary Group on Earth Sciences, Houses of Parliament, London, 16 April 2002.

Culshaw, M. G. 2002. Invited keynote lecture on “Geological maps: their new importance in a user driven digital age.” at the International Association for Engineering Geology and the Environment, 9th International Congress on “Engineering Geology for Developing Countries,” Durban, 16-20 September 2002.

Culshaw, M. G. 2002. Invited lecture on “An engineering geological map for site investigation planning and construction type identification” at the International Association for Engineering Geology and the Environment, 9th International Congress on “Engineering Geology for Developing Countries,” Durban, 16-20 September 2002.

Culshaw, M. G. 2002. Presentation at Geohazard Maps Workshop on “Seismic hazard maps” 9th Congress of the International Association for Engineering Geology and the Environment, 9th International Congress on “Engineering Geology for Developing Countries,” Durban, 16-20 September 2002.

Culshaw, M. G. 2002. Chair, Session on “Engineering geological mapping and soil testing,” 9th Congress of the International Association for Engineering Geology and the Environment, 9th International Congress on “Engineering Geology for Developing Countries,” Durban, 16-20 September 2002.

Culshaw, M. G. 2002. Chair, Session on “Information technology and applied geology,” 9th Congress of the International Association for Engineering Geology and the Environment, 9th International Congress on “Engineering Geology for Developing Countries,” Durban, 16-20 September 2002.

Culshaw, M. G. 2002. Chair, Workshop on “Geohazard maps,” 9th Congress of the International Association for Engineering Geology and the Environment, 9th International Congress on “Engineering Geology for Developing Countries,” Durban, 16-20 September 2002.

Culshaw, M. G. 2002. Invited lecture: “From dig-it-all to digital: the rise and fall and rise again of the geological map.” Institution of Civil Engineers, Wales Association, Ground Engineering Group and the South Wales Regional Group of the Geological Society, Dinner Meeting, Thistle Hotel, Cardiff, Wednesday 4 December 2002.

Culshaw, M. G. 2003. Lecture: “Geohazard assessment at the British Geological Survey.” INCO-EuroGeoSurveys/FOREGS workshop on “Natural Hazards in the EU Research Context,” Vienna, Austria, 24-26 April 2003.

Culshaw, M. G. 2003. Invited lecture: “From dig-it-all to digital: the rise and fall and rise again of the geological map.” East Anglia Regional Group of the Geological Society, University of East Anglia, Norwich, Tuesday 29 April 2003.

Culshaw, M. G. 2003. Chair, Session on “Geology of Urban Areas,” 4th European Congress on Regional Geoscientific Cartography and Information Systems, Bologna, 17-20 June 2003.

Culshaw, M. G. 2003. Invited lecture: “Urban Geoscience.” 4th European Congress on Regional Geoscientific Cartography and Information Systems, Bologna, 17-20 June 2003.

Culshaw, M. G. 2003. Lecture: “Geological Hazards in Britain and Beyond.” Wollaton Natural History Society, Wollaton, Nottingham, 16 July 2003.

Culshaw, M. G. 2003. Chair, Session 2A, International Conference on Problematic Soils, Nottingham Trent University, Nottingham, 28 to 30 July 2003.

Culshaw, M. G. 2003. Invited keynote lecture on “Fills: their engineering character and treatment.” International Conference on Problematic Soils, Nottingham Trent University, Nottingham, 28 to 30 July 2003.

Culshaw, M. G. 2003. Invited keynote lecture on “Geotechnical properties of problem soils formed outside the temperate regions.” International Conference on Problematic Soils, Nottingham Trent University, Nottingham, 28 to 30 July 2003.

Culshaw, M. G. 2003. Invited lecture on “Geology in the city.” East Midlands Geological Society, Nottingham University, Saturday 8 November 2003.

Culshaw, M. G. 2003. Invited lecture on “Helping urban planners.” NERC Urgent Programme Finale meeting, Royal Institution of Chartered Surveyors, London, Thursday 4 December 2003.

Culshaw, M. G. 2004. Invited lecture on “Geological hazards at home and abroad.” Geological Survey of Northern Ireland lecture series on: “Geology works! Earth science in the service of society.” Ulster Museum, Belfast, Monday 19 January 2004.

Culshaw, M. G. 2006. Subsidence 2006 Conference. Post Magazine.

Donnelly, L. J. 2006. Engineering Geological and Geophysical Investigations of a Slope Failure at Edinburgh Castle, Scotland. The Central Scotland Regional Group of the Geological Society.

Duffy, T. 2002. Effective evaluation of environmental issues within a national planning process: enabling environmental concerns to be assessed during the UK development control planning process. Presentation to the 5th Urban Planning and Environment Association Conference. Oxford Brookes University, August 2002.

Entwisle, D. C. 2002. The distribution of clay minerals and their influence on the behaviour of the Lambeth Group. Presentation at “Engineering Geology of the Lambeth Group”. Joint meeting of the Engineering Group and Thames Valley Regional Group of the Geological Society. Reading University, April 2002.

Entwisle, D. C. 2002. The Lithostratigraphy of the Lambeth Group. Presentation at “Engineering Geology of the Lambeth Group”. Joint meeting of the Engineering Group and Thames Valley Regional Group of the Geological Society. Reading University. 10 April 2002.

Entwisle D. C. 2002. The effect of the mineralogy of the Sherwood Sandstone Group on the performance of tunnelling machines. Presentation at “Engineering geology of Classic Formations – Sherwood Sandstone Group.” Joint meeting of the Engineering Group and West Midlands Regional Group of the Geological Society. Wolverhampton University. March 2002.

Entwisle, D., Cameron, D., Ambrose, K. & Bloodworth, A. 2009. Brief overview of the quarried formations around the UK. In: Geotechnics in the Quarrying Industry: Meeting of the Engineering Group of the Geological Society, London, UK, 20 May 2009.

Entwisle, D., Northmore, K., Milodowski, A. & Jefferson, I. 2009. The engineering geology of Loessic Deposits in south east England. In: Engineering geology of the Quaternary deposits, Joint Conference of the Thames Valley Regional Group and the Engineering Group of the Geological Society, Reading, UK, 31 March 2009.

Entwisle, D. C. 2019. 3D geological modelling at the British Geological Survey (BGS). In: NTU-BCA Workshop on 3D Geological Modelling, BCA Academy, Building and Construction Authority, Singapore, 17 January 2019.

Entwisle, D. C. 2019. The application of 3D geological models: the BGS experience. In: Public seminar, Nanyang Technology University, Singapore, 15 January 2019

Forster, A. 2001. An engineering geologist's view of seismic hazard. Research Seminar at the Department of Geological Sciences, Plymouth University, October 2001.

Forster, A. 2001. A landslide defined is a hazard diminished. Seminar on spoil tip stability and landslides: a Local Authority's role. Organized by the National Assembly for Wales, March 2001

Forster, A. 2002. Geohazards, climate change and you. Annual Earth Alert Conference of the Geologists' Association, Scarborough, August 2002.

Forster, A. 2002. Geohazards, climate change and you. Annual Conference of the Earth Science Teachers Association, September 2002.

Forster, A. 2002. The BGS National Landslide Database: the UK perspective. Seminar on Landslides and Landslide Management, Institution of Highways and Transportation, Abergele, September 2002.

Forster, A. 2003. Implications of climate change for hazardous ground conditions in the UK. International Conference on 'Coping with climate change,' Geological Society, London, March 2003.

Fordyce, F. M., Brown, S. E., Ander, E. L., Breward, N. & Lister, T. R. 2003. The urban geochemistry of soils from selected cities in the UK. International Society of Environmental Geochemists Conference, September 2003, Edinburgh.

Gibson, A. D., Forster, A., Poulton, C.V.L., Rowlands, K.A., Jones, L. D., Hobbs, P.R., & Whitworth. M. C. Z. 2003. An integrated method for terrestrial laser-scanning subtle landslide features and their geomorphological setting. Presentation to - Scales and Dynamics in Remote Sensing – Annual Meeting of the Remote Sensing and Photogrammetry Society. Nottingham University, 10 September 2003.

Gibson, A. D., Forster, A., Poulton, C. V. L., Rowlands, K. A., Jones, L. D., Hobbs, P. R. N., Whitworth. M. C. Z. & Giles, D. 2003. Terrestrial LiDAR for landslide investigation. Presentation to – Annual General Meeting of the International Association of Mathematical Geologists, University of Portsmouth, 9 September 2003.

Gibson, A. D., & Hobbs, P. R. N. 2003. Surface Monitoring with Long-Range Terrestrial LiDAR. Presentation to the Annual General Meeting of the Engineering Group of the Geological Society. Burlington House, 29 May 2003.

Gibson, A. D. 2003. Safety and Sustainability in the Coastal Zone. Poster Presentation to SET for BRITAIN, Poster Presentation Reception at the House of Commons, London, 17 March 2003. House of Commons, 17 March 2003.

Gibson A. D. 2002. Landslide hazard assessment of Nefyn Bay, Submission to the Glossop Committee of the Engineering Group of the Geological Society. Burlington House, 30 July 2002.

Gibson, A. D., Foster, A., Culshaw, M. G., Cooper, A. H., Farrant, A., Jackson, N., & Willet, D. 2004. Rapid Geohazard assessment system for the UK Natural Gas Pipeline Network. Lyon conference 2005.

Gunn, D. A. 2000. Planning for secondary seismic hazards in urban development. Presentation to the European Geophysical Society, XXV General Assembly, April 2000, Nice, France.

Gunn, D. A. 2001. Predicting track bed stiffness from existing ground models. Presentation to Railway Engineering, Commonwealth Institute, London, April-May 2001.

Gunn, D. A. 2001. Gas-hydrate sediment properties in improved ground models for slope instability evaluations. Symposium C11, Clathrates, climate and carbon budget (3): Seafloor carbon fluxes and methane, European Union of Geosciences (EUG XI), April, 2001.

Gunn, D. A. 2002. Towards improved ground models for slope instability through better characterisation of gas-hydrate sediments. Second Workshop of the International Committee on Methane Hydrates Research and Development, Naval Research Laboratory, Washington D. C., USA, October 2002.

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Appendix 14 Technical Reports (1969 – 2000) (Chronologically listed)

EG/69/1	Regional geotechnical investigation of the Milton Keynes area:*(Vol. 1 - 22pp), (Vol.2), (Vol.3)*	Cratchley, C. R., Denness, B., Conway, B. W., Hallam, J. R. & McCann, D.
EG/69/2	A report on the geology of the proposed ‘D’ ring motorway between Waltham Cross and Theydon Bois, Essex.	McKeown, M. C.
EG/70/1	Cliff stability at Maryport, Cumberland *(2pp, 2 figs)*	Cratchley, C. R. & Denness, B.
EG/70/2	Preliminary notes on stability of Durlston Cliff, Swanage, Dorset *(2pp, 2 figs)*	Denness, B.
EG/70/3	Slope stability around Cayton Bay, Yorkshire (an application of the Reservoir Principle to a till) *(7pp 4 figs)*	Denness, B.
EG/70/4	A note on a landslip at Hampstead Cliff, Isle of Wight *(2pp)*	Denness, B.
EG/70/5	A note on the instability of the cliffs at Burton-on-Sea, Hampshire *(4pp)*	Denness, B.
EG/70/6	A note on coastal landslipping along the coast of Yorkshire from Filey to Saltburn *(4pp)*	Denness, B.
EG/70/7	Cliff instability at Bowleaze Cove, near Weymouth, Dorset *(7pp)*	Conway, B. W.
EG/70/8	A 48(M) Port Talbot By-Pass. Slip between Groeswen and Bombil *(2pp)*	Denness, B.
EG/70/9	A note on the application of micropalaeontology to landslide analysis at Blackgang, Isle of Wight *(4pp 3 figs)*	Denness, B. & Hart, M.
EG/70/10	Landslip at Sheinton, Shropshire *(44pp)*	Denness, B.
EG/70/11	Lancashire - Yorkshire Motorway M62 Longden End Windy Hill *(12pp, 2 figs, 4 maps)*	Denness, B.
EG/71/1	Slope Stability near N.E. abutment of the Loch Sloy dam *(5pp)*	Denness, B.
EG/71/2	Stability of the Redstone Park housing estate at Redhill, Surrey *(5pp, 2 figs)*	Grainger, P.
EG/71/3	Report on proposed investigation for the general stability of the western cut-off section. Craig Royston pumped storage system. *(7pp)*	Cratchley, C. R.

EG/71/4 Edinburgh sewage scheme - magnetic survey

Conway, B. W.

EG/71/5 Preliminary report on slip in cut BC (M62). Appendix to Geological report for chainage 860 - 995 *(2pp)*

Denness, B.

EG/71/6 The Dundry area near Bristol *(4pp)*

Denness, B.

EG/71/7 Mudflows at Minnis North, Co. Antrim *(7pp)*

Denness, B.

EG/71/8 Edinburgh Corporation Sewage Disposal Scheme. Site Investigations Section One (Bellevue Road to Seafield) *(78pp, logs, street maps)*

Grainger, P. & Cratchley, C. R.

EG/71/9 Portree-Staffin Road, Skye. An engineering geology assessment of two ancient landslip sites *(3pp)*

Denness, B.

EG/71/10 Landslip investigation. Higher Sea Lane, Charmouth, Dorset *(27pp. figs)*

Conway, B. W. & Denness, B.

EG/71/11 Investigations into data storage at the Engineering Geology Unit of the Institute of Geological Sciences *(126 pp, 21 figs)*

Horner, P. C.

EG/71/12 Edinburgh Airport new runway - Engineering Geology comments on geological and other factors likely to affect design

Cratchley, C. R.

EG/71/13 Geological structure of the Dorset Coast Foreshore from Pinhay Bay to West Bay, Bridport.

Conway, B. W.

EG/72/1 Report on a visit to Stonehouse New Town, Lanarkshire *(3pp)*

Culshaw, M. G.

EG/72/2 Comments on the proposed development, St Gildas Convent, Stile Lane, Lyme Regis *(2pp)*

Conway, B. W. & Denness, B.

EG/72/3 Preliminary report on a landslip survey on the North Side of the Ironbridge Gorge *(7pp)*

Culshaw, M. G.

EG/72/4 Edinburgh Corporation Sewage Disposal Scheme. Site Exploration: Contract 18, Effluent Outfall *(13pp, figs, tables, illustrations)*

Tulloch, W. & Culshaw, M. G.

EG/72/5 A preliminary report on the stability of Jockey Bank, Ironbridge.

Culshaw, M. G.

EG/72/6 Results of a borehole programme at Eastborough Farm, Cooling, Kent *(41pp, figs, tables)*

Conway, B. W.

EG/72/7	A geophysical and geological investigation at Barking, Creekmouth, Essex. Conway, B. W. & McCann, D. M.
EG/72/8	Geological structure of the Dorset Coast. Conway, B. W.
EG/72/9	The engineering geology of an area in South Essex *(7 maps, 26 pp incl. figs)* Grainger, P.
EG/72/10	A seismic survey at Grimes Graves, Norfolk *(3pp)* Grainger, P.
EG/72/11	Stability of slope at the top of the escarpment to the south of Bath *(2pp)* Denness, B.
EG/72/12	S.E. Essex project. Wallasea Island Grainger, P.
EG/72/13	Landslip prediction from analysis *(6pp)* Denness, B.
EG/72/14	Landslip prediction from observation *(5pp)* Denness, B.
EG/72/15	Engineering Geology in Chile (WN/0S/72/1) Cratchley, C. R.
EG/72/16	Engineering Geology in Chile (WN/0S/72/2) Denness, B.
EG/73/1	A stability assessment of the North slope of the Ironbridge Gorge, Telford, Shropshire *(32pp, 9pp tabs, 14pp figs)* Culshaw, M. G.
EG/73/2	Maplin/Foulness area - alluvial deposits Conway, B. W.
EG/73/3	Telford Landslip investigations. The Lees/Lee Dingle Area *(4pp, 1 fig)* Culshaw, M. G.
EG/73/4	Acoustic scanning at Whatley Quarry, Frome, Somerset McCann, D.
EG/73/5	A stability assessment of the slopes around Lee Dingle, Telford, Shropshire *(12pp, 6 tables/figs)* Culshaw, M. G.
EG/73/6	Pleistocene history of the Isle of Grain and the Lower Medway Valley Conway, B. W.
EG/73/7	Thames tidal defences, Section III, Fobbing Horse Island Conway, B. W.
EG/73/8	The Maplin Project - Surface access corridors on alluvial deposits *(3pp. 1 fig.)* Conway, B. W. & Henson, M. R.
EG/73/9	S. Essex – Brickearth Grainger, P.

EG/73/10 S. Essex - Pleistocene buried channel

Grainger, P.

EG/73/11 Study tour to Sweden to investigate underground oil storage - engineering geology aspects *(10 pp. figs)*

Worrell, D. M.

EG/73/12 The location and distribution of near-surface inhomogeneities in south east Essex

Carney, J. N. & Welland, M. J. P.

EG/73/13 Landslip studies in relation to roads and route planning

Denness, B.

EG/74/1 A geophysical and geological investigation to determine coal seam continuity at Waleswood, near Sheffield *(9pp, 6 figs)*

Culshaw, M. G.

EG/74/2 Portree - Staffin (A855): Section No. 2 *(4pp, 3 figs.)*

Denness, B.

EG/74/3 Preliminary report on site visit to proposed road widening scheme. A 472 Pontypool – Hafodyrynys (Crumlin Road) improvement *(2pp)*

Denness, B.

EG/74/4 Investigation of possible subsidence in chalk near Meopham, Kent *(8pp, tabs, append.)*

Godson, R.

EG/74/5 Supplement on the engineering geology of the oil terminal site at Flotta, Orkney Islands *(3pp)*

Culshaw, M. G.

EG/74/6 A95 road improvement. Report on rock conditions at Tom-an-Urie, Graigellachie *(3pp, fig, map)*

F May, F. & Worrell, D. M.

EG/74/7 Pontypool to Hafodyrynys (Crumlin Road) improvement *(8pp, 4 fig)*

Taylor, K. & Denness, B.

EG/74/8 Craig Royston Pumped Storage Scheme, Loch Lomond. Report on the results of seismic survey and borehole cores *(5pp)*

Cratchley, C. R.

EG/74/9 North of Scotland Hydro-electric Board - Craig Royston pumped storage scheme. Slope stability below the cut-off site *(4pp)*

Denness, B.

EG/74/10 Eastcliff landslip, Lyme Regis, Dorset *(18pp, maps/figs)*

BW Conway & M Conway, B. W. & Culshaw, M. G.

EG/74/10A Eastcliff landslip, Lyme Regis, Dorset: Supplement

Conway, B. W.

EG/74/11 A feasibility study of determining the joint separation and variation in Yoredale rocks at Rogerley Quarry, Weardale, County Durham *(9pp fig/site plan)*

Godson, R. A. & Culshaw, M. G.

EG/74/12 The use of stereoscopic aerial photographs in the detection and study of mass movement phenomena – with particular reference to ancient or small scale occurrences *(9pp, 8 plates)*

Carney, J. N.

EG/74/13 A photointerpretation of mass movement features along the Antrim coast of Northern Ireland *(77pp, 2 plates)*

Carney, J. N.

EG/74/14 The geomorphology of the Trotternish Peninsula north of Portree, Isle of Skye: A short report on aerial photograph interpretation British Landslips Project EG 418: Photointerpretation of Landslips North of Portree, Isle of Skye *(10pp, figs, photos, map)*

Carney, J. N.

EG/74/15 Ecuador – an assessment of the landslip hazard at the town of Guaranda (1974) Denness, B.

WN/0S/74/1a and WN/0S/74/1b

EG/75/1 Interborehole acoustic measurements on glacial deposits and Lower Palaeozoic rocks at Llyn Peris, North Wales *(30pp, plate, figs/dia)*

McCann, D. & Culshaw, M. G.

EG/75/2 The behaviour of the Hillwood Quarry Dolerite under compression (Brown Lenox and Company Quarry owners) *(3pp, graphs)*

Forster, A.

EG/75/3 The *in situ* detection of changes in rock strength by interborehole acoustic scanning *(4pp)*

Culshaw, M. G. & McCann, D. M.

EG/75/4 Report on landslipping in the Ben Madigan area of Cave Hill, near Belfast, Northern Ireland, with particular reference to a road improvement scheme *(5pp, fig)*

Culshaw, M. G.

EG/75/5 Report on a visit to the site of the new terminal building for Aberdeen Airport *(3pp)*

Culshaw, M. G.

EG/75/6 Quarry face stability at Amberley Chalk Pits, West Sussex (Sussex County Council) *(6pp, figs)*

Culshaw, M. G.

EG/75/7 A feasibility study to determine the variation in thickness of sand beds by geophysical methods at Wolvey, Warwickshire

Godson, R. A.

EG/75/8 Comments on "A study of the propagation of shear waves in Lower Pleistocene Deposits at Sizewell, Suffolk" *(6pp)*

McCann, D. M.

EG/75/9 Discussion of site investigation reports for the proposed development at Dyce Airport, Aberdeen *(7pp)*

Culshaw, M. G.

EG/75/10 The rock falls of James Valley, St Helena. A preliminary report giving a summary of recommendations (ODA) *(17pp, inc. figs)*

Culshaw, M. G.

EG/75/11 The alluvium of the Shell Haven, Canvey Island and Pitsea area of Essex

Conway, B. W.

EG/75/12 The alluvium of the Foulness area of Essex

Conway, B. W.

EG/75/13 Report on a borehole to borehole acoustic scanning survey at Sizewell, Suffolk *(9pp)*

Culshaw, M. G.

EG/75/14 Report on a reconnaissance survey to assess the causes and extent of rock falls in James Valley, St Helena and to recommend possible courses of remedial action. Part I and Part II (ODA) *(70pp inc. figs/tabs, 34pp of photos)*

Culshaw, M. G.

EG/75/15 Quarry face instability, Roundham Coach Works, Paignton, Devon *(12pp, photos/maps)*

Conway, B. W. & Culshaw, M. G.

EG/75/16 A preliminary assessment of stability conditions at the eastern end of the proposed by-pass at Otley, West Yorkshire (West Yorkshire Metropolitan Council) *(25pp)*

Culshaw, M. G. & Duncan, S. V.

EG/75/17 Firth of Forth survey - short report

Baria, R.

EG/75/18 A brief resume of engineering geological mapping in Great Britain and some problems encountered in obtaining a regional cover to geotechnical properties

Northmore, K. J.

EG/75/19 Report on trips to Warrington during 1975 to record tunnelling machine noise by means of surface geophones (DOE) *(8pp)*

Culshaw, M. G.

EG/75/20 South Essex Geological and Geotechnical Survey (Report prepared for the Department of the Environment). Parts 1 - 12 *(1880pp, maps folio, append.)*

Cratchley, C. R., Lake, R. D., Northmore, K. J., Denness, B., Loudon, T. V., Sarginson, M., McCann, D. M., Darwell, J., Hughes, M. & Merriman, R. J.

EG/75/21 South Essex – Brickearth

Grainger, P.

EG/76/1 Report on a trip to Warrington to record tunnelling machine noise by means of surface geophones (DOE) *(6pp)*

Culshaw, M. G.

EG/76/1A Report on a trip to Warrington to record tunnelling machine noise by means of surface geophones – First Supplement (DOE) *(3pp)*

Culshaw, M. G.

EG/76/2 Report on resistivity of 3 rock samples from Llanberis (DES) *(8pp)*

C Barnett, C. & Forster, A.

EG/76/3 An assessment of the effects of resin impregnation on the physical properties of some common building stones (V & A Museum) *(12pp)*

Forster, A. & McCann, D. M.

EG/76/4 Tunnel to surface acoustic fieldwork at Warrington 8th and 9th June 1976 (DOE) *(10pp)*

Duncan, S. V.

EG/76/5 Particle size analysis for samples from Isle of Grain for CEGB *(10pp)*

Hobbs, P.

EG/76/6 Particle size analysis for samples from Isle of Grain for CEGB

Hobbs, P.

EG/76/7 Report on a resistivity survey at Cooling Marshes, Kent *(8pp, 17 figs, 16 tables)*

Culshaw, M. G.

EG/76/7A Supplement on a resistivity survey at Cooling Marshes, Kent (DES) *(4pp, 2 figs, 1 table)*

Green, A. S. P.

EG/76/8 Preliminary report of geophysical measurements made in and around a pockmark - Survey RRS Challenger 17-27 September 1976 (DEn) *(16pp, photo, 10pp figs)*

Jackson, P. & Baria, R.

EG/76/9 Eastcliff landslip, Lyme Regis, Dorset, (Dorset County Council) *(11pp, prints)*

Conway, B. W.

EG/76/10 Coastal Terrain Evaluation of the Charmouth Lyme Regis area of Dorset (DOE)

Conway, B. W.

EG/76/11 Operational report on the Wimpey Sealab, Cruise, Forties Area (DEn) *(28pp)*

Hallam, J. R.

EG/76/12 Geotechnical aspects of the IGS Pockmarks studies Lyme Regis area 1974-1976 (DEn) *(30pp, 31pp figs, table)*

Lambert, J. T. & Hallam, J. R.

EG/76/13 The nature of fissures found in North Sea sediments from Borehole SLN 33 *(18pp)*

Lambert, J. T.

EG/76/14 Detection of cavities by seismic technique -

WN/76/96A Report on data collected at Cocking 10 May 1976 (DEn) *(31pp)*

Baria, R.

EG/76/15 An investigation into the geological feasibility of storing crude oil in unlined caverns in the Hunterston Peninsula, Ayrshire. Parts 1, 2 & 3 *(56pp/123pp)*

Cratchley, C., Tate, M., Price, M., Robertson, A. S., Darton, D. M., Bird, M. J. & Gale, I. N.

EG/76/16 Half-yearly report on the engineering geology of hard and soft rocks in the UK April-September 96 - PA13B

Cratchley, C. R.

EG/77/1 Report on a resistivity and geotechnical survey of a mudflow at Black Ven, Charmouth, during July/August 1976 (DEn) *(47pp)*

Green, A. S. P.

EG/77/2 Representative sampling for seabed foundation design (DEn) *(14pp, 4 figs, 3 tables)*

Denness, B., McCann, D. M. & Lambert, J. T.

EG/77/3 Coastal Industrial Development - areas for immediate investigation

Conway, B. W. & Gostelow, T. P.

EG/77/4 Report of a resistivity survey in Blaina, Gwent South Wales (DES)

Green, A. S. P.

EG/77/5 Evaluation of 'shrimp' system for site investigation (DES) *(10pp)*

Baria, R.

EG/77/6 A study of tunnelling machine noise at Warrington Interim Report PA 13B - April 1976 - March 1977 (DOE) *(18pp)*

Baria, R. & McCann, D. M.

EG/77/7 A preliminary report describing the engineering geology of the Bothkennar area (DOE) *(27pp)*

Hallam, J. R., Lambert, J. T. & Gostelow, T. P.

EG/77/8 Interborehole acoustic measurements at Norman Close, Maidstone, Kent (E G Weekes and Partners) *(7pp, 8 figs, 28 pp b/h logs)*

Green, A., Baria, R. & McCann, D. M.

EG/77/9 Report on the engineering geology of the Bothkennar area (DOE) *(52pp, 25 figs)*

Hallam, J. R., Lambert, J. T. & Gostelow, T. P.

EG/77/10 A regional study of coastal landslips in West Dorset (DOE) *(52pp, 25 figs)*

Conway, B. W.

EG/77/11 A report on valley instability at Blaina, South Wales (DOE) *(83pp, 32 figs)* Gostelow, T. P.

EG/77/12 Report on the M. S. Ferder Drilling Cruise (DEn) *(10pp, 24pp figs/tab)*

Lambert, J. T. & Long, D.

EG/77/13 Eastcliff landslip, Lyme Regis, Dorset (Dorset CC) *(15pp)*

Conway, B. W.

EG/77/14 Resistivity survey of proposed IGS site at Keyworth, Nottingham (DES) *(pp5, 1 map, 3 figs)*

Conway, B. W.

EG/77/15 Landslip and proposed by-pass at Holywell, Clwyd, North Wales (Welsh Office) *(3pp, 2 figs)*

Conway, B. W.

EG/77/16 Acoustic experiments in the Holman's experimental mine near Troon, Cornwall *(9pp)*

McCann, D. M. & Green, A. S. P.

EG/77/17 Magnetic susceptibility and resistivity determinations on three samples supplied by Charter Consolidated Limited (Charter Cons) *(4pp)*

Forster, A.

EG/77/18 A study of borehole geophysical technique for the detection of cavities in a rock mass. Interim Report PA 13B April 1976 - March 1977 (DOE) *(35pp)*

Baria, R. & McCann, D. M.

EG/77/19 Half yearly report on the Engineering Geology of hard and soft rocks in the UK. Contract No DGR 482/45.

Cratchley, C. R.

EG/77/20RAdvisory visit to Korea

Gostelow, T. P.

EG/77/21-24 No record

EG/77/25 Report on a visit to Korea, Burma, Thailand, Sri Lanka and Indonesia.

WC/OR/79/10

Hepworth, J. V. & Cratchley, C. R.

EG/78/1 Resistivity determinations on six samples of rock supplied by Charter Consolidated Limited (ChCsLtd) *(3pp)*

Forster, A.

EG/78/2 Acoustic studies in the Carnmenellis granite at the Holman Experimental Mine near Troon, Cornwall (Harwell) *(22pp)*

Baria, R., Green, A., McCann, D, & Suddaby, D.

EG/78/3 Coastal Industrial Development - areas for long term development (Confidential)

Conway, B. W. & Gostelow, T. P.

EG/78/4 Geotechnical aspects of the 1977 M.V. Emerald Cruises - Field Report (DEn) *(31pp tables/figs)*

Long, D. & Hobbs, P.

EG/78/5 An assessment of geophysical techniques for cavity detection at shallow depth: electrical measurements on the proposed route of the M4 near Bridgend, South Wales (DOE)

Jackson, P. D., Suddaby, D. L. & Baria, R.

EG/78/6 A study of tunnelling machine noise at Warrington for probing ahead of the tunnel (DOE) *(42pp, figs/tables)*

Baria, R., Green, A. S. P., McCann, D. & Suddaby, D. L.

EG/78/7 Engineering geology and foundation conditions of the Bothkennar area: Part 1, vol 1 only (not vol 2) (DOE) *(37pp, 14 figs, 28 plates)*

Lambert, J. T. & Gostelow, T. P.

EG/78/8 Assessment of rock mass conditions using geophysical techniques (DOE) *(27pp, 22 figs)*

Baria, R., McCann, D. M. & Hallam, J. R.

EG/78/9 Laboratory testing of selected samples from the Emerald Cruises 1977 (DEn) *(112pp)*

Long, D.

EG/78/10 Emerald Cruise August 1977 (DEn) Geological and geotechnical examination of vibracore samples (August 1978)

Sample Descriptions (August 1977)

Sample Descriptions (February 1978) Appendix I *(73pp)*

Sample Descriptions (April 1978) Appendix II *(130pp)*

Sample Descriptions (February 1978) Appendix III *(98pp)*

Conway, B. W.

EG/78/11 Geotechnical testing of North Sea sediments from the "Wimpey Sealab" boreholes SLN33 and SLN34 (1975) (DEn) *(127pp, figs & tables)*

Hobbs, P. R. N.

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McCann, D. M. & Conway, B. W.

EG/78/13 Laboratory testing of selected samples from the Emerald Cruises 1977 - II (DEn) *(2pp, 4 figs, 20 tables)*

Long, D. & Hobbs, P. R. N.

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Long, D. & Forster, A.

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Hobbs, P. & Long, D.

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Gostelow, T. P. & Lambert, J. T.

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Northmore, K. J., Duncan, S. V. & Gostelow, T. P.

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Gostelow, T. P.

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EG/78/28	Report on an advisory visit to the Department of Irrigation, Sri Lanka Culshaw, M. G.
EG/78/29	Report on current and proposed Indo-British Technical Cooperation in rock mechanics Cratchley, C. R.
EG/78/30	Advisory visit to South East Asia Hepworth, D. V.
EG/78/31	Geotechnical assessment of rock masses Gostelow, T. P.
EG/78/32	Indo/UK rock mechanics project: geophysical investigations: lecture course and field demonstrations Cratchley, C. R.
EG/78/??	Stability assessment of proposed industrial site, Straton, Midlothian. Gostelow, T. P.
EG/79/1	Landslip survey of the south Wales coalfield valleys. Distribution, classification and catalogue of landslips in the Rhondda and North East survey area (DOE) Northmore, K. J.
EG/79/2	Geotechnical subdivision of the Witch Ground Beds in the Northwest Forties *(22pp)* Long, D.
EG/79/3	Resistivity investigation of the Bothkennar area *(25pp, 19 figs, 3 tabs)* Suddaby, D. L.
EG/79/4	Geotechnical properties of sediments from the borehole 77/75 (North Sea) *(75pp tables/figs/maps)* Long, D. & Hobbs, P.
EG/79/5	Acoustic studies in the Carmenellis granite at Rosemanowes Quarry, Cornwall *(5pp, 5 figs)* McCann, D. & Baria, R.
EG/79/6	Introduction to using the system 45 mini-computer for interactive interpretation on-site *(5pp)* Jackson, P.
EG/79/7	Report on QRA field study meeting held in East-Central Ireland, 7-10 April 1979 (DES) *(18pp)* Jackson, P.
EG/79/8	Geotechnical results from BH 78/9 *(14pp, 51 maps/figs)* Long, D.
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EG/79/10	Eastcliff Landslip, Lyme Regis, Dorset. Summary 1978 (DES) *(8pp, 25 plates, 12 maps)* Conway, B. W.

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Jackson, P.

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Baria, R. & McCann, D. M.

EG/79/21 Measurement of the characteristics of the wide band borehole source (sparker) off Anglesey, using HP45 mini-computer and the transient recorder.

Baria, R.

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Cratchley, C. R.

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Gostelow, T. P.

EG/79/23 Report on a visit to Bangladesh 27 March - 4 April 1979

Hepworth, J. V.

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Horseman, S. T.

EG/80/3 A proposal for the development of a rock mechanics testing facility for research into the geological disposal of high level nuclear waste

McEwan, T. J. & Horseman, S. T.

EG/80/4 South Wales coalfield landslip survey (DOE) Volume 1 - Test (separate Red Box File) *(218pp, 48 figs, 7 tables, 38 plates).* Volume 2 - Catalogue (separate Red Box File) *(131pp, 31 plates, 20 maps)*

Conway, B. W., Forster, A., Northmore, K. J. Barclay, W. J. & Duncan, S. V.

EG/80/S4 Geotechnical aspects of the 1980 Whitethorn seabed sampling cruises

WN/EG/80/54 Long, D. & Moore, I. C.

EG/80/5 The use of aerial photography in the South Wales Coalfield landslip survey (DOE)

Forster, A.

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WN/SC/005 region, Scotland

Smellie, J. L.

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Gostelow, T. P. & Tindale, K.

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EG/80/17 Jamaica Soils Laboratory – 1st March – 17 April 1980

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EG/80/21 Cyprus Soils Laboratory, 25 October - 26 November 1980

Hobbs, P. R. N.

EG/80/22 Report on a visit to the Asian Development bank in Manila, together with visits to the Geological Surveys of Sri Lanka, Bangladesh, The Philippines and to the South East Asia Development Division in Bangkok, Vol. 1, 2 and 3

Habgood, F.

EG/80/23 Report on advisory visits to Thailand, Papua, New Guinea and Indonesia

WC/0R/80/009 and attendance at XV11 Session of CCOP held in Bangkok

Jones, C. R.

EG/80/24 Stability of rock cutting adjacent to the A82 at Stuckgowan

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Jackson, P., Schultheiss, P., Strachan, P. & Baria, R.

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EG/81/6 Recent instability at Senghenydd Village, South Wales (DOE or DOS) Northmore, K. J.

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Rous, P.

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Dessaji, T.

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Culshaw, M. G. & Hallam, J. R.

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Dessaji, T., Sajadi, D. & Jackson, P.

EG/82/2 Interim progress report. Pilot study of the preparation of a landslip hazard map (DES)

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EG/82/3(a) Wide angle seismic reflection profiling on inland waterways

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Sajadi, B.

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Hobbs, P. Avery, L. & Yeow, H. Y.

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P D Jackson, M G Culshaw, D McCann, D., Baria, R., Jackson, P. D., Culshaw, M. G., Green, A. S. P., Suddaby, D. L. & Hallam, J. R.

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Forster, A.

EG/82/7 Report on a field visit to Volos, Greece. July/August 1982 *(23pp)*

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Jackson, P.

EG/82/9 Cromarty Firth Geotechnical Survey *(6 maps, section sheets)*

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EG/82/10 Geotechnical map of Nicosia *(Text and map [1:25 000])*

Hobbs, P. R. N.

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Lim, S. H.

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Garner, M.

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EG/RR/84/1 Shantallow Drainage Scheme, Londonderry, N.I. Shantallow tunnel feasibility study

Northmore, K. J., Culshaw, M. G. & Johnson, T. P.

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Chabela, P. & Culshaw, M.G.

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Culshaw, M. G.

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Entwisle, D. C.

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For: McCutcheon and Wilkinson, Consulting Engineers, and Department of Agriculture, Drainage Division, N.I. (In Confidence)

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CS21/RMI/84/8 Rock mechanics tests on core from borehole SA63S

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WN/RM/84/6	mine, Dudley (blue box file)
	Hallam, J. R. & Mitchell, D. G.
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WN/RM/84/007	MN25 and MN26, Kuwait (Oil Plus Limited)
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CS21/RM8/84/14	Rock mechanics tests on core from borehole MN26 (Minagish
WN/RM/84/008	Field) - Results and interpretation (to Oil Plus Ltd) (C) *(55pp)*
	Winter, M. G. & Horseman, S. T.
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	Horseman, S. T., McCann, D. M., Entwisle, D. C., Jackson, P. D. & Winter, M. G.
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	Cooper, A. H.
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	Entwisle, D. C.
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	Wilson, K. S.

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	Winter, M. G.
EGARP/KW/85/7	Triaxial Test Results for Boom Clay test CIU/54/2 on Block Sample No. 54 *(39pp, 12pp tables)*
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EGARP/KW/85/8	One-dimensional Consolidation Tests for Boom
	Clay test ODC/53/2 on Block Sample No. 53
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	Entwisle, D. & Horseman, S. T.
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EGARP/KW/85/10	Triaxial test results for Boom Clay test CIU/54/3 on Block Sample No. 54 *(49pp)*
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EGARP/KW/85/13	A description of the engineering geological mapping of the sediments of the Volos basin, Greece (including two maps at 1:20,000 scale)
	Culshaw, M. G.
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EGARP/KW/85/16	One-dimensional consolidation test results for Boom Clay Test ODC/53/3 on Block Sample No. 53 Horseman, S. T. & Entwisle, D. C.
EGARP/KW/85/17	One-dimensional consolidation (lateral) test results for results for Boom Clay test ODC/53/4 on Block Sample No. 53 *(35pp)* Horseman, S. T. & Entwisle, D. C.
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EGARP/85/18	NO RECORD
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WN/85/21/R	Calibration of the 35 MPa Triaxial apparatus *(63pp)* Winter, M. G., Hassett, S. P. & Horseman, S. T.
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[Other 1985	Geotechnical testing on soil from the Bridgend area for the Bridgend Environmental Geology Map *(21pp, 1 map, sheet 262)* Entwisle, D. C. NOT NUMBERED]
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EGARP/KW/86/6	Engineering geology of cohesive soils associated with ophiolites projects (ODA) (CIC) Northmore, K. J.
EGARP/KW/86/7	Point load strength index tests on limestone from Northamptonshire (CIC) Culshaw, M. G. & Hassett, S. P.
EGARP/KW/86/8	Groundwater conditions in the vicinity of the M1/M25 interchange, Hertfordshire (CIC) Price, M., Monkhouse, R. & Barker, J.
EGARP/KW/86/9	A Monte Carlo study of pollution migration to a well in the Chalk *(28pp incl. 10 figs and 2 tables)* Barker, J.
EGARP/KW/86/10	One-dimensional consolidation test results for Mercia Mudstone from the Market Weighton borehole Entwisle, D. C.
EGARP/KW/86/11	Point load strength index tests on some granite samples (CIC) Hassett, S. P.
EGARP/WL/86/12	Some aspects of geothermal energy in New Zealand Allen, D. J.
EGARP/KW/86/13	Atterberg Limits and Particle Size Analysis of two gravity cores from the Irish Sea - One 'on-gas', one 'not on-gas' *(35pp)* Entwisle, D. C.
EGARP/WL/86/13	Title not recorded Wilson, K.
EGARP/WL/86/14	Title not recorded Wilson, K.
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EGARP/WL/86/16	Title not recorded Wilson, K.

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EGARP/WL/86/17	Title not recorded Wilson, K.
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EGARP/WL/86/19	North Sea Report Short, N. E. & Bird, M. J.
EGARP/WL/86/20	North Sea Report Short, N. E. & Bird, M. J.
EGARP/AP/LAB/87/1	Core analysis results from BH GSS10/C5, Serowe Botswana *(7pp, 3 figs (large)* Bird, M. J.
EGARP/WL/87/1	The 36th report on the properties of North Sea hydrocarbon reservoir rocks *(6pp)* Bird, M. J.
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EGARP/AP/LAB/87/3	Core analysis results from borehole SC01 Sawston, Cambridgeshire Bird, M. J.
EGARP/WL/87/4	Core analysis techniques for the Department of Energy by BGS Engineering Geology Reservoir Properties Group Butcher, A. S., Bird, M. J. & Short, N. E.
EGARP/WL/87/5	Hydrogeological investigations using piezometers at Chimimbe and Chikobwe Dambo sites, Malawi in August - September 1986 *(40pp)* Allen, D.
EGARP/WL/87/6	39th report on the properties of North Sea hydrocarbon reservoir rocks Butcher, A. S.
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EGARP/KW/87/8/C	Lithological and fracture logs of four boreholes in Weald Clay at Warnham, Sussex for Messrs Cleanaway Limited (Confidential) *(21pp)* Lake, R. D. & Northmore, K. J.
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WN/87/10	Engineering Geology of Tropical Red Clay Soils Project: Report on visits to Kenya and Indonesia, September – November 1986 *(9pp)* Culshaw, M. G.
WN/RR/87/11	Engineering Geology of Tropical Red Clay Soils Project: Report on the proposed programme for sampling and testing in Kenya Northmore, K. J.
EGARP/KW/87/11	Geotechnical stress history testing of Till from Hull Hobbs, P. R. N.
WN/87/12	Geotechnical stress history of Devensian Clay from Hull Hobbs, P. R. N.
WN/88/1	Engineering Geology of Tropical Red Clay Soils Project: Report of Visit to Kenya, 17 July to 25 August 1987 *(21pp, 1 map)* Northmore, K. J.
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WN/88/3	NO RECORD
WN/88/4	A tracer test in the Chalk aquifer near Bricket Wood, Hertfordshire, in connection with the drainage of the M25 Motorway *(29pp)* Atkinson, T. C. & Price, M. Appendix by Barker, J. A.
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WN/94/28 Use of electrical resistivity techniques for detection of gas flow in sand

Meldrum, P. I. & Jackson, P. D.

WN/94/29 A geophysical survey over toxic waste pits at the Horticultural Research Institute, Littlehampton, Sussex

Raines, M. G.

WN/94/30 Field and laboratory resistivity measurements in compacted tropical clay road embankment

Gunn, D. A., Northmore, K. J., Jackson, P. D., Meldrum, P. I. & Jones, L. D.

WN/94/31	The Engineering Geology of British Rocks and Soils. The Gault Clay in England Forster, A., Hobbs, P. R. N., Cripps, A. C., Entwisle, D. C., Fenwick, S. M., Raines, M. G., Hallam, J. R., Jones, L. D., Self, S. J. & Meakin, J. L.
WN/94/32	Development of electrical tomographic imaging and inversion techniques for mineral exploration Ogilvy, R. D., Straub, A. & Sideris, G.
WN/94/33	Use of transient electromagnetics for mapping contaminated groundwater and hydro-stratigraphy, Leon Valley, Mexico Ogilvy, R. D.
WN/94/34	Reconnaissance survey of a landslip at Gringley-on-the-Hill, Nottinghamshire Hobbs, P. R. N. & Culshaw, M. G.
WN/94/35	Geophysical surveys for disused mine shafts at 40 Private Drive, Hollingwood Estate Busby, J. P.
WN/94/36	Geophysical surveys for disused mine shafts at 84 Sycamore Road, Hollingwood Estate Busby, J. P.
WN/94/37	A ground probing radar feasibility survey to determine depth to bedrock adjacent to BT overhead cable poles Busby, J. P. & Greenwood, P. G.
WN/94/38	Pipeline surveys at St Fergus and Cruden Bay and at Peasington for Subsea Offshore Ltd Rippin, G. E. & Cripps, A. C.
WN/94/39	The engineering geology of the Coventry area Fenwick, S. M. M.
WN/94/40	Seismic properties of sea floor sediments and rocks Gunn, D. A., McCann, D., McCann, C. & Sothcott, J.
WN/94/41	Contaminant migration beneath landfill and colliery waste at Bowman's Harbour, Wolverhampton Fenwick, S. M. M.
WN/94/42	Otterton boreholes. Saline intrusion and TEM geophysical survey Beamish, D. & Raines, M.
WN/94/43	Effective strength testing and slope stability of a landslip at Gringley-on the Hill, Notts Hobbs, P. R. N., Jones, L. & Culshaw, M. G.
WN/94/44	Development of electrical tomographic imaging and inversion techniques for mineral exploration - Contract No: BRE2-CT92-0275 Ogilvy, R. D., Straub, A. & Sideris, G.
WN/94/45	Report on a visit to El Salvador - March 1994 SEE PROJECT NOTE 95/45 Gunn, D. A.
WN/94/46	Report on a visit to Costa Rica - October 1994 Gunn, D.

WN/94/47	Report on a visit to El Salvador - October 1994 SEE PROJECT NOTE 94/45 Gunn, D.
WN/94/48	Geophysical characterisation of the onshore Quaternary deposits around Sellafield (1995) Busby, J. P., Peart, R., Cripps, A., Hobbs, P., Rippin, G. & Shedlock, S.
WN/94/49	The laboratory measurement of hydraulic conductivity of Glacial Till from Norfolk and Essex. Entwisle, D. C.
WN/95/1	Trial geophysical and soil gas surveys to assist in the location of faults within the PRZ and for the characterisation of the Quaternary around Sellafield. Version 1 J Busby, J., Beamish, D., Roberts, P. D., Peart, R., Raines, M., Rippin, G. & Flint, R.
WN/95/2	Geotechnical survey of a sandstone outcrop for a retaining wall at Castle Street, Sneinton, Nottingham Hobbs, P. R. N. & Rippin, G. E.
WN/95/3	A geological background for planning and development in Wigan (Replaces WN/94/11 the 1st draft) Vo1. 1 and Vol. 2 Vol. 1 – A geological foundation for planning Vol. 2 – A user's guide to Wigan's ground conditions Forster, A., Culshaw, M. G., Arrick, A. & Johnston, M.
WN/95/4	Further processing of CSAMT survey data and results Beamish, D.
WN/95/5	Characterisation of soils and site screening by non-invasive resistivity surveys: Sellafield, Cumbria Ogilvy, R. D., Raines, M. G, Meldrum, P. I. & Jackson, P. D.
WN/95/6	Quaternary Mapping Methods Project: Ground probing radar survey in Scotland and East Anglia. Part 1. Greenwood, P. G., Raines, M. G. & Auton, C. A. Ground probing radar report. Part II is report no. WN/94/12 'GPR Sections'
WN/95/7	Methods for recognition of geological weakness zones and other surface discontinuities caused by underground mining in Carboniferous terrain Greenwood, P. G., Peart, R. J. & Meldrum, P. I.
WN/95/8	Trial geophysical surveys on the flood plain of the River Tame near Alrewas, on behalf of Tempus Reparatum, March 1995 R J Peart, R. J. & Flint, R.
WN/95/9	A review of the use of cross-hole seismic tomography for rock mass assessment Jackson, P. D. & McCann, D. M.
WN/95/10	Pre-survey modelling for deep salinity mapping EM surveys. A scoping study of deep EM methods to map the salinity distribution in the Sellafield area Beamish, D.
WN/95/11	Hydrogeological classification of superficial clays: apparent resistivity measurements from the Garboldisham, Norfolk pilot study area Busby, J. P., Beamish, D., Peart, R. J. & Meldrum, P. I.

WN/95/12	Geophysical investigations for cavities at the site of the former Victoria Railway Station, Nottingham Busby, J. P., Greenwood, P. G., Jackson, P. D., Raines, M. G. & Jones, L. D.
WN/95/13	Seismic Properties of Sea Floor Sediments and Rocks Vol 2. - 1st May 1995 McCann, D., Gunn, D., McCann, C., Sothcott, J. & Assefa, S. B. (University of Reading)
WN/95/14	A detailed geophysical survey to characterise the sand and gravel deposits at Whitemoor Haye, Alrewas, Staffordshire. Report prepared for Tempus Reporatum Part I and Part II Raines, M. G., Peart, R., Flint, R. & Rippin, G. E.
WN/95/15	Methods of testing for swelling and shrinking of soils Hobbs, P. R. N. & Jones, L. D.
WN/95/16	Some geological aspects of clay swelling and shrinking Gostelow, T. P.
WN/95/17	New laboratory equipment for electrical resistivity/induced polarisation measurements on rocks and sediments Meldrum, P. I.
WN/95/18	Recent uses of MT and MT-profiling in hydrocarbon exploration Beamish, D.
WN/95/19	Position statement PS-D1.55 - Radar Surveys Busby, P. J.
WN/95/20	A magnetic survey to detect dolerite intrusions on the proposed M80 route, Easter Bedcow, Glasgow, Scotland Ogilvy, R. D & Shedlock, S. L.
WN/95/21	Development of electrical tomographic imaging and inversion techniques for mineral exploration Contract No: BRE2-CT92-0275 Periodic Report, November 1994 - April 1995 Ogilvy, R. D., Straub, A., Jackson, P. D. & Sideris, G.
WN/95/22	Methods for the recognition of geological weakness zones and other surface discontinuities caused by underground mining in Carboniferous terrain. Periodic report January - June 1995 Peart, R. J., Flint, R., Greenwood, P. G. & Jackson, P. D.
WN/95/23	Engineering geology of the Minehead area. 1:50 000 Geological Sheet 278. June 1995 Forster, A.
WN/95/24	Marine gas and fluid seepage. Implications for slope instability Gostelow, T. P.
WN/95/25	Magnetotelluric profiling for hydrocarbon exploration: final report Beamish, D.
WN/95/26	Imaging beneath the Antrim basalts and simulation study Beamish, D.

WN/95/27	Processing and interpretation of 3D Rescan. Resistivity data sets, Sellafield, Cumbria - June 1995 Ogilvy, R. D., Jackson, P. D. & Flint, R.
WN/95/28	Calibration and interpretation of ground penetrating radar from around Sellafield Busby, J. P. Eaton, G. P.
WN/95/29	A CCTV inspection of well TA-6 in the Dead Sea area of Southern Jordan - 2 October 1995 Shedlock, S. L.
WN/95/30	3D Rescan resistivity mapping of Quaternary geology, Sellafield, Cumbria, (Issue 1.0) Ogilvy, R. D., Jackson, P. D. Flint, R. C. & Meldrum, P. I.
WN/95/31	Seismic Properties of Sea Floor Sediments and Rocks Vol 3. - 30 Sept 1995 Gunn, D., McCann, D., McCann, C., Sothcott, J. & Assefa, S. B. (University of Reading)
WN/95/32	3D EM Modelling: transmitter coupling effects in CSAMT Beamish, D.
WN/95/33	A real mapping of seasonal changes of water content within surface sediments by electrical resistivity, Sellafield, Cumbria. - 9th Nov Jackson, P. D., Ogilvy, R. D., Flint, R. C. & Meldrum, P. I.
WN/95/34	Thrust mapping with Ground Penetrating Radar in the Thrust Terrain around Sellafield, Cumbria Version 1.0 Busby, J. P. & Raines, M. G.
WN/95/35	Procedures listing for use of Rescan equipment Meldrum, P. I.
WN/95/36	(WC/96/15) Trial surveys with the electro-survey technique in the Red River Basin of Vietnam Peart, R. J. & Davis, J.
WN/95/37	Methods for the recognition of geological weakness zones and other surface discontinuities caused by underground mining in Carboniferous terrain. EC contract 7220-AF136 - Final report: part 1 text – part 2 - figures Greenwood, P. G., Raines, M., Peart, R. J., Williams, C., Jackson, P. D., Meldrum, P. I., Flint, R. & Beamish, D.
WN/95/38	CCTV inspection of Borehole No 1 at Grants Distillery, Girvan - 9th Nov 1995 Shedlock, S.
WN/95/39	Interpretation of Sellafield geotechnical laboratory test data Hobbs, P. R. N., Entwisle, D. C., Jones, L. D., Gunn, D., Cave, M., Horseman, S. & Bloomfield, J.
WN/95/40	Geophysics in the urban environment. Investigation of the Wheal Crelake mine workings beneath Drake Gardens, Tavistock, Devon. Report prepared for the West Devon Council Raines, M. G., Beamish, D. & Smith, K.
WN/95/41	3D Rescan resistivity mapping of Quaternary Geology, Sellafield, Cumbria (Issue 2.0) Ogilvy, R. D., Jackson, P. D., Flint, R. C. & Meldrum, P. I.

WN/95/42	The Engineering Geology of the Cirencester area 1:50.000 geological map sheet 235 - December 1995 Forster, A.
WN/96/1	Development of electrical to magnetic imaging and inversion for mineral exploration techniques: Final Technical Report Ogilvy, P. D., Jackson, P. D., Meldrum, P. I., Hallam, J. R. & Flint, R.
WN/96/2	Fault reactivation and mining subsidence ground deformation investigations in the Leicestershire coalfield on behalf of G A B Robins; Loss Adjusters and Sun Alliance insurance. Donnelly, L. J.
WN/96/3	The laboratory measurement of hydraulic conductivity of Clay-with-Flints from Rothampstead and Soberton, Hampshire Entwisle, D. C.
WN/96/4	The laboratory measurement of hydraulic conductivity of Glacial Till and Lacustrines from Forton Heath and Mulleton Moss, Shropshire Entwisle, D. C.
WN/96/5	Resistivity imaging of dissolution cavities and subsidence features at proposed Morrisons Supermarket Site, Ripon, Yorkshire. Site investigation geophysical survey, Ripon, Yorkshire Meldrum, P. I., Ogilvy, R. D. & Shedlock, S. L.
WN/96/6	Electrokinetic soundings in the vicinity of Sellafield, West Cumbria Beamish, D. & Peart, R. J.
WN/96/7	CCTV inspection of boreholes at Munnington and Golden Square near Sproxton, North Yorkshire. L A Williams Cripps, A. C., Williams, L. A. & Ward, R. S.
WN/96/8	An electromagnetic survey to investigate the recent slumping at the Devizes Football Club, Wiltshire. Raines, M. G.
WN/96/9	Development of electrical tomographic imaging techniques for mineral exploration: Synthesis report – Prepared for Commission of the European Union Ogilvy, R. D., Straub, A. & Sidens, G.
WN/96/10	Development of electrical tomographic imaging techniques: Synthesis Report. Prepared for Commission of the European Union R D Ogilvy, R. D., Straub, A. & Sidens, G.
WN/96/11	Electrokinetic soundings and estimation of hydraulic conductivities at the Hall Farm hydrogeological test site Gardolisham, Norfolk Beamish, D., Peart, R. J. & Wealthall, G.
WN/96/12	Development of electrical tomographic imaging and inversion techniques: Summary Report Ogilvy, R. D., Jackson, P. D. & Straub, A.
WN/96/13	Seismic properties of sea floor sediments and rocks: Vol. 1 and Vol. 2 Gunn, D., McCann, D., McCann, C., Sothcott, J. & Asseia, S. B.
WN/96/14	Failure of the Global Positioning System (GPS) during the monitoring of the Soufriere Hills volcano, Montserrat, West Indies Donnelly, L. J.

WN/96/15	CCTV Inspection of boreholes at Whitbread Beer Company, Samlesbury, Lancashire Shedlock, S. L.
WN/96/16	Detailed gravity traverse across the Ehen buried valley and geological progress for the siting of Quaternary borehole QBH22. March 96. G S Kimbell, Busby, J. P., Kimbell, G. S, Merritt, J. & Raines, M. G.
WN/96/17	A CCTV inspection of No 2 Stores borehole at the Bass Brewery. Burton on Trent Shedlock, S.
WN/96/18	Engineering geology of the Torpoid and Saltash Formation, Plymouth Greenwood, P.
WN/96/19	Non-contact resistivity imaging method for characterising whole round core while in its liner Jackson, P. D. *et. al*
WN/96/20	Development of non-destructive continuous high resolution logging of core using non-contacting azimuthal resistivity measurements – an aid to enhancing of reservoir yield through improved characterisation of core Jackson, P. & Beamish, D.
WN/96/21	Evaluation of the alteration of Borrowdale Volcanics from magnetic susceptibility data Raines, M. G.
WN/96/22	A CCTV inspection of 2 boreholes at Fabro-Nairn, Kirkcaldy Cripps, A. C.
WN/96/23	A borehole CCTV inspection for United Distillers, at Rosmere Maltings, Elgin Cripps, A. C.
WN/96/24	Assessment of the diggability of sandstone rock strata at Blindwells East Northmore, K. J.
WN/96/25	Non-contact temperature measurements of the Soufriere Hills volcanic dome, Monserrat, West Indies using portable infra-red thermometers. Donnelly, L. J.
WN/96/26	The 12 May Tor river pyroclastic flow entering the Atlantic Ocean, Soufriere Hills volcano, West Indies: Helicopter observations. Donnelly, L. J.
WN/96/27	A rapid mineral exploration reconnaissance survey for a rock aggregate resource Montserrat, WI. A pre-feasibility study in conjunction with the British Task Force Donnelly, L. J.
WN/96/28	2D resistivity imaging of leachate plumes from the Thriplow landfill, Cambridge Ogilvy, R. D., Meldrum, P. I., Shedlock, S. L. & Cripps, A. C.
WN/96/29	Potential field modelling along the Lamma Lo Wu profile, Hong Kong Busby, J. P.
WN/96/30	Geological aspects related to tilting and subsidence of the 2nd Green at Ruddington Grange Golf Club Northmore, K. J.

WN/96/31	A geophysical investigation to determine the thickness of Quaternary deposits in the Rheidol Valley of Lovesgrove. (Draft Issue) Raines, M. G. & Cripps, A. C.
WN/96/32	Electrokinetic research at BGS: 1995 Beamish, D. & Peart, R. J.
WN/96/33	A geophysical survey to outline shallow gravels on the Island of Luing on behalf of Strathclyde Regional Council. Peart, R. J., Ball, D. F. & Macdonald, A. M.
WN/96/34	EM modelling of CS & MT data: an investigation of deep structural and saline contributions. Beamish, D.
WN/96/35	Borehole geophysical logging at the Thriplow Landfill Site, Cambridgeshire. Shedlock, S. L.
WN/96/36	Project Pathway; Phase 1 report; data review. Draft report on geophysical review of Weston Quarries. Jackson, P. D., Ogilvy, R. D. Forster, A., Strong, G. E., Busby, J. P., Peart, R. J. & Meldrum, P. I.
WN/96/37	A 4-D seismic tomography investigation at Laportes Maldam Mine, Derbyshire. A strata control investigation to locate sedimentary horizons associated with the ore body and fault zones. Donnelly, L. J. & & Pearce, D. R.
WN/96/38	Exploration for abandoned mine shafts using radon gas soil gas geochemistry Donnelly, L. J. & Bamford, L. V.
WN/96/39	Plymouth Raft: derivation of dynamic modulii from crosshole seismics. Shedlock, S. L. & Donnelly, L. J.
WN/96/40	Prediction of the saline transition fare in proposed Nirex boreholes 16 and 17 using CSAMT data Beamish, D.
WN/96/41 (WN/97/13)	Seismic properties of sea floor sediments and rocks: McCann, C., Assefa, S., Sothcott, J., Gunn, D. A. & Culshaw, M. G.
WN/96/42	Report on a site visit to, and short desk study for, a proposed residential development at 36, 37 Midland Road, Carlton, Nottingham. Hobbs, P. R. N.
WN/96/43	Seismic monitoring of alleged noise at properties near Eltham Road pumping station, West Bridgford, Nottinghamshire Peart, R. J. & Shedlock, S. L.
WN/96/44	Engineering Geology of Bristol. Comments for ALGI Forster, A.
WN/97/1	Slope stability analyses for a proposed residential development at 37/39 Midland Road, Carlton, Nottingham Hobbs, P. R. N.
WN/97/2	A study of the relationship between borehole resistivity and chloride concentration estimates at Sellafield. Beamish, D.

WN/97/3	A comparison of borehole resistivity and the corresponding information obtained from surface geophysical CSAMT sounding data Beamish, D.
WN/97/4	Non-invasive detection of non-aqueous phase liquids (NAPLS) by spectral induced polarisation (SIP) imaging. Ogilvy, R. D.
WN/97/5	Cross hole seismic tomography at Morley Quarry, Leicestershire Donnelly, L., Shedlock, S. & Pearce, D.
WN/97/6	Project pathway: Phase 1 report. Pilot geophysical study at Weston Quarries, North Quarry Jackson, P. D., Ogilvy, R. D., Meldrum & Peart, R. J.
WN/97/7	Determination of excavatability at Scottish Coals Blindwells East extension, opencast site Donnelly, L.
WN/97/8	Rock falls and pyroclastic flows on andesitic domes: observations on the Soufriere Hills volcano, Montserrat, West Indies Donnelly, L.
WN/97/9	Exploration of abandoned mine shafts using thermal techniques Donnelly, L.
WN/97/10	A geophysical survey to determine the position of a blind shaft at the Barnet Tunnel Raines, M. & Greenwood, P.
WN/97/11	An appraisal of electrokinetic sounding Beamish, D. & Peart, R.
WN/97/12	Development of geotechnical capability 77BH: an explanation of electrokinetic surveying with example algorithms for use in water surveying using seismic electric methodology Gunn, D. & Beamish, D.
WN/97/13	Seismic properties of sea floor sediments and rocks: Final report of the laboratory measurements at the PRIS –University of Reading/BGS/April 1996-March 1997 McCann, D., Culshaw, M. & Gunn, D.
WN/97/14	NO REPORT
WN/97/15	The mineralogy of the Mercia Mudstone Group Entwisle, D. C.
WN/97/16	Milton Wellfield, geophysical survey. Raines, M., Greenwood, P., Cripps, A., Hallam, J. & Shedlock, S.
WN/97/17	Mining subsidence, fault reactivation and ground deformation in the Dondsk coal basin, Ukraine (USSR) Donnelly, L. J.
WN/97/18	Resistivity imaging of marine lake sediments, Horsea Island, Portsmouth Ogilvy, R. D. & Raines, M.
WN/97/19	Induced polarization tomography (IPT) for monitoring contaminated land - Progress Report October 1996-March 1997 Ogilvy, R. D., Nissen, J., Evans, F. & Meldrum, P. I.

WN/97/20	Imaging flow path in shale using micro-resistivity imaging: a feasibility study Jackson, P. D., Flint, R. & Entwisle, D. C.
WN/97/21	3D resistivity tomography - towards estimating mass properties Jackson, P. D., Earl, S. J. & Reece, G.
WN/97/22	Geological classification of formations from the Afan-Teifi catchment mapping project Hobbs, P., Hallam, J. & Self, S.
WN/97/23	Coniston copper mines – potential hazard, engineering and environmental implications of ground movements due to collapse of old mine workings in the vicinity of Levers Water Cumbria Donnelly, L. & Dumpleton, S.
WN/97/24	Assessment of rock mass stability for potential failure at Smailholm Tower, Scotland Donnelly, L. J.
WN/97/25	Assessment of rock mass stability for potential failure at Dumbarton Castle, Scotland Donnelly, L. J.
WN/97/26	Investigation to determine the suitability of geophysics for the delineation of geological faults and ground fissures. Glen Douglas Landslide, Loch Long, Scotland Donnelly, L. J.
WN/97/27	The engineering geology of the London area. 1:50 000 geological sheets 256, 257, 270 and 271 Forster, A.
WN/97/28	Landslide survey: West Fleet and Weymouth, East Dorset Culshaw, M. G.
WN/97/29	Field observations and prediction of mining subsidence and tectonic ground deformation, Amaga-Angelopolls coal basin, Colombia, South America Donnelly. L. J.
WN/97/30	The application of British mining subsidence techniques in a region of tectonic and mining instability, Venecia-Bolombala, Colombia Donnelly, L. J.
WN/97/31	Seismic properties of sea floor sediments and rocks: Interim report – April 1997-October 1997 Gunn, D. G., Jones, L. & McCann, D. M.
WN/97/32	Modelling slope stability conditions of the West Shetland slope Vol 1 & 2 Hobbs, P. R. N., Long, D. & Northmore, K. J.
WN/97/33	Resistive tomography of lake bottom sediments: a repeat survey of Harsea Lake, Sept. 1997 Meldrum, P., Jackson, P. D., Ogilvy, R. D. & Flint, R. C.
WN/97/34	Landslide risk assessment in urban zones in Colombia, South America, BGS/INGEOMINAS collaboration Donnelly, L. J.

WN/97/35	Catastrophic landslides in Colombia with emphasis on Medellin and Santa Fe, De Bogota	Donnelly, L. J.
WN/97/36	The rationalisation of the Colombian mining industry. Report on visit to Mevellin and Bogota, September 1997	Donnelly, L. J.
WN/97/37	The potential of cross-hole and downhole geophysical imaging techniques at Tang Cheng, Hong Kong	Jackson, P. D., Evans, C. J., Ellison, R. A. & Flint, R. C.
WN/97/38	Nevado del Ruiz volcano, Galeros volcano and the Manizales Volcanological and Seismological Observatory	Donnelly, L. J.
WN/97/39	Mining-induced ground deformation and tectonic and rainfall induced landslides, Nechi mine, Sinifana coal basin, Antiqua, Colombia	Donnelly, L. J.
WN/97/40	Edinburgh Castle: Esplanade to Johnston Terrace slope stability, desk study and visual inspection report	Hobbs, P. R. N.
WN/98/1	The Engineering Geology of the Sidmouth District 1:50 000 Geology sheets 326/340	Forster, A.
WN/98/2	The Engineering Geology of the Morpeth District 1:50 000 Geology Sheet 14	Donnelly, L. J.
WN/98/3	Thermal, magnetic and electromagnetic geophysics for the detection of abandoned mine workings	Donnelly, L. J. & Hardy, D. V.
WN/98/4	Engineering geology of British rocks and soils: Mercia Mudstone	Hobbs, P. R. N., Hallam, J. R., Jones, L. D., Cripps, A. C., Northmore, K. J., Self, S., Meakin, J., Forster, A. & Entwisle, D. C.
WN/98/5	Edinburgh Castle: Esplanade to Johnston Terrace Slope Stability Ground Investigation Report	Donnelly, L. J., Flint, R. C., Tulloch, G. J., Hobbs, P. R. N., Jackson, P. D. & Ruckley, N.
WN/98/6	Definitions of a realistic search zone 'in the vicinity' of abandoned mine shafts in the urban environment	Donnelly, L. J., Culshaw, M. G. & McCann, D. M.
WN/98/7	Engineering Geological Assessment of Loughborough 1:50,000 Sheet 141	Hobbs, P. R. N.
WN/98/8	The assessment of slope instability for land use planning – a case study on the North East Antrim Coast	Forster, A.
WN/98/9	Fault reactivation and ground deformation investigation Easington Colliery, Co Durham	Donnelly, L. J.

WN/98/10	Seismic properties of sea floor sediments: Final report on the laboratory measurements at the BGS on sediment core sampled from the Barra Fan April 97-March 98 Gunn, D. A., Jones, L., McCann, D. M. Culshaw, M. G., Pearce, J., Hardy, J. V., Newsham, R. & Outhwaite, K.
WN/98/11	Mining subsidence at Bellahouston Park, Glasgow. Assessment of data held by the British Geological Survey and Glasgow City Council. Donnelly, L. J.
WN/98/12C	Seismic properties of sea floor rocks and sediments McCann, C., Asseja, S., Sothcott, J., Gunn, D. A., Jones, L. D., McCann, D., Culshaw, M. G., Newsham, R., Outhwaite, K. E., Pearce, J. & Hardy, J. V.
WN/98/13	The shrinkage and swelling behaviour of the Gault Clay Hobbs, P. R. N. & Jones, L. D.
WN/98/14	The shrinkage and swelling properties of the Mercia Mudstone Group Jones, L. D. & Hobbs, P. R. N.
WN/98/15	Whittle Colliery, Northumberland the environmental and geotechnical implications of minewater recovery Donnelly, L. J., Young, B. & Dumpleton, S.
WN/98/16	No record
WN/98/17	Cross-hole seismic data tomography at The Old Vicarage, Finings Road, Lane End, Wycome, Bucks Jackson, P. D., Gunn, D. A. & Flint, R. C.
WN/98/18	Computer programs to process cross-hole seismic data Gunn, D. A.
WN/98/19	Desk study to Identify ground movements in the vicinity at Hooker Reservoir for the identification of a Fixed Datum Donnelly, L. J & Lake, B.
WN/99/1	Slope stability assessment of the cliff behind the Beachy Head lighthouse Hobbs, P. R. N., Flint, R. C., Balson, P. S., Entwisle, D. C. & Forster, A.
WN/99/2	Report of a walk-over and desk-study for a landslide at Matlock Bath for the purchase of a proposed development (carried out on behalf of Derek Haddan Associates for Andrew Pugh) Hobbs, P. R. N.
WN/99/3	Re-survey of the cliff behind the Beachy Head lighthouse 22nd, 23rd April 1999 Hobbs, P. R. N., Jones, L. D. & Forster, A.
WN/99/4	Impact of earthquake ground motion on the stability of slope sediments using existing ground models Jackson, P. D., Gunn, D., Stoker, M., Holmes, R., Hobbs, P. R. N., Long, D., Walker, A. & Musson, R.
WN/99/5	Perry Hall – Gravelly Sewer Phase 2, Specialist Laboratory Testing Entwisle, D. C., Jones, L. D. & Button, S.
WN/99/6	Survey of the sea-cliff stability at Citadel Hill, Plymouth on 17.11.01 Hobbs, P. R. N.
WN/99/7	Seabed resistivity imager system Gunn, D. & Jackson, P. D.

WN/99/8 Perry Hall to Gravelly – additional laboratory testing Entwisle, D. C., Wragg, J., Milodowski, A. E., Burdon, S. & Cave, M.

WN/00/1 Report of a walk-over and desk-study for a landslide at Belper for the purposes of a proposed development. (Carried out for Derek Haddon Associates on behalf of Derek Hill Associates, Derby)

Hobbs, P. R. N.

WN/00/2 The geology of Bellahouston Park, Glasgow and its influence upon mining related subsidences. Version 2, March 2000

Rogers, S. & Sowerbutts, A.

WN/00/3 Report of a walk-over survey of landslides at Branchal North Wood, Wishaw, North Lanarkshire. Carried out for Halcrow Crouch, Glasgow

Hobbs, P. R. N.

WN/00/4 Report of a trial pit survey for a landslide at Belper for the purposes of a proposed development. (Carried out for Douglas Haddon Associates on behalf of Derek Hill Associated, Derbyshire)

Hobbs, P. R. N.

Appendix 15 Technical Reports (2001 – 2019) (alphabetically by first author)

Ambrose, K., Buckley, D., Entwisle, D., Jones, D., Jordan, C. J., Kessler, H., Kuras, O., Lelliott, M., McManus, K., Nice, S. E., Palmer, R., Pearson, S., Price, S., Scheib, A., Scheib, C. & Smith, B. 2006. The 3D Soils Modelling Project: results, feedback and recommendations of the Brackenhurst site survey 2005. Nottingham, UK, British Geological Survey, 157pp. (IR/06/074)

Arnhardt, R., & Burke, H. 2020. Geological ground model for planning and development for Greater Manchester. Nottingham, UK, British Geological Survey, 66pp. (OR/20/033)

Burke, H. F., Hughes, L., Wakefield, O. J. W., Entwisle, D. C., Waters, C. N., Myers, A., Thorpe, S., Terrington, R., Kessler, H. & Horabin, C. 2015. A 3D geological model for B90745 North Trans Pennine Electrification East between Leeds and York. Nottingham, UK, British Geological Survey, 28pp. (CR/15/004N)

Entwisle, D. C. & Wildman, G. 2010. Creation of the Till Thematic Layer. Nottingham, UK, British Geological Survey, 14pp. (IR/10/041)

Entwisle, D. C., Lawley, R. S. & Lee, K. A. 2012. User guide DiGMapPlus+ engineering properties: use for Engineered Fill dataset (version 1). Nottingham, UK, British Geological Survey, 13pp. (OR/12/091)

Entwisle, D., Lawley, R. & Lee, K. A. 2013. DiGMapPlus Engineering properties: use as engineered fill: methodology report. Nottingham, UK, British Geological Survey, 20pp. (IR/12/079)

Entwisle, D. C., White, J. C., Busby, J. P., Lawley, R. S. & Cooke, I. L. 2014. Electrical resistivity model of Great Britain: user guide. Nottingham, UK, British Geological Survey, 10pp. (OR/14/030)

Entwisle, D., Lee, K. A. & Lawley, R. S. 2015. User guide for 'BGS Civils': a suite of engineering properties datasets. Nottingham, UK, British Geological Survey, 28pp. (OR/15/065)

Entwisle, D. C. 2019. Engineering geology and geotechnical summary of central Glasgow in the vicinity of the UK Geoenergy Observatories field sites. Nottingham, UK, British Geological Survey, 65pp. (OR/19/019)

Forster, A. & Freeborough, K. 2006. A guide to the communication of geohazards information to the public. Nottingham, UK, British Geological Survey (IR/06/009)

Forster, A., Culshaw, M. G., Stuart, M. E., Dunkley, P. N., Musson, R. M. W. & Hooker, P. J. 2002. Assessment of hazard and risk in the geological sciences: a guide to current practice. Nottingham, UK, British Geological Survey (IR/02/169R)

Forster, A., Cooper, A. H., Farrant, A. & Jones, L. D. 2003. The National assessment of the geological hazards – landslide, running sand, compressible soils collapsible soils, dissolution and shrinkable clay soils. Nottingham, UK, British Geological Survey (IR/03/141R)

Harrison, A., White, J., Jones, L., Entwisle, D., Hulbert, A., Lee, K., Mansour, M. & Wang, L. 2020. User guide for the British Geological Survey GeoClimateUKCP09: clay shrink-swell dataset. Nottingham, UK, British Geological Survey, 25pp. (OR/19/064)

Kearsey, T., Gillespie, M., Entwisle, D., Damaschke, M., Wylde, S., Fellgett, M., Kingdon, A., Burkin, J., Starcher, V., Shorter, K., Barron, H., Elsome, J., Barnett, M. & Monaghan, A. 2019. UK Geoenergy Observatories Glasgow: GGC01 cored, seismic monitoring borehole – intermediate data release. Nottingham, UK, British Geological Survey, 36pp. (OR/19/049)

Lee, K. A., Lawley, R. S. & Entwisle, D. 2012. User guide DiGMapPlus+ engineering properties: strength dataset (Version 1). Nottingham, UK, British Geological Survey, 16pp. (OR/12/043)

Lee, K. A., Lawley, R. S. & Entwisle, D. 2012. User guide DiGMapPlus+ engineering properties: excavatability dataset (version 1). Nottingham, UK, British Geological Survey, 12pp. (OR/12/044)

Monaghan, A. A., O Dochartaigh, B., Fordyce, F., Loveless, S., Entwisle, D., Quinn, M., Smith, K., Ellen, R., Arkley, S., Kearsey, T., Campbell, S. D. G., Fellgett, M. & Mosca, I. 2017. UKGEOS: Glasgow Geothermal Energy Research Field Site (GGERFS): initial summary of the geological platform. Nottingham, UK, British Geological Survey, 205pp. (OR/17/006)

Northmore, K. J., Entwisle, D. C., Reeves, H. J., Auton, C. A. & Phillips, E. 2012. Field observations and laboratory test results on tills in the Nairn-Inverness area of NE Scotland. Nottingham, UK, British Geological Survey, 36pp. (OR/08/031)

Self, S., Entwisle, D, & Northmore, K. 2012. The structure and operation of the BGS National Geotechnical Properties Database. Version 2. Nottingham, UK, British Geological Survey, 68pp. (IR/12/056)

Styles, M., Entwisle, D., Gunn, D., Hodgkinson, E., Jackson, P. D., Kemp, S., Nelder, L. M., Northmore, K. & Steadman, E. 2001. A mineralogical examination of a magnetic tropical brown soil from Cambodia and a possible synthetic analogue made with soil from Devon. Keyworth, Nottingham, British Geological Survey, 31pp. (CR/01/096N)

Tye, A. M., Entwisle, D. C. & Newsham, R. 2011. User guide for the British Geological Survey Corrosivity (Ferrous) Dataset. Nottingham, UK, British Geological Survey, 13pp. (OR/11/023)

Tye, A. M., Kirkwood, C., Dearden, R., Rawlins, B. G., Lark, R. M., Lawley, R. L., Entwisle, D. & Mee, K. 2017. Environmental factors influencing pipe failures. Nottingham, UK, British Geological Survey, 85pp. (OR/17/009)

Appendix 16 Laboratory Reports (1969 – 2001)

EG/GPL 0	Density and Porosity Determination on Rock Specimens from East Yorkshire McDowell, P. W.
EG/GPL 1	Spilmersford Borehole. (WN/69/1.4) McCann, D. M.
EG/GPL 2	Spilmersford Borehole (WN70) – 1970 Conway, B. W. & McCann, D. M.
EG/GPL 3	Derbyshire. (WN/70/3.4C) McCann, D. M., Grainger, P. & Collins, P.
EG/GPL 4	Hamswell, Sherston and Yate Boreholes (WN/70/4.4) Collins, P. H. & McCann, D. M.
EG/GPL 5	Malawi 1. (WN/70/5.4) Collins, P.
EG/GPL 6	Shetland Islands 1. (WN/71/6.4) Grainger, P.
EG/GPL 7	Malawi 2. (WN/71/7.4) Sharkey, P. C.
EG/GPL 8	Derbyshire and Charnwood Forest (WN/72/8.4) Sharkey, P. C.
EG/GPL 9	Shetland Islands 2. (WN/72/9.4) Collins, P. H. & Sharkey, P. C.
EG/GPL 10	Borehole GH3, Huntingdon (WN/72/10.4) Sharkey, P. C.
EG/GPL 11	Nepal. (WN/72/11.4) Forster, A.
EG/GPL 11a	Dubai Rock Samples (May 1972) Harding, A. D.
EG/GPL 12	Orkney Islands (WN/72/12.4) McCann, D. M.
EG/GPL 13	Cornwall 1. (WN/72/13.4) McCann, D. M.
EG/GPL 14	Cannington Park, Somerset (WN/72/14.4) McCann, D. M.
EG/GPL 15	Steeple Aston, Oxfordshire (WN/72/15.4) McCann, D. M.
EG/GPL 15a	Barnsdale Landslip – 1972 Forster, A.

EG/GPL 16 Roadstone project (WN/72/16.4)
Sharkey, P. C.

EG/GPL 17 Telford 1. (WN/72/17.4)
Forster, A.

EG/GPL 18 Anglesey and Yorkshire (WN/72/18.4)
McCann, D. M.

EG/GPL 19 Electrical properties of saturated sands (WN/71/19.4)
Grainger, P.

EG/GPL 20/1North Sea (WN/73/20.41C)
Grainger. P.

EG/GPL 20/2North Sea (WN/73/20.42C)
Sarginson, M.

EG/GPL 20/3North Sea (WN/73/20.43C) (photocopy)
?

EG/GPL 21 Foyers, Inverness-shire (WN/73/21.4)
Baria, R. & McCann, D. M.

EG/GPL 22 Tattenhoe Borehole, Buckinghamshire (No report) (WN/80/22.4)

EG/GPL 23 Wilsey Down Borehole, Cornwall (Some paperwork, no report) (WN/80/23.4)

EG/GPL 24 Jurassic limestone, Dorset (Not completed) (WN/80/24/4)

EG/GPL 25 Jurassic limestone, Buckinghamshire (Data available, no report) (WN/80/25.4)

EG/GPL 26 Thorpe Borehole. (WN/73/26.4)
Forster, A.

EG/GPL 27 Cornwall 2. (WN/73.27.4) Combined report
Gibb, J.

EG/GPL 28 Cornwall 3. (WN/73/28.4)
Gibb, J.

EG/GPL 29 Shetland Islands 3. (WN/72/29.4) (Data available, no report)
Sharkey, P. C. & Collins, P. H.

EG/GPL 30 Bryntegg Borehole, North Wales (WN/73/30.4)
McCann, D. M.

EG/GPL 31 Java (WN/71/31.4)
Grainger, P.

EG/GPL 32 Port More Borehole, Northern Ireland. (WN/73/32.4)
McCann, D. M.

EG/GPL 33 Spark discharge control unit. (WN.72.33.4)
McCann, D. M. & Sharkey, P. C.

EG/GPL 34 Reading area (WN/73/34.4)
Forster, A.

EG/GPL 35	Whatley Quarry Borehole, Somerset (WN/73/35.4) Original typescript only
EG/GPL 36	Kielder Tunnel (WN/73/36.4) Ates, M. & McCann, D. M.
EG/GPL 37	Botswana (WN/73/37.4) McCann, D. M.
EG/GPL 38	Anglesey (WN/74/38.4) (Not final report – most of data)
EG/GPL 39	Charmouth Borehole (WN/74/39.4) Culshaw, M. G.
EG/GPL 40	Withycombe Farm Borehole, Oxfordshire (WN.74.40.4) (No complete report - p/c and originals) Godson, R. A.
EG/GPL 41	Burton Row Borehole, Somerset (WN/74/41.4) Godson, R. A.
EG/GPL 42	Borehole temperature probe (WN.73.42.4) (incomplete) originals only Baria, R.
EG/GPL 43	Telford 2. (WN/73/43.4) Forster, A.
EG/GPL 44	Croft, Leicestershire (WN.73.44.4) Forster, A.
EG/GPL 45	Raydale Borehole, Yorkshire (WN/74/45/4) P/c's only
EG/GPL 46	Derbyshire Limestone (WN/74/46.4)
EG/GPL 47	Foyers Borehole, Inverness-shire (WN/80/47.4) (No report available)
EG/GPL 48	Hadleigh Borehole, S. Essex WN/74/48.C) Sarginson, M.
EG/GPL 49	Seychelles (WN/73/49.4) Forster, A.
EG/GPL 50	Hunterston Boreholes (WN.75/50.4)
EG/GPL 51	Kirkcudbrightshire (WN/74/51.4) Forster, A.
EG/GPL 52	Steeple Aston, Oxfordshire (WN/74/52/4) Forster, A.
EG/GPL 53	Steeple Aston, Oxfordshire (WN/74/53.4) McCann, D. M.
EG/GPL 54	South Fambridge, Essex (WN/74/54/4C) McCann, D. M.
EG/GPL 55	North Farm Borehole, Wiltshire (WN/74/55.4) Godson, R. A.
EG/GPL 56	Honeymead Borehole, Devon (WN/74/56.4) Forster, A.

EG/GPL 57	Larne Borehole, Northern Ireland (WN/74/57.4) Forster, A.
EG/GPL 58	Stanford-le-Hope (WN/74/58.4) Godson, R. A.
EG/GPL 59	Colombia (WN/74/59.4) Forster, A.
EG/GPL 60	Chile (WN/74/60.4) (No complete report) Godson, R. A.
EG/GPL 61	South Essex (WN/74/61.4) (unbound) ?
EG/GPL 62	Orkney (WN/74/62.4) Forster, A.
EG/GPL 63	Dartmoor (WN/75/63.4) Forster, A.
EG/GPL 64	Jurassic limestone, Cotswolds (WN/80/64.4) ?
EG/GPL 65	South Essex (WN/74/65.4) Forster, A. & Darwell, J. L. ?
EG/GPL 66	Bristol Channel (WN/74/66.4) Forster, A.
EG/GPL 67	Jurassic limestone, Pres.(?) (WN/76/67.4) Unbound ?
EG/GPL 68	North Wales (WN/74/68.4) ?
EG/GPL 69	Withycombe Farm, Oxfordshire (WN/74/69.4) Forster, A.
EG/GPL 70	South East Essex (WN/74/70.4) Darwell, J. L.
EG/GPL 71	Lyme Bay (WN/75/71.4) Darton, D. M.
EG/GPL 72	Llanberis (WN/75/72.4) Forster, A. or Darwell, J. L.
EG/GPL 73	Eyam Borehole (WN/74/73.4) Forster, A.
EG/GPL 74	Settle (WN/75/74.4) Forster, A.
EG/GPL 75	Aust Cliff (WN/75/75.4) Forster, A.

EG/GPL 76	St Lucia (WN/75/76.4) Forster, A.
EG/GPL 77	Anthracite, Pembroke (WN/75/77.4) Forster, A.
EG/GPL 78	Craven Fault Area (WN/75/78.4) (some data) ?
EG/GPL 79	Castleside Quarry (WN/75/79.4) ?
EG/GPL 80	Cleeve Common Borehole (WN/80/80.4) ?
EG/GPL 81	Ardgay (WN/75/81.4) Forster, A.
EG/GPL 82	Blackstockarton Moor (WN/76/82.4) (Unbound) ?
EG/GPL 83	North Wales (WN/76/83.4) Forster, A.
EG/GPL/76/84	Density, porosity, magnetic susceptibility and sonic velocity determination on 31 samples from, Magilligan, County Londonderry, Ireland Forster, A.
EG/GPL 85	Ketton Stone (WN/76/85.4) (Nothing) ?
EG/GPL 86	Bolivia (WN/76/86.4) (Unbound) Forster, A.
EG/GPL 87	Clachie Bridge Borehole (WN/76/87.4) (Unbound) Forster, A.
EG/GPL 88	Atherstone (WN/76/88.4) (Unbound) Barnett, C.
EG/GPL 89	Londonderry (WN/76/89.4) Barnett, C. & Forster, A.
EG/GPL 90	Concrete (WN/76/90.4) (Nothing) ?
EG/GPL 91	Sandown Bay, Isle of Wight (WN/76/91.4) (No report) ?
EG/GPL 92	West Lulworth Borehole (WN/76/92.4) Green, A. S. P.
EG/GPL 93	Rothamstead (WM/76/93.4) (Nothing) ?
EG/GPL 94	Alexandra Parade Borehole (WN/80/94.4) (Nothing) ?

EG/GPL 95	CEGB Conductivity (WN/76/95.4) (Nothing)
	?
EG/GPL/76/96	Geophysical properties of selected rock samples from a borehole in Cocking, West Sussex
	Green, A. S. P.
EG/GPL/76/97	Density, porosity and sonic velocity determinations on rock types of Cambrian age from the Llyn Peris area of North Wales.
	Culshaw, M. G.
EG/GPL 98	Dorset Coast 68 (WN/76/98.4)
	Green, A. S. P.
EG/GPL 99a	Dorset Coast 76 (WN/76/99.4)
	Forster, A. & Mathews, M.
EG/GPL 100	Costa Rica (WN/76/100.4)
	Forster, A. & Mathews, M.
EG/GPL 101	Atherstone (WN/76/101.4)
	Forster, A.
EG/GPL 102	Wrexham (WN/76/102.4)
	Forster, A.
EG/GPL 103	Shetlands (WN/76.103.4)
	Forster, A.
EG/GPL 104	Beckermonds Scar (WN/78/104.4)
	Forster, A.
EG/GPL 105	Grudie (WN/77/105.4)
	Forster, A.
EG/GPL 106	Panama (WN/777/106.4) Data available
	Forster, A.
EG/GPL 107	Ecuador (WN/77/107.4)
	Forster, A.
EC/GPL 108	Burma (WN/77/108.4) Little data available
	?
EG/GPL 109	Korea (WN/77/109.4)
	Forster, A.
EG/GPL 110	Merthyr Tydfil (WN/77/110.4)
	Forster, A.
EG/GPL 111	Rotherwood Borehole (WN/77/111.4)
	Green, A. S. P.
EG/GPL 112	Barrowhill Quarry (WN/77/112.4)
	Forster, A.
EP/GPL 113	Cornwall (Lizard) (WN/77/113.4)
	Forster, A.

EG/GPL 114	Cannington Park Borehole (WN.77/114.4) Little data ?
EP/GPL 115	Rotherwood Borehole (11) (WN.77/115.4) Forster, A.
EP/GPL 116	Panama (WN/77/116.4) Forster, A.
EG/GPL 117	Charter Consolidated (1) (WN/77/117.4) Forster, A.
EG/GPL 118	Unst, Shetlands (WN/77/118.4) Forster, A.
EG/GPL 119	Clwyd, Wales (WN/77/119.4) Forster, A.
EG/GPL 120	Tilmanstone - Abandoned (WN/77/120.4) ?
EG/GPL 121	Chatburn Limestone (WN/77/121.4) Forster, A.
EG/GPL 122	Charter Consolidated (11) (WN/78/122.4) Forster, A.
EG/GPL 123	Unst Borehole (WN/78/123.4) ?
EG/GPL 124	SLM (WN/78/124.4) – 1978 ?
EG/GPL 125	Alvor Chromite (WN/78/125.4) ?
EG/GPL 126	Duchy Peru, Cornwall (Little data, no report) (WN/78/126.4) ?
EG/GPL 127	Glinton No 1 B.H. (Nothing) (WN/79/127.4) ?
EG/GPL 128	Bolivia (Little data) (WN/79/128.4) Forster, A.
EG/GPL 129	West Somerset 1980 Sathianathan, R.
EG/GPL 130	Shap 1982 Entwisle, D. C.
EG/GPL 131	Lake District 1982 Entwisle, D. C.
EG/GPL 132	North West Wales 1982 Entwisle, D. C.

EG/GPL 133	Colombia 1982
	Entwisle, D. C.
EG/GPL 134	Skiddaw Borehole 1982
	Entwisle, D. C.
EG/GPL 135	North Norfolk Basement 1982
	Entwisle, D. C.
EG/GPL 136	Cairngorm and Mount Battock 1982
	Entwisle, D. C.
EG/GPL 137	Ballater and Bennachire Boreholes 1982
	Entwisle, D. C.
EG/GPL 138	Lake District 1983
	Entwisle, D. C.
EG/GPL 139	Hollowell Borehole 1983
	Entwisle, D. C.
EG/GPL 140	East Midlands Deep Borehole 1984
	Entwisle, D. C.
EG/GPL 141	Shelve Inlier 1984
	Entwisle, D. C.
EG/GPL 142	East Midlands Deep Borehole 2 1984
	Entwisle, D. C.
EG/GPL 143	East Midlands Deep Borehole 3 1984
	Entwisle, D. C.
EG/GPL 144	Ballahulish 1984
	Tucker, G. H. B. & Entwisle, D. C.
EG/GPL 145	Lake District 1984
	Entwisle, D. C.
EG/GPL 146	Shelve Interior 1984
	Entwisle, D. C.
EG/GPL 147	North Wales Nant Quarry 1984
	Entwisle, D. C.
EG/GPL 148	Shantallow 1984
	Winter, M. G.
EG/GPL 149	B P Minerals (In Confidence) 1984
	Entwisle, D. C.
EG/GPL 150	Shantallow 1984
	Entwisle, D. C.
EG/GPL 151	BP Minerals (In Confidence) 1984
	?

EG/GPL 152 Kenya (Chyulu Hills) Lava and Basement 1984
Entwisle, D. C. & Marharian-Massihi, A.

EG/GPL 152(2) Peru 1984
Entwisle, D. C.

EG/GPL 153 Cefn-y-fedw sandstone, North Wales 1984
Entwisle, D. C.

EG/GPL 154 The density, porosity, resistivity, magnetic susceptibility and sonic velocity of 10 rock samples from Peru
Entwisle, D. C.

EG/GPL 155 Peru 1985
Entwisle, D. C.

EG/GPL 156 Rock Samples from the Higher Ludbrook Borehole No. 1
Entwisle, D. C.

157-174 NO RECORD-

EG/85/1 A memorandum on - The correction of axial deformation for rig stretch and temperature effects on load cell calibration for the 35 MPa triaxial apparatus
Winter, M. G. & Horseman, S. T.

EG/85/2 A memorandum on - description and calibration of the Modifications to the Cell Pressure application and monitoring system for the 35 MPa triaxial apparatus
Horseman, S. T. & Winter, M. G.

EG/85/3 A Memorandum on - the analysis of shear stage data from the 35 MPa triaxial apparatus
Winter, M. G. & Horseman, S. T.

EG/85/4 A memorandum on - ambient temperature triaxial tests on Boom Clay: preliminary comparisons with Ismes data
Horseman, S. T. & Winter, M. G.

EG/85/5 A memorandum on - the determination of void ratio changes during undrained heating of Boom Clay specimens in the 35 MPa triaxial apparatus
Winter, M. G. & Horseman, S. T.

WN/GL/87/003R Core analysis results from borehole SC0, Sawston, Cambridgeshire – 1987
Bird, M. J.

EG/GPL 175 Caulca, Columbia 1987
Entwisle, D. C.

EG/GPL 176 Density and porosity determinations on samples from Scotland for BP Minerals International Ltd
Entwisle, D. C.

EG/GPL 177 Lleyn Peninsula, N. Wales 1988
Entwisle, D. C.

EG/GPL 177A Lleyn Peninsula, N. Wales (Sarn Complex) 1988

Entwisle, D. C.

EG/GPL 178 Dyfed, South Wales 1988

Entwisle, D. C.

EG/GPL 179 Basaltic Lavas, Devon 1988

Entwisle, D. C.

EG/GPL 180 N. W. Wash, Lincolnshire 1988

Entwisle, D. C.

EGG/GPL 181 Garloch, Grampian 1988

Entwisle, D. C.

EGG/GPL 182 Density, porosity, sonic velocity and unconfined compressive strength. Determination on Carboniferous Limestone from the Cambridge Deep Borehole

Entwisle, D. C.

183-189 NO RECORD-

EGG/GPL 190c Density, porosity and induced magnetic susceptibility determinations on twenty seven rock samples supplied by Ech Stratigraphical Services Ltd, of Guildford, Surrey, 1990

Entwisle, D. C.

EGG/GPL 191 Density and porosity on forty five rock samples from the Eycott Volcanic Group, Cockermouth, Cumbria

Entwisle, D. C.

EGG/GPL 192c Density and porosity on a number of sub-samples from four large casstone samples from a quarry near Kings Lynn, 1991

Entwisle, D. C.

EGG/GPL 193c Specific gravity of three limestone samples of Carboniferous Limestone from Derbyshire.

Entwisle, D. C.

EGG/GPL 194 Density and porosity on thirty seven specimens from thirteen sites in Central Wales

Entwisle, D. C.

WN/GL/86/001 Porosity and density results from Chimimbe BH3, Malawi

Bird, M. J.

WN/GL/86/002 Core analysis results of the Glen Rothes borehole (1986)

Bird, M. J.

WN/GL/86/002 Core analysis results from bank left outfall drain project boreholes, Sanghur Pakistan (1987)

Bird, M. J.

WN/GL/87/001 Core analysis results from the BH GSS 10/CS, Serowe, Botswana (1987)

Bird, M. J.

WN/GL/87/003 Core analysis results from borehole SC01 Sawston, Cambridgeshire (1987)

Bird, M. J.

END OF GPL SERIES

THE FOLLOWING ARE LABORATORY REPORTS BUT NUMBERED DIFFERENTLY IT IS NOT CLEAR WHAT HAPPENED TO REPORTS PREPARED IN 1988, 89, 90 AND 91

EGG/92/1	Density, porosity and induced magnetic susceptibility determinations on twenty one rock samples from Dyfed, Powys and Worcestershire Entwisle, D. C.
EGG/92/2	Density and sonic velocity on four samples from two boreholes in Cheshire as part of the Cheshire Basin Project Entwisle, D. C.
EGG/92/3	Density and porosity determinations on fourteen rock samples from Coventry Jones, D. & Entwisle, D. C.
EGG/92/4	Density and porosity determinations on thirty Dalradian rock samples for the Grampian Geophysics Interpretation Project Jones, L. & Entwisle, D. C.
EGG/92/5	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Pit 1, 1.70m Entwisle, D. C.
EGG/92/6	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Pit 2, 1.00m Entwisle, D. C.
EGG/92/7	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Pit 3, 1.00m Entwisle, D. C.
EGG/92/8	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Pit 3, 2.00m Entwisle, D. C.
EGG/92/9	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Pit 4, 2.00m Entwisle, D. C.
EGG/92/10	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Pit 5, 1.50m Entwisle, D. C.
EGG/92/11	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Pit 6, 2.70m Entwisle, D. C.
EGG/92/12	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Pit 7. 2.00m Entwisle, D. C.
EGG/92/13	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Borehole K89/3B 1.10m, 2.20m, 5.10m Entwisle, D. C.

EGG/92/14	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Borehole K89/3F 0.61m Entwisle, D. C.
EGG/92/15	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Borehole 3F 2.20m Entwisle, D. C.
EGG/92/16	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Borehole 3F 4.60m Entwisle, D. C.
EGG/92/17	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Borehole K89/4, 2.10m, 5.00m, 8.00m Entwisle, D. C.
EGG/92/18	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Cemususs Dam Site, Pit 15, 1.60m, Pit 22, 1.20m, Pit 22, 1.55m Entwisle, D. C.
EGG/92/19	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Kenya Eldama Ravine compacted road fill 3" and 4" diameter sub samples Entwisle, D. C.
EGG/92/20	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 1, 2.00m Entwisle, D. C.
EGG/92/21	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 2, 2.00m Entwisle, D. C.
EGG/92/22	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 3, 1.70m Entwisle, D. C.
EGG/92/23	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 4, 2.00m Entwisle, D. C.
EGG/92/24	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 5, 2.00m Entwisle, D. C.
EGG/92/25	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 6, 2.00m Entwisle, D. C.
EGG/92/26	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 7, 2.00m Entwisle, D. C.
EGG/92/27	Engineering Geology of a Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 8, 2.00m Entwisle, D. C.

EGG/92/28	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 9, 2.00m Entwisle, D. C.
EGG/92/29	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 10, 3.0m, 4.0m, 5.0m Entwisle, D. C.
EGG/92/30	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 11, 3.0m, 4.0m, 5.0m Entwisle, D. C.
EGG/92/31	Engineering Geology of Tropical Red Clay Soil: consolidation of a sample from Indonesia Pit 12, 3.0m, 4.0m, 5.0m. Entwisle, D. C.
EGG/92/32	(No Report)
EGG/92/33	Gault Clay Project. Determination of liquid, plastic and linear shrinkage limits (Aresley, Klondyke Farm Boreholes) Grantham, T.
EGG/92/34	Density and porosity determinations on forty four Dalradian rock samples for the Grampian Geophysics Interpretation Project 77BA Part 2 Jones, L. & Entwisle, D. C.
EGG/92/35	Density and porosity determinations on Dalradian rock samples for the Grampian Geophysics Interpretation Project 77BD Part 3 Jones, L. & Entwisle, D. C.
EGG/92/36	Atterberg limits, particle size and residual shear strength of borehole samples from two boreholes near Shaftesbury, Dorset Entwisle, D. C.
EGG/92/37	Particle size determining on allophanic soil. Indonesia point 9, 1.0m using different methods of pretreatment. Entwisle, D. C.
93/1	Density and porosity, determination of 10 samples from Islay and the Western Highland granite complex for the Geophysical Interpretation Project. Entwisle, D. C.
93/2	Residual shear strength of six samples from two boreholes. Arlesey, Bedfordshire and Klondyke Farm, Cambridgeshire. Entwisle, D. C
93/3	Set-up and calibration of standard 100mm triaxial apparatus for use with GDS HSDAC data logging system Hobbs, P. & Jones, L.
93/4	The engineering geology of British rocks and soils. The Gault Clay in England. Particle size and gravity testing. Jones, L.
95/5	The engineering geology of British rocks and soils. The Gault Clay of England. Consolidation of a sample from Klondyke Farm borehole, 6.77m Entwisle, D. C.

93/6 The engineering geology of British soils and rocks. The Gault Clay of England. Consolidation of Arlesey borehole 15.65m

Entwisle, D. C.

93/8 The engineering geology of British soils and rocks. The Gault Clay of England. Consolidation of Klondyke Farm BH 14.45m

Entwisle, D. C.

93/9 The engineering geology of British soils and rocks. The Gault Clay of England. Consolidation of Klondyke Farm BH 23.50m

Entwisle, D. C.

93/10 The engineering geology of British soils and rocks. The Gault Clay of England. Consolidation of Klondyke Farm BH 27.00m

Entwisle, D. C.

93/11 The engineering geology of British soils and rocks. The Gault Clay of England. Consolidation of Arlesey BH 34.45m

Entwisle, D. C.

93/12 The engineering geology of British soil and rocks. The Gault Clay of England. Consolidation of Arlesey BH 46.39m

Entwisle, D. C.

93/13 The engineering geology of British soils and rocks. The Gault Clay of England. Consolidation of Arlesey BH 55.52m

Entwisle, D. C.

93/14 Density and porosity determinations on eighteen rock samples from the Loch Maree and Cairlock areas, Western Highlands, Scotland for the Lewisian base metals project.

Entwisle, D. C.

93/15 Density and porosity determinations on eleven rock samples from the Solway area, Scotland for the Solway M.R.P. project.

Entwisle, D. C.

93/16 Comparison of Bison instrument 3101A and Bartington instruments MS2 magnetic susceptibility metres on samples of rock core

Jones, L. D.

93/17 The engineering geology of British soils and rocks. The Gault Clay of England. Multi-stage effective stress triaxial testing of Klondyke Farm Borehole, 6.77

Entwisle, D. C.

93/18 The engineering geology of British soils and rocks. The Gault Clay of England. Multi-stage, effective stress triaxial testing of Klondyke Farm Borehole, 10.50m

Entwisle, D. C.

93/19 The engineering geology of British soils and rocks. The Gault Clay of England multi-stage, effective stress, triaxial testing, of Klondyke Farm Borehole 14.5-14.75

Entwisle, D. C.

93/20 The engineering geology of British soils and rocks. The Gault Clay of England. Multi-stage effective stress, triaxial testing of Klondyke Farm, Borehole 23-50-23.75m

Entwisle, D. C.

93/21 The engineering geology of British soils and rocks. The Gault Clay of England. Multi-stage effective stress, triaxial testing of Klondyke Farm. Borehole 27.0-27.25

Entwisle, D. C.

93/22 The engineering geology of British soils and rocks. The Gault Clay of England. Multi-stage effective stress, triaxial testing of Arlesey 35.45-35.70m

Entwisle, D. C.

93/23 ULS of boulders from Long Eaton

Jones, L. D. & Entwisle, D. C.

94/01 Oedometer consolidation testing of calcareous pelagic oozes and saprolitic Clays from ODP Leg 144

Jones, L. & Hobbs, P.

94/02 Sources of building stone for new Parliament Building - Phase 2: compressive strength and porosity results from selected UK quarry sites Jones, L., Northmore, K. J. & Entwisle, D. C.

94/03 Analysis of soil from Japan and recommendations for a UK source of similar material

Northmore, K. J. & Inglethorpe, S.

94/04 Collection and dialysis of 'River Terrace Brickearth' samples and comparison with properties of 'standard' soil from Japan

Northmore, K. J. & Entwisle, D. C.

94/05 Density + effective porosity determinations on rock samples for the crystal studies - North Britain Project, PA77BA

Jones, L.

94/06 Density + effective porosity determinations on rock samples for the Southern Uplands Project, PA71CB

Jones, L.

94/07 Density + effective porosity determinations on rock samples for the crystal studies - North Britain Project, PA77BA (Part 2)

Jones, L.

94/08 Falling head permeability tests on Till from Wolverhampton

Hobbs, P.

94/09 Unconfined compression strength for boulders from Lancaster

Jones, L.

94/10 Triaxial tests - Gringley-on-the-Hill

Jones, L. & Hobbs, P.

94/11 Unconfined compressive strength on 7 boulders from Lancaster

Jones, L.

94/12 Sage Engineering Ltd. Thermal conductivity of rock and soil samples 6th October 1994

Gunn, D. A.

95/1 Density and porosity of Sherwood Sandstone and Carboniferous Limestone samples from the Limestone Hill No 1, Ashbourne, Derbyshire

Entwisle, D. C.

95/2	Density and porosity of Numerian Sandstone, Siltstone and Mudstone samples from the Bradup Borehole, Bradford, West Yorkshire Entwisle, D. C.
95/3	Density and porosity of Triassic Breccia and Sandstone and Devon Sandstone samples from near Minehead, Somerset Entwisle, D. C.
95/4	Methods of shrinking + swelling apparatus + applicability Jones, L. D.
95/5	Density, porosity, compressive strength, polished stone value and sodium sulphate crystallisation of samples from a block of Exeter rock Entwisle, D. C. & Northmore, K. J.
95/6	Uniaxial compressive strength of samples from 17 boulder from Kelvin Valley glacial till, Glasgow Entwisle, D. C., Jones, L. D. & Northmore, K. J.
95/7	Oedometer consolidation tests on marine clays from ODP leg 155: Amazon Fan Entwisle, D. C., Jones, L. D. & Hobbs, P.
95/8	Density and porosity of 3 samples of Carboniferous Limestone from Derbyshire Entwisle, D. C.
95/9	Density and porosity of Tertiary Volcanic rocks from 29 sites in Ardnamuchan, Mull and Skye Entwisle, D. C.
95/10	Density and porosity of Charnian (Precambrian) Rocks from the Blackprouit area south west of Shepshed, near Loughborough, Leicester Entwisle, D. C.
95/11	Wardell Armstrong Consultants Ltd, unconfined compressive strength & asbestos testing on Maltese Limestone Jones, L.
95/12	Present & future routes for laboratory testing data/results Jones, L.
95/13	Magnetic susceptibility of limestone samples for runway aggregate (Wimpey Minerals Ltd) Hobbs, P.
96/1	Density and porosity determinations of Carboniferous and Lower Palaeozoic rocks from the Ticknall (Calite Abbey) Borehole Entwisle, D. C.
96/2	Determination of the swelling & shrinking properties of the Gault Clay Jones, L., Hobbs, P. & Cripps, A.
96/3	Density and porosity determinations on thirty one core hand specimens of various rock types from Hong Kong. Entwisle, D. C.
96/4	Saturated density and induced magnetic susceptibility of cores from BGS offshore boreholes west of the Hebrides. Entwisle, D. C.

96/5	Density, porosity, uniaxial compressive strength and flexural strength of eight blocks of “Crema di Capri” marble from Cordoba, Cabra, Portugal Hobbs, P. R. N., Entwisle, D. C. & Jones, L.
96/6	U C S boulders South Wales Entwisle, D. C.
96/7	Swansea Bay glacial till boulders (Thyssen Geotechnics) Entwisle, D. C. & Hobbs, P. R. N.
96/8	Swansea Bay Glacial Till boulders Entwisle, D. C.
96/9	Plasticity, particle size, consolidation, swelling and residual strength of Mercia Mudstone from Cropwell Bishop Gypsum East and Langley-on-the-Hill Entwisle, D. C.
96/10	Thermal expansion of sandy limestone rock samples Gunn, D. A.
97/1	Sellafield geological investigations for deep radioactive waste repository Discontinuity log for borehole RCFI from 735.80 to 800.58m Donnelly, L. J.
97/2	Sellafield geological investigations for deep radioactive waste repository Discontinuity log for borehole RCFI from 805.00 to 842.30m Donnelly, L. J.
97/3	Uniaxial compressive strength and point load strength of cores from boulders taken from glacial till in Swansea, South Wales (City and County of Swansea) Entwisle, D. C.
97/4	Geophysical laboratory testing of rock sample from the Middle East for BHP Minerals Ltd Hobbs, P., Meldrum, P. & Jones, L.
97/5	Density, porosity and sonic velocity determinations on selected core samples of various rock types from the Palaeozoic London Basement Entwisle, D. C.
97/6	Liquid limit, plastic limit and moisture content of a clay from Shropshire Jones, L. D.
97/7	Density and porosity of Lower Greensand core samples from 4 boreholes Entwisle, D. C.
97/8	Liquid limit, plastic limit and moisture content of a sample of clay - provided by S A Coombes Jones, L. D.
97/9	Index and oedometer consolidation testing of a glaciolacustrine clay from the Afan-Teifi Catchment, W Wales Hobbs, P. & Jones, L.
97/10	Unconfined compressive strength and density tests on igneous rocks for Hyundai Engineering & Construction Co. Ltd Jones, L.

97/11	Density, porosity, coefficient of absorption saturation coefficient strength of sub samples from 2 blocks of Bulwell stone, Linby Entwisle, D. C.
97/12	Density, porosity, coefficient of absorption saturation coefficient and uniaxial compressive strength of sub samples from 2 blocks of Bulwell stone, from the Yellow Stone Quarry Entwisle, D. C.
97/13	Summary of visit to Colombia, September 1997 Donnelly, L. J.
97/14	Density and porosity on rock samples from the Monadhliath area, Scotland Entwisle, D. C.
97/15	Thermal properties of core samples taken from the Oriactico site Gunn, D. A.
98/1	No Report
98/2	Geotechnical properties of the Sesame Core Jones, L. D.
98/3	Determination of the shrinking and swelling properties of the Mercia Mudstone Jones, L. D.
98/4	Landslides and mudflows along the Antrim basalt escarpment, and in Belfast City, Northern Ireland Donnelly, L. J.
98/5	Shrinkage limit testing (BS 1377, TRRL method) of clays from the Gault Clay, London Clay, Reading, and Afron Teifi formations Hobbs, P. R. N.
98/6	Density and porosity on rock samples from the Isle of Skye, Scotland Entwisle, D. C.
98/7	Density and porosity of rock samples from the Southern Highlands, Scotland Entwisle, D. C.
98/8	Engineering laboratory determination on samples of building stone from Glasgow Cathedral and Rosslyn Chapel Entwisle, D. C. & Allen, M.
98/9	Boulders from Manhole 12, Swansea Bay BWIS Contract 6 (Tarmac/Soletanche) Entwisle, D. C.
98/10	Shrinkage Limit testing (BS 1377, TRL method) of clays from the Mercia Mudstone Group Hobbs, P. R. N.
98/11	No report

98/12 Density and porosity and uniaxial compressive strength of three rocks from Singapore

Entwisle, D. C.

98/13 Density and porosity of rock samples from the Monadhliath area, Scotland

Entwisle, D. C.

98/14 Safety regulations and precautions to be observed when working in the ‘Coastal and Engineering Geology’ Laboratories and stores at Keyworth (version 6:30/9/98)

Northmore, K. J.

98/15 Density, porosity, saturation coefficient and water absorption of two samples of Old Red Sandstone for the renovation of Pitmuies

Entwisle, D. C.

98/16 Engineering laboratory determinations on a block sample of Old Red Sandstone from the Inverness area

Entwisle, D. C.

99/1 Engineering laboratory determination on a block of Lower Carboniferous Sandstones

Entwisle, D. C.

99/2 Density and porosity of core samples of Permo-Trias sandstones and siltstones and hand specimens of various Ordovician and Silurian rocks from Dumfriesshire

Entwisle, D. C.

99/3 Density, porosity, unconfined compressive strength and triaxial strength on a chalk boulder from Beachy Head

Entwisle, D. C.

99/4 GASPRO Project Bid

Gunn, D.

99/5 Researching and maintaining gas generation in sand sediments Henshaw, A.

99/6 A note on dealing with earthquakes in cities of developing countries

Gunn, D.

99/7 Determination of the shrinking and swelling properties of the clays at the Lambeth Walk

Jones, L. D.

2000/1 EGS XXV: Visit Report – June 2000 Gunn, D.

2000/2 Density, porosity, water absorption, saturation coefficient, compressive strength and acid impression determination on samples from the Swinton Quarry, Bordan. – June 2000

Entwisle, D. C.

2000/3 ESF Exploratory Workshop on Seafloor Carbon Flu via Methane – June 2000

Gunn, D.

2001/1 Density and porosity of core samples from borehole AD25, NGR NJ96875E 37155N in the ARJHRATH – Dudwick Area, Aberdeenshire, Scotland

Entwisle, D. C. & Huergo, C.

2001/2	Density, porosity, water absorption, saturation inefficient, compression strength and sodium sulphate crystallisation determination on samples of Stainton Sandstone and Woodkirk Stone for Arch Henderson Ltd, Dundee Entwisle, D. C. & Allen, M.
2001/3C	Triaxial hydraulic conductivity determinations on three BES – crushed millstone grit mines for Wardell Armstrong and AIG. Entwisle, D. C.

Appendix 17 Laboratory Reports for the NIREX Project (1991 – 1995)

Sellafield Borehole No. 2

Hobbs, P. R. N., Entwisle, D. C., Jones, L. D. & Busby T., 1991. Sellafield BH2 - Geotechnical and Geophysical Results - St. Bees Sandstone, Part 1. (3 parts). CCP Report No. CC91S/018/IF-A-C.

Abdeldayem, A. L. & Tarling, D. H. 1991. Magnetic Analysis of Selected Samples of Sellafield BH2 Permo-Triassic Core. (1991) A.L. CCP Report No. CC91S/039/IF-A-C.

Hobbs, P. R. N., Entwisle D. C., Jones, L. D. & Collins, B.1991. Sellafield Borehole 2 - Geotechnical and Geophysical Results, Borrowdale Volcanic Group - Part 1. (4 parts). CCP Report No. CC91S/056/IF-A-C.

Abdeldayem, A. L. & Tarling, D. H. 1991. Magnetic Analysis of 35 Samples of Sellafield BH2 Permo-Triassic Core. CCP Report No. CC91S/064/IF-A-C.

Soos, T. 1991. Thermal Properties of Selected Samples from Sellafield BH2 Core. CCP Report No. CC91S/066/IF-A-C

Abdeldayem, A. L. & Tarling, D. H. 1992. Magnetic Analysis of Selected BVG Samples from Sellafield BH2. CCP Report No. CC92S/081/IF-A-C.

Hobbs, P. R. N., Entwisle, D. C., Jones, L. D., Collins, B. & Jones, D. 1992. Sellafield Borehole No. 2 - Geotechnical and Geophysical Results (part 2) CCP Report No. CC92S/088/IF-A-C.

McCann, C. & Marks, S. G. 1992. P- and S-wave Measurements on Core Samples from Sellafield BH2. CCP Report No. CC92S/104/IF-A-C

Gunn, D. 1992.Specific Heat Capacity of Rock Samples Taken from Sellafield BH2 Core. CCP Report No. CC92S/127/IS-A-C

Gunn, D. 1992. Thermal Expansion of Rock Samples Taken from Sellafield BH2 Core. CCP Report No. CC92S/158/IF-A-C.

Gunn, D. 1992. Thermal Conductivity of Rock Samples taken from Sellafield BH2 Core. CCP Report No. CC92S/185/IF-A-C.

Hobbs, P. R. N., Entwisle, D. C., Jones, L., Collins, B. & Raines, M. G. 1992. Sellafield 2, Permo-Trias: Intact Rock Properties of core from the Permo-Trias from Sellafield Borehole No. 2. Compiled Factual Report. CCP Report No. CC92S/198/CF-1-A. Nirex report No. 201.

Hobbs, P. R. N., Entwisle, D. C., Jones, L., Collins, B. & Raines, M. G. 1992. Sellafield 2, Borrowdale Volcanic Group. Intact Rock Properties of core from the Borrowdale Volcanic Group from Sellafield Borehole No.2. CCP Report No. CC92S/204/CF-1-A. Nirex Report No. 209.

Sellafield Borehole No. 3

Abdeldayem, A. L. & Tarling, D. H. 1992. Magnetic Analysis of Selected Samples from the St. Bees Sediments of Sellafield BH3. CCP Report No. CC92S/100/IF-A-C

Hobbs, P. R. N., Entwisle, D. C., Jones, L., Collins, B. & Jones, D. 1992. Sellafield Borehole No. 3: Geotechnical Results (Permo-Trias - Part 1). CCP Report No. CC92S/109/IF-A-C

Hobbs, P. R. N., Entwisle, D. C., Jones, L., Collins, B. & Jones, D. 1992. Sellafield Borehole No. 3: Geophysical Results (Permo-Trias - Part 1). CCP Report No. CC92S/110/IF-A-C.

Hobbs, P. R. N., Entwisle, D. C., Jones, L., Collins, B. & Jones, D. 1992.Sellafield Borehole No. 3: Geotechnical Results (Carboniferous Limestone - Part 1) CCP Report No. CC92S/111/IF-A-C.

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Tarling, D. H., Bowers, R., Davies, P. H. & Abdeldayem, A. 1992. Magnetic Analysis of Selected Samples. Sellafield BH3. CCP Report No. CC92S/136/IF-A-C.

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Gunn, D. 1993. Thermal Conductivity of Rock Samples taken from Sellafield BH3 Core. CCP Report No. CC93S/232/IF-A-C.

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Gunn, D. 1993. Compressional and Shear Wave Velocity of Rock Samples taken from Sellafield BH3 Core. CCP Report No. CC93S/250/IF-A-C.

Entwisle, D. C, Hobbs, P. R. N., Jones, L. D., Collins, B., Raines, M, G, & Gunn, D. 1993.Intact rock properties of core of the Permo-Trias from Sellafield borehole No. 3. CCP Report No. CC93S/312/CF-1-A. Nirex report No. 222

Entwisle, D. C., Hobbs, P. R. N., Jones, L. D., Collins, B., Raines, M. G. & Gunn, D. 1993. Intact rock properties of core of the Carboniferous Limestone from Sellafield borehole No. 3. CCP Report No. CC93S/313/CF-1-A. Nirex report No. 228.

Entwisle, D. C., Hobbs, P. R. N., Jones, L. D., Collins, B. & Raines, M. G. 1993.Intact rock properties of core of the Borrowdale Volcanic Group from Sellafield borehole No. 3. CCP Report No. CC93S/314/CF-1-A. Nirex report No. 229.

Sellafield Borehole No. 4

Hobbs, P. R. N., Entwisle, D. C., Jones, L., Collins, B. & Jones, D. 1992. Sellafield Borehole No. 4: Geotechnical Results (Part 1, volumes 1). CCP Report No. CC92S/139/IF-A-C.

Hobbs, P. R. N., Entwisle, D. C., Jones, L., Collins, B. & Jones, D. 1992. Sellafield Borehole No. 4: Geophysical Results (Part 1, volume 2). CCP Report No. CC92S/140/IF-A-C

Hobbs, P. R. N., Entwisle, D. C., Jones, L., Collins, B. & Jones, D. 1992. Sellafield Borehole No. 4 - Geophysical Results (Part 2). CCP report No. CC92S/197/IF-A-C

Gunn, D. 1993. Compressional and Shear Wave Velocity of Rock Samples taken from Sellafield BH4 Core. CCP Report No. CC93S/251/IF-A-C.

Tarling, D. H. & Shi, H. 1993. Magnetic Analysis of Selected Sellafield Borehole 4 Core Samples. CCP Report No. CC93S/269/IF-A-C.

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Hobbs, P. R. N., Entwisle, D. C., Jones, L., Collins, B., Jones, D. & Raines, M. G. 1992. Intact rock properties of core of the Borrowdale Volcanic Group from Sellafield borehole No. 4. CCP Report No. CC93S/315/CF-1-A. Nirex report No. 528.

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Hobbs, P. R. N., Entwisle, D. C., Jones, L. & Collins, B. 1992. Sellafield Borehole No. 5 - Geotechnical Results Permo-Trias. CCP Report No. CC92S/181/IF-A-C

Hobbs, P. R. N., Entwisle, D. C., Jones, L. & Collins, B. 1992. Sellafield Borehole No. 5 - Geophysical Results Permo-Trias. CCP Report No. CC92S/182/IF-A-C.

Hobbs, P. R. N., Entwisle, D. C., Jones, L. & Collins, B. 1992.Sellafield Borehole No. 5 - Geotechnical Results Borrowdale Volcanic Group. CCP report No. CC92S/183/IF-A-C.

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Tarling, D. H. & Shi, H. 1993. Magnetic Analysis of Selected Sellafield Borehole 5 Core Samples CCP Report No. CC93S/270/IF-A-C.

Entwisle, D. C., Hobbs, P. R. N., Jones, L. D., Raines, M. G. & Gunn, D. 1993. Intact rock properties of core of the Permo-Trias from Sellafield borehole No. 5. CCP Report No. CC93S/316/CF-1-A. Nirex report No. 529.

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Raines, M. G. 1995. Results of magnetic Susceptibility Measurements on the BVG cores of Sellafield Boreholes 8A, 8B, 11A, 13A and 14A. CCP Report No. CC95S/617/IF-A-C

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Appendix 18 Project Notes (1991 – 2000)

91/1 Opportunities for sub-surface geo-electrical surveys in the search for new ore reserves at the Tara Mines Property, County Meath, Northern Ireland

Evans, A. D.

91/2 Report on a visit to Zimbabwe by a hydrogeological team. 23 Sept - 12 Oct 91

Peart, R. J. & Shedlock, S.

91/3 Report on a short liaison visit to the Geological Survey and Mines Department Entebbe, Uganda 13 - 16 October 1991

Peart, R. J.

92/1 Fault detection using resistivity measurements at Marston Vale & Bedfordshire

Busby, J. & Peart, R. J.

92/2 Geoelectrical traverses to detect shallow pore-water chemistry variations across the western edge of Black Wood, Hampshire

Peart, R. J.

92/3 Visit to Oman for tender prep and submission

Shedlock, S.

92/4 Engineering Geology of Tropical Red Soils Project: Report on ODA funded Research to 31st March 1992

Northmore, K. J.

92/4 Ground probing radar surveys notes, Stratford upon Avon

Greenwood, P. G.

92/5 Ground probing radar surveys at Breedon-on-the-Hill Church, Leicestershire

Greenwood, P. G.

92/6 Induced Polarisation and Magnetic susceptibility observation from boreholes in igneous and metamorphic rocks at Claymires, near Knock, Banffshire

Evans, A. D.

92/7 The Windows Show, Olympia

Thompson, G.

92/8 Interim Report on El-Barrocal 22/4 - 2/5S

Shedlock, S.

92/9 Geotechnical sampling methods for Tropical Red Clay Soils. Report of visit to Kenya 6.1.92 - 25.3.92

Hallam, J. R. & Northmore, K. J.

92/10 Wide-band electromagnetic sensors

Beamish, D.

92/11 SGI Explorer Course

Thompson, G.

92/12 Review of Database Development Package

Thompson, G.

92/13	SAS Version 6.06 Course	Thompson, G.
92/14	Leicester Polytechnic Assignment 2	Thompson, G.
92/15	Windows - based Database Development Packages	Thompson, G.
92/16	Non-invasive waste site characterisation by tracer and geometric imaging tracer	Ogilvy, R. D.
92/17	Review of Student Placement at BGS	Thompson, G.
92/18	Seismic refraction survey at Badagnano, Italy on behalf of Geosystem srl	Peart, R.
92/19	A cross-hole seismic tomography survey at Badagnano near Carpeneto, Italy	Shedlock, S. L.
92/20	Methods for recognition of geological weakness zones and their surface discontinuities caused by underground mining in Carboniferous terrain	Peart, R. J., Raines, M. G. & Rippin, G. E.
92/21	Rainfall induced landslides in the Mediterranean mountainous zone of Europe. The preparation of hazard maps in selected areas of Italy, Spain and Greece using a geographic information system (GIS) CEC Epoch Contract 0029. Progress Report September 1992	Gostelow, T. P.
92/22	Geophysical investigations in the Wibtoft area -1:10,000 sheets SP48NE, SP 48 SE and SP58SW. Part of 1:50,000 sheet 169 Coventry	Raines, M. G.
92/23	The shear strength of three marine sediments	Entwisle, D. C.
92/24	Graphics software for display of acquired data using Gragflibs routines from Sucrasoft	Meldrum, P.
92/25	Report on DDP Leg 144. Atolls and Guyots II Majuro-Yokohama. 18 May-22 July 1992	Hobbs, P.
92/26	Report on visit to Kenya 22 November-5 December 1992	Northmore, K. & Jackson, P.
92/27	QA/QC procedures - 1. Office procedures and policies	Page, J. H.
93/1	The geology and geography of Costa Rica with particular reference to secondary seismic hazards	Forster, A.

93/2	The geology and geography of China with particular reference to secondary seismic hazards Forster, A.
93/3	Report on a visit to Costa Rica, 7-20 February 1993 Culshaw, M. G. & Gunn, D. A.
93/4	A cross-hole seismic tomographic survey at Wood Lane, West Bromwich on behalf of British Geotechnical. Shedlock, S. L.
93/5	Seminar on Professional Affairs (Geological Society 11 March 1993) Summary notes Northmore, K. J.
93/6	Rescan resistivity mapping system: - hardware overview Meldrum, P. I. & Jackson, P. D.
93/7	Rescan resistivity mapping and monitoring system Meldrum, P. I., Jackson, P. D. & Bosworth, N.
93/8	Decoding instrumentation for selecting electrodes from within a very large array Meldrum, P. I., Jackson, P. D. & Bosworth, N.
93/9	A field instrument for re-programming Erpoms for electrode selection. Meldrum, P. I. & Bosworth, N.
93/10	A general purpose constant current source for resistivity prospecting in a wide range of environmental conditions Meldrum, P. I. & Jackson, P. D.
93/11	Noise rejections in resistivity measurements Meldrum, P.
93/12	Laboratory instrumentation for measurement of the resistivity of rock cores Meldrum, P. I., Bosworth, N., Bradley, D. & Jackson, P. D.
93/13	Interfacing for resistivity prospecting Meldrum, P. I. & Bosworth, N.
93/14	Feasibility report on the application of GIS Gunn, D.
93/15	Geophysical logging of a borehole at Felling Hall, Norfolk Cripps, A. C.
93/16	Fullers Earth clay identification in borehole geophysical logs at Birchwood Pumping Station, Wakeham Cripps. A. C.
93/17	Density, porosity and resistivity results of Sherwood Sandstone Entwisle, D.
93/18	SAE/TAR spreadsheet system on Microsoft Excel Operating instructions Colston, M.
93/19	? Colston, M.

93/20	Report on visit to Kenya. 28 March - 29 April 1993	Meldrum, P. I. & Hallam, J. R.
93/21	EM noise sources on the Keyworth site.	Beamish, D.
93/22	Secondary seismic hazard project report. Visit to China 9 August - 29 August 1993	Forster, A.
93/23	Secondary seismic hazards project. Visit to Costa Rica. 15 August - 18 September 1993	Gunn, D. A. & Culshaw, M. G.
93/24	Natural Disasters: Protecting Vulnerable Communities, IDNDR 13-15 October, 1993. A Conference Report	Gunn, D. A.
93/25	ODP Leg 144 Post-Cruise Meeting 2-11 Oct 1993, Sicily	Hobbs, P. R. N.
93/26	Wigan-Applied Geological Mapping Project. Report to the Steering Committee	Forster, A.
94/1	Azimuthal apparent resistivity measurement for fracture mapping: Initial field trails	Busby, J. P.
94/2	EGG Business Report - February 1994	Ogilvy, R. D.
94/3	Moisture monitoring in road embankments	Gunn, D., Jackson, P. D., Northmore, K., Meldrum, P. & Jones, L.
94/4	Secondary seismic hazards project. Visit to China, 16-22 January 1994.	Culshaw, M. G. & Forster, A.
94/5	Report on visit to Kenya, 13-25 September 1994	Meldrum, P.
94/6	Report on visit to Kenya, 6-18 December 1993	Meldrum, P. & Gunn, D. A.
94/7	Procedures listing for use of Rescan system at embankment sites, Kenya	Meldrum, P. I. & Gunn, D. A.
94/8	Detection?	
94/9	Wigan Applied Geological Mapping Project Report to the Steering Committee, May 1994	Foster, A.
94/10	Report on a visit to Costa Rica - 13 March to 19 March 1994	Gunn, D.
94/11	Secondary seismic hazard project - Report on a visit to China 6-20 June 1994	Gunn, D. A. & Jackson, P. D.
94/12	GGSD Business Review - July 94	Ogilvy, R. D.

94/13 Comments on the Ground Probing Radar surveys completed by DFA and BGS during 1993 (CEG Germany Project)

Greenwood, P. G.

94/14 Trial pit logging - Sellafield preliminary report 10.94-21.10.94

Cripps, A.

94/15 Commercialisation of BGS Technology and Software

Ogilvy, R. D.

94/16 Geomorphology and Hazards Conference Visit Report

Flint, R.

95/1 Report on ground probing radar survey - Beaufort Gardens, Bishopbriggs

Shedlock, S. L. & Raines, M. G.

95/2 EGG Business Review

Ogilvy, R. D.

95/3 Azimuthal seismic velocity measurements for fracture mapping: initial field trials

Peart, R. J.

95/4 Joint azimuthal apparent resistivity and seismic velocity measurements for fracture mapping; initial field trials

Busby, J. P. & Peart, R. J.

95/5 Report on a Ground Probing Radar survey at Donington, Telford

Shedlock, S. L.

95/6 Adit detection by a geophysical survey – Leadhills

Shedlock, S. L.

95/7 Secondary Seismic Hazard Project - Report on a visit to China 22-30 March 1995

Culshaw, M. G. & Forster, A.

95/8 CCTV Inspection of boreholes at Enderby, Leicester 6 March 1995

Shedlock, S. L.

95/9 EKS Test Records

Beamish, D. & Peart, R.

95/10 Development of Induced Polarization IPT for mapping of contaminated land 94/98

Ogilvy, R. D.

95/11 Engineering Geology of UK Rocks and Soils - Mercia Mudstone - Report No 1994/95

Forster, A. *et al.*

95/12 Report on a visit to Costa Rica - 6-11 March 1995

Gunn, D.

95/13 Report on a visit to El Salvador, 11-13 March 1995

Gunn, D.

95/14 Visit report following field work in The Red River Basin, Vietnam

Peart, R. J. & Davis, J.

95/15	The geology of Weston Point, Runcorn Forster, A.
95/16	The use of ground probing radar to detect toxic waste pits at the Horticultural Research Institute, Littlehampton Peart, R. J. & Rippin, G. E.
95/17	Investigation into resistivity techniques - induced polarisation. New laboratory equipment for electrical resistivity induced polarisation measurements on rocks and sediments Meldrum, P. I.
95/18	Brite Euram. Summary of field notes on measurements carried out at a mine site July 16 - August 7 1994 Meldrum, P. I., Ogilvy, R. D., Jackson, P. D. & Shedlock, S.
95/19	Report on field work Saaraland Germany - Resistivity surveys September 15-24 1995 Meldrum, P. I. & Williams, C.
95/20	Brite Euram, Summary of field work Stratori, Greece, October 2-14 1994 Meldrum, P. I., Ogilvy, R. D., Jackson, P. D. & Hallam, J. R.
95/21	Summary of field visit Kenya March 26 - April 7 1995 Meldrum, P. I.
95/22	Reports on desk study and field work at Chestnut Avenue, Walderslade, Chatham Meldrum, P. I. & Hobbs, P. R. N.
95/23	Preliminary report into the application of neural networks to image re-construction in geophysical tomography Reeves, J. (Vacation student report), Jackson, P. & Gunn, D. (supervisors)
95/24	EGG Business Review September 1995 Ogilvy, R. D.
95/25	Geophysical investigation to determine thickness of “Clay with Flints” at Hawkinge, Folkestone, Kent Raines, M. G. & Jones, L. D.
95/26	Proposal to EC Standards, Measurement & Testing Programme Ogilvy, R. D.
95/27	Cropwell Bishop Quarry Sampling Report Forster, A. & Hobbs, P. R. N.
95/28	Report on a visit to Zimbabwe – ODA Project R6232 – Development of a new well siting technique R Peart & Davies, J.
96/1	Geophysical investigation proposed Morrison Site, Ripon, Yorkshire Meldrum, P., Ogilvy, R. & Shedlock, S.
96/2	UK National Fault Reactivation Register - A proposal (Commercial-in-confidence) Donnelly, L. J.
96/3	BC Research Scheme Civil Engineering Department University of Rome Gostelow, T. P.

96/4	Training course in the application of a PC based G/S to Geological Hazard Mapping Gibson, J.
96/5	Assessment methodology for the production of Secondary Seismic Hazards Maps in El Salvador Gibson, J. & Gunn, D.
96/6	3D resistivity modelling applied to reconnaissance channel mapping Busby, J. P.
96/7	Underground P-wave seismic tomography at Milldam Mine, Derbyshire. Investigations to locate shale horizons associated with the orebody. Interim report: geophone and hydrophone suitability Donnelly, L. J. Shedlock, S. L. Meldrum, P. I. & Jackson, P. D.
96/8	Engineering Geology of UK Rocks and Soils. Mercia Mudstone Geotechnical Literature Review Hobbs, P. R. N.
96/9	Technology Foresight into Capability Development. Development of Geotechnical Capability. Project 77BH 1995-1996 Jackson, P. D., Beamish, D., Busby, J. P., Donnelly, L. J., Flint, R. C., Greenwood, P. G., Gunn, D. A., Hallam, Hallam, J. R., Meldrum, P. I., Ogilvy, R. D., Raines, M. & Shedlock, S. L.
96/10	Field weekend “Gypsum Dissolution” subsidence features, landsliding and shallow mining in North Yorkshire Northmore, K. J. & Cooper, A.
96/11	Electrokinetic research at BGS – 1995 Beamish, D. & Peart, R.
96/12	Report on a visit to Egypt. ODA Project R6232 12 - 26 April 1996 Peart, R. & Davies, J.
96/13	Core Micro - Resistivity system July 1996 Flint, R.
96/14	? Flint, R.
96/15	Opportunities for the British Geological Survey in Colombia, Trinidad and Tobago and Venezuela. Report on the visit to Colombia and Trinidad & Tobago, June 1996. Commercial in Confidence Donnelly, L. J.
96/16	Coal mining and oil exploration in Colombia and the potential future role of the British Geological Survey. August 1996 Commercial-in-confidence Donnelly, L. J.
96/17	Report on visit (and sampling) to Arlesey and Leighton Buzzard brickpits for project 77BH. August 1996 Jones, L., Hobbs, P. & Cripps, A.
96/18	Velocity modelling of Ballotini sediments with controls on the model from laboratory measurements. September 1996 Edwards, J.

96/19	Swelling and shrinkage of soil sites 1996 Jones, L. D. & Cripps, A.
96/19	Mercia Mudstone Report 1995/1996 Forster, A.
97/1	Environmental diagnostics, predicting the transport behaviour of dense immiscible liquids in unsaturated zones of fractured porous rocks Jackson, P. D., Gunn, D. A., Laurence, A. R. Baker, J. & Bloomfield, J.
97/2	Laboratory equipment and initial testing on 82FG gas migration project Jones, L. D. & Flint, R. C.
97/3	Report on the IDNDR audit meeting, 13 February 1997 Gunn, D.
97/4	Geophysical techniques in site investigation Donnelly, L. J.
97/5	Selected photographs of recent volcanic activity. Soufrierre Hills Volcano, Montserrat, West Indies. From the British Geological Survey request of the Overseas Development Administration. (ODA) Donnelly, L. J.
97/6	Brief history of the involvement of the British Geological Survey in Colombia Donnelly, L. J.
97/7	The detection of a buried mineshaft at Lacey Fields Road, Langley Mill Raines, M. G.
97/8	Landslide field visit to Calderdale and Kirklees, West Yorkshire 6/7 May 1997 (72DT A12) (text, sketch maps, photos) Hobbs, P.
97/9	? Northmore, K.
97/10	Report on visits to various sites for sampling for Mercia Mudstone project (77BD) Cripps, A. & Jones, L.
97/11	Density, porosity, coefficient of absorption, saturation coefficient and uniaxial compressive strength of sub samples from 2 blocks of Bulwell stone, Linby Entwisle, D. C.
97/12	Business with Colombia: El Dorado: Land of Opportunities Donnelly, L. J.
97/13	Coastal and Engineering Geology Group, Geophysics mass properties Database ?
97/13	Summary of visit to Colombia, South America – September 1997 Donnelly, L. J.
97/14	(Contents transferred to technical report) Hobbs, P.
97/15	Euroconference - control and management of major natural risk Gunn, D.

98/1 Risk assessment for contaminated land and geological hazards

Donnelly, L. J.

98/2 Properties of Sesame Core Database

Jones, L. D.

98/3 Pit 6E Low Level Radio-active Waste Repository UKAEA, Dounreay, Scotland. Report on an initial site visit to Dounreay to discuss potential geological investigations

Donnelly, L. J.

98/4 The Engineering Geology of British Rocks and Soils. The results of a survey of opinion on the choice to be studied.

Forster, A.

98/5 Report on Conference Visit to OI 98 Brighton

Jones, L.

98/6 Sampling techniques for UK Clay Soils

Jones, L.

98/7 Mining subsidence at Carrickfergus Salt Mines, Northern Ireland

Donnelly, L. J.

98/8 Report on attendance at the annual meeting of the International Council for the exploration for the seas (ICES) Working Group on the effects of extraction of marine sediments at the Marine Ecosystem (WGEXT), Holland 20-24 April

Humphreys, B.

98/9 Report on sampling various locations for visits to Lambeth Group Project

Jones, L. D.

99/1 Report of the Programme Development Group for Coastal and Coastal and Engineering Geology

Rees, J. G.

99/2 Visit to a landslide at The Coombs, Ainthorpe, North Yorkshire, 29 April 1999

Forster, A.

99/3 Gas production, transport and stability in deep sea sediments – The involvement of the DGS in an EC 5th Framework Project

Gunn, D.

99/4 Cliff behind the Beach Head lighthouse. Re-survey on 9.7.99 Hobbs, P. & Slater, M.

99/5 CCTV. Logging of Deep Borehole No.2

Jones, L.

99/6 Laboratory course notes – June 1999

Entwisle, D. C.

99/7 A note on dealing with earthquakes in cites of developing countries

Gunn, D.

99/8 Re-survey of the cliff behind the Beachy Head lighthouse on 8.11.99 Hobbs, P. & Jarrow, A.

2000/1 European Geophysical Society XXV General Assembly, Nice, France – Visit Report

Gunn, D. A.

2000/1 Hatton-silk Willoughby pipeline – concept report – site visit 10.12.99

Hobbs, P. & Barron, A. M.

2000/2 Landslide of the Dorset Coast between Lyme Regis and Hengulbury Head

Forster, A.

2000/3 Result of user survey into shrink/swell behaviour

Jones, L. D.

2000/4 CCTV survey of 14 boreholes for the Environment Agency in Devon

Jones, L. D.

Appendix 19 Administrative Files

History of the Engineering Geology Filing System and Displacement to NGRC

June Page, Personal Secretary

ENGINEERING GEOLOGY GROUP, APPLIED ENGINEERING GEOLOGY 1980-1990
ENGINEERING GEOLOGY AND GEOPHYSICS GROUP, 1991-1997
COASTAL AND ENGINEERING GEOLOGY 1997-1999 - (files were merged during this Period but then split again in 2000 with Coastal files going to the Coastal Programme)
URBAN GEOSCIENCE AND GEOLOGICAL HAZARDS, PHYSICAL HAZARDS, 2000-2006

CEG/OS/ADB	Asian Development Bank
CEG/OS/AFGHAN	Afghanistan
CEG/OS/ALB	Albania
CEG/OS/ANT	Antigua
CEG/OS/ARG	Argentina
EG/37	Argentina
CEG/OS/AUS	Australia
CEG/OS/BAH	Bahrain
CEG/OS//BANG	Bangladesh
EG/48	Bangladesh
CEG/OS/BAR	Barbados
CEG/OS/BEL	Belgium Geological Survey
CEG/OS/BOL	Bolivia
CEG/OS/BOS	Bosnia Herzegovina
CEG/OS/BOT	Botswana
CEG/OS/BRAZ	Brazil
CEG/OS/BRGM	BRGM
CEG/OS/BRU	Brunei
CEG/OS/BUL	Bulgaria
CEG/OS/CAN	Canada
CEG/OS/CCOP	CCOP
CEG/OS/CHILE	Chile
EG/31	Chile
CEG/OS/CHINA	China
EG/49	China
CEG/OS/COL	Colombia
EG/33	Colombia
CEG/OS/CRO	Croatia
CEG/OS/CYP	Cyprus
EG/43	Cyprus
CEG/OS/CZS	Czechoslovakia
CEG/OS/DEN	Denmark
EG/46	Dominica

CEG/OS/DOM	Dominican Republic
CEG/OS/DUB	Dubai
CEG/OS/ECU	Ecuador
EG/35	Ecuador
CEG/OS/ELSAL	El Salvador
CEG/OS/EUR	Europe
CEG/OS/EGT	Egypt
CEG/OS/ETH	Ethiopia
CEG/OS/ETH-CCD	Ethiopia – CCD/Phase II
CEG/OS/FALK	Falkland Islands
CEG/OS/FIJI	Fiji
EG/42	Fiji
CEG/OS/GAMB	Gambia
CEG/OS/GEN	General Overseas (no specific country)
CEG/OS/GER	Germany
CEG/OS/GIB	Gibraltar
CEG/OS/GRE	Greece
EG/47	Greece
CEG/OS/HON	Honduras
CEG/OS/HONG	Hong Kong
CEG/OS/HONG/GEO	Hong Kong - Geotechnical Engineering Office
CEG/OS/IND	India
EG/34	India
CEG/OS/INDON	Indonesia
EG/39	Indonesia
CEG/OS/IDB	Interamerican Development Bank
CEG/OS/IOC	Intergovernmental Oceanographic Commission (IOC)
CEG/OS/IRE	Ireland - Ireland Gas Pipeline
CEG/OS/ITA	Italy
CEG/OS/JAM	Jamaica
EG/32	Jamaica
CEG/OS/JAP	Japan
CEG/OS/JOR	Jordon
CEG/OS/KEN	Kenya
EG/41	Kenya
CEG/OS/KOR	Korea
EG/36	Korea
CEG/OS/KIR	Kiri Bati
CEG/OS/KYRG	Kyrgyzstan
CEG/OS/LAOS	Laos
CEG/OS/LIT	Lithuania
CEG/OS/MAL	Malawi

CEG/OS/MALAY	Malaysia
CEG/OS/MALT	Malta
CEG/OS/MEX	Mexico
CEG/OS/MONT	Montserrat
CEG/OS/MOR	Morocco
CEG/OS/MOZ	Mozambique
CEG/OS /MYA	Myanmar
CEG/OS/NAM	Namibia
CEG/OS/NATO	NATO
CEG/OS/NEP	Nepal
EG/45	Nepal
CEG/OS/NETH	Netherlands
CEG/OS/NIG	Nigeria
CEG/OS/OMAN	Oman
CEG/OS/PAK	Pakistan
CEG/OS/PAN	Panama
CEG/OS/PERU	Peru
CEG/OS/PNG	Papua New Guinea
CEG/OS/PHIL	Philippines
CEG/OS/POL	Poland
CEG/OS/POR	Portugal
CEG/OS/ROM	Romania
CEG/OS/RUS	Russia
CEG/OS/RWA	Rwanda
CEG/OS/ST.HEL	St. Helena
EG/38	St. Helena
CEG/OS/SAUDI	Saudi Arabia
CEG/OS/SEY	Seychelles
EG/40	Seychelles
CEG/OS/SLVK	Slovakia
CEG/OS/SING	Singapore
CEG/OS/SLOV	Slovenia
CEG/OS/SA	South Africa
CEG/OS/SOPAC	SOPAC
CEG/OS/SPN	Spain
CEG/OS/SRI	Sri Lanka
EG/44	Sri Lanka
CEG/OS/SYR	Syrian Arab Republic
CEG/OS/TAI	Taiwan
CEG/OS/THAI	Thailand
CEG/OS/TUN	Tunisia
CEG/OS/TURK	Turkey

CEG/OS/UGA	Uganda
CEG/OS/UNES	UNESCO - IGCP
CEG/OS/UKR	Ukraine
CEG/OS/USA	United States of America
CEG/OS/VNM	Vietnam
CEG/OS/WB	World Bank
CEG/OS/WHO	World Health Organisation
CEG/OS/YEM	Yemen
CEG/OS/ZIM	Zimbabwe

EG/1/9	Organisating Laboratory Testing
EG/3/2	Equipment Laboratory Hard Rock
EG/3/3	Equipment Laboratory Soft Rock
EG/3/4	Equipment Laboratory Electronic/Geophysical
EG/8/4	Laboratory Reports
EG/11/2	Enquiries I.G.S. Laboratory Tests
EG/11/3	Enquiries I.G.S. Laboratory Reports
EG/12/1/3	General (Jan 70- Dec 71)
EG/12/2	Laboratory Tests
P/COM/83JG	Commercial Lab Work – MOVED TO LAB FILE SERIES

RP = RESEARCH PROGRAMMES - FIELD/COMMERCIAL FILES - 1970s-1980s

EG/1/10	CREST Proposals - In Confidence
EG/1/13	Repayment Project Proposals
EG/6/1	RP Field General
EG/6/1/1	RP Field - Scotland
EG/6/2	RP Field Synopses
EG/6/3	Landslips
EG/6/3/1A/B	Landslips (1971-1973) (1974-)
EG/6/3/4	South Wales Landslips
EG/6/3/5	Glyarhigos Farm Landslip (Dulais 6a)
EG/6/3/6	Tarren Pwll-Glo Landslip (Rhondda Fawr 50)
EG/6/4/A/B	Milton Keynes Programme (1968-1969) (1970-
EG/6/4/1	Tattenhoe Borehole
EG/6/4/2	Linford Wood Game Damage
EG/6/4/3	Milton Keynes - Grice Project
EG/6/5/A/B	Dorset Coast (1969-1970), (1971 -
EG/6/5/1	Lyme Bay Marine Survey
EG/6/5/2	Higher Sea Lane Charmouth
EG/6/5/4	Lyme Regis Charmouth Borehole Contract
EG/6/6	RP Field Inland Waterways

EG/6/7	RP Petrockstow
EG/6/8	RP Field Tonbridge & Sevenoaks
EG/6/9	RP Field Mundford
EG/6/10/1	RP Field Foyers Pumped Storage Scheme
EG/6/10/2	RP Field Loch Carron
EG/6/11	RP Field Oxford Clay Survey
EG/6/12A/B/C	RP Field Telford (June 70 - August 72) August 72
EG/6/13	RP Field Warrington New Town
EG/6/14	RP Field Craig Royston
EG/6/15	RP Field Thames Alluvium Tilbury
EG/6/15/1	Thames Subsidence
EG/6/16/1A/B	RP Field S. Essex General (Nov. 71 - Dec 73)
EG/6/16/2	RP Field S. Essex Internal
EG/6/16/3	RP Field S. Essex Estimates
EG/6/16/3/1	RP Field S. Essex Costing - Wimpey Contract
EG/6/16/3/2	RP Field S. Essex Costing - Contract Testing
EG/6/16/4	RP Field S. Essex Computing
EG/6/16/5A/B	RP Field S. Essex Minutes of Meetings (Feb. 72 - Dec. 73)
EG/6/16/6A/B	RP Field S. Essex Data Management (Oct 72 - Nov 73)
EG/6/16/7	RP Field S. Essex Access
EG/6/16/8	RP Field S. Essex Reports to DOE - in confidence
EG/6/16/9	RP Field S. Essex Geophysical Surveys
EG/6/10	Damage to 33kV Cable in S. Essex
EG/6/17	RP Field Stonehouse New Town (Oct. 71-Feb. 72)
EG/6/18	RP Field Tunnels
EG/6/19	RP Field Velocity Scanning
EG/6/20	RP Field Kielder Waterscheme Experimental Tunnel
EG/6/21/1	RP Field Offshore Geotechnical Studies General - in confidence
EG/6/21/2	RP Field Offshore Geotechnical Studies CGU II Edinburgh
EG/6/21/3	RP Field Offshore Geotechnical Studies CGU I Leeds
EG/6/21/4	RP Field Offshore Geotechnical Studies Pockmarks
EG/6/21/5	Data banking of Shallow Offshore Data
EG/6/22	Flotta, Orkney - Oil Storage Tanks
EG/6/23	Central Lancashire New Town
EG/6/24	Jurassic Limestones
EG/6/25	Norwich - Fieldwork
EG/6/26	Scottish Development Sites
EG/6/27	Seismic Reflection Surveys
EG/6/28	Cornish Granite - Geothermal
EG/6/29	Radioactive Waste
EG/6/29/1	Harwell Borehole
EG/6/30	Underground Storage

EG/6/31	Barry Buddon
EG/6/32	Seafloor Geophysical Probes
EG/6/33	Bath
EG/6/34	NERC Marchwood Deep Borehole Site Investigation
EG/6/35	Newborough Test Bed Site
EG/6/36	Hythe/New Romney
EG/6/37	Engineering Seismology - General (Cavity Detection)
EG/10/1	Publications I.G.S.
EG/12/3	Venice Special Project
EG/12/7	South Wales Landslips Enquiries
EG/12/7/1	Pantteg Landslip
EG/12/7/3	East Pentwyn and Bournville Landslips
EG/18/1	Spinner Magnetometer, Imperial College
EG/18/2	In-Site Probes, U.C. of North Wales
EG/18/3	Shallow Water Seismic Profiling System, Reading University
EG/18/4	Geotechnical Mapping of Sea Floor Sediments in Tremadoc Bay
EG/18/5	Geotechnical Mapping of Sea Floor Sediments Using Geophysical Techniques
EG/18/6	In-Situ Dynamic Moduli of Sea Floor Sediments
EG/20/1	General
EG/20/2	Edinburgh (Sewer)
EG/20/3	Edinburgh (Airport)
EG/20/4	Resistivity and Formation Factor
EG/20/5	Northampton Water Project
EG/20/6	Hunterston Underground Oil Storage Logging Investigation
EG/20/7	Crigellachie Road Improvement Scheme - Banffshire
EG/20/8	Telford Development Corporation - Landslide studies

RP = RESEARCH PROGRAMMES - FIELD/COMMERCIAL FILES - 1980s-1990s

P/COR/70BJ	GGS Geotechnical Porosity Data
P/COR/70MG	Geohazards and Insurance Risk
P/COR/70ZU/EAP	University Collaboration Proposals - Engineering Maps UK
P/COR/72BJ	Cornwall and South Devon
P/COR/72BP	Wessex Basin
P/COR/72BP	Wincanton Memoirs/Dorset Coast Memoir - Landslides
P/COR/72BR	Lyme Bay and Bristol Channel
P/COR/72DT	Huddersfield – Leeds
P/COR/72DY	Nottingham Project
P/COR/72FC	Cirencester Memoir
P/COR/72FL	Chiltons
P/COR/72FO	East Anglia Memoir

P/COR/72FZ	London
P/COR/73DB	Databasing Digital Inf. Comp Support
P/COR/75FD	Dual Porosity Res.
P/COR/75FE	Wolverhampton Project
P/COR/76CM	Chalk Aquifer
P/COR/77BD	Engineering bah. Of UK rocks and soils – Gault Clay
P/COR/77BH	Geophysical Borehole Logging
P/COR/77BH	Geophysical Properties of the Rock Mass
P/COR/77BH	Swell/Shrink Characteristics of British mud rocks
P/COR/77FD	London Clay Scoping Studies
P/COR/77TT	ODP Leg 155
P/COR/77WW	ODP Leg 144
P/COR/77YY	ODP Leg 133
P/COR/77ZZ	Archaeology
P/COR/78DS	BGS Information for the Construction Industry and Planners
P/COR/79DA	Drilling Procedure
P/COR/79DA	Quaternary Mapping Methods Project
P/COM/MIS	Miscellaneous Projects
P/COM/09AF	Bradford
P/COM/09EA	Wigan Files 1,2 and 3
P/COM/09RA	Thames Gateway
P/COR/12EG	Zimbabwe
P/COR/12EL	Geotechnical Sampling Methods
P/COM/12EU	Tropical Red Clays
P/COM/12GB	Secondary Seismic Hazards
P/COM/12GB/GM2	GMS General Management
P/COM/12GB	China
P/COM/12GB	Costa Rica
P/COM/12GB	El Salvador
P/COM/12GD	Slope Movement Hazard
P/COM/12GE	ODA R&D project
P/COM/12GE-tech	ODA tech
P/COM/12GR	Costa Rica File 1
P/COM/13EU	Red Clay Soils
P/COM/14HA	TEM Soundings Leam Areg Mexico
P/COM/46XXXD11	Hydrographics at Blackwood, Hampshire
P/COM/E60A	Review of Natural Contamination
P/COM/70EB	Rescan 1
P/R&D/80EA	Rainfall Induced Landslides File 1
P/COM/80EB	Fault Detection Germany
P/COM/80EC	CEC Brite-Euram Electrical Tomography File 1 and 2
P/COM/80EC	Technical

P/COM/80HD	SEEPS
P/COM/81DA	Dounreay
P/COM/81GA	Gibb Sub Contract
P/COM/81PW	Review of Nirex Reports
P/COM/82CE	Geophysical Investigation Tech. – CIRIA Civil Engineering
P/COM/82FA	Landfills on groundwater quality
P/COM/82JM	Seismic Tomography
P/COM/82JY	OS Magnetotelluric Survey
P/COM/83AE	Clay Squeezing
P/COM/83JB	Corescan
P/COM/83AG	Snowdonia 93
P/COM/83GI	Pathway
P/COM/83JA	Internal Mail
P/COM/83JA	Seismic Properties of Sea Floor Sediments Files 1-3
P/COM/83JA	Review
P/COM/83JB	CORSCAN
P/COM/83JB	LAMBDA – Files 1-4
P/COM/83JC	MSC in Contaminated Land Management
P/COM/83JF	Borehole Logging
P/COM/83JH	Study of Ure Bridge
P/COM/83JH	Glen Douglas Embankment
P/COM/83JH/STDG	St Dogmaels Landslip
P/COM/83JJ	Casington Colliery
P/COM/83JJ	Brighton Pipeline
P/COM/83JJ	UKAEA – Dounreay
P/COM/83JK	Geotek Image sea floor experiences – US Navy
P/COM/83JN	US Navy
P/COM/83JN	Beachy Head
P/COM/83JP	Commercialisation of BGS Sparker Source
P/COM/83JQ	Sea Floor Experiments
P/COM/83JT	ODP High T resistivity tool, Files 1 and 2
P/COM/83JT	BSNC LINK Project (London Clay)
P/COM/83JU	Geotek
P/COM/83JW	Commercial Geophysics. Eng. Geophysical Commercial Surveys
P/COM/83JY	Ground Motion Amplification Study
P/COM/83LG	Ghasp I
P/COM/85JX	Non-Contact Core Imaging Project.
P/COM/85JY	Non Contract Core Imaging Project
P/COM/R	British Gas Holly Hill
P/COR/R	Minor Repayments
P/COM/PROP	Proposals

	Channel Tunnel
PM/09AD	Wrexham
PM/09AE	Birmingham West
PM/09LW	Bath
PM/09RB	Southampton Thematic Mapping Project
PM/R&D/3DGM	3-D Geological Models
PM/R&D	Research and Development
PM/09RJ	Deeside Contract
PM/09RH	South West Essex Thematic Mapping
PM/09RL	Castleford - Pontefract
PM/R1	Coventry Nuneaton Thematic Mapping Project
PM/09RJ	Thematic Maps Nottingham Files 1 and 2
PM/CR/11-13EU	Red Clay Soils
PM/37GA	Test Programme. Belgium
PM/59A	West Midlands, Dudley
PM/76BA	Newborough Test Bed Site
PM/79BA	Finance Statement
PM/79DA	Land Surveying Drilling Financial Statement
PM/MODP	MOD Navy
P/COM	Monitoring Progress Report
PM/MR	Minor Repayments Specific
PM/83	Londonderry Shantalow Drainage
PM/83	Minor Repayment General Correspondence
PM/83R	Oil Plus Ltd – Rock Mechanics Test
PM/83RD/	Underground Cavities
PM/83RH	Minor Repayments CEGB landslip
PM/83RL	Dunbar Castle Rock
PM/83RT	British Gas

URBAN GEOSCIENCE AND GEOLOGICAL HAZARDS (UGGH) PHYSICAL HAZARDS (PH) COMMERCIAL FILES

UGHP/P/COM/E1054F72	PRESENCE
UGHP/P/COM/E1110R83/F	URGENT/DETR – Contracts/Proposals/Finance/Quality Plan
UGHP/P/COM/E1110R83/G	URGENT/DETR – General File
UGHP/P/COM/E1110R83/M	URGENT/DETR – Project Meetings
UGHP/P/COM/E1110R83/MS	URGENT/DETR – Miscellaneous Issues
UGHP/P/COM/E110R83/R	URGENT/DETR - Reports
UGHP/P/COM/E110R83/SC	URGENT/DETR – Steering Committee
UGHP/P/COM/E1111R83	PSinSAR – Nigel Press Associates/BNSC
UGHP/P/COM/E1126R84	HYDRAPHYS
UGHP/SP	SPECIAL PROJECTS

UGHP/SP/PSinSAR	Subsidence Study using PSinSAR
UGHP/SP/DGSM	DGSM
UGHP/SP/QMT	Quaternary Methodologies and Training Programme (QMT) – ESB70900109
UGHP/P/COM/E1231R83/CBA	Terrafirma – Cost Benefit Analysis
UGHP/P/COM/E1231R83/CLM	Terrafirma – Co-location meetings
UGHP/P/COM/E1231R83/CUG	Terrafirma – Core User Group
UGHP/P/COM/E1231R83/D	Terrafirma - Dossiers
UGHP/P/COM/E1231R83/F	Terrafirma – Contracts/Proposals/Finance
UGHP/P/COM/E1231R83/G	Terrafirma – General
UGHP/P/COM/E1231R83/MPR	Terrafirma – Monthly Progress Reports
UGHP/P/COM/E1231R83/MS	Terrafirma – Miscellaneous
UGHP/P/COM/E1231R83/PUB	Terrafirma – Publicity/Web Pages
UGHP/P/COM/E1231R83/SW	Terrafirma – Statement of Work
UGHP/P/COM/E1231R83/PMO	Terrafirma – PMO – Milan
UGHP/P/COM/E1231R83/PM1	Terrafirma – PM1 – Utrecht
UGHP/P/COM/E1231R83/PM2	Terrafirma – PM2 – Paris
UGHP/P/COM/E1231R83/PM3	Terrafirma – PM3 – Keyworth
UGHP/P/COM/E1231R83/PM4	Terrafirma – PM4 – Frascati
UGHP/P/COM/E1231R83/PM5	Terrafirma – PM5 - Warsaw
UGHP/P/COM/E1231R83/PM6	Terrafirma – PM6 – Frascati
UGHP/P/COM/E2285R83 – Con	PSIC 4 - Contracts/Proposals/Finance
UGHP/P/COM/E2285R83-General	PSIC 4 - General
UGHP/P/COM/E2285R83-MTS	PSIC 4 - Minutes of Meetings
UGHP/P/COM/E2285R83-RTS	PSIC 4 - Reports
UGHP/P/COM/E2279R83 – BG	Terrafirma 2 – Budget
UGHP/P/COM/E2279R83 – CON	Terrafirma 2 – Contracts/Proposals/Finance
UGHP/P/COM/E2279R83 - GEN	Terrafirma 2 – General
UGHP/P/COM/E2279R83 – MTG	Terrafirma 2 - Meetings
UGHP/P/COM/E2279R83 – SLA	Service Level Agreements
UGHP/P/COM/E1449R83	Land use Planning
UGHP/P/COM/E1492R83	Ben Rhydding Landslide Assessment
UGHP/P/COM/E1450F83	Clyde Basin Environmental Project
UGHP/P/COM/E1551R83	UNESCO/GARS
UGHP/P/COM/E1579R83	PIPEMON
UGHP/P/COM/E1718R75	Task 4. Environment Belfast Map Scoping Study
UGHP/P/COM/E1727R83	Seaham Fissures Project
UGHP/P/COM/E1773N83	EISP-NERC Business Case Phase 2
UGHP/P/COM/E1778R83	Huntsmens Petro.
UGHP/P/COM/E2169R83	Probability of Landslide Impacts on Pipelines
UGHP/P/COM/71900038/39	Dounreay – Geotechnical logging and Geotechnical laboratory testing

UGHP/P/COM/81900071	Bath Stone Mines
UGHP/P/COM/83900259	CCTV Surveys
UGHP/P/COM/83900130	Scoping Study of Maputo Landslips – Mozambique
UGHP/P/COM/83900323	Commercial engineering geology – minor repayment jobs (file formerly CEG/P/COM/83JJ)
UGHP/P/COM/83900332	Landslide Hazard Assessment for Advantica/Transco
UGHP/P/COM/83900525	Cross hole Seismic Investigation
UGHP/P/COM/E1148R83	Glasgow City Council – Digital Geological Information (see also 83JE closed file) (Bellahouston Park)

SCIENCE BUDGET PROJECTS FROM 2000

UGHP/EGRS/M	ENGINEERING GEOLOGY OF UK ROCKS AND SOILS, MANAGEMENT FILE

UGHP/EGRS/BE	Brickearth
UGHP/EGRS/CLD	Clyde Engineering Geology
UGHP/EGRS/DA	Databasing Information
UGHP/EGRS/GGA	Anisotropy of Core Samples
UGHP/EGRS/HYACINTH	Hyacinth
UGHP/EGRS/GGP/RTS	Railway Trackbed Stiffness
UGHP/EGRS/LBA1	Lambda – Non contact resistivity - Geotek
UGHP/EGRS/LBA2	Carbonate Porosity Modelling
UGHP/EGRS/LG	Lambeth Group
UGHP/EGRS/LS	Lias Group
UGHP/EGRS/MM	Mercia Mudstone
UGHP/EGRS/MC	Mersey Corridor Engineering
UGHP/EGRS/LD	London engineering geology
UGHP/EGRS/RGG	Railway geophysics and geotechnics
UGHPEGRS/TILLS	Glacial Tills
UGHP/EGRS/USN	US Navy – 3D Inhomogenity

UGHP/GHR/M	GEOHAZARD AND RISK, MANAGEMENT FILE

UGHP/GHR/CCI	Climate Change Impacts
UGHP/GHR/CS	Coast Scanning
UGHP/GHR/DA	Databasing
UGHP/GHR/DSOL	Dissolution project
UGHP/GHR/EF	Erosion/flooding
UGHP/GHR/EF/WRC	Modelling Flood Risks within Welsh River catchments

UGHP/GHR/H&R	Generic study of hazard and risk project
UGHP/GHR/LSD	Landslides project – see also Filing System in K014
UGHP/GHR/LSD/NG	Landslide Hazard Assessment of the Nefyn Coastal Zone, Gwynedd
UGHP/GHR/SHF	Detection of shafts project

UGHP/GHR/SS	Shrink/swell clays project

UGHP/UG/M	URBAN GEOSCIENCE, MANAGEMENT FILE

UGHP/UG/AGU	Shallow and Perched Aquifers
UGHP/UG/3-D	3-D Rock Mass
UGHP/UG/CB	Clyde Basin
UGHP/UG/GSUE	Geochemical Surveys of the Urban Environment (GSUE)
UGHP/UG/IT	Development of improved IT
UGHP/UG/LD	London
UGHP/UG/LM	Lower Mersey Corridor
UGHP/UG/MAN	Manchester
UGHP/UG/NMB	SE Northumberland
UGHP/UG/PCL	Prioritisation of Contaminated Land
UGHP/UG/SD	Superficial deposits
UGHP/UG/S-PT	Swansea – Port Talbot
UGHP/UG/TG	Thames Gateway
UGGH/UG/AT	Atlantis Project
UGHP/UG/WE	Weathering

UGHP/PROPBASE	PROPBASE

UGHP/PROP/MAN	Management
UGHP/PROP/GGP	Geophysical & Geotechnical property relationships

CEG/NERC1/AT	Awards and Training - **NGRC**
CEG/NERC1/QR	Quinquennial Reviews - NGRC
CEG/NERC2/CEH	
CEG/NERC2/COM	NERC Component Bodies - NGRC
CEG/NERC3/CFM	CFM Implementation Team - NGRC
CEG/NERC3/BRIDGE	High Resolution - Reykjanes Bridge - NGRC
CEG/NERC3/FREE	Forecasting Risk from Extreme Events (FREE) - NGRC
CEG/NERC3/M2M	Fluid Saturated Rocks - NGRC
CEG/NERC3/NICOSS	Non-Invasive Characterisation of the shallow sub-surface - NGRC
CEG/NERC3/ODP	Ocean Drilling Programme - project proposals & pre-contract corr., scientific NGRC
CEG/NERC3/ODUGP/P/DMP	ODP -Downhole Measurement Panel - NGRC
CEG/NERC3/RS	NERC Airborne Remote Sensing Campaign - NGRC
CEG/NERC3/UR	Urban Regeneration of the environment - NGRC

CEG/AD/RP	Report Worksheets – CLOSED FILE - NGRC
CEG/BD2/ALGI	ALGI Technical Group - NGRC
CEG/BD2/CLTF	Contaminated Land Task Force, meetings, general, technical - NGRC
CEG/BD2/CORS	CORSCAN - NGRC
CEG/BD2/DR	Drilling - NGRC
CEG/BD2/EC/LIFE	EU Life – Environmental Programme - NGRC
CEG/BD2/EC/C&S	European Coal and Steel Research Fund - NGRC
CEG/BD2/EG	Engineering Geology Capability - NGRC
CEG/BD2/GP	Geophysics Capability - NGRC
CEG/BD2/HAZ	Hazards - NGRC
CEG/BD2/HGTF	Hydrogeology Business Task Force - NGRC
CEG/BD2/ICI	ICI project - NGRC
CEG/BD2/LSP	Landslips also South Wales Landslip - NGRC
CEG/BD2/MIN-G	Mining – General - NGRC
CEG/BD2/RADW	Radioactive Waste Disposal - NGRC
CEG/BD2/RES	Rescan Commercialisation - NGRC
CEG/BD2/QM	Quaternary Mapping Review - NGRC
CEG/BD2/SEIS	Seismic Tomography - NGRC
CEG/BD2/SSIS	Site Specific Information Services - NGRC
CEG/BD2/TFOR	Technology Foresight Challenge - NGRC

CEG/COM/ENQ…	ENQUIRIES from 1995-2000 under EGG and CG and CEG Groups CLOSED sy
CEG/COM/ENQ…	MINOR REPAYMENT WORK, 83JJ, Successful enquiries 1995-2000

CEG/COM/CM	Computing committees - information, minutes, actions - NGRC
CEG/COM/DB	Databases,- BGS, divisional and group - NGRC
CEG/COM/DPA	Data Protection Act - NGRC
CEG/COM/LA	Licence Agreements - NGRC
CEG/COM/SH	Software and hardware - NGRC

CEG/GB/CEC	Commission of the European Community - NGRC
CEG/GB/CS	Commonwealth Secretariat - NGRC
CEG/GB/CSA	Chief Scientific Advisor - NGRC
CEG/GB/DERA	Defence Evaluation Research Agency - NGRC
CEG/GB/DFID/KAR	DFID/KAR Programme Proposals and Information - NGRC
CEG/GB/DTI	Department of Trade and Industry - NGRC
CEG/GB/DTI/MRP	Mineral Reconnaissance Programme - NGRC
CEG/GB/DTI/OST	Office of Science and Technology - NGRC
CEG/GB/DTI/SCTF	Soil Decontamination Task Force - NGRC
CEG/GB/EN	English Nature - NGRC
CEG/GB/MOD	Ministry of Defence - NGRC
CEG/GB/POST	Parliamentary Office of Science and Technology (POST) - NGRC

CEG/GB/SOEND	Scottish Office Environmental Dept. - NGRC
CEG/GB/TH	Trinity House - NGRC

CEG/LSU/AGID	The Joint Association of Geoscientists in International Development (AGID) - NG
CEG/LSU/BR	Borehole Research Group of the Geological Society - NGRC
CEG/LSU/EG/EM	East Midlands Group of the Geological Society - NGRC
CEG/LSU/ENGEO	Engineering Geology Journal - NGRC
CEG/LSU/EG/WPREG	EG Working Party Report Engineering Geophysics - NGRC
CEG/LSU/IAEG/GHM	Geo Hazard Project - NGRC
CEG/LSU/ICE/SISG	Site Investigation Steering Group - NGRC
CEG/LSU/ICES/MGR	Managing Geotechnical Risk - Steering Group - NGRC
CEG/LSU/ICL	Landslides and Cultural Heritage – International Consortium on Landslides - NG

Universities and Colleges

CEG/LSU/BAN	Bangor – COASTAL AND NGRC
CEG/LSU/BELQ	Belfast – Queens University - NGRC
CEG/LSU/BR	Bristol – COASTAL - NGRC
CEG/LSU/BRD	Bradford – NGRC
CEG/LSU/COG	Cogeoenvironmental - NGRC
CEG/LSU/ED	Edinburgh – DRAW - NGRC
CEG/LSU/HW	Heriot Watt – COASTAL AND NGRC
CEG/LSU/LIV	Liverpool College – NGRC - COASTAL
CEG/LSU/LOIC	London - Imperial College of Science, Technology & Medicine - NGRC
CEG/LSU/LRH	London – Royal Holloway - NGRC
CEG/LSU/LOUC	London - University College - NGRC
CEG/LSU/MAN	Manchester – UMIST - NGRC
CEG/LSU/MCR	Manchester - NGRC
CEG/LSU/MX	Middlesex - NGRC
CEG/LSU/NAT	Natal - NGRC
CEG/LSU/NTU	Nottingham Trent University - NGRC
CEG/LSU/NU	Nottingham University - NGRC
CEG/LSU/PLY	Plymouth Polytechnic – COASTAL - NGRC
CEG/LSU/PRT	Portsmouth - NGRC
CEG/LSU/RG	Reading/PRIS – NGRC – COASTAL
CEG/LSU/SH	Sheffield - NGRC
CEG/LSU/UGEN	University Link Scheme – General – COASTAL/NGRC
CEG/LSU/UNIV	Universities – General – COASTAL/NGRC
CEG/LSU/YK	York - NGRC

CEG/CL/BG	British Gas and **Transco -** NGRC

CEG/ST/ABI	Association of British Insurers - NGRC
CEG/ST/BCL	British Council - NGRC
CEG/ST/BSI	British Standards Institution - NGRC
CEG/ST/BRE	Building Research Establishment - NGRC
CEG/ST/CA	Coal Authority - NGRC
CEG/ST/CC	Countryside Commission - COASTAL
CEG/ST/EA	Environment Agency - NGRC
CEG/ST/LA	Local Authorities – COASTAL AND NGRC
CEG/ST/MIRO	Mineral Industry Research Organisation - NGRC
CEG/ST/NHBC	National House Building Council - NGRC
CEG/ST/NPL	National Physical Lab - NGRC
CEG/ST/NT	National Trust - NGRC
CEG/ST/RDA	Regional Development Agencies - NGRC
CEG/ST/SNH	Scottish Natural Heritage - NGRC
CEG/ST/SSLRC	Soil Survey and Land Research Centre - NGRC
CEG/ST/TRL	Transport and Road Research Laboratory (now TRL) - NGRC

	RESCAN
	CORSCAN
	Patents
	Legal Commercial
	Sparker

CEG/BD2/GP	Geophysical capability - business
CEG/GM/BD/PAT	Patents, IPR, Trademarks
UGHP/P/COM/E1110R83/F	URGENT, EISP Phase 2
UGHP/SP/QMT	Quaternary methodologies and Training Programme (QMT) - File 2

UGHP/PM/BUS/EP	Business Proposals – European - NGRC
UGHP/PM/BUS/F6	Framework 6 - NGRC

UGHP/PM/BUS/INTERREG – Interreg - NGRC

CEG/ST/RT	Rail Track
CEG/ST/EP	English Partnerships
CEG/LSU/ICE	Institute of Civil Engineers
CEG/GB/HA	Highways Agency
CEG/GB/ODPM	Office of the Deputy Prime Minister
CEG/GB/DFID	Department for International Development/Natural resources systems
CEG/GB/DEFRA	DEFRA

CEG/GB/SE	Scottish Executive
CEG/GB/NAW	National Assembly of Wales
CEG/GB/EG	Eurogeosurveys contact
CEG/LSU/ILRG	International Landslide Research Group
CEG/LSU/NEW	Newcastle upon Tyne - File 3
CEG/LSU/LEI	University of Leicester
CEG/LSU/LUT	Loughborough University of Technology
CEG/LSU/PLYM	Plymouth University
CEG/GM/DOT	Department of Transport
CEG/LSU/LDS	University of Leeds
CEGLRD/IGS(s)	Integrated Geoscience Surveys - Southern Britain
CEG/ENQ/GEN	Enquiries, general - non recording - file 3 - circa 2000/2001
CEG/ENQ/GEN	Enquiries, general - circa 2001