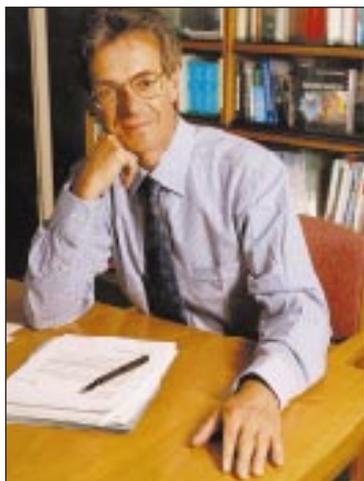




British Geological Survey

# Annual Report 1997-1998

# Foreword



The British Geological Survey (BGS) is an important part of the Natural Environment Research Council (NERC) and I take pleasure in contributing this Foreword to their Annual Report for 1997/98.

During the past four and a half years I have made numerous enjoyable visits to Keyworth and Edinburgh to learn of the work in progress there. This year I was especially privileged to be invited to join the Director and BGS staff on a

field trip to the Lake District; this provided me with insight into the skill, enthusiasm and dedication of those working in the field on mapping programmes.

The period covered by the report has been one of great change for the BGS. It underwent a major, five-yearly review of its entire Core Programme of public-good science. This review culminated in a thorough Science and Management Audit and I am happy to say that the BGS came out of the review process with its stock riding high. At the same time there were changes at the management level with the arrival of a new Director, Dr David Falvey, and the establishment of the BGS Board, under its Chairman Dr Eric Hassall. These changes occurred against a backdrop of change at the national level, with the new Labour Government taking a very active interest in science, and its contribution to society, as part of their Comprehensive Spending

Review; a review which, as you will have seen, produced a very positive outcome in terms of funding for science.

I am pleased to see that the new management arrangements put in place at the BGS are already having an impact. Recommendations from the reviews of 1997 have been taken on board throughout the organisation and measures are being put in place to meet them. The reviews did identify two programme areas which required strengthening and in these areas Programme Development Groups have been established by the BGS Board to do just that. On top of this, the new Director has set in motion a wide-ranging strategic planning exercise. Involving staff at all levels within the BGS and also customer consultation, this process is designed to position the BGS to meet the challenges facing the geosciences at the start of the new millennium.

Despite this year of change, the BGS has continued to deliver against the agreed programme objectives in both its Core Strategic and Commissioned Research programmes. The fact that progress was maintained against targets during this period is a testament to the professionalism and dedication of every member of BGS staff. This report clearly sets out that progress, illustrating the relevance of the science, the benefits it brings to society, and the contribution it can make toward achieving the goal of sustainable development. And geoscience clearly has a vital role to play in achieving that goal: in finding the resources that society needs; in helping to dispose safely of the waste society produces; and in understanding the risks and hazards associated with both these activities. It is a role which puts the BGS at the heart of the science that the NERC must deliver for the nation.

## Professor John Krebs FRS

*Chief Executive of the Natural Environment Research Council.*

## Main cover photograph

This shows the effect of volcanic ash on the centre of Plymouth, the former capital town of Montserrat in the Eastern Caribbean. In the picture, a phone box and the war memorial on the seafront are partially covered by ash and debris deposited by pyroclastic flows and subsequent mudflows since June 1997. Volcanic activity since July 1995 has rendered a large part of the south of Montserrat uninhabitable. Numerous pyroclastic flows have travelled down all flanks of the Soufrière Hills volcano (*background to photo*), destroying a large part of several towns, including Plymouth, and inundated valuable agricultural land. 19 people were killed by pyroclastic flows in the summer of 1997. The BGS has been involved in the monitoring programme of the Montserrat Volcano Observatory since early in the crisis as part of a multidisciplinary and multi-organisation project funded by DFID (*page 27*). (*Photo by G E Norton*).



## Small cover photographs

Thick Ordovician sandstone turbidites (*pale*) interbedded with mudstones (*dark*) north of Ceibwr Bay, west of Cardigan, SW Wales. A study in the architecture and dynamics of these rocks, which were strongly folded during the Caledonian Orogeny, is being undertaken as part of the primary survey of the Cardigan area (*page 5*). (*Photo by R A Waters*).

Cenozoic amber from a Baltic tree containing a fungus gnat and a spider is one of the illustrations in the new BGS Popular Publication *Fossils—the story of life* (*page 18*). (*Photo: BGS/Sedgwick Museum*).

The Permian trace fossil *Umfolozzia longula*, found during the Falkland Islands mapping (*page 23*), is one detail in the evidence linking the islands' rock formations with those of South Africa. (*Photo by D T Aldiss*).

The macroseismic survey for the magnitude 2.8 ML Dartmouth earthquake, 16 October 1997, 00:19 UTC, see Geophysical Monitoring (*page 10*). Areas of EMS intensities 3 and 4 are depicted. The epicentre is shown as a yellow star.

## Bibliographical reference

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# **Report of the British Geological Survey 1997–98**

## ***The Mission of the British Geological Survey is to:***

***Advance geoscientific knowledge of the United Kingdom landmass and its adjacent continental shelf by means of systematic surveying and data collection, long-term monitoring and high-quality research.***

***Provide comprehensive, objective, impartial and up-to-date geoscientific information, advice and services which meet the needs of customers in the industrial, engineering governmental and scientific communities of the UK and overseas, thereby contributing to the economic competitiveness of the United Kingdom, the effectiveness of public services and policy, and quality of life.***

***Enhance the UK science base by providing knowledge, information, education and training in the geosciences, and promote the public understanding of the relevance of geoscience to resource and environment issues.***

**Natural Environment Research Council**

# Contents



C F Adkin

*'Gene' Shoemaker died tragically only months after delivering our Distinguished Lecture of 1997 and receiving his medal (above). He was probably the most influential planetary geologist of our age. His ashes are on board Lunar Prospector, and will eventually land on the Moon.*

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P A Tod



**British  
Geological  
Survey**

*Dr John Carney demonstrates hand-augering as part of an orientation course for those BGS staff without formal geological training.*

# Director's Introduction



I am delighted to have this opportunity to introduce the BGS Annual Report for 1997/98, the first during my term of office as Director. It gives me a chance to reflect on a busy first year in the job and to look forward to some of the things I hope to achieve during what I am sure will be a long and happy association with the BGS.

When I became Director in January 1998, I inherited a successful organisation which was emerging from a series of demanding reviews with great credit. My predecessor, Peter Cook, working with a proactive Programme Board, laid the foundations for that success. Since the start of 1998 the Board has been re-constituted as the BGS Board, with responsibility across all BGS activities. I look forward to building on these foundations with the new Board.

I must say that I have been impressed with the range of expertise and the quality of the science to be found in the BGS. The breadth and depth of the staff's capabilities, when combined with the unique data and knowledge held by the BGS, present a significant opportunity to provide the nation with both scientific and economic benefits. The contents of this report show that the BGS has much to offer across a range of overlapping issues: energy, minerals, water and land resources; geological hazards and risks; waste and pollution; and the impacts of global change.

It is far easier to build from a position of strength than from one of decline. For this reason I concluded that 1998, being the first year without a major external review for some considerable time, presented the BGS with a golden opportunity to plan for a successful future. I therefore initiated a major strategic planning exercise, a process which has now been running for eight months. It has involved contributions from all kinds of people, from junior staff to the BGS Board, and will increasingly involve our stakeholders in Government, industry and the universities, too. Its aim is to produce a new Strategic Plan for the BGS which will set the context for future Business and Programme Planning and guide the organisation into the new millennium.

The process is not yet complete, but it is possible to set out a few of the emerging elements of the new strategy. I will confine myself to just two. Firstly, the BGS will become more and more closely allied with the needs of its customers, working in partnership with them to set the direction for BGS science. This

partnership approach will take various forms, from user panels for the BGS's public-good programme to more formal consortia with industrial and commercial partners, where appropriate. The second element can be summarised as a change in emphasis from data acquisition to data exploitation. Of course, there will be a continuing need to acquire new and better data, but in the future the emphasis will be placed firmly on providing solutions to problems and helping customers to realise opportunities.

These two key elements of the new strategy are linked intimately, because it is through closer relationships with customers that the BGS will develop a fuller understanding of the problems and opportunities facing society. In this respect, the new strategy will focus the BGS on the delivery of 'outcomes' which match BGS data, knowledge and expertise to society's needs. This promises an exciting future for the BGS — for the problems may be great but the opportunities are many.

**David A Falvey**

*Director of the British Geological Survey  
November 1998.*



*Winter at the Keyworth site (photo: P A Tod).*

*The BGS is dedicated to provide, on maps and in databases and written accounts, geological information for all parts of Great Britain and her territorial waters, commensurate with the needs of the whole user community.*

*View looking north-north-west from Ben Venue over Loch Katrine. The hills in the foreground are underlain by Southern Highland Group rocks, giving way to progressively older rocks northwards.*



C W Thomas

#### CORE STRATEGIC PROGRAMME

*This, the principal business task of the BGS, entails long-term mapping/surveying monitoring databasing supporting scientific research and the provision of scientific advice. The Core Strategic Programme contains the underpinning scientific activity which provides geoscientific information in support of decision making by public and private bodies at national to local levels on broad issues relating to resources, land use, geohazards and the environment. A small, but key element of the Core Strategic Programme is the promotion of the public understanding of science. The programme's primary funding is from the Science Budget.*

## Geological Mapping of Britain

The 15-year programme of geological mapping carried out within the Multidisciplinary Regional Surveys sub-programme was started in 1990/91. The cumulative output over the seven years is 159 resurveyed or revised 1:50 000 geological maps, 62 memoirs, three new editions of regional guides and two sub-surface memoirs. During the current year 3303 square kilometres were resurveyed or revised; 299 1:10 000 maps were released to the public (including 24 digital maps) and 103 technical reports written. Eight shallow boreholes, totalling 667 metres, were drilled.

- **Southern Highlands:** mapping efforts have concentrated on the turbiditic Southern Highland Group (*below left*). The work has been particularly useful in developing theories relating to Dalradian structural development, both in terms of proposing mechanisms for cleavage growth, and refining the larger scale tectonic collisional models that imply movement towards the north-east during the peak of the Grampian orogeny. Collaboration with the universities of Edinburgh and Leicester, and the East Kilbride Reactor Centre aims to characterise an important volcanoclastic unit, termed the Green Beds. Preliminary Green Bed geochemical data suggests that they originate from a mixed plume- and N-MORB\* basaltic source. Stream sediment geochemistry is helping to unravel the original basin architecture of the Southern Highland Group turbidite sediments.
- **East Grampian:** cathode luminescence work on thin sections from Dalradian metacarbonate rocks collected in the Tomintoul area has enabled mapping of detailed variations in their strontium content. Preliminary results from the Tayvallich Limestone in the south-western part of the Grampian Highlands suggest that  $\text{Sr}^{87/86}$  ratios may be compatible with Neoproterozoic sea water curves. This technique allows an assessment of the age of the meta-limestone to be made independently of

\*See list of Acronyms (Appendix 8).

## PARTNERSHIP

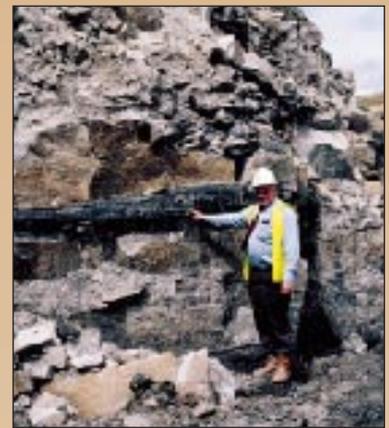


## PROGRAMME

***This is an extension of the Core Strategic Programme, consisting of research activities co-funded by the BGS from Science Budget appropriations, and by partners in the private and public sectors (including the EU). Co-funded projects address surveying and generic research issues relevant to the BGS Core Strategic Programme and to the strategic interests of the co-funding partners. Co-funding helps demonstrate specific customer support for elements of our core strategic programme and is expected to expand in the future.***

other isotopic and stratigraphical constraints.

- **Monadhliath:** with more than 65% of the Central Highlands now covered at the 1:50 000 scale, regional syntheses and a multi-disciplinary approach have been successfully combined to identify a series of marine rift basins of Proterozoic age. Ongoing detailed Quaternary mapping and microstructural studies of glaciolacustrine sediments (*bottom right*) have provided new data and ideas on the patterns of ice movement and deglaciation in the Spey valley and across the Central Highlands.
- **Midland Valley:** work continued on the revision of the Lanark district (Sheet 23), where new opencast mining exploration data has enabled the compilation of a complete Carboniferous sequence in the Coalburn-Douglas area. In the Kilmarnock district (Sheet 22), completion of the survey has enabled a revision of the lithostratigraphy and the clarification of the volcanic processes that produced the Clyde Plateau Volcanic Formation. A regional Midland Valley project was initiated to produce a 3-D computer model of geological surfaces across the region from digital data sets.
- **Southern Uplands:** in the Leadhills district (Sheet 15E) conodont evidence has proved three new localities of Arenig rocks. Detailed revision of the Llandovery graptolite biostratigraphy continues to provide invaluable input to the core mapping programme, particularly in understanding the plexus of tract-bounding faults within the Gala Group in the Thornhill (Sheet 9E) and Moffat (Sheet 16W) districts.
- **Tyne Alston:** revision mapping of the Rothbury district (Sheet 9) concentrated mainly on a reinterpretation of the outcrops of the Cementstone and Fell Sandstone groups. The occurrence of large calcite petrifications of *Cordaites* trees from the Middle Coal Measures, found in an opencast coal mine near Chester-le-Street (Sheet 20 Newcastle upon Tyne) was investigated in collaboration with staff of Durham and London universities (*right*). Proposals to investigate the nature and distribution of mine gas emissions, mainly the mixture of nitrogen and carbon dioxide known as 'stythe', in the Northumberland Coalfield has attracted media attention.
- **Lake District:** the Borrowdale Volcanic Group has been traced to the Appleby district (Sheet 30). Many andesite sheets have been recorded in the dominantly volcanoclastic upper part of the group. Farther south, in the Kendal district, detailed work on the upper part of the sedimentary Windermere Supergroup has established systematic lithological variation which will necessitate a partial revision of the local lithostratigraphy.
- **East Midlands:** research into the subsurface geology of the Loughborough district (Sheet 141) continued with the drilling of a 175 metre-deep hole at Worthington, just west of the Carboniferous Limestone inlier at Breedon Cloud. The borehole proved Lower Coal Measures, down to the Subcrenatum Marine Band, resting on 117 metres of Namurian strata of the Millstone Grit Group. The resurvey of the Melton Mowbray district (Sheet 142) commenced at the beginning of the year. Mapping in the western and southern parts of the sheet has considerably refined the complex drift geology of the Wreake valley; the Bytham Sand and Gravel of pre-Anglian age is overlain by interbedded tills, glaciolacustrine and glaciofluvial deposits of Anglian age.



B Young

*Large petrified Cordaites trunk in sandstone above High Main Coal, Prior's Close North Opencast site, Great Lumley, near Chester-le-Street, County Durham.*



F I MacTaggart

*Small-scale compressional fault with sheared mudstone and disrupted bedding; glaciolacustrine deposits, Raitt's Burn, Spey Valley.*

# Geological Mapping of Britain (continued)

● **Yorkshire:** The five kilometre-long Standedge Canal Tunnel (*below*), built over 200 years ago, was formerly an important trans-Pennine transport route. In advance of remedial work to reopen the tunnel for use in time for the new millennium, British Waterways provided the BGS a unique opportunity to access the entire tunnel. The section records an upward transition from the turbidites of the Shale Grit and Grindslow Shales, deposited in a prodelta or delta slope environment, to the dominantly fluvio-deltaic Kinderscout Grits, deposited on a delta top. This work represents part of an ongoing programme of resurvey of four 1:50 000 Series maps in West Yorkshire. The resurvey of the Wakefield and Bradford sheets is now complete; Huddersfield is nearing completion, and Leeds has been started.



C N Waters

View of Marsden Portal at the entrance of the Standedge Tunnel.

- **West Midlands:** modelling of the Triassic aquifer (*right*) has benefitted from a suite of recently released maps covering part of the Stafford Basin. The integration of seismic data with downhole geophysics and surface mapping has led to a better understanding of the subsurface structure of the Basin, and of the distribution of the Permo-Triassic formations that are an important source of groundwater for public consumption.
  - **Hampshire Basin:** mapping of the Alresford area (Sheet 300) was completed ahead of schedule. This was greatly assisted by the interpretation of 1:25 000 scale stereo air photography using the ImageStation system to produce 'headup' screen images in stereo on which digital linework was interpreted. This new approach to field mapping considerably enhances the production rate in the field and allows targeting of difficult ground. Work has started on ImageStation processing of the photographs for the Winchester area (Sheet 299).
  - **Cotswolds:** the first detailed survey of the Moreton-in-Marsh area (Sheet 217) is nearly complete. Two hitherto unknown outliers of the Middle Jurassic Cornbrash and Kellaways formations have been discovered. The pattern of faulting reflects the deep-seated 'Vale of Moreton Axis', on the eastern margin of the Worcester Basin. Cambering and gulling are widespread in the district, and are important in relation to construction projects. They have been mapped and investigated using geophysical methods including ground penetrating radar and the NERC's Airborne Thematic Mapper.
  - **East Anglia:** the Cromer region (Sheet 131) lies at the interface between deposits of three ice sheets: the British Eastern Ice Sheet, the Scandinavian Ice Sheet of Anglian age, and the younger Devensian Ice Sheet. Remarkably fresh landforms, such as the Blakeney 'esker' and smaller isolated gravel outcrops in the Glaven valley, are considered by some to be constructional glacial landforms, and by others as erosional features. Our research, in collaboration with Royal Holloway, University of London and the University of Brighton, is targeted at determining the provenance, depositional environment and age of these gravels.
  - **London Basin:** mapping west of London has enabled the pre-Anglian courses of the rivers Blackwater, Kennet and Thames to be determined. A model incorporating outcrop and borehole data has led to the determination of dominant north-west-trending faults in the region. They are thought to be the surface expression of basement structures (one underlies the Windsor dome) that may have significant implications for assessment of the Variscan front.
- The Quaternary deposits of the Reading area (Sheet 268) have been reclassified into a series of river terrace deposits relating to the drainage of the proto-Kennet and Thames rivers, together with periglacial weathering and mass-movement deposits. Data from two boreholes have allowed considerable refinement of the Palaeogene stratigraphy.
- **Cornwall and South Devon:** mapping of the Torquay region (Sheet 350) has revealed a 'high' at least 20 kilometres wide to the north of the Looe Basin in the Variscan rifted passive margin of central Cornwall and south Devon. Multiple reef and carbonate complexes developed during the Mid to Late Devonian on this 'high', where it was shielded from clastic sedimentary supply by the formation of a faulted sedimentary basin to the north.
- Collaborative BGS/Durham University CASE research on the Lizard (Sheet 359) has established that different peridotites of the ophiolite complex are related to changing pressure and temperature conditions during tectonically controlled mantle uplift. The distribution of peridotite types has been mapped out in detail.
- **Lyme Bay to Bristol Channel:** the survey of the Triassic, Cretaceous and Tertiary rocks of the Sidmouth area



D M Bridge

*Rock strata which comprise part of the Staffordshire Basin Triassic aquifer: the photograph shows the junction between the weakly-cemented Wildmoor Sandstone and the overlying basal conglomeratic unit of the Bromsgrove Sandstone, Tong Forge, Staffordshire.*

(Sheet 326) continued. Around Beer, an extensive layer of partially dissolved Chalk is underlain by intact Chalk and overlain by Tertiary Clay-with-flints. The position of the partially decalcified layer, which is 15 to 20 metres thick, suggests that it is a Tertiary feature. It may represent an intermediate stage in the formation of Clay-with-flints. Similar, large-scale, pervasive, karstic features are preserved beneath chalk valleys throughout southern England and are probably related in origin to the Beer occurrences. Their recognition has important geotechnical and hydrogeological implications.

● **Swanage:** mapping of the Swanage area (Sheet 343) has been completed. The dominant feature of this district is the approximately east – west Purbeck Monocline and associated fault, which has resulted in a narrow belt of steeply dipping, locally overturned strata. The Palaeogene basin that lies on the north side of this structure comprises a thin London Clay and a much thicker Poole Formation. Within the Poole Formation, a series of clay members include internationally important ball-clay deposits. Close to the monocline the host clays occupy a narrow, structurally complex area.

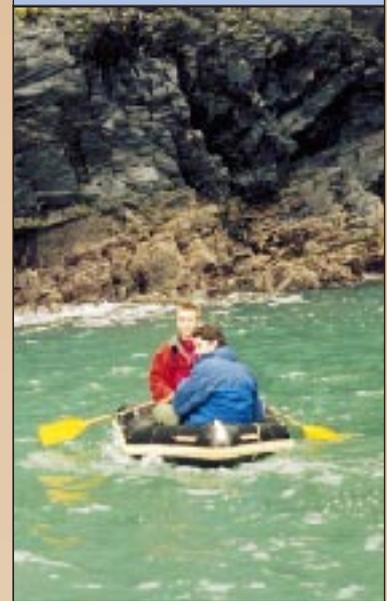
● **Research and Development:** the highlight was the completion of a prototype system to enable geologists to

compile digital field information and other datasets such as mine plans, using PC-based Microstation software. The system is fully compatible with that used by Cartographic Services to produce 1:10 000 and 1:50 000 scale maps and will enable the rapid development of customised map-based products for commercial applications.

● **Continuous revision:** the purpose of this programme, which is of considerable long-term strategic importance, is to address the on-going needs of the geoscience map and data-using community for areas both within and outside the map sheets designated within the 15-year plan. It is carried out by a process of focused data acquisition, databasing and subsequent map revision at scales of 1:10 000 and 1:50 000 for areas, mainly urban, where the demand is high. Revised maps are now available for the Sheffield, Bristol/Bath, Beaconsfield/Reigate and Glasgow areas.

In Scotland, a proactive policy of data acquisition was pursued, with three BGS boreholes and 30 commercial boreholes examined and data incorporated in correction copies. In addition, 22 non-coal mine plans, 3100 mine entries and 14 000 records of quarries were researched, validated and entered into digital datasets.

● **Cardigan:** the Moylgrove Group is a poorly known, late Ordovician, deep-water turbidite sequence that is splendidly exposed in the sea cliffs between Cardigan and Newport in south-west Wales (*below*). A study of the architecture and dynamics of this deformed sandy turbidite system is being undertaken as part of the primary survey of the Cardigan area (Sheet 193).



R A Waters

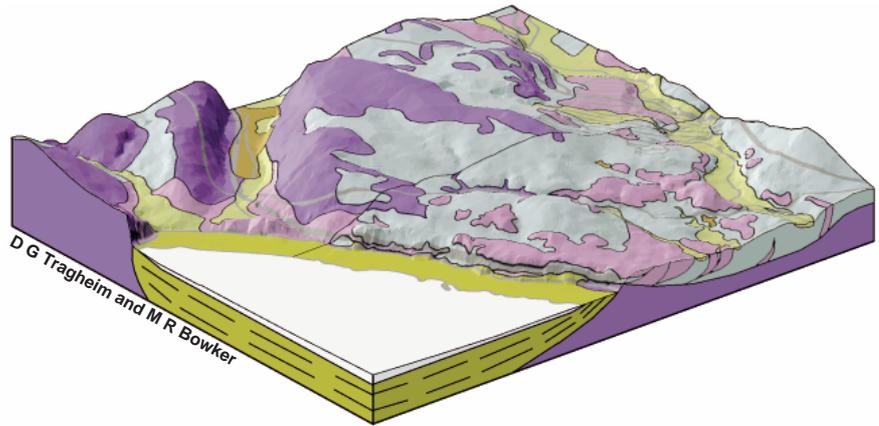
*BGS geologists landing by inflatable to collect graptolite fossils, necessary for the correlation of these Moylgrove sequences. The inaccessibility of the cliffs has precluded a detailed study until now, but the survey is totally dependent on access from the sea.*

# Geological Mapping of Britain (continued)

## PARTNERSHIP PROGRAMME

**Ground level change in the Thames Estuary:** a review was made of potential causes of ground movement and rates of change that may influence the risk of flooding in the next millennium and beyond. The study (in the second year of three) is being carried out for the Environment Agency, in collaboration with the Institute of Engineering Survey and Space Geodesy, Nottingham University.

**Afon Teifi Catchment Survey:** this project, co-funded by a consortium of Local Authorities and the Environment Agency, was completed this year. It has involved the production of 1:25 000 scale maps of the catchment, together with six thematic maps and a Technical Report. Most of the effort focused on the Quaternary deposits. The study, together with two deep boreholes, drilled in abandoned segments of the Teifi valley, has thrown new light on the Quaternary history of the area (*far right*).



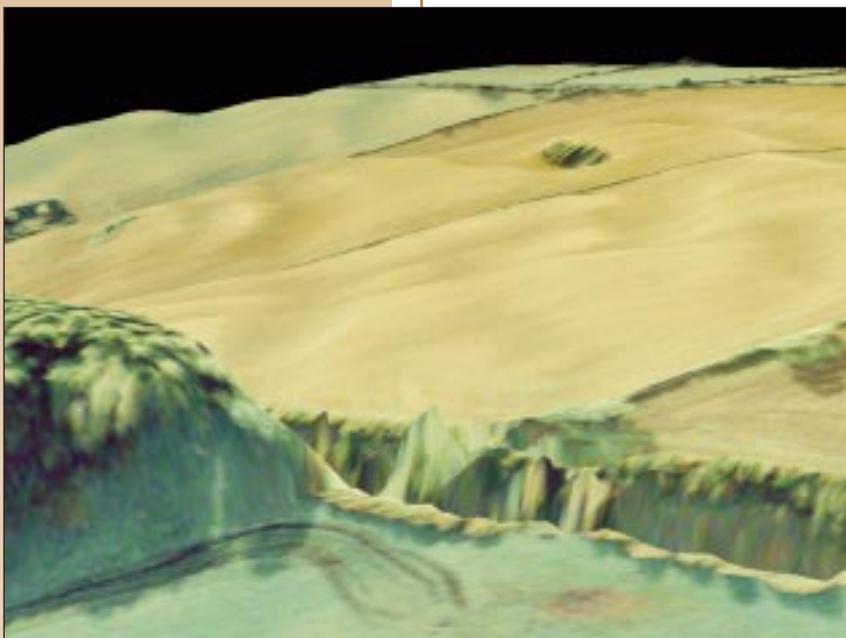
*St Bees area, Lake District: an oblique perspective looking north-east showing Quaternary geology draped over a terrain model produced by digital photogrammetry. Drift-free solid geology is in purple, Boulder Clay in light blue, glaciofluvial deposits (sand and gravel) in pink, river alluvium in pale yellow, marine alluvium in dark yellow, and peat in orange-brown. The cross section shows imbricate slices of sand and gravel wedges caused by glaciotectonics. The area of the image is 34 km<sup>2</sup>.*

## Remote Sensing

Remote sensing covers a wide range of Earth observation techniques from satellite and airborne imagery (*below*) to classical photogeology and digital photogrammetry. The BGS programmes are designed to utilise these techniques to help improve productivity and cost-effectiveness.

## Digital Photogrammetry

A major focus in recent years has been the development of new applications of digital photogrammetry aimed at improving the efficiency of the UK geological mapping programme. These techniques enable on-screen interactive geomorphological interpretation to be carried out of 3-D stereomodels and oblique perspectives derived from high resolution aerial photographs (*above*). Photogrammetry reduces the amount of time needed for fieldwork and thus can improve the speed and cost-effectiveness of mapping programmes. Inputs have been provided to several mapping projects including Alresford, Melton, Winchester and Huddersfield.



*View of an original 1:5000 scale orthophoto draped over a DTM, near Bourton-on-the-Water, Cotswolds, southern England. It shows an unusual pattern of topographic depressions in Middle Jurassic limestones. Rock exposures in the railway cutting, combined with ground penetrating radar, show that the hollows are related to extensional half-graben faults due to mass movement of the limestones above weaker clays at depth.*

D G Tragheim

### Namurian Flooding Events (Realising Our Potential Award)

Studies of catastrophically rapid glacioeustatic marine flooding events in the Namurian of the Central Pennine Basin reveal that they provide the time framework upon which Namurian sequence stratigraphy and lithostratigraphy is interpreted.

Graphic correlation indicates that flooding surfaces are sensitive to differential subsidence, and provides a tool for constraining subtle changes in syndepositional tectonics and differential compaction. Transgressive deposits are rare. Many of the fluvial sediments belong to the highstand phase rather than the early transgressive phase of marine flooding; this is contrary to some recently published models.

### Small-Scale Maps

Regional contour maps at 1:1.5 million scale of the Top Chalk/Base Tertiary of the entire UK (onshore and offshore), the base Chalk of the North Sea (partial) and the base Cretaceous of the North Sea (partial) have been compiled from a variety of sources. Preliminary work for the production of GIS coverages for these structural surfaces has begun, together with rudimentary procedures for generating cross-sections and fault displacement statistics from these coverages. A preliminary 3-D model of major crustal faults and Moho surfaces in southern England is nearing completion

### Minehead Mapping

Following work in the Bristol Channel (1:50 000 Sheet 278 Minehead) an alternative explanation has been advanced for a prominent seismic reflector, originally identified as pre-Devonian metamorphic basement. This reflector is interpreted as the top of the Carboniferous Limestone. This interpretation produces geological relationships which are best explained by reviving Ussher's theory of the Cannington Park Thrust, which has emplaced Devonian and older rocks on Carboniferous Limestone and overlying Silesian, south of Cannington Park and extending westwards offshore.

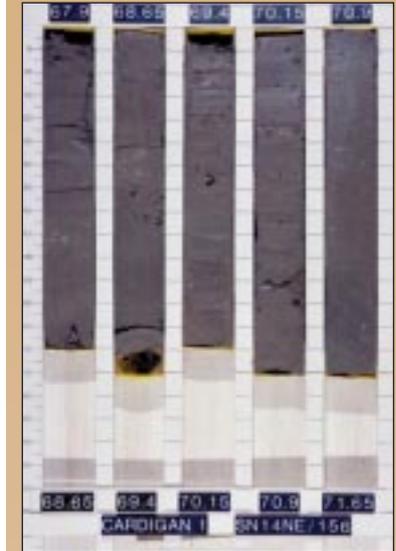
### Cheshire-Staffordshire- Derbyshire Project

Two unconformities are recognised in the subsurface of the Cheshire Basin. The main regional unconformity lies at the base of the Collyhurst Sandstone, caused by folding

and uplift of pre-Permian strata during the Variscan Orogeny. In the southwest and around Milton Green the Warwickshire Group (Erbistock to Ruabon Marl formations) are unconformable on Coal Measures, Millstone Grit, Carboniferous Limestone and older rocks. This relationship persists in the subsurface. Subsurface mapping in Derbyshire shows evidence of Dinantian tilt-blocks dipping southwest.

### Engineering Behaviour of British Rock and Soil Formations

- The analysis of the geotechnical database of the Mercia Mudstone for the effects of regional variation, stratigraphical position and weathering grade has been completed.
- A report on the geotechnical shrinking and swelling properties of the Mercia Mudstone has been finalised.
- The first draft of the monograph on the Engineering Geology of the Mercia Mudstone has been completed.
- Compilation of a geotechnical database for the Palaeocene Lambeth Group is well advanced.
- Field visits to exposures of the Lambeth Group (*below*) have yielded disturbed samples for geotechnical testing and highlighted the engineering complexity of the group.
- A survey of leading engineering geologists in commerce and academia showed continuing support for the Engineering Properties Project and indicated that Lias Clay, Coal Measures Mudrocks and the London Clay should be given high priority for future study.



*Glaciolacustrine clays, exhibiting silt laminae, soft sediment deformation and dropstones (pebbles dropped from icebergs), from a cored borehole (67.9 to 71.65 m depth) near Cardigan. The clays form the lower part of a very thick sequence of glaciolacustrine sediments deposited in a major proglacial lake, ponded by the onshore advance of an Irish Sea ice sheet during the last ice age.*

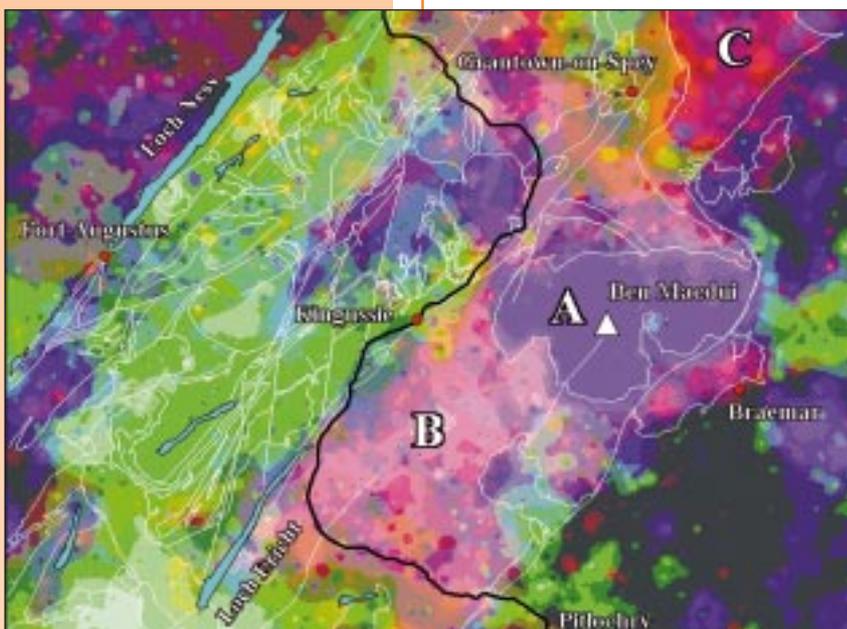
*Alum Bay, Isle of Wight. The vertical-dipping Reading Formation of the Lambeth Group is bounded to the left by London Clay and to the right by Chalk. An earth-flow in the clay of the Reading Formation is 'moving' down the cliff, towards the viewer.*



K J Northmore

*The BGS carries out systematic geochemical surveying of the UK and maintains national databases of geochemical, radiometric and mineral data.*

(Below) *Three-component map for zirconium (red), strontium (green) and rubidium (blue) in stream sediment over part of the central Highlands of Scotland. The highly evolved Cairngorm Granite (A) is clearly defined by high levels of rubidium and low strontium and zirconium. The Strath Tummel Basin (B), part of the Glen Spean–Strath Tummel Subgroup of the Grampian Group, is marked by high levels of zirconium and rubidium (pink hues), reflecting the predominance of K-feldspar and detrital mineral assemblages. The outcrop of this subgroup to the north-east, the Cromdale Basin (C), has a similar signature (the darker colours indicate lower values) but shows less contrast with the geochemistry of the surrounding rocks. The A9 road is shown in black.*



# Minerals and Geochemistry

Striking the balance between the need for a sustainable environment and the need for mineral products requires authoritative, systematic information. Technology Foresight has identified the problems and challenges associated with the stages of the natural resource cycle, from exploration, through the identification, extraction, processing and industrial use of resources, to the disposal of waste and the remediation and aftercare of contaminated land. Collectively, the projects that make up the Minerals and Geochemistry Core Strategic Programme offer the impartial expertise, knowledge and information on which sound economic and environmental decisions can be based at every stage of the cycle. They also provide fundamental data in support of geological mapping.

## G-BASE

The Geochemical Baseline Survey of the Environment (G-BASE) provides baseline geochemical data for soils, stream sediments and waters for economic and environmental applications. In 1997, suites of geochemical samples (stream sediments, stream waters and soils) were collected over an area of 5200 square kilometres in the East Midlands, including both rural and urban areas.

The geochemical atlas for North-west England and North Wales was completed. A hydrogeochemical atlas of Wales (the first of its kind) is in preparation, containing stream water chemistry at a resolution of one sample per two square kilometres. A thematic section to this atlas illustrates how the data may be used to interpret key issues such as regional controls on trace-element speciation, acid rain and eutrofication. G-BASE data are being used to assist in geological interpretation in Scotland (*below left*).

On the international level, the BGS continued to take the lead in initiatives to harmonise geochemical maps and mapping in Europe and worldwide.

## MINGOL (Minerals GIS On-Line)

The basic structure for this minerals information system is now complete, and a CD-ROM is available for demonstration purposes. Data from the DETR-commissioned county Mineral Resource Planning maps for Staffordshire and South Wales were successfully incorporated into MINGOL during the year, and additional maps will be added as they are published. Maps showing the Economic Planning Regions and production data for construction minerals are now available, as well as a national index of mineral exploration data. Revision and updating of the BRITPITS dataset was completed, providing information for a new edition of the Directory of Mines and Quarries (DMQ). Work continued on the 1:250 000 mineral resource map series: the first map, covering the Lake District, is well advanced. Further commodity chapters and a glossary were drafted for a new publication, *Mineral Resources of Britain*.

## Gold in Extensional Basins

A new project on the metallogeny of gold in the Dalradian of the Scottish Highlands involves the multidisciplinary study of various types of gold mineralisation in order to understand its distribution in terms of the sedimentary, magmatic and tectonic development of the Dalradian basin. It is planned to develop a unifying predictive model for the identification of prospective targets in this and similar terrains elsewhere in the world.

**Trace-element Distributions: a New Approach**

A novel approach to the measurement of trace-element distributions in soils and sediments is being developed, which is simpler to carry out than traditional extraction schemes and is more flexible and selective in identifying the presence of different physico-chemical components. The method uses nitric acid as a non-specific extractant. Under different experimental conditions, different proportions of metals are extracted from different phases. After chemical analysis of the resulting solutions, chemometric processing is used to identify and quantify the various components.

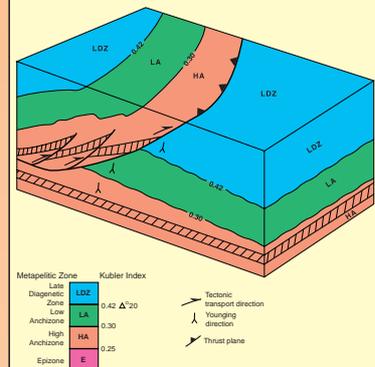
**NERS (Natural Environmental Radioactivity Survey)**

Revised versions of the Liverpool Bay 1:250 000 scale radon potential and gamma-ray-dose maps were prepared. The radon sheet now incorporates the effect of unconsolidated drift deposits as well as the solid rocks, a major advance on earlier products. Similar revision of the Lake District maps was brought close to completion and work commenced on the East Midlands sheet. Studies were continued into the influence of mineralogy on radon emanation for selected rock units, e.g. being the Northampton Sand Formation which is known to have relatively high radon emanation.

PARTNERSHIP		PROGRAMME
<p><b>Interlaboratory comparison:</b> a project supported by the EU has been set up to improve collaboration between the geochemical laboratories of geological surveys in western and eastern Europe (Netherlands, Finland, UK, Estonia, Lithuania, Czech Republic, Slovak Republic, Poland, Romania, Russia and Hungary). The aim of the project is to assess the comparability of data provided by each laboratory for geochemical mapping purposes, to facilitate data interpretation across national borders. During the first year, each laboratory has provided data for an interlaboratory proficiency testing scheme and information on their analytical methods as the basis for detailed assessment of appropriate analytical strategies.</p>		<p><b>Metal-contaminated canal mud:</b> a collaborative study with the University of Nottingham investigated metal contamination of muds from the Birmingham canal system. Cryogenic SEM techniques have been developed to provide detailed petrographic information on the nature of the anthropogenic Cu, Zn, Pb, Fe and P in the unconsolidated sediments. The BGS cryoSEM enables the muds to be examined wet and reduces the disruption of primary fabrics associated with sample drying for conventional SEM. This approach has enabled the processes controlling the 'early diagenetic' mobilisation and fixation of the metals to be evaluated.</p>
<p><b>UK coal resources:</b> the preparation of a map of UK coal resources at a scale of 1:1 000 000, for completion in 1998, was undertaken with the support of the Coal Authority. The map will illustrate the extent, as projections to surface areas, of different categories of resources and former resources of coal and coal-bed methane. The map will include coals of all ages, with an indication of the sub-surface geometry of the resources, both onshore and offshore. The objective of the map is to provide a synopsis for the benefit of both initial environmental assessment and resource management. All the data, including detailed information on production sites, will be integrated into the BGS minerals GIS system (MINGOL).</p>		<p><b>Mineral deposit evaluation:</b> the principal aims of this partnership project between the BGS, who acted as project leaders, DTI, KRJA Systems Ltd and Anglesey Mining plc were to test a mineral exploration methodology based on the PIMA (Portable Infrared Mineral Analyser) and the VULCAN 3-D modelling system, and transfer the methodology to minerals-sector SMEs.</p>
<p><b>Midland Valley of Scotland:</b> a digital database of Mineral Resources in the Midland Valley was prepared in collaboration with Scottish Natural Heritage. Data includes sand and gravel, hard rock aggregate, limestone and coal.</p>		<p>The PIMA was successful in detecting distinctive mineral assemblages related to lithology and hydrothermal alteration at Parys Mountain (right), and 3-D modelling with integrated geological and geochemical data is assisting in metallogenetic studies and the delineation of ore zones. The results also indicate that both PIMA and VULCAN have more general applicability to mineral exploration in other geological environments in Britain. Together they form a powerful combination, with the potential to suggest where a borehole has passed close to a buried ore deposit without intersecting it.</p>

**Basin Maturity**

Basin maturity surveys of UK Palaeozoic basins have shown that distinctive patterns of metapelitic zones indicated by clay-mineral crystallinity are the result of burial and heat flow in different geotectonic settings. Deep-burial and low-heat-flow conditions are characteristic of the Scottish Southern Uplands terrane and the Windermere Supergroup. The Welsh Basin and the Skiddaw Basin in the Lake District are high-heat-flow extensional basins. The Variscan basin of south-west England represents passive-margin sequences which acquired a pattern of burial metamorphism prior to the development of a fold-and-thrust belt.

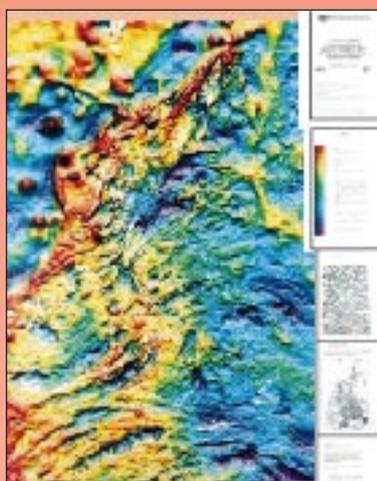


*Block diagram showing inverted pattern of metapelitic zones developed in a typical fold-and-thrust belt. Such patterns are found in low-grade metamorphic terranes on the flanks of major alpine-type orogenic belts.*



**T B Colman**  
*PIMA analysing altered volcanic rock at outcrop, Parys Mountain.*

*The studies of the physical properties of rocks are applied to the solutions of engineering geotechnical, geomagnetic, and seismic problems, to the exploration for mineral deposits and hydrocarbons, and to the understanding of 3-D crustal structure.*



I F Smith  
*Gravity and magnetic maps of Britain, Ireland and adjacent areas, published as part of the BGS 1:1 500 000 scale map series.*

# Geophysics

## National Geophysical Mapping and Databank

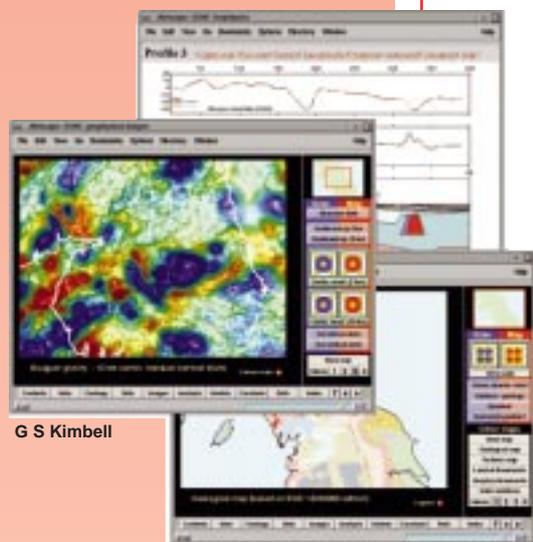
Gravity measurements were made over the Orkney Islands to bring the coverage of this area up to the national standard; the data have been incorporated into the National Gravity Databank. Two maps at 1:1 500 000 scale were published showing gravity and magnetic anomalies over Britain, Ireland and adjacent areas using colour shaded-relief presentation (*left*). Two 1:1 000 000 magnetic anomaly maps were prepared for cartographic enhancement. A prototype graphical interface was developed to browse information held in the Geophysical Surveys databank; this provides access to line-based ground and airborne surveys.

## Regional Crustal Structure

The regional gravity and magnetic data acquired over the UK are being interpreted systematically and the results presented on interactive CD-ROMs. An important input to the interpretation for the current Southern Scotland/Northern England study (*below left*) has been a model for the structure of the cover sequence based on seismic reflection data and developed during earlier BGS projects. Integration of seismic, gravity, magnetic and geological data allows the development of a more complete, three-dimensional model for the crust. Work has commenced on the investigation of the Southern and Eastern England region.

## Interpretation Software

The Colmap (geophysical imaging), Ararat (track-data processing), Wellog (borehole data processing and display) and Gravmag (2.5-D modelling)



G S Kimbell

*(Left) Geophysical data from southern Scotland and northern England displayed using an interface that allows rapid access to a wide range of images and models for the region.*

packages have all been upgraded. Further major upgrades have been made to the 3-D gravity and magnetic modelling programs (Gmod/Bmod), including magnetic layer optimisation and experimental, combined gravity/magnetic optimisation routines. The 3-D software is now being integrated into a workstation-based seismic/gravity/magnetic interpretation package under an agreement with Ark Geophysics.

## Geophysical Monitoring

The UK magnetic observatories at Lerwick, Eskdalemuir and Hartland, and the 141-station UK seismic network were maintained, and improvements made to instrumentation and data collection. Geomagnetic and seismic data were retrieved to Edinburgh automatically under computer control and data products published in electronic form on the World-Wide-Web, providing a seven-day, 24-hour service to academia, government and commerce. Co-operation with other European institutions to promote the rapid exchange of seismic data continued and, through the INTERMAGNET programme, data from a global set of magnetic observatories were exchanged in near real time with agencies in the US, Canada, Japan and France.

## Multicomponent Seismology

Studies of the effects of large faults and fractures on seismic waves have demonstrated the potential for the theoretical techniques developed to be used to assess the sealing capacity of faults in hydrocarbon reservoirs.

## Geotechnical Capability

'Civil Engineering uses of Geophysics' users' input is now being incorporated into the second draft of this report for the Construction Industry Research and Information Association (CIRIA) and the Geological Society.

A database has been designed to enable geophysical properties to be used in geological ground models at the desk study phase of geotechnical site investigations.

## PARTNERSHIP



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**Hi-RES:** the BGS is leading an initiative to fly a new airborne High-Resolution Resource and Environmental Survey (Hi-RES) of the UK. In collaboration with World Geoscience, surveying has commenced on the first phase of this project, which involves magnetic, radiometric and electromagnetic measurements along closely spaced (400 metres) survey lines covering a 200x 70 kilometres swathe across central England. This phase of data acquisition is due to be completed during 1998.

**Rock mass research:** hydrocarbon exploration and waste disposal research need to understand the mechanisms of fluid flow through low-permeability fractured rocks. Boreholes provide a detailed one-dimensional examination of the rock mass, but, to determine the distribution of rock properties away from boreholes, wireline measurements and core sample determinations need to be linked to the broad data coverage provided by seismic surveys. Recent BGS research has led to new techniques for estimating porosity and permeability from acoustic impedance.

**EUROPROBE:** has been supported by the European Science Foundation since 1992. The BGS provides scientific management of the TESZ project. Three project symposia were held. The BGS participates in the 'PACE' TMR research network, funded by the EC's Human Capital and Mobility Programme; two teams are studying the potential field geophysics and isotopic history of the TESZ. Regional magnetic, gravity (geoid) and topographic maps have been generated, and magnetic and gravity modelling has been integrated with seismic and structural interpretation with particular emphasis on the East European Craton/Magnitogorsk volcanic arc collision zone.

**Edinburgh Anisotropy Project:** the EAP consortium grew to include 15 operating, service and software companies sponsoring research into advanced seismic methods. Processing algorithms and interpretational techniques were developed for application to data from vertical cable and sea-bed sensors (*right*) and issues affecting the quality of data acquired on the sea bed were explored. New processing methods were devised for application to towed streamer data. Ideas on using converted shear waves to image beneath basalts, accounting for multiple reflections and other processing problems, were developed and tested.

**Magnetic modelling:** the UK Health and Safety Executive and an oil industry con-

sortium supported the production of the 1997 revision of the BGS Global Geomagnetic Model (BGGM) which incorporates observatory, satellite, land survey and marine magnetic data collected by organisations world-wide. The BGGM provides magnetic reference data for directional drilling of oil and gas wells, helping to achieve geological targets and avoid well collisions. A UK magnetic model was produced, using data from the UK repeat station network, to provide the magnetic information required for Ordnance Survey maps.

**Earthquake Monitoring and Information Service:** the UK seismic monitoring and information service has been supported for nine years by a broadly-based group of customers led by the DETR, including the nuclear, water and oil industries together with a number of public bodies. Seismic activity is monitored throughout the UK using a network of 141 seismometers with information about significant earthquakes disseminated rapidly. The data are compiled into monthly and annual bulletins and reports, which are used to develop the database for seismic hazard assessment.

**Seismic risk for the reinsurance industry:** together with Hiscox Syndicates Ltd, the BGS launched a new system to enable reinsurers to assess earthquake risk (*above right*), in terms of monetary losses, to insurance portfolios. The system, called MONICA, consists of a PC-based seismic risk program and a set of regional data files for different parts of the world. The reinsurance underwriter can handle the program from the insurance viewpoint without needing to understand the geophysical side of the system.

**URALIDES:** this project investigates the Ural Orogen, and BGS participation in the 'URO' TMR research network is providing important new information on the evolution of the fundamental boundary between the crust of Europe and Asia.

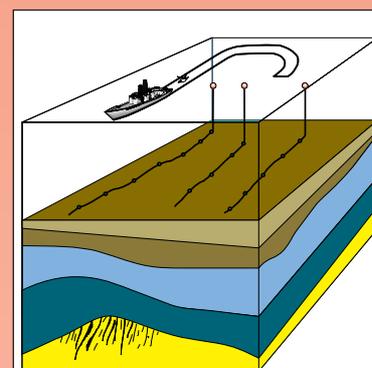
**Enterprise Oil (LAMBDA II):** the impact of fine scale sedimentary structure on petrophysical properties, used to define the reservoir model, has been demonstrated, and the need to image downhole core at the same scale has been established.

**Fractured carbonate core:** a novel technique has been developed for mapping connected fractures, and demonstrated using core from a tight carbonate reservoir. A report has been completed and a patent application filed.

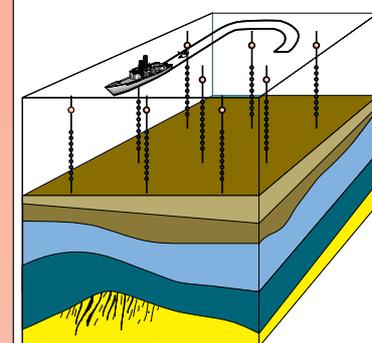


Courtesy of Geophysical Survey of Slovenia

*Damage from the 1998 Bovec earthquake, Slovenia — a reminder that damaging earthquakes can strike outside areas normally regarded as earthquake-prone.*



Sea-bottom Seismic

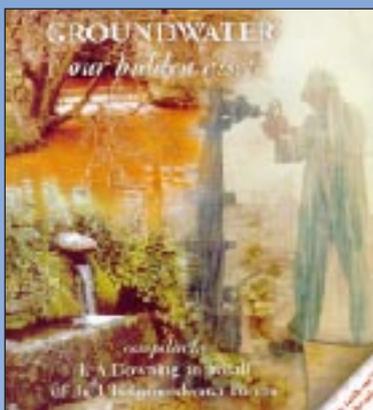


Vertical Cable Seismic

C D MacBeth

*Seismic data acquisition using sea-floor and vertical cable sensors.*

*Research into Britain's groundwater occurrence, movement and quality is applied to groundwater assessment, development and management.*



Groundwater – our hidden asset  
*a booklet to increase awareness of groundwater among the public.*



D K Buckley  
*Geophysical logging and geochemical sampling at the Lytchett Minster ASR trial, Dorset.*

# Hydrogeology

## National Groundwater Survey

The aim of this survey is to produce a series of comprehensive descriptions of the major British aquifers and their groundwater resources. This is carried out in close collaboration with the Environment Agency, water companies and universities in the study areas. The regional survey programme has initiated studies of the Chalk aquifer in the Wessex Basin and the North Downs. The detailed chalk stratigraphy developed over the last few years in the core mapping programme is to be linked to flow horizons in the chalk aquifer to improve the understanding of chalk hydrogeology.

## Groundwater Data Dissemination

The BGS is the custodian of several groundwater datasets of national importance, including 100 000 well records and data on aquifer properties, water chemistry, water levels and geophysics. To provide users of this data with improved access, the Groundwater Data Dissemination project concentrated on developing an integrated database, bringing together existing digital information with key elements of the paper archives. The new WellMaster database is complemented by on-line storage of scanned images of well records, and forms the basis both for answering routine enquiries and for developing a new generation of digital hydrogeological maps and derivative products such as CD-ROMs and on-line databases.

## Geophysical Logging Activities

Geophysical logs of 93 boreholes have been completed during the year. Nine boreholes were logged for BGS stratigraphical purposes, and 23 for other purposes, mainly hydrogeology; 61 were completed for water companies (left), environment agencies and engineering consultancies. New software has considerably enhanced interpretation and allowed the group to provide sealed cross-sections employing the logging data.

## Transport and Fate of Pesticides

In this joint project with the Institute of Hydrology, work has continued on

studying the movement of water and solutes from the land surface into the Chalk aquifer. At the field site in Hampshire, sampling of groundwater for pesticides during recharge events has continued, and data from a more restricted range of soil instrumentation has been collected and interpreted in relation to the timing and amounts of preferential flow in the Chalk unsaturated zone. Further unsaturated coring was undertaken to look for pesticide residues and an applied bromide tracer in the Chalk matrix. In the laboratory, microcosm experiments by both the BGS and IH to determine the factors controlling pesticide degradation in the unsaturated zone have continued.

## Minor Aquifers

This project on the physical properties of the minor aquifers of England and Wales follows on the success of the manual and CD-ROM database of major aquifers properties data which was published early in 1998.

## Geosphere Waste Containment

A radial array of instrumented boreholes in the Mercia Mudstone Group under the Keyworth site was successfully used for a series of in-situ, gas-injection experiments. High-quality test data have been obtained which match observations made previously in the laboratory. The field results have added to our understanding of how gases move through mudrocks, and have demonstrated that the application of conventional two-phase flow theory does not best describe the transport of high-pressure gases through clay-rich media.

## Fluid-rock Reactions and Properties

The rate and mechanism of reactions between fluids and minerals have important consequences for the extractive (e.g. hydrocarbons, metallic minerals) and disposal (e.g. landfill, nuclear) industries. New experimental equipment has been developed to study these reactions and enhance our ability to predict pollution problems and help improve extraction technologies.

**PARTNERSHIP**



**PROGRAMME**

**Major-aquifer properties:** the Aquifer Properties Manual has now been published. This is the product of a three-year collaborative study between the BGS and the Environment Agency. It describes the physical hydraulic properties of six major aquifers in England and Wales, and is accompanied by a CD-ROM containing summary data (pumping tests and core analyses) for over 2000 sites.

**Nitrate in the Yorkshire Chalk:** a project, co-funded by the BGS and Yorkshire Water, to predict groundwater nitrate concentrations in the Chalk aquifer of East Yorkshire has been completed.

**PALAEAUX:** this European Union-funded project, involving partners from Estonia, Denmark, France, Belgium, The Netherlands, United Kingdom, Switzerland, Spain and Portugal, has been investigating the geochemical and other evidence for palaeowater occurrence as background to improved management of groundwater resources in coastal regions under severe pressure due to human settlements, industry and tourism.

**Natural baseline quality of UK groundwaters:** phase I of a joint project with the Environment Agency has been completed covering seven areas of the main UK aquifers which should be the pilot project for a nationwide study. These regional studies will serve as references against which current and targeted groundwater quality may be measured (*right*).

**Natural attenuation of organic pollutants in groundwater:** in conjunction with the University of Sheffield and the Institute of Freshwater Ecology, redox zones have been mapped out in the contaminant plume in the Triassic sandstone aquifer beneath a coal distillation plant in the Midlands.

**UK Groundwater Forum:** this forum provides a creative meeting ground to promote wider understanding of groundwater issues and identify national priorities. The recent publication (*left*) of the book *Groundwater – our hidden asset* will increase awareness of groundwater among the public

**Potential for ASR in Britain:** BGS/EA/UKWIR co-funded a study to review the potential for Aquifer Storage Recovery in Britain (*right*), highlighting the issues involved through seminars and wide consultation. Regulatory issues were addressed and generic research needs were identified.

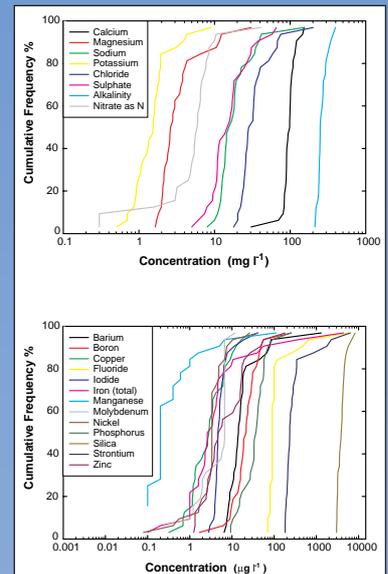
**Lowflows, groundwater and wetland interaction:** this project (funded by the EA, UKWIR and NERC) developed a framework aimed at achieving environmental sustainability based on consideration of the driving forces causing river and wetland degradation and the constraints on groundwater management.

**Scottish hydrogeology:** the BGS, along with the Scottish Environment Protection Agency and the water authorities, is co-funding both a study of the major Devonian aquifer in Fife and the development of a groundwater database for Scotland.

**Effect of old landfills on groundwater quality:** boreholes into the Middle Chalk outside a landfill are sampled bimonthly and are automatically logged for water levels and electrical conductivity in order to calibrate a contaminant transport model. The boreholes have been used for pesticide monitoring for the Environment Agency.

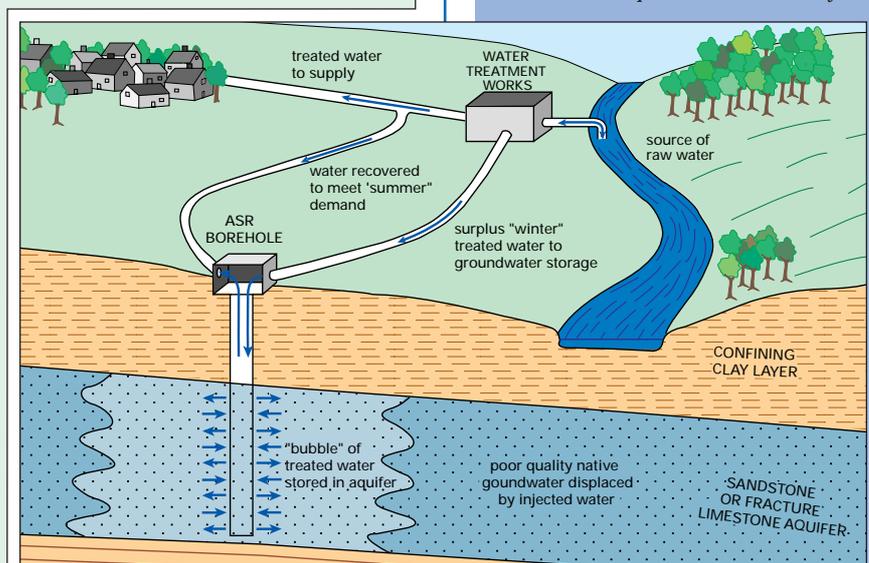
**National Groundwater Survey–tracer studies:** following a three year project co-funded by the Environment Agency, a Manual of Tracer Testing has been produced.

**Hydraulic conductivity in tills:** in the Cottingham area of East Yorkshire, groundwater is abstracted from adits in the Chalk. The Chalk is overlain by tills, and work is under way, co-funded by the Environment Agency and Yorkshire Water, to provide the regulator and operator with information on clay thickness and clay persistence which will enable an informed judgment of which areas might be more at risk from pollution near the adits.



*Cumulative frequency plots are being used to display baseline concentrations of solutes in UK aquifers.*

*Aquifer Storage Recovery (ASR) utilises the vast capacity of aquifers to store potable water which is injected during periods of excess (winter) for use in times of shortage. This technique can use aquifers that contain poor quality native water by creating a 'bubble' of fresh water in the aquifer for later recovery.*

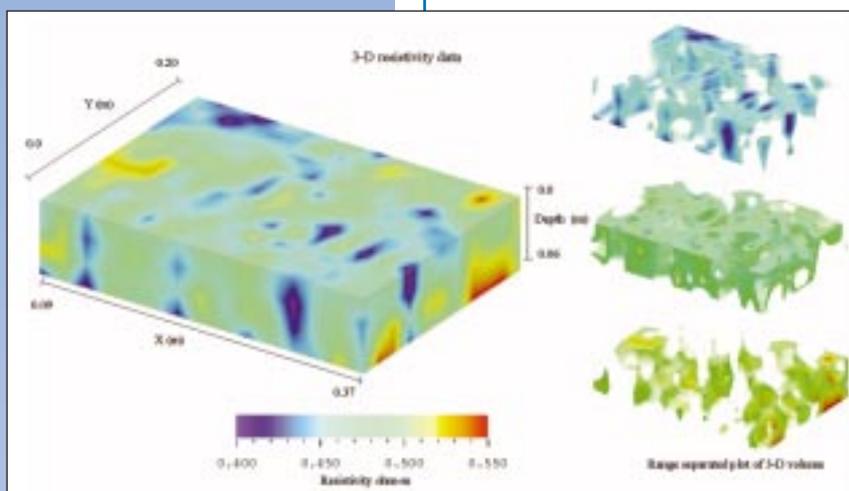


*Geological studies of Britains coasts and beneath her seas are important for the economic development and environmental planning of the nation.*

**Offshore Map Series**

As part of the continuing map revision programme revisions of the 1:250 000 series sheets for Sula Sgeir Solid Geology, Shetland Sea Bed Sediments and Shetland Quaternary Geology have been completed. These maps include significant amounts of new data, mainly from the hydrocarbon industry, which has become available in recent years. The maps cover areas of direct interest to the oil industry in its exploration and development to the north-west of Scotland.

*(Below) Fine-scale sediment heterogeneity has been investigated in three dimensions in collaboration with the US Navy using a novel resistivity technique.*



# Marine and Coastal Geology



C D R Evans  
*Deep wave-cut notch into Late Pleistocene limestone on the south-east coast of Barbados.*

## Coastal and Estuarine Evolution Project

The scientific objective of the Coastal and Estuarine Evolution Project is to produce innovative methods and conceptual models that can be used in the fields of coastal erosion and sediment budgets, estuarine geomorphological change, and sediment consolidation and flood risk. New technologies used include GIS, digital photogrammetry, and LIDAR. Particular areas that have been developed during the year are the

sedimentary history and geomorphological evolution of the Humber estuary and the erosion of the Holderness coast.

The reconstruction of past changes in geomorphology, climate, pollutants and land-use of the coastal zone are important in order to place modern records into a long-term context. Geoscience data covering the last few centuries, linking the sedimentary record and archival data, can produce detailed and accurate reconstructions of the coastal environment for use in predictive models.

Databases compiled under the LOIS programme for the English North Sea coast are being enhanced by the addition of greater detail on sediment properties and geotechnical data. Many aspects of the Holocene sequences in coastal lowlands of eastern England and offshore areas of the North Sea have already been examined, and other regions will be considered in the future.

## Holderness

Digital photogrammetry has been successfully applied in a study designed to understand and quantify the nature of coastal erosion along the east coast of England. This has provided detailed information on the nature of the processes and their variations in space and time.

## PARTNERSHIP



**Nearshore Zone Strategic Survey:** the project is co-funded by the Department of the Environment, Transport and the Regions, and aims to provide guidance to those formulating and evaluating the procedures for the licensing of marine aggregates. A digital compilation of geological data has been completed for a zone, up to 20 kilometres wide, offshore from Portland Bill to Flamborough Head.

**Barbados Coastal Conservation**

**Programme:** an evaluation of the coastal zone off eastern Barbados was carried out by Sir William Halcrow and Partners, with the BGS providing a geological overview (*left*). Onshore, digital geological maps were prepared using the mapping of Professor Robert Speed. Offshore, new bathymetric, seismic and sampling data were interpreted, allowing the identification of major canyons within a few hundred metres off the eastern coast of the island, and an extensive cover of Holocene sediments off the Scotland district.

**Gdansk Gulf Basin:** this two-year project is co-funded by the EU, and is in its final year. The project is aimed at the harmonisation of marine environmental monitoring methods between Central and Eastern European Countries (CEEC) and EU countries and involves partners from Poland and Lithuania. Sampling and analytical methodologies are being tested on two transects, each about 50 kilometres long, in the Gdansk Gulf Basin.

**North West European Gas atlas:** geological institutes from five countries in north-west Europe, funded by the EU, have prepared an atlas of natural gas composition in the North-west European Gas basin, supported by large national databases. Standard procedures were established for determining molecular and isotopic composition, using samples from across the project area, and recommendations were made on the documentation of new international standard terminology for natural gases.

**Regional revision:** offshore stratigraphic nomenclature revision continued with the publication of three volumes:

*Lithostratigraphic Nomenclature of the Triassic, Permian and Carboniferous of the UK Offshore East Irish Basin* (sponsored by a consortium of four oil companies); *Pre-Tertiary Lithostratigraphy of the UK North West Margin* and *Lithostratigraphy and Sequence Stratigraphy of the Early Palaeogene of the UK North West Margin* (both sponsored by a consortium of eleven companies).

**US Navy (Geotech sea-floor image sub-surface):** a paper was prepared describing a

## PROGRAMME

novel approach to determining sea-floor sediment heterogeneity and pore style using a combination of X-radiography and 2-D resistivity imaging. Push-in probes were also developed and deployed in dense sands (*left*).

**ENAM II:** work in this second year of the EU funded European North Atlantic Margin project has focused on the analysis of data from the Traenadjupet slide off Norway, correlation of UK and Norwegian Tertiary and Pleistocene stratigraphies around the southern margins of the North Sea Fan, and the extension of the UK Rockall seismic stratigraphy southwards into the Irish sector.

**CORSAIRES:** this programme is a EU Concerted Action intended to encourage the use of offshore coring and drilling to ground truth seismic surveys and to contribute across a broad spectrum of scientific investigations.

**Equipment development:** two major successes were achieved with the completion and successful testing of the EU-funded Hammer Corer and the development of the BRIDGE drill as part of the NERC BRIDGE programme. In a further EU funded project (HYACE) work started on the construction of a pressure core sampler and laboratory chamber for the recovery and examination of gas hydrate and other cores under in situ conditions. Design improvements, based on the BRIDGE drill development, were incorporated into the BGS six metre rockdrill/vibrocorer (*above right*) for work in Antarctica and the Indian Ocean.

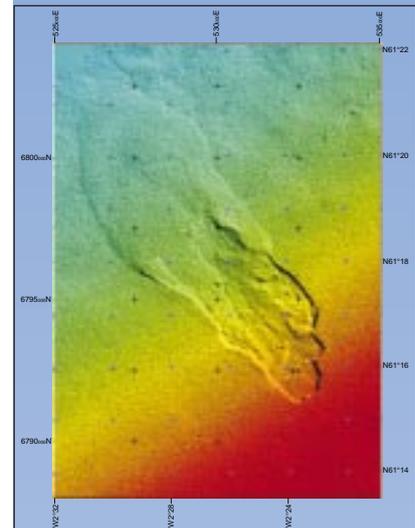
**Rockall Consortium:** now comprising 14 companies, it sponsored a major seismic experiment aimed at improving the ability to image structure beneath the thick Tertiary basalt cover in the Rockall area. This synthetic aperture experiment involved two ships simultaneously firing and receiving data at fixed offsets while additional information was collected using a string of ocean bed seismometers (OBS) laid along the ship's track.

**Western Frontiers Association:** now comprising 15 oil companies and the HSE, the WFA sponsored projects to investigate the nature of the seabed, its stability and potential hazards which may affect oil development. Studies included investigations of the nature and extent of shallow gas and potential distribution of gas hydrates which theoretical studies suggest may be present over large areas of the slope west of Shetland and in the Faeroe Channel. A mosaic was prepared covering the whole of the eastern slope of the Faeroe-Shetland Channel (*right*).



A C Skinner

*The BGS six metre rockdrill/vibrocorer being deployed from the NERC ship, RRS James Clark Ross, off the Antarctic Peninsula during a coring programme being conducted for the British Antarctic Survey.*



D Long/J Bulat

*The AFEN slide, situated some 90 km north-west of Shetland on the Faeroe/Shetland Channel slope at 500 m water depth. The slide is 13 km long and three km wide on a slope of one degree. The image has been created using the first (seabed) acoustic signal return from a conventional 3-D exploration seismic data set.*

*The National Geosciences Information Service provides access to, and data and advice from, collections of bibliographic and cartographic material, records, samples, and digital databases.*

**The BGS Web Site**

The BGS Internet web site underwent a comprehensive redesign using up-to-date techniques. In order to ensure the site is kept up-to-date all pages are reviewed at least every three months. The site has been designed to an overall corporate style which has been documented as a set of standards and guidelines – thus individual Groups in BGS produce their own pages which fit together into the overall framework. Some free products are provided as downloadable files on the site: these include the BGS Rock Classification Scheme (Volume 1, Igneous Rocks); a lithostratigraphical framework of the Carboniferous Rocks of the Midland Valley of Scotland; and a stratigraphical framework for the Ordovician of Snowdonia and the Lleyn Peninsula.

(Below) *The BGS Web Site Home Page.*

# Records and Databases

## BGS-geoIDS Project

The aim of the project is to build an integrated geoscience digital database system. BGS has been building digital databases for many years but the majority of these address specific problems or support individual projects. The result is that the BGS has numerous 'island databases' which are not linked to each other. At the simplest, the BGS-geoIDS Project intends to map these islands and build bridges between them. The envisaged benefit is that the wealth of digital data that the BGS holds will be more readily available to staff who will be able to develop new products and services for the customers of the BGS.

## Year 2000 Project

Like many other major organisations the BGS is actively addressing the Year 2000 Problem, in both the way it will affect the BGS and the way that it will affect our customers. During 1997, a team has been investigating the likely impact of this problem. We are confident that all our products and services will be Year 2000 compliant.

## Digital Report Generating System (DRGS)

The aim of the DRGS is to develop a system for producing customer-specified reports for customer-specified areas, linked through a GIS to the geological map, and

capable of being published on paper or on the Internet. The London memoir has been used as a test document with some sections being 'marked-up' using SGML. All relevant 1:10 000 scale maps have been input to the ArcView GIS for linking to the text. This allows text to be classified both spatially, through the map, and on the basis of one or more subject topics, through SGML. As a result it becomes possible to retrieve the relevant pieces of text from, potentially, a range of original reports; this is the first step to reconstructing them into a new user-specified report.

## Geochemistry Databases and Software Development

These databases are increasingly comprehensive, containing data for the UK on:

- geochemistry of stream sediments, panned concentrates, waters, soils, rocks and drill core;
- petrology of rock samples;
- mineral occurrences.

These databases have been implemented on an ORACLE server and the user can retrieve information via PC programs, such as Access. GIS is being used to visualise the data in a spatial context and to combine it with other BGS datasets, such as the digital geological map, allowing better integration and new approaches to prospectivity and geological mapping.

## Collections Administration

There were a number of major acquisitions to the core archive including the last tranche of released onshore hydrocarbon material from DTI, and further onshore drillcore and samples donated by SOCO UK Limited and Edinburgh Oil and Gas. Material from a total 194 boreholes was received during the year.

Significant new additions to the records archive included prospect and interpreted data from the ex-British Coal archives and two large donations of 1200 road and site investigation reports. A total of 3200 separate donations including geological data were received from over 100 companies.



## Borehole Database

The project to eliminate the backlog of registered borehole records is proceeding to schedule. In this second year a total of 118 000 boreholes were registered, reducing the total backlog in Keyworth and Edinburgh by 39%.

The borehole index has now been made available to a number of Value Added Resellers (VAR) and records can now be selected and purchased over the Internet through a service provided by Intergraph Limited. There has been a significant number of new enquiries generated by VAR products.

## Database Development

Effort was directed during the year towards strategic addition to and improvement of the content of the BGS Lexicon of named rock units, a vital dictionary underpinning several other BGS systems. An application was developed to allow external users to access Lexicon data via the World Wide Web, and proved to be a popular site amongst the growing number of the BGS free products on the WWW.

## National Offshore Database

Since the offshore mapping programme ceased in the early 1990s acquisition of new data has been greatly reduced. Recently, large amounts of seismic data have been released. Initial data acquisition is focused on projects to investigate the nature, stratigraphy and thickness of the Tertiary basalts in the Rockall area and to attempt to image the underlying sediments. Transfer of marine cores and samples to the Edinburgh offshore archive is almost complete; this collection is being augmented by donations from industry and Government Departments. New digital databases and products have been developed and a POSC-compliant database index of hydrocarbon wells has been created.

## BGS Landslide Database

The landslide database is updated continually as additional data becomes available. Details of all UK onshore landslides identified as part of the mapping programme and other BGS landslide investigations are recorded on this database.

The database is created in Microsoft Access. Currently, it holds information on nearly 300 landslides, and records such details as location, grid coordinates, geological materials involved in the movement, classification details and whether active or non-active at the time of

the walkover survey. Additional information records whether any damage has been observed and if any relevant ground investigation reports are available for the landslide area.

## Stratigraphic Surfaces Database

This underpins the production of contour maps, and continues to be developed and populated. One-way travel times are included. Recovery and integration of various old or defunct databases, in combination with new entries, has resulted in this database containing location data for 11 000 boreholes, both onshore and offshore, with depths to 6000 stratigraphic surfaces in 4000 boreholes. Initial results of integration of this database with the BGS WELLOG database of geophysical logs are encouraging, promising the automatic determination of physical properties in user-selected stratigraphic intervals.

## High Resolution Stratigraphy Project

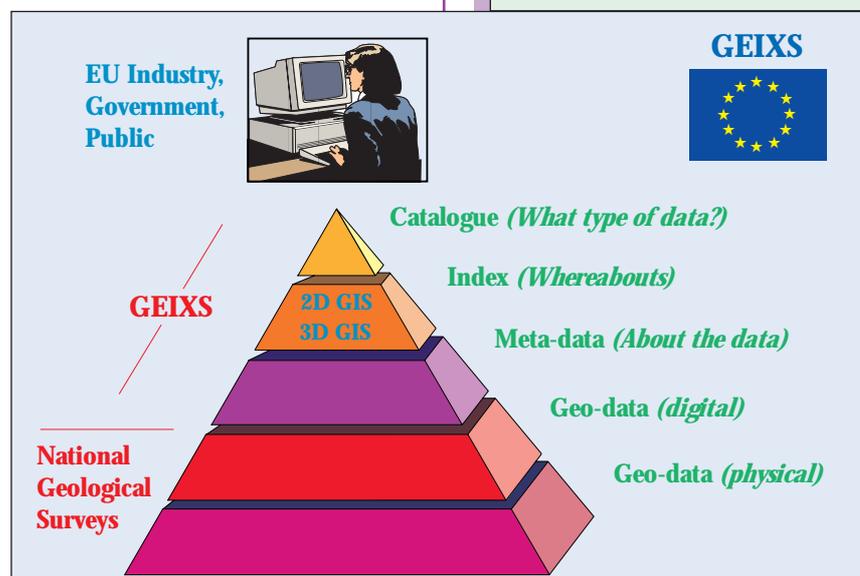
This project has focussed on the development of hypertext-linked files containing stratigraphic information for electronic publication. Files on chronostratigraphy, lithostratigraphy, biostratigraphy, bentonites, isotope stratigraphy and important sections have been compiled for the type Ludlow Series, and have been linked to provide what is literally a web of information. Further compilations are in hand on aspects of Lower Cretaceous, Upper Jurassic, Upper Triassic and Tertiary stratigraphy. The Ludlow study is a pilot study, leading the way to the interactive publication of stratigraphic information on the BGS website.

## PARTNERSHIP PROGRAMME

### The Geological Electronic Information Exchange System (GEIXS)

This two year project, led by BGS, involves as partners all 15 Geological Surveys of the EU, along with EuroGeoSurveys, the Surveys' umbrella organisation, and Matra Datavision as an industrial partner. The project is 50% funded under the EU Fourth Framework ESPRIT programme and aims to gather metadata on the geoscience data holdings of the Surveys and make these available through a free user-friendly interface on the Internet. Key aspects of the first year of the project have involved the development of a single metadata format to be used by all Surveys, the development of a common data entry interface, and the incorporation in the application of a multilingual thesaurus to make retrieval language independent.

(Below) *A schematic representation of geoscience data.*



*The BGS is pledged to bring science to the people.*



*Popular Publications.*

# Science for All

## Publications

These are listed in Appendix 3 and included the following:

- 16 new 1: 50 000 scale maps to advance copy release in digital and plot-on-demand form.
- 24 new 1: 50 000 scale maps to release in printed form.
- Two 1: 1500 000 scale geophysical image maps.
- 11 new memoirs.
- *Earthwise* magazines on *Geology for the Community* and *The BGS and Europe*.

## Popular Publications

The following publications were produced under the *Earthwise*<sup>TM</sup> label (see left):

- Three more Holiday Geology guides — *Westminster, St Paul's* and *Mining in West Cornwall*.
- Two Holiday Geology maps — *North York Moors* and *Lake District*.
- One Fossil Focus guide — *Foraminifera*.
- Three books: *Earthquakes — our trembling planet*; *Fossils — the story of life*; and *Groundwater — our hidden asset* (see page 12).

## Customer Services

New flyers and catalogues continue to be produced to promote new products, the new catalogue of Popular Products with a print run of 8000 has been most successful. Emphasis has been placed on promoting the more popular *Earthwise*<sup>TM</sup> publications in magazine advertisements. Innovative promotions such as magazine led competitions and prize draws, sponsoring and the use of advertorials have taken place. Sales stands were taken to several special events such as geology fairs. Business relationships with agents for the BGS and *Earthwise*<sup>TM</sup> publications were strengthened. The Approved Suppliers' network increased to 65 resellers.

## Information and Advice

During the year approximately 25 000 enquiries were received, of these 17 600 were handled by the Information Services

Enquiry points, providing a comprehensive service to the members of the public, industry and geoscience communities. The number of enquiries handled by Central Enquiries and Borehole Records has increased over the past year by 29%. All were handled within the customer response targets.

The number of chargeable enquiries has increased by 6% and there has been an increase in the total income derived from enquiries of 22%.

## Library

Two externally funded projects to scan geological photographs in the BGS collections have been approved. The Scottish Cultural Resources Access Network (SCRAN) project will digitise over 3000 images of Scotland while the JISC Image Digitisation Initiative (JIDI) will cover several classic geological areas in the UK. Once completed these digital images will form the first phase of the BGS digital image databank providing access to BGS resources over the Internet.

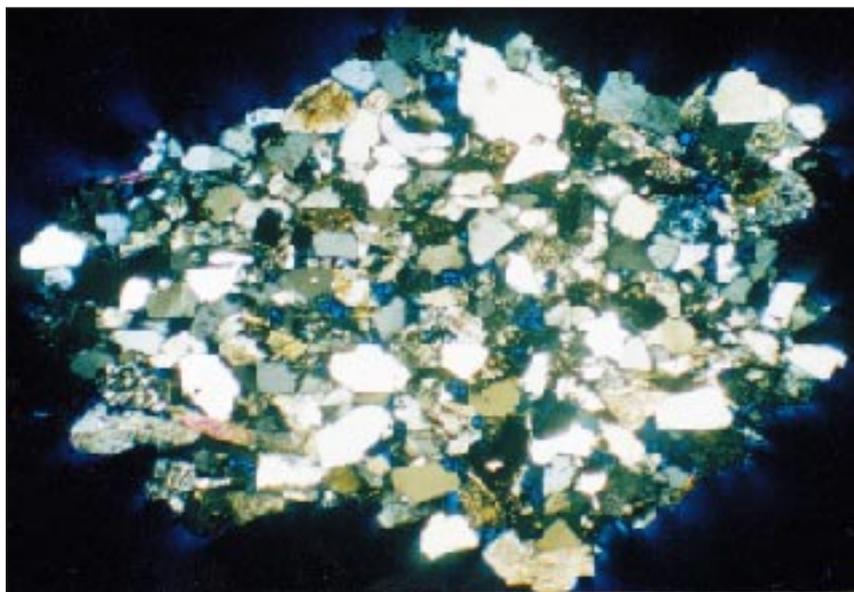
A full review of Commercial Library Management Systems was completed during the year with the objective of replacing the current LIBERTAS system during the next financial year.

## Copyright

Continuing priority has been placed on enforcing the Survey's rights under the Copyright Act. An increasing number of companies are recognising the legal necessity of acquiring copyright licences for use of analogue and digital materials. The IPR manager is now processing over 55 copyright enquiries a month and income has increased by 10% over the year.

## Media Fellowship

J M West was awarded a Media Fellowship from the British Association for the Advancement of Science and spent eight weeks working with the BBC Radio Science Unit at Broadcasting House London. She is now in regular contact with producers, providing geological stories which have been used in national and World Service programmes.



*A thin section from an 8-mm chip of the Stone of Destiny. This sample, collected in 1865 by Sir A C Ramsey, was re-investigated following the popular interest that arose during the return of the Stone of Destiny to Scotland. Petrographical analysis shows that the Stone is similar to the Lower Old Red Sandstone from the Perth area, in particular that exposed near Scone Palace. Between crossed polars, the mineral constituents of the Stone (quartz, feldspar and mica) show a range of white and grey colours; the bright blue areas of resin impregnation indicate the porosity.*

## 50th Anniversary

In 1997, to mark its formation in 1947, the GSNI launched a major exhibition illustrating its role and the importance of the earth sciences to the economic and social life of Northern Ireland. The exhibition will tour venues throughout Ireland until 1999.

## Training

- BGS staff attended over 211 in-house and other training courses.
- An IT training strategy was successfully introduced.
- A language training strategy was successfully implemented.
- Several new courses were brought on-stream including instruction in ICP-AES, Visual Basic for Applications and VB for Programming, PowerPoint and Prince 2.
- An IT training room was brought on-stream in Murchison House.
- An Open University-accredited, internal PhD programme was successfully launched.
- BGS staff contributed successfully to the new MSc Course in *Contaminated Land Management* run by Nottingham Trent University.

## Public Understanding of Science

The BGS welcomes opportunities to promote the earth sciences generally and to publicise its activities. Public understanding of science activities included:

- The seventh successful season of an evening class given in conjunction with the University of Nottingham Department of Continuing Education.
- Talks on the work of the BGS to community groups such as The University of the Third Age (U3A) and Probus.
- Numerous guided tours of the Keyworth site including an introduction to the history and current activities of the BGS.
- Support for schools on request in the form of visits, provision of information and participation in the NERC Schools Liaison Officer Network.
- Provision of careers information and attendance at careers fairs.
- Participation in national and regional PUS events such as Scottish Geology Week and the Edinburgh Science Festival.
- Development of the relaunched BGS Web Site as a major source of information on the earth sciences.

## PARTNERSHIP PROGRAMME

### Archaeometric Petrology

Modern mineralogical and petrological techniques were used as part of a study into the provenance of Scottish medieval pottery, in collaboration with the Royal Museum of Scotland and members of the Medieval Archaeological Research Group. Examination of thin sections of pottery shards has been used as part of an intergrated study to locate the clay source areas around ancient kiln sites. This work has also provided potentially important microtextural information concerning the mode of manufacture of the pottery.

### Quarries of Scotland

An illustrated guide to Scottish geology and stone working methods based on the BGS photographic archive was prepared for Historic Scotland and published by them.

## .. Press Office .. Press Office ..

The office continued to issue news releases for science stories on a regional, national and international basis, and to encourage geoscience awareness in the media. The BGS has worked in cooperation with the BBC and many other media during the year.

A total of 66 news releases were issued, and coverage was obtained in all media. From January 1998 a new system of media quantification was adopted using the system OTV (opportunity to view).

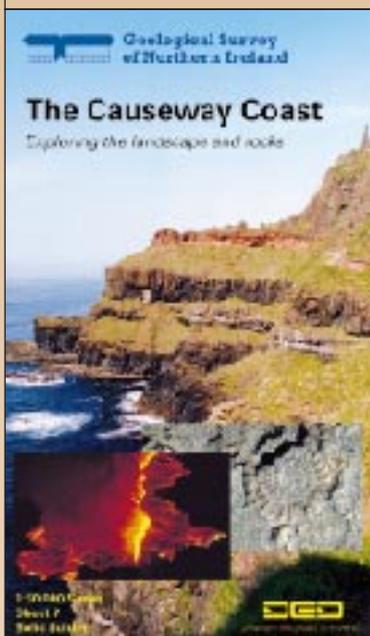
Regional and specialist news releases are adapted into 'information sheets' for MP's to enable them to keep abreast of their local geological issues.

*Earthnews* summarises news releases monthly and is circulated to journalists, the BGS Board, PR 'allies' and all staff.

The in-house *Diary* is circulated to all staff monthly.

*The Geological Survey of Northern Ireland (GSNI) is an office of the Department of Economic Development. It is led and staffed by BGS scientists.*

- Work was completed on a new edition of the 1: 50 000 Series Causeway Coast Sheet 7 (*below*). This map combines a traditionally styled map face with general information of interest to tourists. It includes photographs, block diagrams and text (in three languages) explaining the formation of the Giant's Causeway, which is a designated World Heritage Site.



# Northern Ireland

- The GSNI continued to advise the Mineral and Petroleum Unit of the Department of Economic Development and to monitor all licensed mineral and hydrocarbon exploration activities in Northern Ireland.
- Hydrocarbon exploration continued in counties Antrim, Tyrone and Fermanagh. Exploration for gold and base metals continued at a high level; almost all prospective areas in counties Londonderry, Tyrone and Fermanagh were held under licence or subject to licence application by the year end.
- With the assistance of the BGS, the GSNI continued to develop a range of databases (*above right*). This project will improve storage and handling of extensive data holdings and enable the Survey to develop new services for customers in future.
- A new edition of the Geological Map of Northern Ireland (1: 250 000 Solid Edition) was published. The new map incorporates the most up to date linework from the 1: 50 000 series maps, with some contributions from academic sources.
- Detailed mapping continued in the northern Sperrin Mountains in the area around Dungiven (Sheet 18). The discovery of gold mineralisation in the southern Sperrins and to the west of Omagh continues to act as an important impetus to commercial gold exploration throughout the area, and highlights the requirement for the GSNI to provide detailed geological maps of these structurally complex Dalradian strata.
- The Plateau Resources Project involves reconnaissance mapping and compilation of new editions for four 1: 50 000 sheets covering much of the area of Palaeogene basalts in County Antrim. It has benefited greatly from the availability of recently reprocessed geophysical data which has improved modelling of the Mesozoic basins that lie beneath the Antrim Lavas.
- During 1997/98, work progressed on three sheets. Coleraine (Sheet 13) was completed and will be published in



*Storing data on the GSNI database.*

1998. Fieldwork was completed on Maghera (Sheet 19) and Ballymena (Sheet 20), and both maps are currently being compiled.

- The new Geophysical Atlas for Northern Ireland was published. This contains 30 digitally-processed images (1: 250 000 scale) of the Northern Ireland regional gravity and aeromagnetic data sets. This product is aimed at potential markets in the hydrocarbon and mineral exploration sectors.
- A pilot study of landslips on the Antrim coast was successfully completed. This project involved classifying landslips and assessing stability. It is hoped that in the near future, similar work will be extended to all landslip areas in Northern Ireland and will be of particular use to planners.
- The GSNI and the Geological Survey of Ireland continued to work closely on tourism, mineral and related projects funded through the European Union, the International Fund for Ireland and local councils. These projects are designed to develop the rural economies in the border counties.
- Work continued to develop and market the concept of 'Landscape Tourism'. During the year, a number of 'Drives and Walks' packages were published, and work is now nearing completion on the *Landscapes from Stone* map, a 1: 250 000-scale tourist map of the north of Ireland showing features of geological and geomorphological interest.

# Isotope Geosciences

The NERC Isotope Geoscience Laboratory (NIGL) is one of the largest and most comprehensive environmental geoscience isotopic laboratories in the United Kingdom, with both stable and radiogenic isotopic analytical facilities. It is funded by a science budget allocation from the Science Programmes Directorate of NERC. In July 1997 the BGS became responsible for its administration. NIGL undertakes collaborative research into stable (H, C, N, O, S) and radiogenic (Rb-Sr, Sm-Nd, Lu-Hf, U-Th-Pb) isotope geochemistry and environmental chemistry. NIGL has for many years provided isotopic research services to the BGS.

## Advanced Analytical Facilities for the Millennium

State of the art mass spectrometry at the NIGL includes a new acquisition, the ICP multiple collector mass spectrometer (ICP-MC-MS) (*below*). This new instrument was paid for by contributions from NERC Science Programmes Directorate, the BGS, the British Antarctic Survey and the University of Leicester. The instrument will provide the ability to make high-precision isotopic measurements on many elements much more cost effectively than with conventional methods, and together with the laser micro-sampling capability (to be established in 1999), will allow the BGS and collaborating research partners to use isotopic methods in geo-

logical and environmental science in ways not possible before.

## Changes in Sulphur Pollution over 140 Years

The contribution of anthropogenic atmospheric sulphur, mainly from coal burning, has been revealed in grasses using sulphur isotopic measurements. This work, in collaboration with ICAR-Rothamsted, used the irreplaceable 140-year collection of annual grass cuttings at the Park Grass Experiment Site. Samples from the last 30 years record the sulphur isotopic signature of major reductions in sulphur emissions due to tighter environmental controls.

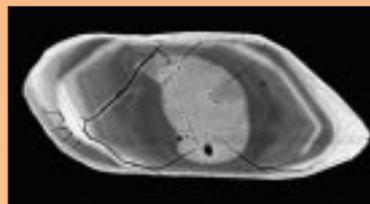
## Kimberlites

A study with Durham University into the origin, mantle dynamics and geochemistry of oceanic basalts and kimberlites, has used Hf and Nd isotopes and the new ICP-MC-MS to identify the ancient, relatively non-radiogenic Hf and Nd isotopic characteristics of a postulated mantle geochemical component to kimberlites.

## Uranium Fuel Quality

U and Th isotopic measurements conducted with VG Elemental and URENCO UK Ltd using the new ICP-MC-MS have provided a more cost-effective and precise method to monitor uranium-fuel quality procedures for the nuclear industry. This work has been an unexpected benefit of the U-Pb geochronology programme.

*The NERC Isotope Geoscience Laboratory (NIGL) is administered by the BGS and funded from the NERC Science Programmes Directorate.*



*Backscattered Scanning Electron Microscope image of a zircon grain, showing complex growth zones. U-Pb studies of such minerals provided evidence for Precambrian metamorphism (c. 800 million years ago) in the central Highlands of Scotland.*

## Strontium Isotopes in Hydrogeology

Strontium isotopes are playing an increasing role in hydrogeological studies. The  $^{87}\text{Sr}/^{86}\text{Sr}$  ratio has been used as a natural tracer to determine weathering rates and flow routes through an upland catchment in Wales and to study the evolution of groundwater in the Grand Erg Oriental basin of north Africa and in the chalk aquifer systems of the UK.

As part of a larger hydrogeochemical project in the Kamchatka Peninsula, Russian Far East, Sr, Pb and S isotopes were used to study travertine deposits, thermal and recharge waters and the local host-rock environment. The results provided valuable information on both the active and the palaeowater systems in the Rodnikovoe area.



*(Left) New mass spectrometer facilities will open new avenues in isotopic studies in the earth and environmental sciences. Featured (left to right) are Prof A Saunders and Dr K Edwards (Leicester University) Prof J Plant and Dr D Falvey (BGS) and Prof R Parrish (BGS/Leicester University).*

*The synergy between UK-based work and overseas operations is one of the BGS's greatest strengths.*

**DFID Mining Adviser**

The Mining Adviser for the Department for International Development (DFID) has continued to work in the former Soviet Union — in Russia, in Western Siberia and the Eastern Donbass. Work in the Western Donbass (Ukraine) also continued, with substantial success. A new phase of cooperation provides direct assistance to the Ministry of Coal in Kiev.

In Egypt, the Maghara Coal Project is now drawing to a close and will bring over eight years of effort to an end.

The Adviser remained involved with the DFID-funded elements of the World Bank's environmentally concerned minerals project in Ecuador.

An increased amount of time has been devoted to the DFID's Knowledge and Research (KAR) programmes, which have expanded during the year.

**Mining-licence Information System**

The aim of this project, funded by the DFID, is to promote efficient procedures for the management of mineral-exploration and mining licences, thereby encouraging investment in the mining sector of developing countries. A generalised model of a PC-based, licence-management system was produced after detailed study of the systems used in Botswana, Guyana and Malaysia, for implementation as a working PC database in Guyana.

COMMISSIONED PROGRAMME

*These short- and medium-term activities, undertaken in response to direct commissions from customers in both the private and public sectors, are fully funded by them. Projects utilise and build on expertise developed within the Core Strategic Programme and return knowledge and skills to it. The commissioned programme helps the BGS maintain strong scientific depth and expertise.*

***International Development and Assistance — Mapping and Minerals***



**P N Dunkley**

*Moving camp in the Western Cordillera of southern Ecuador. The serrated peaks of Cerro Escaleras (4400 metres), seen in the background, are composed of Early Oligocene andesite lavas and breccias intruded by dykes.*

**Bolivia**

BGS, in cooperation with SERGEOMIN, the National Geological and Mineral Service of Bolivia, was supported by the World Bank in the design and installation of a geological and minerals database.

**Botswana**

During the year the DFID-funded Adviser to Director, BGS, finished his contract, thus closing 33 years of continuously maintained support by the BGS. He completed the new 1:1 000 000 geological map of Botswana, currently in press. The Adviser was responsible for the geological mapping programme of the Botswana Geological Survey Department and also liaised with exploration companies in the design of their prospection programmes.

**Ecuador**

Five residential BGS staff based in Quito have, with their counterparts, been concerned with geological and geochemical mapping of the Western Cordillera (above) since 1995. DFID support for this project is complemented by World Bank funding for a separate investigation: *the Assessment of Ore Districts*, to which three BGS geologists are currently assigned.

**Guyana**

The Guyana Geology and Mines Commission (GGMC) maintains the national archives of geological information and regulates the activities of the mining sector. The BGS has been assisting the GGMC in the development of computing facilities, databasing and training with

support from the Commonwealth Secretariat via the Commonwealth Fund for Technical Cooperation.

### Hong Kong

The Head of the Hong Kong Geological Survey and one other staff member are on 'leave of absence' from the BGS and working under contract at the Geotechnical Engineering Office of the Civil Engineering Department of the Hong Kong Special Administration Region of China. They will continue to work for the new administration until 1999.

### Jordan

An institutional twinning relationship exists between the Natural Resources Authority (NRA) and the BGS, stemming from work started in 1984 on the 1:50 000 national geological map series.

### Namibia

A project supported by EU/SYSMIN funding to set up an industrial minerals laboratory and to prepare a related modern inventory and database, had acknowledged success by 1997. One BGS geologist is now on a residential assignment to complete a follow-on project to provide a broad-based counterpart training programme and an improved information service to the mining industry.

### Pacific Islands

The Training Coordinator of the South Pacific Applied Geoscience Commission (SOPAC) is a BGS staff member on secondment, funded by CFTC for two years from 1997. His duty is to arrange training for young geoscientists in most of the South Pacific island states. The primary objective of SOPAC is to assist its member countries in the identification and assessment of the marine and other non-living resource potential of their respective national offshore areas.

### Papua New Guinea

Training in remote sensing, image analysis and GIS formed a major component of a project funded by CCOP under their Coastplan programme. The project utilised a time series of Landsat imagery to study changes in the coastal zone around Lae, the country's second city, in order to understand the dynamics affecting this region.

### Sri Lanka

A series of full colour 1:100 000 scale geological maps produced in cooperation with

the Geological Survey & Mines Bureau with support from the World Bank was completed in 1996/97. During 1997/1998 a compilation map at 1:250 000 was produced with the aid of funding from the British High Commission.

### Suriname

Two senior BGS geologists participated in an EU-funded contract to provide recommendations for setting up a Minerals Institute, and advice on changes of legislation for the mining sector.

### Zambia

A two year project to edit, produce and publish a backlog of geological maps and reports is being undertaken with EU/SYSMIN funding and follows a previous World Bank-supported publication project.

The World Bank is now supporting a multi-disciplinary geoscientific survey in northern Zambia undertaken jointly by the BGS and the Zambian Geological Survey Department. The project will involve geological mapping, geochemistry, data-basing, training and assessment of the mineral resources and economic mineral potential of the region to encourage investment in the Zambian minerals sector. The BGS is providing a two-man residential team supported by a number of short-term inputs.

The BGS, in collaboration with the Zambian Geological Survey and Intermediate Technology Zimbabwe, undertook a DFID-supported project aimed at encouraging the development of affordable lime for agriculture and water treatment. Results were disseminated at a Workshop.

### Geochemical Atlases

**Southern Sumatra:** this volume, the second in a series of Indonesian Geochemical Atlases, is the final product from a long period of collaborative work between the Indonesian Ministry of Mines (Directorate of Mineral Resources) and the BGS, supported by the DFID. The atlas shows geochemical images for 15 elements determined in over 13 000 stream-sediment samples collected over a period of ten years.

**Hong Kong:** the BGS made a significant contribution to the production of the Hong Kong Geochemical Atlas, under contract to the Hong Kong government. Geochemical images for 36 elements determined on stream sediments were produced, accompanied by a detailed account of the geochemistry of each element.

### Indonesia

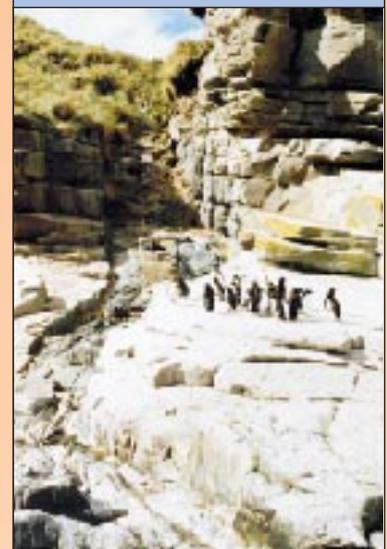
A BGS geophysicist undertook a mission for the Asian Development Bank in connection with a proposed aerogeophysical programme for Kalimantan and Sulawesi.

### Peru

An Honorary Research Associate of the BGS, Dr John Cobbing, was presented with a commemorative medal at the Peruvian National Geological Congress for his years of work in the country. The congress visited Iskay Cruz zinc mine, originally discovered by BGS geologists and geophysicists whilst undertaking work financed by the DFID.

### Falkland Islands

The geologist resident in Stanley since 1996 returned to Keyworth to complete the compilation of 1:250 000 geological maps covering the islands, and to prepare the maps and report for printing. The work was commissioned by the Falkland Islands Government and undertaken in cooperation with the first Falkland Islands geology graduate.



D T Aldiss

*A multiple Jurassic dolerite dyke intrudes gently dipping, Siluro-Devonian, marine sandstones at Rockhopper Penguin Rookery on New Island, Falkland Islands.*

## ***International Development and Assistance — Groundwater and Pollution***

### **Eritrea**

A variety of geophysical techniques was applied successfully to groundwater studies in Eritrea as part of an EU-funded appraisal of regional water resources. Electromagnetic, resistivity and magnetic profiles identified fracture zones and variations in overburden thickness within basaltic and basement terrains which were tested by drilling.

### **Jordan**

The Water Authority of Jordan (WAJ) is undertaking a study of domestically used groundwater containing natural radionuclides. The DFID is facilitating the BGS to cooperate in this project.

### **Mediterranean Region**

Azimuthal resistivity and electro-kinetic sounding methods were used in Cyprus and Israel as part of an integrated geophysical approach to the rational management and exploration of groundwater resources in 'at risk' aquifers of the Mediterranean region. Initial results from this collaborative CEC/INCO project showed the difficulty in acquiring consistent data over both

pillow lavas and sedimentary sequences and the techniques are being further developed to take account of this.

### **Mexico**

This has been the final year of a joint project — *Impact of Wastewater Re-use on Groundwater Quality in the Mezquital Valley*— with the National Water Commission of Mexico funded by the DFID. The overall objective was to determine the effects of wastewater reuse on groundwater resources. Irrigation with wastewater (*right*) from Mexico City has been established for many years and the large volumes of water imported into the valley have raised groundwater levels, created new groundwater discharge points and provides water supplies for up to 500 000 people in the valley. Sampling has shown that the groundwater underlying the irrigated part of the valley is affected by deep percolation from wastewater in the irrigation canals and from fields.

### **Nigeria**

The Oju LGA Benue State Water Supply Project is funded by the DFID; the BGS is working with WaterAid to help develop sustainable village level water supplies in an area with the worst health and poverty indicators in Nigeria. The hydrogeology of the area is complex and has required detailed investigations (*left*). These have included drilling, test pumping; geophysics and hydrochemical surveys. Groundwater development maps that can be readily used by the Local Government Authorities and Non-Government Organisations (NGOs) have been produced and appropriate well siting methods devised.

### **Palestine**

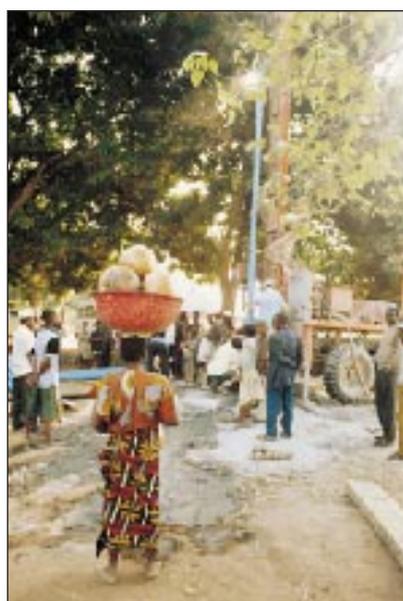
As part of the DFID programme of assistance to the Palestinian National Authority, the BGS has continued work on developing an understanding of the hydrogeology of the West Bank mountain aquifer. This is the source of most of the water to local populations and will be a key element in the final settlement with Israel. The BGS arranged study tours of the UK by Palestinian professionals, and a plan for hydrometric monitoring to

### **Urban Areas**

Many cities in developing countries are dependent on groundwater aquifers as a source of water supply. However, uncontrolled groundwater development and waste disposal is leading, in many places, to serious groundwater degradation. Against this background the BGS, and seven overseas partners, have begun work on a DFID-funded project entitled *Tools for Assessing and Managing Groundwater Pollution Threats in Urban Areas*.

### **Small Island Water Information System**

Working in collaboration with the Commonwealth Science Council an information system for water professionals working in Small Island Developing States has been developed. Small islands present particular challenges to the hydrogeologist, with limited groundwater resources under increasing stress from population growth and industrial and tourist developments. Using a combination of Internet and CD-ROM the network is expected to commence operation in 1998.



**D M J MacDonald**  
*Exploration borehole being drilled at Odaleko village, Eastern Nigeria*



M E Stuart

*River transporting untreated wastewater to the irrigation area, Rio Salado, Mezquital, Mexico.*

improve long-term aquifer management has been prepared. Future projects are aimed at a better understanding of the overall water resource and the social and economic implications of water scarcity.

### South Pacific

A BGS Hydrogeologist is currently seconded to the Secretariat of the South Pacific Applied Geoscience Commission (SOPAC) where he is the Training Coordinator. The Secretariat represents geoscientific interests for 17 member countries. Duties include organising scholarships and fellowships, the lecturing of certificate courses and seminars, the convening of workshops and advising on hydrogeological activities.

### Vanuatu

A BGS Hydrogeologist, funded by the DFID, is supporting the Department of Geology, Mines and Water Resources. His duties are principally concerned with ensuring adequate domestic water supply to communities on outlying islands. The main source of potable water in the urban and rural areas of Vanuatu is groundwater.

### Groundwater Protection

Infiltration of wastewater to aquifers frequently occurs as an unplanned consequence of activities such as agricultural irrigation with wastewater or disposal to surface canals. This study — *Protecting Groundwater beneath Wastewater Recharge Sites*— funded by the DFID, has focussed on the pollution of groundwater by both organic and inorganic compounds at recharge sites in Mexico, Jordan and Thailand. Little evidence for the transmission of toxic anthropogenic compounds to groundwater was found, although salinity can be a serious problem for both potable

supply and agricultural use. Guidelines for managing the impact on groundwater at such sites have been developed.

### ARGOSS

The provision of safe drinking water and sanitation are key elements for the improvement of health in many developing countries. As resources are rarely adequate to provide water supplies and sewerage systems universally, the most cost-effective solution is often to construct low-yielding boreholes and on-site sanitation. The BGS is undertaking a DFID-funded project *Assessing Risk to Groundwater from On-Site Sanitation* (ARGOSS) with the aim of preparing guidelines for the siting of on-site sanitation in relation to water supply wells.

### Groundwater Dependent Areas

Although the need for an integrated approach to rural water supply and sanitation is now widely accepted, guidance on how to achieve it is universally lacking. A collaborative project between WEDEC at Loughborough University and the BGS aims to prepare and field test guidelines that will enable a government to design an integrated programme. The draft guidelines have so far been field tested in Zimbabwe and will shortly be taken to Zambia.

### World Bank Policy Paper #390

As part of the UK's multilateral aid programme, funded by the DFID as part of its Knowledge and Research initiative, and at the request of the World Bank's Transportation Water and Urban Development Strategy Division, the BGS has produced a major review of urban groundwater issues, focused specifically on cities of the developing world.

### Pollution Risk

This DFID-funded research project aims to assess the risk to deep urban groundwaters used for public supply from the on-site disposal of urban wastewaters. Employing detailed field studies conducted with local project partners (a government agency, a regional university and a water services cooperative) in Hat Yai, Thailand, and Santa Cruz, Bolivia, the project studied the two main alluvial aquifer settings (shallow and deep water-tables).

### DFID Hydrogeological Adviser

The BGS has continued to provide advice to the DFID and to agencies of the UN system, to colleagues from developing countries and to NGOs through the post of Hydrogeological Adviser to the DFID. In particular, the Adviser participated in a meeting of UK and International NGOs working on emergency settlements and disaster relief, for which rapid provision of safe drinking water is often a major concern. The Adviser has continued to participate on behalf of the BGS in the Water Focus Group of the DFID, and to manage and promote the continuing research programme in the water sector.

## *International Development and Assistance — Hydrocarbons*

### Caspian Sea

An assessment of hydrocarbon potential has been made in five existing fields offshore from Baku as part of rehabilitation programmes of the older oil fields in Azerbaijan. This involved on site analysis of data as well as UK based studies and presentations to oil companies to promote the area.

### China

A study of coalbed methane production, commissioned by the Asian Development Bank, reviewed the present utilisation of coalbed methane in China and identified and prioritised potential projects and locations where further ADB assistance would be environmentally significant, technically feasible, and economically viable. The study found that large amounts of methane are vented from Chinese coal mining operations (*below*). Some is drained to enhance mine safety and allow uninterrupted mining. Although mixed with air, it is sufficiently rich to form effectively a free source of fuel at the pithead, and is best used for domestic supply and electricity generation. A favourable location for a mine gas utilisation project was identified, where the domestic supply market is saturated and there is scope for optimising usage by electricity generation.

### Falkland Islands

Technical and management support was provided to the FIG's offshore exploration programme. Licensees completed initial seismic acquisition programmes and presented drilling proposals. The BGS interpreted the data and advised the FIG on the proposals and issue of well

consents. Work started on the first of five commitment wells by Amerada Hess. The BGS monitored these activities for the FIG, and provided technical advice to the FIG in the South West Atlantic Hydrocarbons Commission in tripartite talks between the UK, Argentina and the FIG. The BGS undertook environmental baseline studies in collaboration with other NERC and Argentinian institutes as part of its work for the South West Hydrocarbon Commission.

### Indonesia

The final Indonesian petroleum geology student at Heriot-Watt University completed her MPhil, thus concluding the £5 million DFID programme of support for LEMIGAS (Indonesian State Hydrocarbon organisation).

### Papua New Guinea

The petroleum exploration and development technical assistance project for the Government of Papua New Guinea, funded by the World Bank will run until late 1999. The BGS has managed a multi-disciplinary team of petroleum geoscientists, legal and fiscal experts, pipeline, drilling and production engineers and information technology specialists. The team is supported by a variety of short-term expertise integrated with the residential input. Team members provided general training and legal and economic guidance. Specifically, they have assisted decisions on the PNG Refinery Bid; privatisation of the government share of oil and gas field equity; landowner issues; drafting of oil and gas legislation; and model agreements.

### Seabed Project

This is a joint industry collaborative project between a group of companies who hold deep-water licences in the Norwegian sector. BGS assisted in the interpretation of seismic data, identified potential hazards to oil development and established a Cenozoic stratigraphy for the area. This work is helping to develop a unified understanding of the Cenozoic geology of the North European Atlantic Margin from the South West Approaches to the Barents Sea.

### Basin Assessments

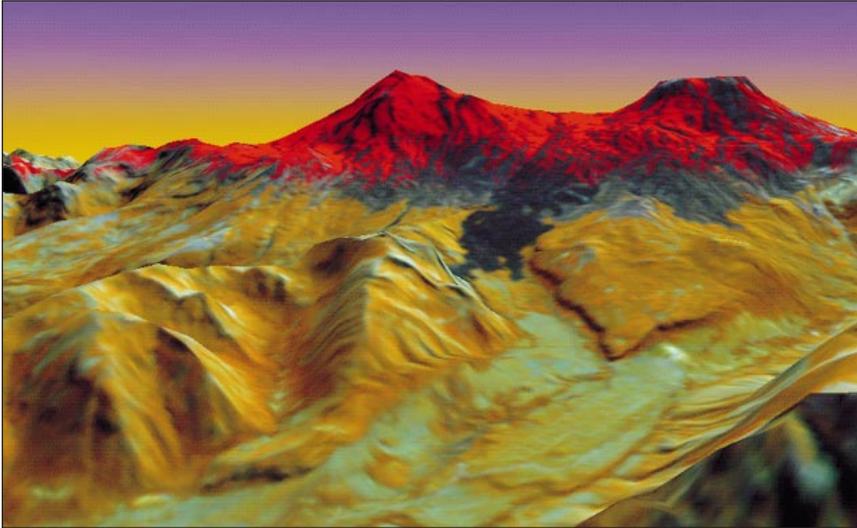
A number of projects have been carried out for individual companies and groups of companies to provide hydrocarbon assessments of sedimentary basins in a number of locations around the world. In addition, speculative seismic surveys have been designed for contracting companies in the North Sea, the Faroes, UK and Irish Rockall areas and in the Porcupine Seabight, and the data have been subsequently interpreted and reports prepared for clients. Companies use this information in their prioritising of basin potential and development of licence bidding strategies.

(Right) *Coalbed methane production at Jincheng, Shanxi Province, North China.*



S Holloway

## International Development and Assistance — Geohazards



*Computer-generated view of Nevados de Chillán volcano, Chile, produced by draping a false-colour composite of a Landsat image (bands 4-5-7) on a digital elevation model. The red colour on the volcano is actually snow: the black deposit in the valley (centre) is an old lava flow.*

### Chile

The preparation of volcanic hazard maps for the Chillán (*above*) and Villarica volcanoes in Chile continued as part of a research study being carried out for DFID. The approach combines geological information on past volcanic activity with information derived from interpretation of satellite imagery and digital elevation data to model the likely course of future eruptive events. GIS data combinations and perspectives are used to present the information in an easily comprehensible manner.

### Colombia

A BGS engineering geologist has been working with the Colombian authorities concerned with coal mining engineering and mine stability. In conjunction with the Geological Survey of Colombia he was involved in urban landslide hazard investigations and with the Manizales Volcanological and Seismological Observatory on volcano slope instability problems.

### Hong Kong

The Tung Chung Project, funded by the Hong Kong Government, investigated complex ground conditions that pose problems for foundation design and construction of Tung Chung New Town, sited near to the new Hong Kong airport. The cornerstone of the work was a consis-

tent approach to describing and interpreting more than 400 borehole cores, enabling interpretation of archival borehole logs and core photographs to be made with greater confidence than hitherto. The BGS has completed a Seismic Monitoring Network for Hong Kong and are engaged in engineering geology studies of the New Airport.

Geotechnical surveys of landslip hazards in Hong Kong have been supported by mineralogical and microtextural studies. The landslips occur in kaolinised volcanoclastic rocks which show high proportions of halloysite in clay gouges and slip clays developed along slip planes. Microtextures in the clay gouges indicate that a series of movements occurred along some slip planes, separated by static intervals associated with deposition of ferromanganese minerals.

### Jordan

The DFID-funded programme came to a close in April 1998. It focussed on training in environmental thematic mapping and hazard assessment, concentrating on the coastal area in and adjacent to the city of Aqaba, and included advice on the establishment of an associated database. The project was considered a great success by the Jordanian authorities and further work is planned in other urban centres.

### Montserrat

There is continuing concern by the British Government for the people of this British Dependent Territory. The eruption of the Soufrière Hills Volcano has led to evacuation of the population from the southern part of the island (*see cover photo*) and to devastation of a number of villages and farm land on all flanks of the volcano, with loss of homes and livelihoods. The eruption has been monitored throughout by the BGS and the Montserrat Volcano Observatory (MVO) which advises on the activity of the volcano and the hazards that it poses. The BGS is contracted by the DFID to manage the scientific staff and equipment inputs to the observatory.

The BGS has also been working with the Montserrat Volcano Observatory, the Institute of Occupational Medicine (Edinburgh) and the Universities of Bristol and Cambridge in a collaborative study, funded by the DFID, on the composition of ash from the recent eruptions. Chemical and physical analyses have been undertaken using various techniques to classify ashes related to the different phases of the eruption. Studies have revealed unusually high levels of crystalline silica (cristobalite), which is known to be injurious to health.

### Landslide Hazards

Remote sensing and GIS analysis form the basis of a study funded under the DFID Knowledge & Research programme aimed at developing a strategy for producing rapid landslide hazard maps for use in developing countries. The study is being carried out in collaboration with partners in Jamaica and Slovakia. It builds on earlier work which showed that general landslide susceptibility could be determined by correlating past events with geological and land use factors, and modelling the relationships using a GIS.

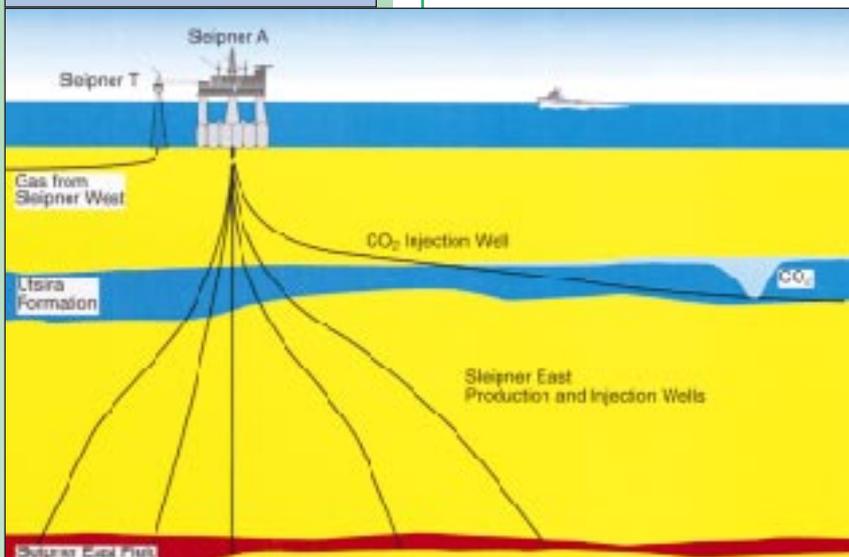
*Environmental problems cause increasing concern to developing countries and the BGS is well qualified to carry out research and seek solutions*

### Geological Disposal of CO<sub>2</sub>

BGS participates in projects promoting the geological disposal of CO<sub>2</sub> which at present is emitted into the atmosphere in vast quantities where it enhances the natural greenhouse effect.

Geological disposal of CO<sub>2</sub> is already a reality. Statoil and their partners are currently disposing of 1 million tonnes of CO<sub>2</sub> a year at the Sleipner West gas field in the Norwegian sector of the North Sea. The CO<sub>2</sub> is injected into a sandstone reservoir above the natural gas reservoir. BGS is involved in a major proposal to the EU THERMIE programme to monitor the underground disposal of CO<sub>2</sub> at the Sleipner West gas field.

(Below) *CO<sub>2</sub> injection project at Sleipner West.*



Courtesy: Statoil

## ***International Development and Assistance — Environmental Geoscience***

### Environmental Arsenic Exposure

A study of mining-related arsenic contamination in the Ron Phibun district of Thailand, funded by the DFID has shown that shallow groundwater contains high arsenic concentrations, precluding its use as a supply of drinking water. The source of the arsenic in groundwater was considered to be arsenopyrite in alluvial sediments. Bedrock tin mining and attendant processing were not thought to be causative factors, but it is possible that the mobilisation of arsenic was exacerbated by dewatering during the mining of alluvial tin.

High concentrations of arsenic in groundwater in Bangladesh pose a potentially serious health problem. The arsenic is 'natural' in the sense that it is derived from the alluvial sediments that exist in much of Bangladesh. There is still a lack of reliable information about the scale of the problem in terms of the size of population at risk, its geographical extent, underlying causes, the absolute concentrations of arsenic in groundwater and future trends. Basic geological, hydrogeological and geochemical data are needed to assess these issues and to define appropriate solutions. The problem is made all the more difficult because of the large number of shallow tubewells (*above*) in the affected areas, perhaps as many two



C A Milne

*Flushing a hand-pump tubewell prior to sampling, Bangladesh.*

million. Many of these are likely to be unaffected, but defining those that are, presents a major challenge for all concerned.

### Agricultural Pollution in the Caribbean

A review of currently available information on movement of sediments and pollutants of agricultural origin into the coastal zone in the Caribbean and their impact on coastal zone resources was prepared for the DFID Land-Water Interface Programme.

### Land Ocean Contaminant Study (LOCS)

As part of this DFID-funded study, chemical analysis of samples of surface waters, suspended particulate matter and sea-bed sediments in Sepetiba Bay, Brazil showed that land-derived anthropogenic fluxes of most heavy metals are low relative to the natural detrital sediment loading. At present, zinc and cadmium are the only metals present at levels that are potentially hazardous to marine life and humans. Most contaminants are stored in the sediment delta systems at the mouths of the main distributaries entering the bay, or down current from them; consequently, little anthropogenic metal has reached the Atlantic.



*The BGS display on monitoring environmental change at the Royal Society Exhibition.*

### Pollution in East Africa

As part of the UNEP GPA (Global Programme of Action), a report was compiled by the BGS on land-based sources of pollution and their impacts on the marine, coastal and freshwater environment of East Africa, in conjunction with the Institute of Marine Sciences, Zanzibar. A workshop was held in October 1997, at which a draft was prepared for a Strategic Action Plan to minimise the impacts of pollution in East Africa.

### Fish Ear-bones as Environmental Monitors

Skills developed for the microanalysis of geological materials have been applied to the otoliths (ear-bones) of fish from Bangladesh, Indonesia and Papua New Guinea, in work carried out for the Marine Research Division of CSIRO (Australia). The compositions of otoliths reflect the water chemistry in which the fish have grown, and therefore variations may be used to track the movement of fish between saline and fresh water or to monitor contamination.

This work also formed part of a major presentation entitled *Aquatic Life Charts Environmental Change* shown at the annual Royal Society *Frontiers in Science* Exhibition in London (above) attended by senior figures from the world of science, government, industry and, perhaps most important, our ultimate sponsors, the general public.

### Trace Elements in Food

Exposure to potentially toxic trace elements and pathogens in the developing

world is considered to be mainly the result of drinking contaminated water. However, collaborative studies with the Center for International Child Health (Great Ormond Street, London) and Mulago Hospital (Kampala, Uganda), funded by the DFID, have shown that exposure may also result from the deliberate ingestion of soil or the contamination of food during preparation. Such contamination exposes the population to increased levels of potential toxic trace elements and pathogenic organisms from the soil, but it also increases the concentration of essential elements such as iron and magnesium in the diet. An understanding of both the geochemistry of the soil and nutritional status is therefore important in targeting remedial measures.

### Mayak Project

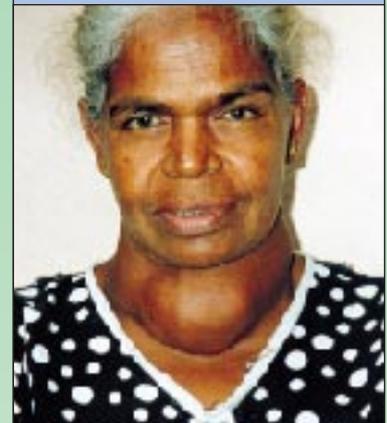
Under its EC-funded Mayak project with AEA Technology, Harwell, the BGS is helping Russian experts to assess the radioactive waste arising from previous nuclear programmes and disposal options at the large nuclear-fuel reprocessing site, formerly Chelyabinsk-65, in the foothills east of the Ural Mountains.

### Mitigation of Mining-related Mercury Pollution Hazards

A DFID-funded assessment of human mercury exposure on the Philippines, based on analysis of hair samples, showed that ballmill operators and workers processing mercury-contaminated tailings in cyanidation plants are prone to elevated exposure, for which appropriate remedial strategies may be required.

### Prediction and Remediation of Human Selenium Imbalances

A DFID-funded investigation of the relationship between environmental selenium and oesophageal cancer in the Cixian area of China showed that selenium concentrations in soil, drinking water, grain and human hair increase from the low to high cancer incidence villages. This suggests that selenium deficiency is not a causative factor in oesophageal cancer here. A study in Sri Lanka evaluated the relationship between environmental and dietary levels of selenium and iodine and the incidence of goitre, an iodine-deficiency disease. Levels of iodine in drinking water and rice are much lower in villages where goitre is a problem than in villages where goitre does not occur. Selenium deficiency and potential goitrogens in red rice may also be potentiating factors in the aetiology of goitre in south-west Sri Lanka.



F M Fordyce

*Woman suffering from goitre, one of the primary health effects of iodine deficiency.*

# Resources — Minerals

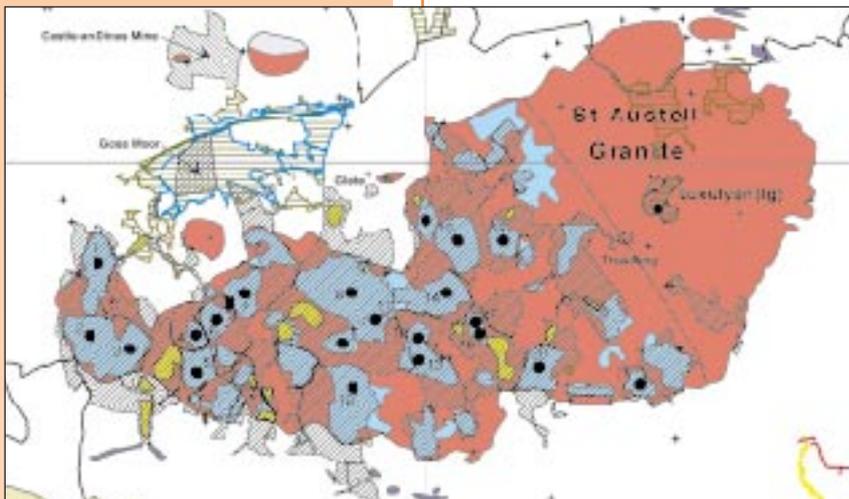
## PIMA

Spectral geology, as a service to the minerals industry and BGS projects, is an area of increasing importance for the BGS in terms of both ground-based systems and new satellite sensors. The PIMA (Portable Infrared Mineral Analyser) is a handheld shortwave infrared spectrometer capable of identifying a range of clays, sulphates and carbonates — minerals typical of hydrothermal alteration assemblages. The PIMA has been used in commercial investigations in Anglesey, Devon, Ochills and Ecuador.

## Trace Elements in Cement

Philips Analytical X-ray (Cambridge) commissioned a complete calibration package for the analysis of trace elements in cement products and by-products, using X-ray fluorescence (XRF) spectrometry. The package consists of 16 standards, two drift correction samples and two XRF software applications capable of calibrating a Philips XRF spectrometer for 11 major and 34 trace elements.

(Below) *Part of the Mineral Resources Map of Cornwall, showing resources, planning permissions and planning constraints in the St Austell china clay area.*



## Minerals Programme

This programme, funded by the DTI, comprises a minerals information and advisory service and activities aimed at stimulating the creation of wealth from Britain's mineral resources. Work on the wealth-creation aspects included publication of a report describing new evidence of mineralisation in the Lewisian supracrustal rocks of north-west Scotland. Sulphide-bearing and banded iron formation rocks were found to contain local gold and merit further investigation for their economic potential.

Another report on the mineral potential of the Dalradian rocks of north-east Scotland for stratabound (SEDEX) deposits contained a review of existing data plus new geochemical and geophysical information interpreted in the light of recent geological mapping. The most promising area for the discovery of stratabound base-metal deposits was considered to be in the Upper Deveron near Wellheads.

The information and advisory service provided information to Government and Industry on all aspects of minerals exploration, development, production and trade, making extensive use of databases supported by the programme. Work included participation in the International Strategic Metals Issues (ISMI) Working Group and in an International Consultative Group in Non-ferrous Metal Statistics. The World Mineral Statistics database, which is compiled from official sources and in consultation with major producers, traders and other international

organisations, was updated and the publication *World Mineral Statistics 1992-96* produced from it. *The United Kingdom Minerals Yearbook 1997*, which provides more detailed statistics for the UK and includes commentary and graphics, was also published with the assistance of funding from the DETR and DTI.

## Mineral Resource Information

This DETR-funded project has developed systems for the collection and display of data on mineral resources and the environmental constraints that may affect their extraction, for selected areas of England and Wales. Such information is essential for the preparation and review of Mineral Local Plans. Maps, and associated reports, on Cornwall (*below left*) and South Wales were published during the year and work on a further six counties is well advanced. A primary objective of the work is to provide baseline data on mineral resources in a consistent format for the long term. All the data are held in digital form, enabling easy revision and customisation to meet individual user needs.

## Minerals of East Dorset

The BGS started a multidisciplinary study on behalf of the DETR, to provide up-to-date information on the mineral resources of the Tertiary Basin of east Dorset and their relationship to planning issues. The area contains nationally important resources of ball clay as well as sand and gravel. It is also highly valued for its habitats of national and international significance, particularly the heathlands.

## Computer-based 3-D Modelling

Using VULCAN software, work was undertaken on modelling metalliferous mineral and coal prospects in Britain and overseas for SMEs. The models generated by this powerful system assisted the clients in estimating the resources present, highlighting information gaps, and identifying and helping to resolve geological and other problems.

## Building Stones

A study, commissioned by CADW Welsh Historic Monuments, investigated the sources of building stone used in the Cistercian Tintern Abbey, Gwent.

# Resources — Oil and Gas

## FieldBank

In collaboration with ARK Geophysics, Petroleum Exploration Computer Consultants (PECC) and the Petroleum Open Software Corporation (POSC), and with part-funding from Department of Trade and Industry (OSI), the BGS has developed an extension to the POSC Epicentre data model for gravity and magnetic data, and set up a commercial database service for the oil industry. The system is now established at Keyworth using the PECC PetroVision data browser as a fully commercial venture and is accessible to customers via ISDN lines and the Internet.

## IIFR

The IIFR (Interpolation In-Field Referencing) technique, co-developed with Sperry-Sun Drilling Services, provides accurate estimates of the strength and direction of the geomagnetic field at drilling locations to improve the accuracy of well-bore surveys made using magnetic survey tools. For UK offshore fields this is achieved by combining the BGM, local aeromagnetic survey measurements and data from the BGS magnetic observatories. IIFR was applied at eleven offshore oil fields in the North Sea region, and the BGS commissioned aeromagnetic surveys over three 50 x 50 kilometre areas. On or close to land conventional magnetic survey techniques are applied. Commissioned surveys were carried out in Germany and Alaska (*below*).



J G Carrigan

## DTI – Oil and Gas Division

A BGS team of geologists and seismic interpreters provide advice to the Oil and Gas Division of the DTI to assist the Department in the management of the UK oil and gas resources. The work is carried out in strict confidence. Data provided by the industry under the various petroleum regulations are used by the BGS team to assess field and basin potential, to estimate reserves and provide broadly based geological advice to the DTI's own technical team.

## Atlantic Margin

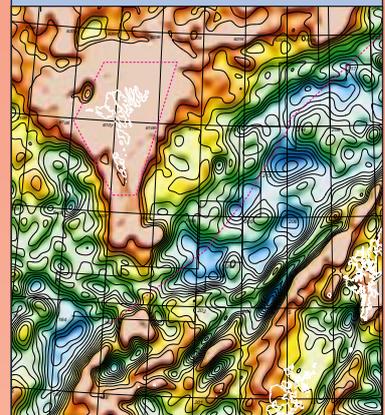
Oil companies commissioned 2-D and 3-D gravity and magnetic modelling, which was integrated with seismic reflection interpretation in the investigation of the Atlantic margin.

## Reservoir Mineralogy and Fracturing

The results of studies into the distribution of the natural radioactive elements U, Th, and K in North Sea reservoir rocks has enabled gamma-ray wireline logs to be more realistically interpreted. Relationships between fracturing history, fracture mineralisation and diagenetic effects have been explored by detailed petrographic analysis in order to evaluate their influence on reservoir properties. Clients include Shell UK Exploration and Production Limited and BP Exploration Operating Company Limited, and there has been close collaboration with the universities of Aberdeen and Leeds.

## Geophysical Image Atlas

An Interpreters' Supplement to the *Geophysical Image Atlas* was developed as an aid to hydrocarbon exploration in the UK Atlantic margin. Volumes 9S (Shetland-Faeroes) and 10S (Hebrides-Rockall) were supplied to customers and volume 11S (Hatton Bank) was taken to production stage. The main elements are: combined images of gravity and magnetic anomaly data; anomaly source locations from Euler deconvolution; and apparent basin thickness maps derived from 3-D gravity modelling of the lithosphere to depths of 40-45 kilometres.



R M Carruthers

*An interpretation of the apparent basin thickness off northern Britain as derived from 3-D gravity modelling. The Faeroe Islands (to the NW) and the Orkney and Shetland Islands (to the SE) are outlined in white. Areas with shallow basement and igneous complexes are indicated by orange shades whereas the thicker basins appear in blue. The modelling was carried out using the BGS Gmod software.*

(Left) *Magnetic survey measurements being made at Prudhoe Bay, Alaska, in support of oil industry operations.*

# Geology and Geohazards

## World Stratotype

The contract to supervise the acquisition of rock cores and geophysical logs through the full thickness of the Kimmeridge Clay forms part of the NERC Rapid Global Geological Events (RGGE) special topic to study past climatic changes in as great detail as practicable in a selected interval of the geological column. The Kimmeridge Clay provides an unbroken sequence of highly fossiliferous marine mudstones, about 150 million years old, which represent about three million years of Earth history. They contain rhythmic variations in clay mineralogy, fauna and organic content that reflect past climatic and sea-level changes. The aim of the project is to try to identify climatic changes that resulted from variations in the radiant heat received from the sun, which are thought to occur in 21 000 to 250 000-year cycles. The RGGE results will enable long-term climatic cycles to be recognised, which cannot be identified from the available short-term historical climatic records.

(Below) *World stratotype for the Kimmeridgian – Portlandian Stage Boundary: Houns-tout, Isle of Purbeck, Dorset.*

## Seismic Properties of Marine Sediments

The study of the acoustic properties of marine sediments is of interest in understanding the processes of wave propagation, refraction, and reflection at boundaries in the vicinity of the sea floor. Understanding how these properties change in a normally consolidated sediment is essential in the formulation of improved 'seismo-acoustic propagation-loss models' of the marine sub-surface. Many models of the near sea bed tend to simplifications as there is far more structure, especially in the Quaternary sediments, than appears on these models. Information gathered from sampling and laboratory testing programmes can improve these models by providing both seismic and geotechnical property data.

The Defence Evaluation and Research Agency (DERA) recognised this need and commissioned a collaborative project between Reading University, Postgraduate Research Institute for Sedimentology (PRIS) and the BGS to develop a database with acoustic, mineralogical and geotechnical information pertaining to the rocks and sediments of the offshore UK. This database would provide the key relationships used to produce seismic property pseudo-sections used in scenario models for the detection of anomalous bodies using sonar techniques.

## Geomagnetically Induced Currents (GICs)

The National Grid Company needs assessment of hazards posed to its electricity distribution networks by GICs which, during magnetic storms, may cause transformer overheating or even trip safety devices. In March 1989, close to the last solar activity maximum, magnetic storm-induced GICs in the Hydro-Quebec system caused catastrophic failure. Magnetic storms will become more frequent over the next few years as the next solar maximum approaches and so the GIC hazard will increase. The BGS has begun a study of GICs including the development of a new 3-D electrical conductivity model of the British Isles.

## Rockall Margin

Site specific studies have been carried out for a number of companies, particularly associated with the possible presence of shallow gas, gas hydrates or unstable slopes. This work has been done either for Environmental Impact Assessments or as part of the site investigation during field development

## Radon

The DETR has contracted the BGS, as part of a joint project with the NRPB, to produce geological radon-potential maps for selected parts of England which will identify areas where radon concentrations are most likely to have greater than 5% probability of being above the Action Level. The main objective of the project is to identify with greater precision the location of homes likely to be above the Radon Action Level and to inform any future radon measurement campaigns.

## GHASP

GHASP (Geo-Hazards Assessment and Susceptibility Programme) is a Geographical Information System (GIS) describing the components of subsidence hazard in a format suitable for use by insurance underwriters. The system is based on expert interpretations of five risk layers with the user interface being postcode sectors. Numerical values of hazard can be exported for incorporation into the user's database.



R W Gallois



R D Ogilvy

*Deployment of RESCAN electrode cable assembly on lake floor by divers.*

### Resistivity Imaging

On behalf of DERA, the BGS was commissioned by Ultra Electronics to carry out trial RESCAN resistivity measurements on the floor of an artificial marine lake, Horsea Island, Portsmouth — the first attempt to use the system in a marine environment (*above*). The experiments were designed to map the lake-bottom sediments below 6–7 metres of highly conductive sea water. The results confirmed that while the sea water dominates the measured resistivities at short electrode spacings, advanced tomographic inversion techniques permitted the successful imaging of structure, degree of fracturing and sea-water saturation levels, in the underlying chalk.

### Cuttings Mounds

Several studies have been undertaken for Shell UK to sample and core cuttings piles near or under drill platforms.

Operationally this can be difficult, as in the case of investigation under the Fulmar A platform in the North Sea, where cores were collected using the BGS's six metre vibrocorer deployed from a rig supply vessel between the legs of the working platform. Here a number of cores were successfully collected which sampled through the cuttings pile and into the original sea bed. They were logged and sub-sampled for detailed geochemical analysis, providing evidence of the levels of diffusion from the mud and cuttings pile.

### Department of the Environment Transport and the Regions

Three reports for the DETR discuss how earth science information is presented

and can be better utilised in the planning and execution of major development initiatives. Case studies, the views of user communities and a guide to best practice are the core of the output.

### Geotek Core Imaging System

A non-contacting resistivity system is being developed in conjunction with Geotek (to sell as additional sensor for their core logger) for imaging slabbed core and whole core while still in its liner.

### Commercial Geophysics

Commercial cross-borehole seismic surveys have been designed and undertaken for clients in the UK and Hong Kong.

Electrical resistivity imaging has been undertaken on the seabed for the Defence Research Agency and used as part of a study into the stability of Edinburgh Castle (*right*).

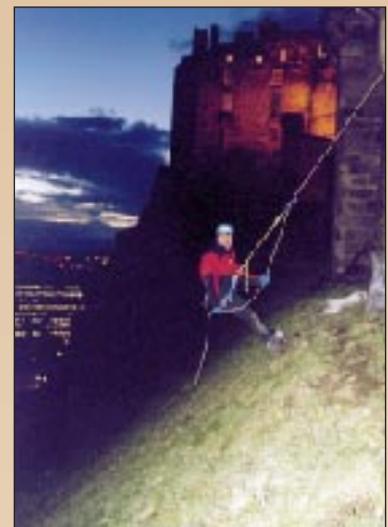
### SW England

Contract work by the University of East Anglia on the magnetostratigraphy of the 'New Red Sandstone' (Permo-Triassic) of south-west England has resulted in the establishment of a sequence of magneto-zones in the biostratigraphically barren Aylesbeare Mudstone, indicating the first definitive evidence of a Triassic (Smithian-Spathian) age for that unit. The important consequence is that the base of the Mesozoic must now be sought in the upper part of the Exeter Group, which underlies the Aylesbeare Mudstone Group.

Work has continued on the geological assessment of Devonport Dockyard in association with the Babbie Group.

### Commercialisation of BGS Borehole Seismic Sources

The BGS has developed a range of borehole seismic sources for the generation of compressional and vertically polarised shear-wave signals. The designs are unique to the BGS and a marketing agreement has been concluded with Allied Associates Geophysical Ltd to promote and sell these devices for site-investigation surveys, including cavity detection, fault and fracture delineation, rock-mass characterisation for the radwaste industry and the determination of in-situ geomechanical properties. A shear-wave source was recently sold to the Institute of Engineering Seismology and Earthquake Engineering (ITZAK), Greece.



L J Donnelly

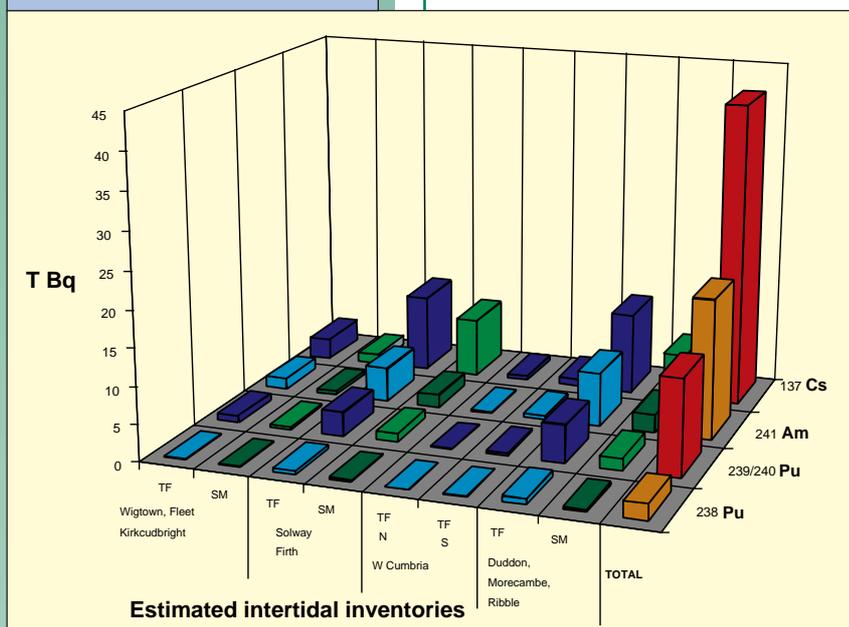
*Mid-winter work on the Edinburgh Castle landslide: a BGS geologist laying geophysical lines.*

# Environmental Geoscience

## Radioactivity in the Irish Sea

A MAFF-funded study of radionuclides in Irish Sea intertidal sediments was completed. This provided detailed information on the distribution of  $^{137}\text{Cs}$  in the sediments of the eastern Irish Sea and showed clear reductions in the  $^{137}\text{Cs}$  content over time as discharges from Sellafield have reduced. Estimation of the relationships between  $^{137}\text{Cs}$ ,  $^{241}\text{Am}$  and Pu isotopes in the sediments enabled inventories of these relatively long-lived radionuclides in the sediments to be calculated.

(Below) *Estimated inventories of radionuclides in Irish Sea Intertidal sediments (TF, tidal flat; SM, salt marsh).*



## Nirex

The BGS has continued to provide extensive geoscience consultancy services to United Kingdom Nirex Limited, despite the termination of the Sellafield investigations following the Secretary of State for the Environment's rejection of their proposal to build an underground laboratory as a precursor to construction of a deep repository for intermediate level radioactive waste. Much of the work was concerned with the 'mothballing' of the Sellafield studies and comprised the finalisation of open-file reports on the results of recent investigations and the completion of the Nirex Digital Geoscience Database (NDGD) and related GIS addition, which contains all the basic earth-science data collected during the programme.

## Rock Fractures

Petrographic characterisation of fractured rock and associated mineralisation from the Sellafield site has continued as part of the completion of the Nirex site investigation programmes. Much of the work focussed on the mineralogical characterisation of fractures and porous rock associated with active groundwater flow.

## Resistivity Imaging

The BGS-designed RESCAN resistivity imaging system was successfully applied, under contract to Nirex, to mapping the spatial heterogeneity and volumetric distribution of the Quaternary sequence at Sellafield. Sufficient geoelectric contrast existed between boulder beds, gravels and clays to differentiate these horizons. The results confirmed that the Quaternary sequence can exhibit a high degree of heterogeneity, particularly in the stream flood plain where depositional patterns are constantly changing.

## Fluid-rock Reactions

Pore fluids leaching from a cement-dominated waste repository can be highly reactive towards the rocks hosting the repository. The BGS has spent several years investigating these reactions for Nirex by a variety of laboratory experiments and computer modelling studies. Recent work has included the continued improvement of computer codes capable of predicting alkali fluid-rock reaction, and the revision of numerous reports detailing recent work.

## Analcite Dissolution Kinetics

The construction of caverns for the deep underground disposal of radioactive waste is likely to use significant quantities of cement. The interaction of highly alkaline cement pore fluids with clay minerals is likely to form the mineral analcite, for which few kinetic and thermodynamic data exist at present. Understanding the rate and magnitude of reactions involving analcite is important for the accurate prediction of long term reactions in the vicinity of the waste. The BGS is currently conducting experiments, funded by PNC to determine the rate at which analcite reacts over a range of temperatures and fluid compositions.

## REX Project

This project, funded by the Power Reactor and Nuclear Fuel Development Corporation, Japan, involved a study of microbial effects on redox conditions in relation to the geological disposal of radioactive waste, linked to the Aspo Hard Rock Laboratory in Sweden.



R D Ogilvy

*Pumping of coal-tar to remediate a former gasworks site.*

### Extraction and Characterisation of Pore-waters in Clays

In the construction of underground repositories for the disposal of radioactive waste, an understanding of the chemical composition of groundwaters flowing through the proposed geological formation is critical. The target formation is usually chosen to have a low permeability to help minimise the risk of long-term transport of radionuclides into the biosphere. The BGS has carried out three contract research projects with European nuclear waste agencies (NAGRA, who lead a consortium of countries characterising the Opalinus clay formation; the French nuclear waste agency ANDRA; and IPSN who are carrying out studies on the Tournemire Shale Formation).

### IPT

The EU is funding an assessment of the use of Induced Polarisation Tomography (IPT) for the non-invasive geoelectric mapping of subsurface contaminants, particularly oils and solvents. It is postulated that contaminants which interact with the pore-mineral interface or block ion mobility may give rise to anomalous IP effects. The consortium partnership comprises the BGS (coordinator), ABEM Instrument (Sweden) and BG Technology (formerly British Gas). Field trials have been undertaken at ex-gasworks sites, in conjunction with BG Technology plc (*above*).

### Microbiological Contaminants

A detailed review of microbiological contaminants in groundwater, carried out by the BGS and the Robens Institute, University of Surrey for the Environment Agency, included: protocols for assessing

the microbiological safety of drinking waters; removal of microbiological contaminants across septic tanks and package treatment plants; and the effects of bioremediation on groundwater quality in terms of microbiology and chemistry.

### Marine Survey, California

Modifications to the BGS towed seabed gamma-ray spectrometer (EEL) system enabled it to be used at much greater depths than previously, for collaborative work with the US Geological Survey and the US Environmental Protection Agency in a survey of the Farallon Radioactive Waste Dump Site off California.

### Monitoring the Test Ban Treaty

The BGS has been awarded the contract to establish the UK National Data Centre (NDC) to monitor the Comprehensive Test Ban Treaty (CTBT) by seismic identification of underground nuclear explosions. This involves the analysis of seismic data from a global network of seismic stations and arrays, including the UK array at Eskdalemuir, for which the NDC has responsibility. The NDC data processing system is being developed in collaboration with AWE Blacknest.

### Potentially Toxic Elements in Welsh Stream Waters

This project, funded by the NERC Environmental Diagnostics thematic programme used a speciation model to predict the chemical form of potentially toxic metals such as lead, cadmium and zinc in stream water. The data were used to identify areas where metal concentrations were above Environmental Quality Standards for freshwater fish (salmonids).

### EQUIP

Work commenced on an EC-supported international project to investigate how deep groundwater systems at potential repository sites have responded to changes in climatic and hydrogeological conditions during the Quaternary. EQUIP (Evidence from Quaternary Infills for Palaeohydrogeology) extends work undertaken by the BGS for UK Nirex Ltd at Sellafield in west Cumbria, and uses mineralogical features to provide information on how the modern deep groundwater system has evolved. The work reveals a close relationship between the occurrence and distribution of the latest generation of calcite and present-day groundwater flow in deep (up to two kilometres) site-investigation boreholes.



A E Milodowski

*Cathodoluminescence (CL) image of late-stage calcite mineralisation reveals complex, fine-scale growth zoning of bright and dark luminescence zones controlled by variations in trace elements incorporated in the crystal lattice during its growth from recent groundwater. The zoning preserves a record of mineral precipitation and corrosion, and microchemical variation reflecting the history of changes in groundwater composition.*

# Environmental Geoscience (continued)

## Effect of Landfill Sites on Groundwater Quality

RESCAN resistivity imaging surveys were undertaken for the EA at the closed Thriplow Landfill, Cambridgeshire, to help define the spatial limits and 3-D geometry of the deposited waste and to identify possible leachate flow-paths. The landfill was operated on the dilute and disperse principle and hence the underlying Chalk (an important aquifer) could be vulnerable to contaminant infiltration.

(Below) *The RESCAN images confirmed that the landfill did not occupy a single quarry but comprised several discrete pits, all of which were filled and subsequently covered by a thin layer of surficial back-fill. The waste deposits are characterised by very low resistivity values (colour-coded red). The edges of the pits are clearly delineated, a result that is supported by photogeological evidence. The low resistivity values below the base of the pits are attributed to the infiltration of leachate and preferential flow-paths associated with fracture zones within the Chalk.*



D K Buckley

*Sampling and geophysical logging of groundwater in north-west Skye.*

## Scottish Hydrogeology

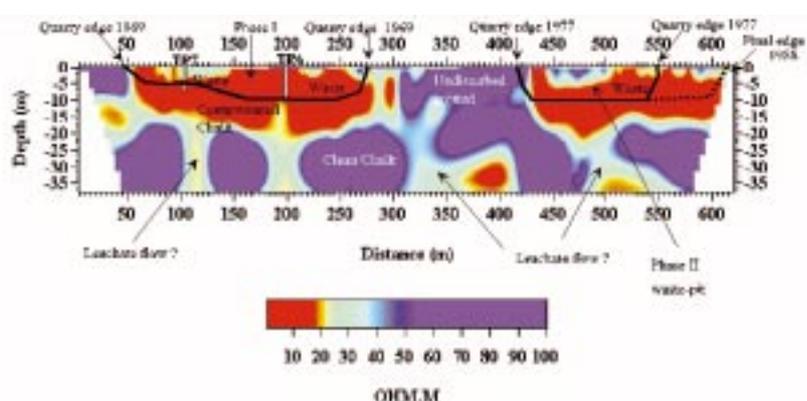
Our understanding of aquifer characteristics in Scotland is steadily increasing as groundwater development maintains a high level of interest. Several aquifers are now under investigation for public supply usage owing to the advantages of groundwater over surface supplies in certain circumstances. With the forthcoming implementation of European legislation, it is hoped that the opportunity will arise to

commence the integrated monitoring and data collection of aquifers in Scotland. The Hydrogeology Group has provided support and advice to the Water Authorities, the SEPA and the Scottish Office on strategic issues regarding protection and management. A groundwater database is being produced as well as a series of vulnerability maps covering the main areas in Scotland where groundwater is abstracted (*above*).

## Northern Ireland

Multi-element analyses of stream sediments and stream waters, funded by the Environment Service (DOE-NI) and the Department of Economic Development (DED), now provide comprehensive geochemical coverage of western Northern Ireland. The dataset covers more than 70 elements, including very low level analyses of elements such as Mo in stream waters using ICP-MS. The successful systematic application of this technique in Northern Ireland represents a significant step forward in regional geochemical mapping, allowing new information to be obtained on a range of environmentally sensitive elements in the hydrosphere.

### INVERTED TRUE RESISTIVITY IMAGE, LINE 11, DOMESTIC LANDFILL SITE



### Chemical-waste Deposits and Flow-paths

RESCAN resistivity tomography, VLF-Resistivity and Transient Electromagnetic surveys were successfully applied in an ICI-funded project to the non-invasive mapping of chemical wastes deposited in disused sandstone quarries. The surveys helped to delineate the concealed edges and base of the sandstone quarries prior to the siting of monitoring boreholes and provided valuable physical insight on waste composition, quarry geometry and contaminant migration pathways.

### Impact of Farm Wastes Stores on Groundwater Quality

This MAFF-funded project focuses on the potential threat to groundwater from unlined slurry lagoons. In England and Wales, there could be up to 11 500 such stores some of which are located above the major Chalk and Triassic Sandstone aquifers. One likely impact is the potentially large nitrogen (ammonium and nitrate) load, another is the introduction of micro-organisms such as *Cryptosporidia*. Studies have shown that raw slurry can penetrate to depth through fractures in the rock matrix. Future work intends to assess the extent of the problem nationwide and to suggest ways in which potentially serious pollution problems might be reduced or eliminated.

### Scotland

The mapping of Edinburgh Sheet 32E was adapted to provide East of Scotland Water with a geological map and report on the proposed major Esk Valley Purification Scheme.

The City of Edinburgh Council commissioned reports on potentially contaminated land in Granton. This work was a joint venture with Edinburgh University.

### Environmental Database

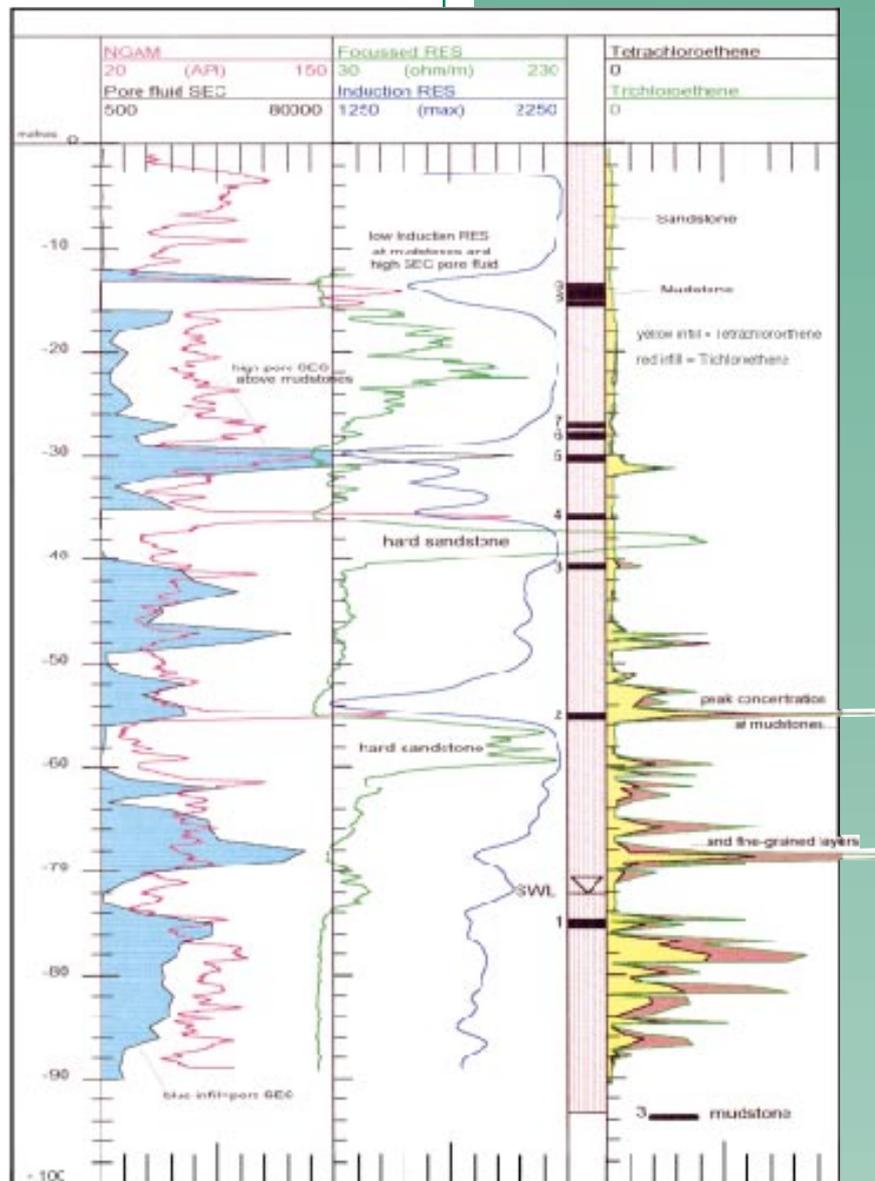
Work has also been done to prepare a multidisciplinary database of environmentally related information to assist oil companies in the preparation of Environmental Assessments in the Rockall area. This work has been done in collaboration with other NERC institutes and provides a considerable cost saving for the companies in the preparation of their cases.

### Transport Behaviour of Contaminants

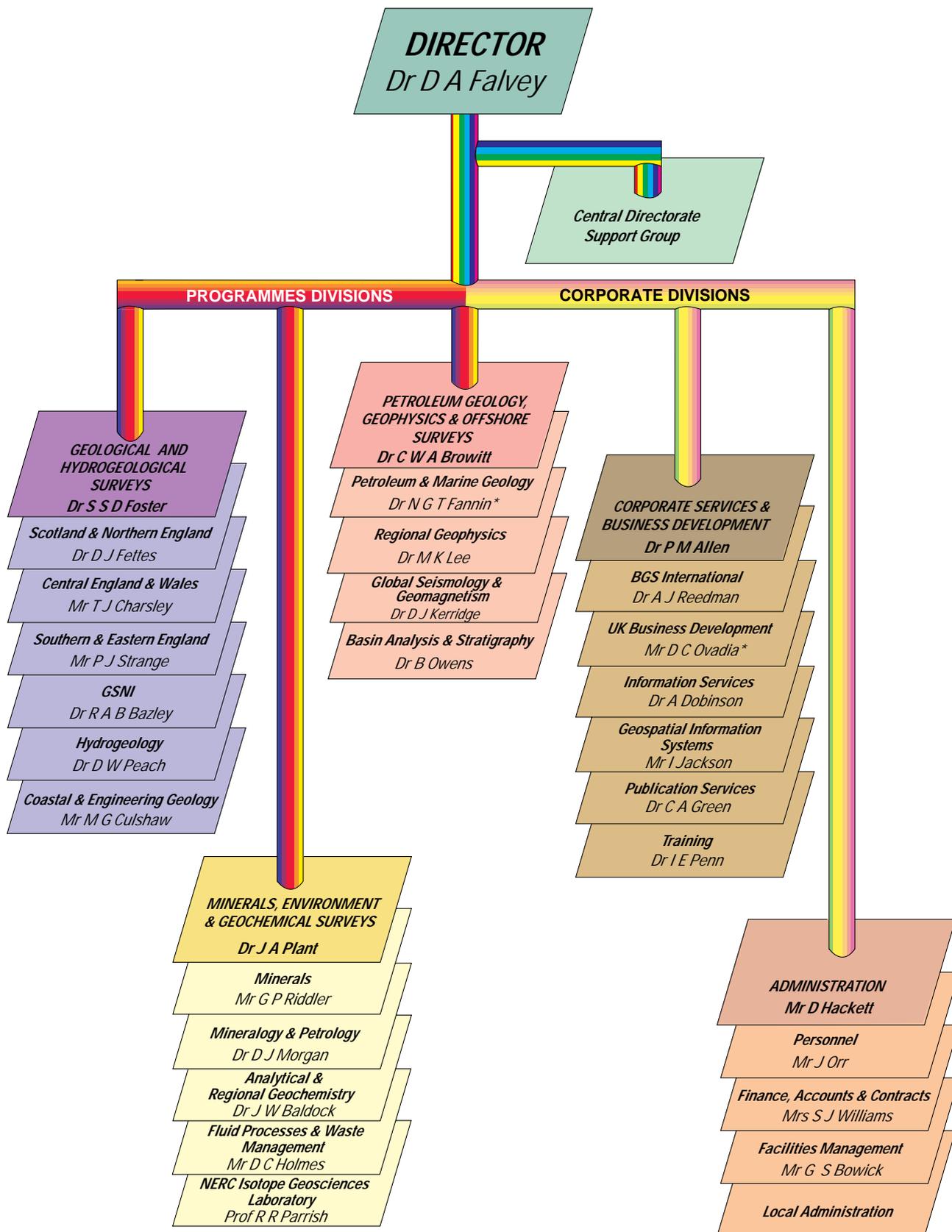
Drilling and sampling of four deep-cored boreholes in the Permo-Triassic

Sandstone Aquifer was completed close to a site where chemical wastes had been disposed previously. The unsaturated zone was 60 to 75 metres thick, and extracting pore fluids from the drill core represented the only means of sampling this zone. Detailed profiles of porewater chemistry with depth were determined for a range of contaminants including the halogenated solvents (*below*). These demonstrated that movement of water and aqueous phase contaminants was largely controlled by lithology and fine-scale laminations. This research for ICI confirmed the complex behaviour of contaminant migration and the importance of integrated investigations to include borehole geophysics, porewater analysis and geological and aquifer characterisation of the core.

(Below) Geophysical logging confirmed 'ponding' of contaminants on layers of low permeability (mudstones, cemented sandstones).



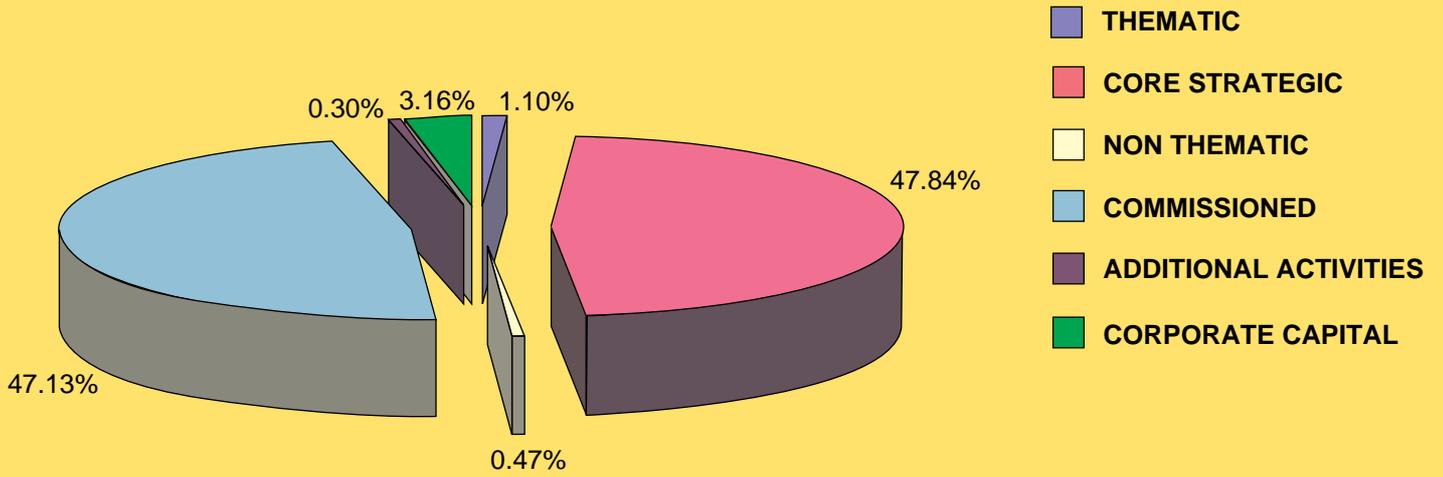
# Appendix 1 Organisation



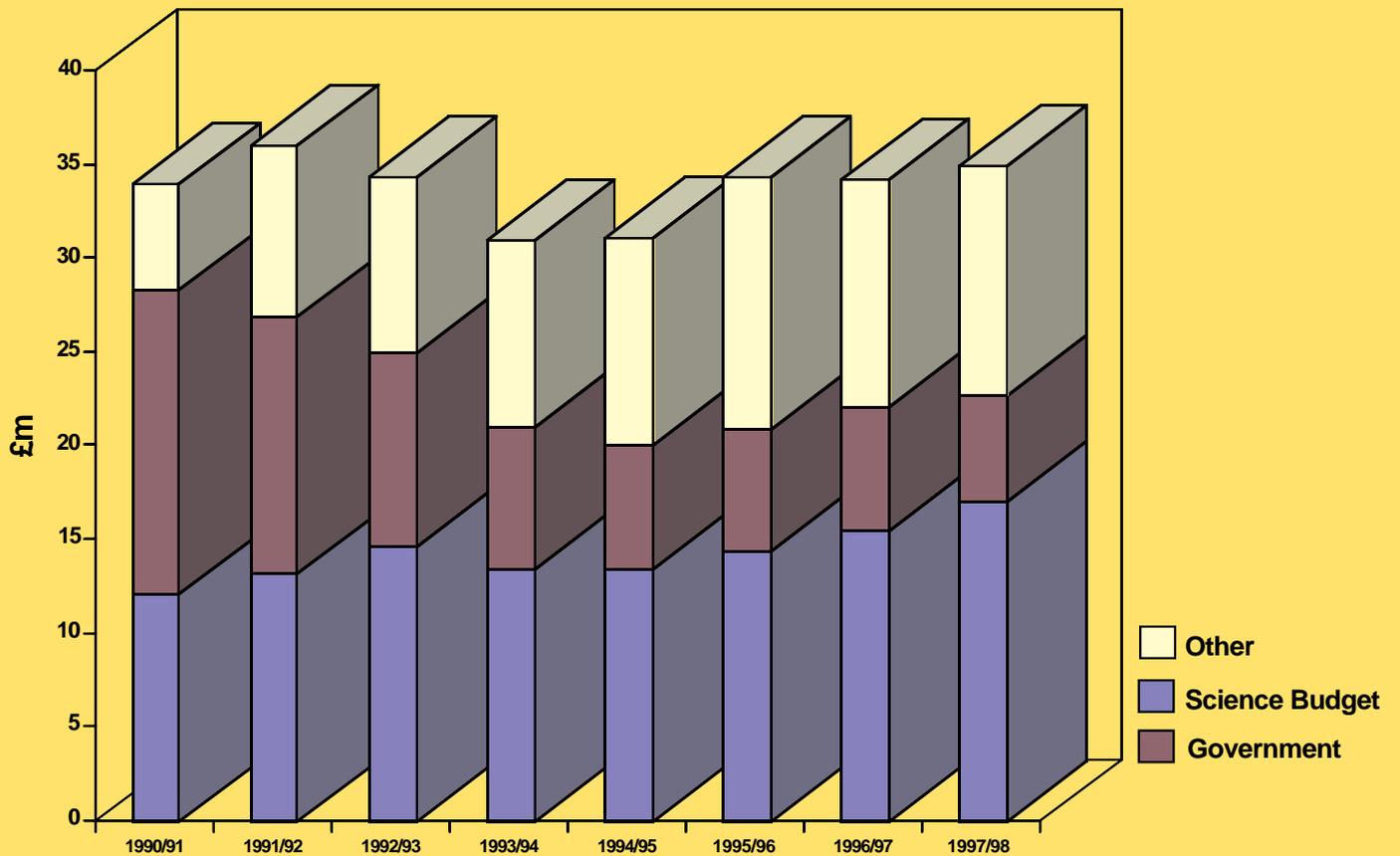
\* Acting head

# Appendix 2 Finance

## BGS EXPENDITURE — 1997/98



## SOURCES OF BGS INCOME 1990/91 — 1997/98 (at 1997/98 prices)



# Appendix 3 Publishing

## Interim issue of maps

To ensure the earliest possible release of current geological data to the public, all new 1: 50 000 maps are first made available in digital form and as electrostatic plots (on-demand), in advance of litho printing. The purchase of an electrostatic plot entitles the customer to a free copy of the printed map if and when this is published.

## MAPS PUBLISHED

The following abbreviations are used throughout: S – solid; D – drift; S&D – solid and drift; SwD – solid with drift; S,D – both editions on one sheet; Q – Quaternary; PQ – Pre-Quaternary; † – provisional edition.

### 1: 1 500 000

Colour shaded relief gravity anomaly map of Great Britain, Ireland and adjacent seas  
Colour shaded relief magnetic anomaly map of Great Britain, Ireland and adjacent seas

### 1: 250 000

Tyne-Tees S (2nd edition)  
Northern Ireland S (2nd edition)

### 1: 50 000 (PRINTED)

#### ENGLAND AND WALES

10	Newbiggin S,S&D
23	Cockermouth S
23	Cockermouth S&D
35/44	Whitby and Scalby † S&D
40	Kirby Stephen † S&D
41	Richmond † S&D
47	Bootle S, S&D
48	Ulverston S
48	Ulverston S&D
50	Hawes † S&D
73	Hornsea † S&D
119	Snowdon S
119	Snowdon S&D
129	The Wash S&D
270	South London S&D
271	Dartford S&D
278/part 294	Minehead S&D

#### SCOTLAND

31E	Falkirk S
31E	Falkirk S&D
66E	Banchory S&D
84W	Fortrose S&D
85W	Knockando S
114 E	Tongue S

#### COASTAL GEOLOGY — England and Wales

Parts 257, 258, 259, 271, 272, 273 Inner Thames Estuary PQ&Q

### 1: 50 000 (ELECTROSTATIC PLOT)

#### ENGLAND AND WALES

34	Guisborough † S&D
38	Ambleside S&D
54	Scarborough † S&D
73	Hornsea S&D
235	Cirencester S&D
271	Dartford S&D
316	Fareham S&D
348	Plymouth S&D

#### SCOTLAND

19	South Islay † S&D
32W	Livingstone S
40E	Kircaldy S&D
40E	Kircaldy S
42/51W	Tiree and Coll † S&D
43S	Ross of Mull † S&D
102E	Lairg S&D

#### INTERNATIONAL

##### SRI LANKA

Geological map of Central and Western Sri Lanka (1: 250 000)  
Kochchikade–Attanagalla (1: 100 000)  
Nuwara Eliya–Haputale (1: 100 000)

## BOOKS PUBLISHED

### ANNUAL REPORT

Report for 1996/97

### SHEET MEMOIRS

#### ENGLAND AND WALES

28/37/47	West Cumbria
119	Snowdon
123	Stoke-on-Trent
178/179	Llanilar and Rhayader
335/336	Trevoze Head and Camelford

#### SCOTLAND

23W	Hamilton
30E	Glasgow
63W	Glen Roy
60	Rum and the adjacent islands
73W	Invermoriston
76E/76W	Inverurie and Alford

### LITHOSTRATIGRAPHIC ATLAS

UK North West Margin, Vol. 2

### TECHNICAL REPORTS

HS/97/1 Effective health and Safety management of geoscience fieldwork  
WE/97/5 The hydrogeological behaviour of the clay-with-flints of southern England

## RESEARCH REPORTS

SF/98/1 The Midas Project — Multidataset analysis for the development of gold exploration models in western Europe

## MINERAL RESOURCES

United Kingdom minerals yearbook 1996

## MAGAZINES

*Earthwise*, Issues 10, 11

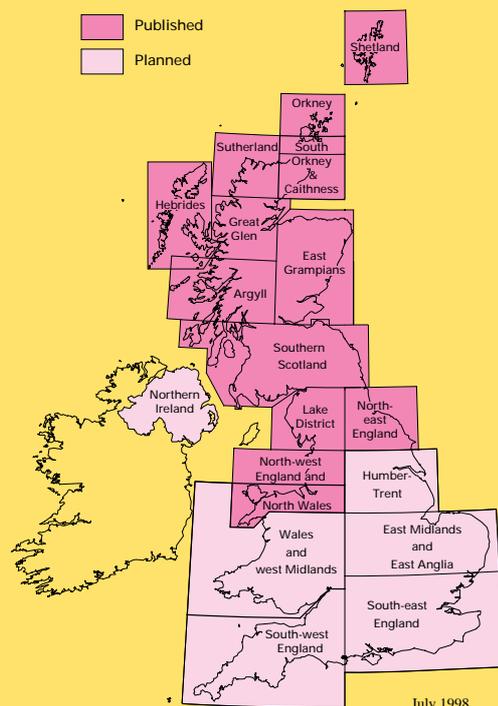
## POPULAR PUBLICATIONS

Discovering geology card — *Fossil focus: Foraminifera*  
Holiday geology guide — *Mining in west Cornwall*  
Holiday geology guide — *Westminster*  
Holiday geology guide — *St Paul's*  
Holiday geology map — *North York Moors*  
Holiday geology map — *Lake District*  
Fossils — the story of life  
Earthquakes — our trembling planet  
Groundwater — our hidden asset

## GEOMAGNETIC BULLETIN

No.26

INDEX TO AREAS COVERED BY GEOCHEMICAL ATLASES

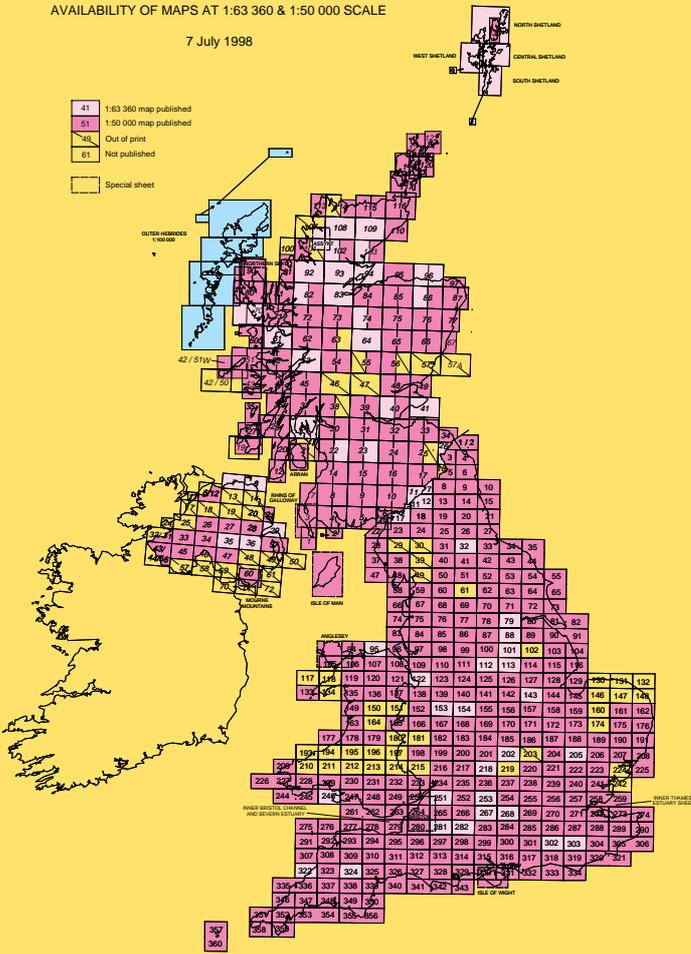


July 1998

AVAILABILITY OF MAPS AT 1:63 360 & 1:50 000 SCALE

7 July 1998

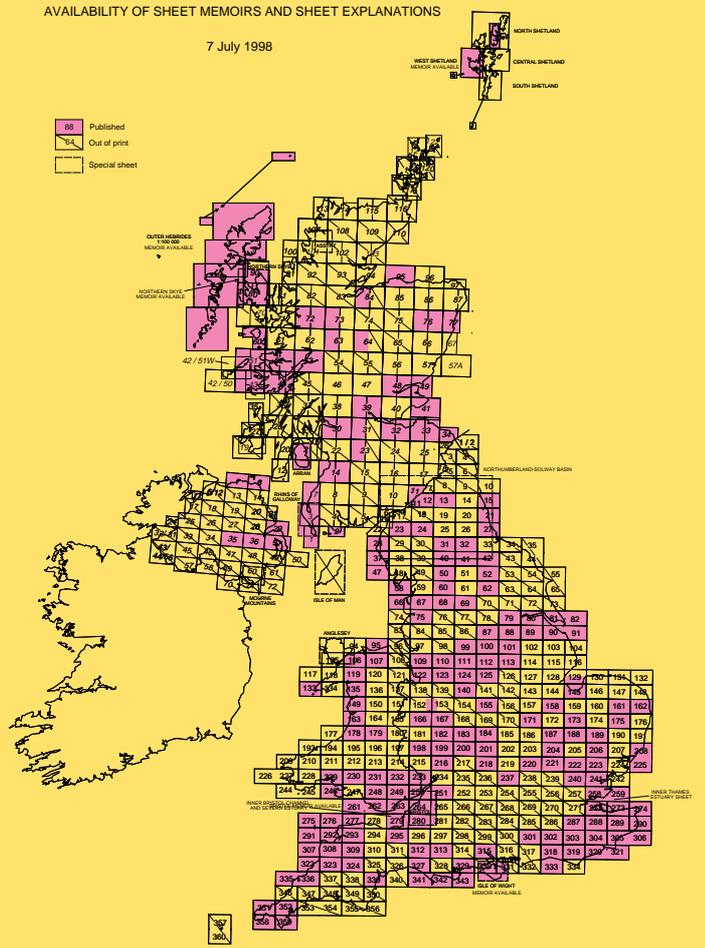
- 41 1:63 360 map published
- 51 1:50 000 map published
- 74 Out of print
- 61 Not published
- Special sheet



AVAILABILITY OF SHEET MEMOIRS AND SHEET EXPLANATIONS

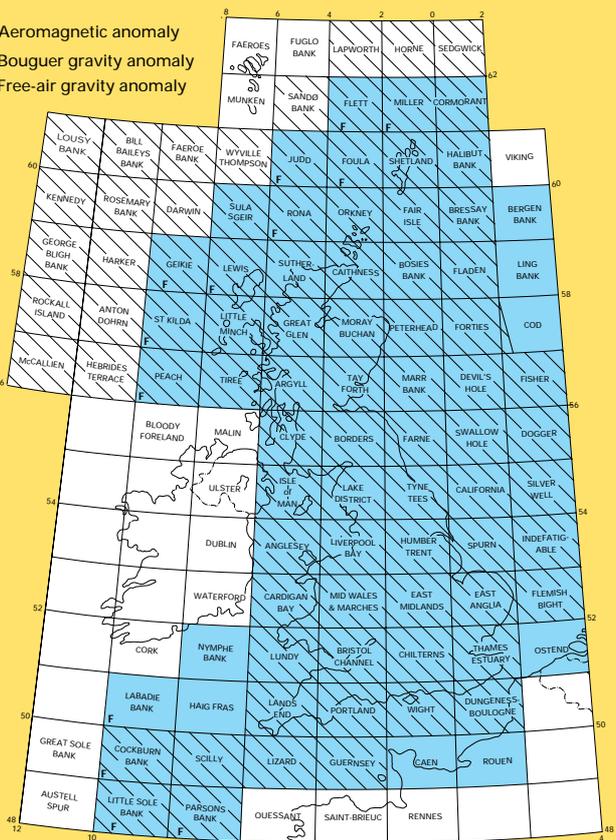
7 July 1998

- 58 Published
- 74 Out of print
- Special sheet



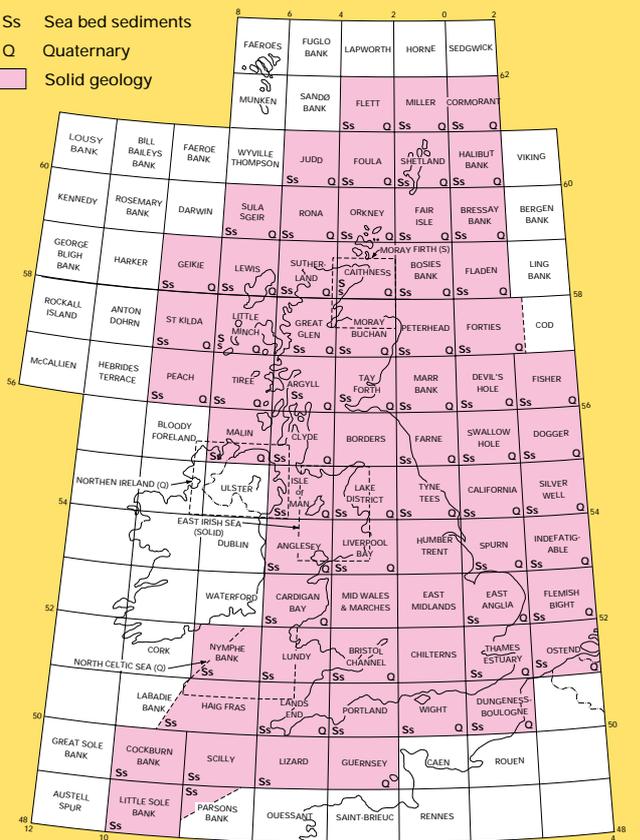
AVAILABILITY OF GEOPHYSICAL MAPS  
1:250 000 SCALE U.T.M. SERIES

- Aeromagnetic anomaly
- Bouguer gravity anomaly
- F Free-air gravity anomaly



AVAILABILITY OF GEOLOGICAL MAPS  
1:250 000 SCALE U.T.M. SERIES

- Ss Sea bed sediments
- Q Quaternary
- Solid geology



## TECHNICAL REPORTS

(made available by the authors' group)

### Onshore Geology

WA/94/79 Geology of the Sutton-in-Craven and Steeton and Cowling areas.

WA/94/80 Geology of the Keighley area 1: 10 000 sheet SE04SE: part of 1: 50 000 sheet 69 (Bradford).

WA/95/12 Geological notes and local details for 1: 10 000 Sheet TG41NW (Potter Heigham): part of 1: 50 000 Sheet 148 (North Walsham).

WA/96/5 Geological notes and local details for 1: 10 000 sheet TG32NE (Lessingham): part of 1: 50 000 sheet 148 (North Walsham).

WA/96/29 A lithostratigraphical framework for the carboniferous rocks of the Midland Valley of Scotland.

WA/96/30 Gypsum: Geology, Quarrying, Mining and Geological Hazards in the Chellaston and Aston-on-Trent areas, 1: 10 000 sheets SK33SE, SK32NE, SK43SW and SK42NW: part of 1: 50 000 sheet 141 (Loughborough).

WA/96/80 Geology of the Sherrifhales area, 1: 10 000 sheet SJ71SE and part of SJ71NE: part of 1: 50 000 sheet 153 (Wolverhampton).

WA/96/82 Geology of the district between Wolverhampton and Penkridge: part of 1: 50 000 Sheet 153 (Wolverhampton)

WA/96/89 Economic geology of the Schiehallion district, Central Highlands of Scotland (Sheet 55W Scotland).

WA/96/90 Kirkby Stephen Provisional Map, Sheet 40.

WA/96/100 Geology of the Long Whaddon district.

WA/97/2 Geology of the Stretton and Repton areas, 1: 10 000 sheets SK22NE and 32 NW: part of 1: 50 000 sheet 141 (Loughborough) and a minor part of sheet 140 (Burton upon Trent).

WA/97/3 Geology of the Etwall area, 1: 10 000 sheet SK23SE: part of 1: 50 000 sheet 141 (Loughborough) and a minor part of sheet 140 (Burton upon Trent)

WA/97/4 Geology of the Kegworth area, 1: 10 000 sheet SK 42 NE: part of 1: 50 000 sheet 141 (Loughborough).

WA/97/9 The Skiddaw Group and its contact with surrounding rocks in the Bampton Inlier, Cumbria.

WA/97/10 Geology of the East Meon/Clanfield district (Hampshire), 1: 10 000 sheets SU62SE and SU61NE: part of 1: 50 000 sheets 316 (Fareham) and 300 (Alresford).

WA/97/13 Geology of the area between Bordon Camp and Alton, Hampshire, 1: 10 000 sheets SU73NE, and the eastern half of SU73NW: part of 1: 50 000 Geological Sheet 300 (Alresford).

WA/97/16 Geology of the Owermoigne-Wool district (Dorset), 1:10 000 sheets SY78NE (Owermoigne) and SY88NW (Wool): part of 1: 50 000 sheets 328 (Dorchester) and 342 (Weymouth).

WA/97/21 Geology of the Crawick and Kirklea areas, explanation of 1: 10 000 sheets NS71SE and NE: part of 1: 50 000 sheets (New Cumnock) and 15E (Leadhills).

WA/97/22 Geology of the Silsden and Cononley district, 1: 10 000 sheets SE04NW and SD94NE. Part of 1: 50 000 sheet 69 (Bradford).

WA/97/23 Geological notes and local details for 1: 10 000 sheet TG42SW (Hickling): part of 1: 50 000 sheet 148 (North Walsham).

WA/97/24 Geological notes and local details for 1: 10 000 sheet TG21NE (Belaugh): part of 1: 50 000 sheets 147 (Aylsham) and 148 (North Walsham).

WA/97/25 Geological notes and local details for 1: 10 000 sheet TG22SE (Scottow): part of 1: 50 000 sheets (Aylsham) and 148 (North Walsham).

WA/97/39 Stratigraphic correlation in the Central Highlands: results and implications of recent fieldwork in Ardverrick forest and the south-eastern Monadhliath Mountains.

WA/97/43 Geology of the Stinsford-Puddletown district (Dorset), 1: 10 000 sheets SY79SW (Stinsford) and SY79SE (Puddletown): part of 1: 50 000 sheet 328 (Dorchester).

WA/97/45 Geology of the Briantspuddle–Bloxworth district. (Dorset), 1: 10 000 sheets SY89SW (Briantspuddle) and SY89SE (Bloxworth): part of 1: 50 000 sheet 328 (Dorchester).

WA/97/46 Geology of the West Leake area 1: 10 000 sheet SK52NW: part of 1: 50 000 sheet 141 (Loughborough) and 142 (Melton Mowbray)

WA/97/47 Geology of the Bishops Castle district, 1: 10 000 sheet SO38NW and part of SO38NE: part of 1: 50 000 series sheet 165 (Montgomery).

WA/97/48 Geochemistry and biostratigraphy of Southern Upland Cherts.

WA/97/49 Geology of the Glespin, Wildshaw, Douglas Water and Happendon areas, explanation of 1: 10 000 sheets NS82NW, NS82NE, NS83NE and NS83SE: part of 1: 50 000 sheet Lanark (23E).

WA/97/50 Geology of the Budleigh Salterton district (Devon), 1: 10 000 sheet SY08SE: part of 1: 50 000 sheets 339 (Newton Abbot) and 326/340 (Sidmouth and Otterton).

WA/97/58 Observations of coal cleats in British coalfields.

WA/97/59 Geology of the Yeadon and Bramhope areas, 1: 10 000 sheet SE24SW and SE: part of 1: 50 000 sheet 69 (Bradford).

WA/97/64 Geology of the Littleover area, 1: 10 000 sheet SK33SW: part of 1: 50 000 sheet 141 (Loughborough).

WA/97/67 Geology of the Howgate Mouth area, explanation of 1: 10 000 sheet NS93SW: part of 1: 50 000 sheet Lanark (23E).

WA/97/68 Geology of the area between Golden Pot and Bentley, Alton, Hampshire, 1: 10 000 sheets SU74SE and SU74SW: part of 1: 50 000 Geological sheets 284 (Basingstoke) and 300 (Alresford).

WA/97/72 Cleavage data and stereograms for the Skiddaw Group Inlier, 1: 50 000 sheets 23 (Cockermouth) and 29 (Keswick).

WA/97/75 Geological notes and local details for 1: 10 000 sheet TG32SW (Ashmanhaugh): part of 1: 50 000 sheet 148 (North Walsham).

WA/97/77 Geological notes and local details for 1: 10 000 sheet TG22NE (Westwick): part of 1: 50 000 sheets 147 (Aylsham) and 148 (North Walsham).

WA/97/81 The geochemistry of Dalradian metacarbonate rocks from the Schiehallion District and Blargie, Laggan: implications for stratigraphical correlations in the Geal Charn-Ossian Steep Belt.

WA/97/87 Monadhliath project: progress report and Mapping Programme for 1998-2005.

### Marine Geology

WB/97/30 Particle size and macrofauna of Holocene sediments in the BGS borehole 71/65 in the Wash.

### Overseas Geology

WC/95/50 Sustainability of yield from wells and boreholes in crystalline basement aquifers.

WC/96/17 A groundwater hazard assessment scheme for solid waste disposal summary report.

WC/96/42 Contaminant transport and storage in the estuarine creek systems of Mombasa, Kenya.

WC/96/52 Studies of selenium distribution in soil, grain, drinking water and human hair samples from the Keshan Disease belt of Zhangjiakou District, Hebei Province, China.

WC/96/55 Assessment of mercury contamination in the Ponce Enriquez artisanal gold mining area, Ecuador

WC/96/56 Groundwater management in drought prone areas of Africa: South Africa inception report.

WC/96/64 Unconsolidated sedimentary aquifers: Review No 14–Groundwater modelling in aquifer management.

WC/97/1 Simple modelling to illustrate the impact of drought on groundwater availability.

WC/97/2 Well and borehole siting by electrokinetic sounding and associated experimental observations in Bikita District, Southern Zimbabwe.

WC/97/9 Groundwater data management by the Malawian Ministry of Irrigation and Water Development—a case study.

WC/97/10 Groundwater data management by the Ghana Water and Sewerage Corporation, Northern District—a case study.

WC/97/11 Assessment of pollution risk to deep aquifers from urban wastewaters: Santa Cruz City report.

WC/97/14 A review of gold particle-size and recovery methods.

WC/97/17 Gypsum Geohazards: their impact on development—Project Summary Report.

WC/97/19 Land-derived contaminant influx to Jakarta Bay, Indonesia. Volume 1: Geochemistry of marine water and sediment.

WC/97/31 Electro kinetic measurements in various hydrogeological environments of Zimbabwe, 1995.

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# Appendix 4 Staff List, March 1998

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<i>PSec</i>	8(A)	Mrs Carter, Stella M¶ Mrs Richards, Marjorie¶	<i>PTO</i>	7(T)	Mr Young, Robert M*
<i>Grd 7</i>	4(S)	Dr Brereton, Nicholas R <i>FGS CGeol MIP CPhys</i> Dr Busby, Jonathan P <i>FGS CGeol</i> Mr Carruthers, Richard M Mr Dabek, Zygmunt K Dr Evans, Christopher J Mr Greenwood, Peter G <i>FGS CGeol</i> Mr Kimbell, Geoffrey S Mr Peart, Roger J Mr Rollin, Keith E Mr Smith, Ian F	Eskdalemuir		
<i>SSO</i>	5(S)	Mr Chacksfield, Barrie C Mr Pedley, Robert C Mr Williamson, J Paul	<i>SGB2</i>	9(T)	Mrs Scott, Margaret¶
<i>HSO</i>	6(S)	Mrs Kimbell, Sarah F¶ Mr Kingdon, Andrew Mr Raines, Michael G Mr Royles, Christopher P Mr Walker, Adrian S D	<i>TEC 2</i>	9(T)	Mr Scott, William E
<i>SO</i>	7(S)	Miss Heaven, Rachel E Mrs Self, Suzanne J¶	Hartland		
<i>ASO</i>	8(S)	Mr Morgan, David J R	<i>PGS E</i>	8(T)	Mr Pringle, Colin R
Murchison House					
<i>(Grd 7)</i>	4(S)	Dr Evans, John R	Overseas Posting		
<i>SSO</i>	5(S)	Mr Edwards, John W F Mr Mould, Alan S Mr Sankey, Michael J	<i>HSO</i>	6(S)	Mr Baptie, Brian J
<i>ASO</i>	8(S)	Mrs White, Pamela A*	Basin Analysis & Stratigraphy		
Global Seismology & Geomagnetism					
Murchison House					
<i>Group Manager Grade 6</i>					
		Dr Kerridge, David J	Keyworth		
<i>PSec</i>	8(A)	Ms Aitken, Rose A R Mrs Milne, Margaret	<i>Group Manager Grade 6</i>		
<i>(Grd 7)</i>	4(S)	Mr Barraclough, David R <i>MIP CPhys</i> Dr Booth, David C Dr Clark, Toby D G <i>MIP CPhys</i> Dr Li Xiang, Yang Dr Macbeth, Colin D Dr Musson, Roger M W Mr Riddick, John C Miss Walker, Alice B		3(S) Dr Owens, Bernard	
<i>SSO</i>	5(S)	Mr Laughlin, John Dr Liu, Enru	<i>PSec</i>	8(A)	Mrs Lines, Janet¶
			<i>(Grd 7)</i>	4(S)	Mr Chadwick, R Andrew <i>FGS CGeol</i> Dr Cox, Beris M <i>FGS CGeol</i> Dr Holloway, Samuel <i>FGS CGeol</i> Dr Kirby, Gary A Dr Knox, Robert W O Dr Lott, Graham K Dr Molyneux, Stewart G Mr Morton, Andrew C¶ Dr Pharaoh, Timothy C <i>FGS CGeol</i> Dr Riding, James B <i>FGS CGeol</i> Dr Riley, Nicholas J <i>FGS CGeol</i> Mr Smith, Nigel J P <i>FGS CGeol</i> Dr Warrington, Geoffrey <i>FGS CGeol</i> Dr Wilkinson, Ian P <i>FGS CGeol</i>
			<i>SSO</i>	5(S)	Dr Evans, David J Ms Halls, Claire R¶ Dr Jones, Neil S Mr Rowley, William J Mr Tunnicliff, Stephen P
			<i>HSO</i>	6(S)	Dr Baily, Heather E Dr Williams, Mark Mr Woods, Mark A
			<i>SO</i>	7(S)	Mr Hulbert, Andrew G
			<i>ASO</i>	8(S)	Mrs Johnson, Kerry L Miss Kyffin-Hughes, Jane E Miss Shaw, Karen L Mrs Taylor, Pauline
UK Business Development					
Keyworth					
<i>Group Manager Grade 6</i>					
				3(S) Mr Ovadia, David * <i>MBCS CEng</i>	
<i>PSec</i>	8(A)	Mrs Swift, Jacqueline <i>AIQPS</i>			
<i>(Grd 7)</i>	4(S)	Mr Brown, Malcolm J <i>MIMM CEng</i> Dr Holliday, Douglas W Dr Whittaker, Alfred <i>FGS CGeol</i>	<i>PSec</i>	8(A)	Mrs Swift, Jacqueline <i>AIQPS</i>
<i>SSO</i>	5(S)	Dr Alexander, Jean <i>MCIM</i>	<i>(Grd 7)</i>	4(S)	Mr Brown, Malcolm J <i>MIMM CEng</i> Dr Holliday, Douglas W Dr Whittaker, Alfred <i>FGS CGeol</i>
<i>IO</i>	6(T)	Mrs Heason, Hilary J <i>MIPR</i>	<i>SSO</i>	5(S)	Dr Alexander, Jean <i>MCIM</i>
<i>AIO</i>	7(T)	Mrs Gutteridge, Linda	<i>IO</i>	6(T)	Mrs Heason, Hilary J <i>MIPR</i>
Wallingford					
<i>(Grd 7)</i>	4(S)	Mr Allen, David J <i>FGS CGeol</i>	<i>AIO</i>	7(T)	Mrs Gutteridge, Linda
Information Services					
Keyworth					
<i>Group Manager Grade 6</i>					
				3(S) Dr Dobinson, Alan	
<i>PSec</i>	8(A)	Ms Heard, Tracey L			

## Collections Administration (Materials)

### Keyworth

(Grd 7) 4(S) Mr Hollyer, Stuart E  
 SO 7(S) Mr Wheatley, Christopher W  
 AO 8(A) Mrs Wright, June L¶  
 Tec 1 8(T) Mr Bennett, David J  
 Tec 2 9(T) Mr Naylor, Michael D  
 Mr Renshaw, Brian  
 Mr Renshaw, Scott

## Collections Administration (Documentary)

### LIBRARY

#### Keyworth

##### PLib Grade 7(L)

4(L) Mr McKenna, Graham ALA MIS  
 SLib 5(L) Mrs Anderson, Jennifer E¶ ALA  
 Lib 6(L) Miss Benson, Janet E ALA  
 Miss Bird, Joan V ALA  
 Mrs Fileman, Janet ALA  
 Miss Hurst, Jennifer ALA  
 Mr Prince, Stephen J ALA  
 AO 8(A) Mrs Barkworth, Julia A¶  
 Miss Hinde, Joanne L  
 Mrs Langton, Louisa J¶  
 Miss Self, Joanne J  
 Mr Swift, Martyn C  
 SGB2 9(T) Mrs Hodges, Sheila A  
 Mr Holley, George C¶

#### Murchison House

Lib 6(L) Mr McIntosh, Robert P  
 AO 8(A) Mrs Gray, Gale E

### RECORDS

#### Keyworth

H5O 6(S) Mr Bowie, Roderick C  
 AO 8(A) Mrs Blatherwick, Susan J  
 Miss Booth, Joanne H  
 Mrs Bridge, Geraldine  
 Miss Cottingham, Alison L  
 Miss Disney, Avril C  
 Mrs Fitch, Lisa J  
 Mr Newham, Wayne T  
 AA 9(A) Mr Davis, John J

#### Murchison House

SO 7(S) Mr Gillanders, Richard J  
 AO 8(A) Miss Dunlop, Alison  
 Mrs Mann, Elizabeth  
 Mr Morrison, Arthur  
 Mr Smith, Matthew J  
 Mr Swanney, Michael S

### BOREHOLE DATABASE

#### Keyworth

SO 7(S) Mrs Bowie, Joanne H\*  
 Mr Stirland, Karl C

### CUSTOMER SERVICES

#### Keyworth

SSO 5(S) Ms Parnham, Jennifer J ALA  
 H5O 6(S) Mr Clayton, Alan R  
 EO 7(A) Mr Page, Ivan K  
 AO 8(A) Mrs Tina P Hackett¶  
 Mrs Harvey, Juliet M  
 Mr Haughton, Brian T  
 Mrs Murray, Christina  
 Mrs Oldham, Yvette J¶  
 Mrs Roach, Shirley D  
 Mrs Robson, Carole G  
 Mrs Wiseman, Helen P¶  
 SGB1 8(T) Mr Goodman, Stephen J  
 SGB2 9(T) Mr Smith, Graham J  
 Mrs Wafforne, Paula¶

### Murchison House

AO 8(A) Mrs Turnbull, Lesley  
 Ty 9(A) Mrs Moir, Wanda J

### London Office

H5O 6(S) Miss Brackell, Sylvia J  
 SO 7(S) Mrs Messenger, Vivienne R\*

### Enquiries Officer

#### Keyworth

SSO 5(S) Mr Evans, Antony D

### DATABASE MANAGEMENT

#### Keyworth

SSO 5(S) Dr Lowe, David J FGS CGeol  
 ASO 8(S) Miss West, Amanda R

## Geospatial Information Systems

### Keyworth

#### Group Manager Grade 6

3(S) Mr Jackson, Ian  
 P5ec 8(A) Mrs Walters, Glennis A  
 (Grd 7) 4(S) Mr Giles, Jeremy R A FGS CGeol FIAP  
 Dr Greenbaum, David  
 Dr O'Connor, Eugene A  
 SSO 5(S) Mr Adlam, Keith A M  
 Mr Cannell, Brian  
 Dr McDonald, Andrew J W  
 Dr Tragheim, Douglas G  
 H5O 6(S) Miss Baxendale, Hazel J  
 Mr Denniss, Anthony M  
 Mr Gibson, John R  
 Mr Killen, Anthony J  
 Ms McLaren, Fiona E¶  
 Mr Riddick, Andrew T  
 Ms Walsby, Jennifer C  
 SO 7(S) Mr Baker, Garry R  
 Mr Bell, Patrick D  
 Mr Greally, Kevin B  
 Mr Hulland, Vincent J  
 Mr Marchant, Andrew P  
 Mr Sheath, Daniel P¶  
 Miss Sykes, Jennifer S  
 Mrs Wallwin, Sally  
 ASO 8(S) Mr Molineaux, Paul J  
 AO 8(A) Mrs Chew, Susan J A

### Murchison House

(Grd 7) 4(S) Mr Laxton, John L  
 SSO 5(S) Mr Robson, Peter G  
 Mr Holmes, Keith A  
 H5O 6(S) Mr Lawrie, Kenneth I G  
 HEO(C) 6(C) Mr Duffy, Timothy R  
 ASO 8(S) Mrs Kilpatrick, Karen M

## Publication Services

### Keyworth

#### Group Manager Grade 7

4(S) Dr Green, Christopher A  
 P5ec 8(A) Mrs Swift, Jacqueline AIQPS

### BOOK PRODUCTION

SSO 5(S) Miss Simmons, Molly B  
 AIO 7(T) Mr Stevenson, John P  
 GO 7(T) Mrs Rayner, Deborah C  
 SM3 8(T) Ms Evans, Jennifer B A  
 Mr Minks, Adrian R  
 Ms Norman, Jacqueline  
 Mr Smedley, John B  
 Ty 9(A) Mrs Hutchinson, Angela R  
 Mrs Morton, Amina

## CARTOGRAPHY

### Keyworth

SMCO 5(M) Mr Becken, Kevin H  
 HMCO 6(M) Mr Clifton, Anthony W  
 Mr Myers, Antony H  
 Mr Parnaby, Roger J  
 Mr Rippon, Simon J  
 MCO 7(M) Mrs Adkin, Caroline F  
 Mr Arbon, John W  
 Mrs Arbon, Kathryn A¶  
 Mr Armstrong, Robert W  
 Mr Bowker, Martin R  
 Miss Bray, Susan  
 Mr Cooke, Ian L  
 Mr Cooper, Robert J\*  
 Mrs Daley, Deborah L P  
 Mr Demaine, Ronald J  
 Mr Hodgson, Jeremy D  
 Mr Hurst, Stephen E  
 Mr Lappage, Paul  
 Mr Ledgard, Michael B  
 Mrs Mawer, Carole H  
 Mrs Myers, Sheila B¶  
 Mr Rayner, James I  
 Mrs Scott, Elizabeth J  
 Mrs Simpson, Caron  
 Mr Spencer, Niall A  
 Mr Turner, Paul  
 Mr Wardle, Christopher  
 Mr Wilkinson, Ian J  
 Miss Wood, Sophie E  
 MCTG1 8(M) Miss Bradley, Mary A  
 Mrs Kmiecik, Jayne E  
 Mr Tuggey, Graham  
 Mr Wilkinson, Stephen C

### Overseas Posting

HMCO 6(M) Mr Murray, Christopher G

### Murchison House

SMCO 5(M) Mr Ramsay, Robert B  
 HMCO 6(M) Mr Mennim, Keith C  
 Mr Stewart, Alistair M  
 MCO 7(M) Miss Anderson, Christina  
 Miss Barclay, Joyce  
 Mr Blenkinsop, Anthony  
 Mrs Cherrie, Marjory M  
 Mr Herbertson, Keith F  
 Mr Horsburgh, Stuart W  
 Mr Long, Roderick M  
 Mr Meikle, John L  
 Mrs Oliver, Lesley M  
 Mr Ritchie, Calum  
 Mrs Sanders, Carol J  
 Mrs Wild, Sally A L¶  
 Mr Wood, Gary R  
 MCTG1 8(M) Mrs Carson, Christine E  
 Mr Denholm, William H  
 Mr Drennan, Eric P

## PHOTOGRAPHY

### Keyworth

HPHO 6(P) Mr Tod, Paul A  
 PHO 7(P) Mr Cullen, Timothy P D S  
 AA 9(A) Mr Goddard, Mark A

### Murchison House

HPHO 6(P) Mr Bain, Thomas S M  
 PHO 7(P) Mr MacTaggart, Fergus I

## PUBLIC UNDERSTANDING OF SCIENCE

### Keyworth

Grd 7 4(S) Dr Litherland, Martin FGS CGeol  
 MIMM CEng  
 SSO 5(S) Dr Thomas, Joanna E¶

## Training & Staff Development

### Keyworth

#### Co-ordinator (Grd 7)

4(S)	Dr Penn, Ian E	<i>FGS CGeol</i>
	Dr Crow, Michael J	<i>FGS CGeol</i>
		<i>MIMM CEng</i>
AO	8(A)	Mrs Hale, Pamela I
Ty	9(A)	Miss Yarwood, Emma J

## Honorary Research Associate

Dr Loudon, T V

## Grade abbreviations

AA	Administrative Assistant
AIO	Assistant Information Officer
ALib	Assistant Librarian
AO	Administrative Officer
ASO	Assistant Scientific Officer
EO	Executive Officer
GO	Graphics Officer
GTG	Graphics Technical Grade
HEO	Higher Executive Officer
HMCO	Higher Mapping and Charting Officer
HPhO	Higher Photographic Officer
HPTO	Higher Professional and Technical Officer
HSO	Higher Scientific Officer
IO	Information Officer
Lib	Librarian
MCO	Mapping and Charting Officer
MCT	Mapping and Charting Technical Grade
Mess	Messenger
PGS	Process and General
PhO	Photographic Officer
PLib	Principal Librarian
PSec	Personal Secretary

PTO	Professional and Technical Officer
SEO	Senior Executive Officer
SG	Support Grade
SLib	Senior Librarian
SM	Support Manager
SMCO	Senior Mapping and Charting Officer
SMess	Senior Messenger
SO	Scientific Officer
SPSec	Senior Personal Secretary
SPTO	Senior Professional and Technical Officer
SSO	Senior Scientific Officer
StO	Stores Officer
Tech	Technical Grade
Tel	Telephonist
Ty	Typist

## Professional accreditations

ALA	Associate of Library Association
AIQPS	Associate of the Institute of Qualified Private Secretaries
CIPS	Chartered Institute of Purchasing and Supply
Eur Ing	European Federation of National Engineering Associations
FIAP	Fellow of the Institute of Analysts and Programmers
FGEMM	Fellow of the Gemmological Association of Great Britain
FGS CGeol	Fellow of the Geological Society, Chartered Geologist
FIMM CEng	Fellow of the Institution of Mining and Metallurgy, Chartered Engineer
FIWEM	Fellow of the Chartered Institution of Water & Environmental Management
IEEIE	Institute of Electrical and Electronic Incorporated Engineer
MBCS CEng	Member of the British Computer Society, Chartered Engineer

MBIFM	Member of the British Institute of Facilities Management
MCIBSE CEng	Member of the Chartered Institution of Building Service Engineers, Chartered Engineer
MCIM	Member of the Chartered Institute of Marketing
MICE CEng	Member of the Institution of Civil Engineers, Chartered Engineer
MB CBiol	Member of the Institute of Biology, Chartered Biologist
MIEE CEng	Member of the Institution of Electrical Engineers, Chartered Engineer
MIS	Member of the Institution of Information Scientists
MIMM CEng	Member of the Institution of Mining and Metallurgy, Chartered Engineer
MP CPhys	Member of the Institute of Physics, Chartered Physicist
MIPR	Member of the Institute of Public Relations
MOISH RSP	Member of Occupational Safety and Health, Registrar of Safety Practitioners
MRSC CChem	Member of the Royal Society of Chemistry, Chartered Chemist

¶ Part-time  
★ Temporary promotion  
\* On unpaid leave

# Appendix 5 Academic collaboration

The BGS collaborates with research institutes within the NERC and the other research councils. It also collaborates with other academic institutions in a worldwide network of research projects, which include contracted input to the core programme and research and teaching arrangements. The following cover most examples:

**Aberdeen University:** *Mineral geochemistry provenance studies*

**Abo University (Finland):** *Sulphur isotope systematics in peat – Finland.*

**Arhus University (Denmark):** *Seismic stratigraphy in the Rockall Trough*

**Australian National University (Canberra):** *Detrital zircon geochronology; Geology of the Lizard Complex*

**Barcelona University:** *Microbeam techniques for single inclusion analysis*

**Bergen University (Norway):** *Margin studies*

**BGR (Germany):** *Hammer corer*

**Binghamton University (NY, USA):** *Secular variation in seawater chemistry*

**Birmingham University:** *Jurassic palynology; High resolution stable isotope investigation of speleothems; Karstic capture of climatic chemical signals; Rare earth element mobility in south Greenland; Reactive carbonate in glacial systems; Copper and polymetallic deposits, Muster Basin, Ireland.*

**Bogazici University (Istanbul):** *Westward drift, historical geomagnetic field data*

**Bradford University:** *Pb and Sr isotope composition of human dental enamel as an indicator of ancient population dynamics.*

**Bristol University:** *Volcanic hazards; Origin of compositional variations in volcanic rocks of Santorini Volcano, Greece; Seismic tomography and scattering*

**British Antarctic Survey:** *Geophysical and sampling operations, sediment drifts and contourites*

**Brno University (Czech Republic):** *Statistical treatment of heavy mineral data*

**Brunel University:** *Fault reactivation*

**Budapest University:** *PGE-rich magmatic fluids*

**Cambridge University:** *Geological map of Westerdale and the Howgill Fells; Hydrothermal alteration and geochemical fluxes in young oceanic crust; SEM & XRD volcanic ash filters; Stable isotope dendroclimatological study; Biostratigraphy and palaeolimnology of late-glacial and Holocene lake marls; Biostratigraphy, palaeoecology and geochemistry of a long Quaternary lacustrine sequence from NW Greece; Formation of clear facies basal ice at Alpine glaciers; Triassic clay minerals, fracture modelling; U-Th-Pb analysis of Managotry monazite; Volcanic hazards*

**Charles University (Czech Republic):** *Skarn mineralisation, Bohemian Massif.*

**Chile University:** *Crustal Evolution of the West Antarctic Peninsula and Patagonia.*

**Clausthal University (Germany):** *Annot sandstone provenance*

**Coventry University:** *Stable isotope and luminescence characteristics of Holocene slug calcite.*

**CNRS, Lille (France):** *Ordovician acritarchs*

**CRNS Toulouse:** *Microscale fluid inclusion interactions*

**Coimbra University (Portugal):** *Gold metallogenesis in central Portugal*

**Copenhagen University (Denmark):** *TESZ research*

**Cork University (Ireland):** *Margin studies*

**CSIC Barcelona:** *Trace elements in coals*

**Czech Geological Survey:** *TESZ research*

**Derby University:** *Bivalves as environmental monitors.*

**Dublin Institute of Advanced Studies (DIAS):** *Gravity maps of UK and Ireland*

**Dublin University College (Ireland):** *Geomechanical modelling and reservoir anisotropy*

**Dundee University:** *Petroleum Law and Policy*

**Durham/Glasgow Universities:** *British Regional Geology: Tertiary Volcanic Districts*

**Durham University:** *Geology of the Lizard Complex; Hafnium isotope constraints on the source regions of kimberlites and lamproites; Isotopic evidence for mantle convection at the ridge-trench intersection, Northern Lau Basin; Lizard ophiolite evolution; O + C in carbonate samples of Cretaceous Dolomites from Egypt; Stublick Fault Zone*

**East Anglia University:** *Isotopic composition of Pb in seal teeth; Magnetostratigraphy of the New Red Sandstone; Permian–Triassic magnetostratigraphy*

**East Kilbride Reactor Centre:** *Investigation of the Green Beds, Southern Highlands Project*

**Edinburgh University:** *Contaminated land in Granton;*

**Edinburgh University:** *Oersted magnetic survey satellite; Fracture modelling; BRIDGE drill; Coring advice and supplies; Quaternary of north-east Scotland; Radiolarian and conodont biostratigraphy in the Southern Uplands; Southern Highlands Project; Stable Isotope and Glacier Dynamics*

**Exeter University:** *Correlation of gas emissions with seismicity; Lectures to undergraduates*

**Galway University College (Ireland):** *Magnetic maps of UK and Ireland*

**Gent University (Belgium):** *Margin studies and CORSAIRES, TESZ research*

**GeoForschungsZentrum (Germany):** *TESZ research*

**Geological Survey of Canada:** *Magnetic maps*

**Geological Survey of Ireland:** *Gravity and magnetic maps of UK and Ireland*

**GEOMAR (Germany):** *Margin studies*

**GEUS (Denmark):** *Margin studies*

**Giessen University (Germany):** *TESZ research*

**Glasgow/Durham Universities:** *Geochemistry and biostratigraphy of Southern Upland Arenig sequences*

**Glasgow University:** *The timing of orogenic events in the Scottish Highlands; Wide-angle seismic studies*

**Gottingen University:** *Chemistry of Messinian brines; Fluid inclusions in halite*

**Granada University (Spain):** *Uralides research; Spanish fluorite deposits*

**Heriot Watt University:** *Advanced seismic methods; Geomechanical modelling and reservoir anisotropy; HYACE, Geotechnics and sedimentology; Petroleum engineering and training*

**Huddersfield University:** *Karst research*

**Hull University:** *Adviser on geochemistry course*

**ICTJA, Barcelona (Spain):** *Uralides research*

**IFREMER (France):** *Margin studies*

**IGME Athens:** *Aegean epithermal deposits*

**Institut Français du Pétrole (France):** *Geomechanical modelling and reservoir anisotropy*

**Institute of Geophysics, Ekaterinburg (Russia):** *Uralides research*

**Iowa State Survey, USA:** *Mississippian biostratigraphy*

**Irish Marine Data Centre:** *Margin studies*

**ITGE Madrid:** *Cantabrian talc deposits*

**Karlsruhe University (Germany):** *Uralides research*

**Keele University:** *Triassic palynology; TESZ research; Palaeozoic amalgamation of Central Europe*

**Kingston University:** *Isotopic study of peraluminous magmatism in Peru; Non-marine ostracods in Central Mexico; Palaeoenvironmental reconstruction in central Mexico; Silicic magmatism related to continental breakup; Ostracod shell chemistry in palaeoclimatic reconstruction*

**KVI Groningen:** *Environmental radioactivity*

**Lancaster University:** *External examiner for Environmental Science BSc; Oxygen isotope analysis of lacustrine diatoms; Volcano monitoring*

- Leeds University:** *Historical geomagnetic field data; Volcano monitoring; Holocene and historic environmental change in the Yorkshire Ouse, Tees and Tweed Basins; Fluid fluxes of the Upper and Lower Oceanic Crust; Leaching behaviour of fly ash from incineration*
- Leicester University:** *Sm-Nd and U-Pb systematics; Accretion in N. Greece; Subduction-accretion as a crustal growth mechanism; Concretionary carbonates and sulphates in the Oxford Clay; DNA of fossil bacteria; Green Beds, Southern Highlands Project; Escondida and Zaldívar porphyry Cu deposits, Chile; Mineralisation in West Turkey; Plume-related magmatism, Gobi Desert; Isotopic characterisation of plume components, Colombian picritic/komatiitic lavas; Petrogenetic significance of dyke swarms; Proterozoic evolution of Outer Hebrides; Revision of the Wenlock graptolite biozones of the Builtth Mudstones; Silurian micropalaeontology; Borehole research; Crustal structure; Tectonic Evolution of the Bhutan Himalaya; Generation of primitive continental crust, Aruba, Dutch Antilles*
- Liverpool University:** *Hirnantian (late Ashgill) glacioeustatic sequences, Southern Welsh Basin; Bioavailability of heavy metals; Carboniferous sequence stratigraphy and sedimentology; Supervision of PhD; Tertiary dykes in the Southern Uplands*
- Ljubljana University (Slovenia):** *Early carbonate cave development*
- London (Birkbeck College):** *Analysis of single particles; Metamorphic survey of 1:50 000 Series sheets 193 and 194; Metamorphic map for the Windermere Supergroup, Kirkby Lonsdale District; Lower crust of the Archaean Baltic Shield*
- London (Imperial College):** *Sediment-hosted gold mineralization in the Permo-Tria of SW Guizhou, PRC; Fracturing, fluid processes and mineralisation; northern Chile; Supervision of PhD*
- London (Kings College):** *Gypsum in the Namib Naukluft Park and the Tunisian Atlas Mountains; Modelling of carbon fluxes in a meromictic lake (Malham Tarn) Yorkshire; Stable isotopes, Chara calcite*
- London (Royal Holloway & Bedford New College):** *West Mediterranean stratigraphy; Hafnium characterisation of the Icelandic plume source and related geochemical gradient; Lectures to undergraduates; East Anglia Project*
- London School of Hygiene and Tropical Medicines:** *Waste-water re-use Mezquital Valley (Mexico)*
- London (University College):** *Geomechanical modelling and reservoir anisotropy; Geophysical Surveys; Nitrate in chalk*
- Loughborough University:** *Late Quaternary palaeoclimates and palaeoenvironments of the Konya basin, Turkey; Rural water supply and sanitation*
- Louvain Catholique Universitéde (Belgium):** *Basin maturity*
- Manchester University:** *Enclave-host relations in two Scottish granitoids.*
- Medieval Archaeological Research Group (MARG):** *Archeometric petrology*
- Modena University (Italy):** *Crustal xenoliths in South American volcanic rocks.*
- Montpellier University (France):** *Geomechanical modelling and reservoir anisotropy, TESZ research*
- Nottingham Trent University:** *Contaminated land; Course provider in contaminated land management MSc; Risk assessment of contaminated soils*
- Nottingham University:** *Environmental councillor, and special professor; Institute of Engineering survey and space geodesy; CASE studentships in digital photogrammetry; Mineralogy of canal muds; Petrography; Rate of dissolution of certain zeolite minerals; Resource utilisation by indigenous tree species in tropical agroforestry systems*
- Netherlands Institute for Sea Research:** *Seismic stratigraphy in Rockall Trough*
- Newcastle University:** *Alternative food sources for coral-reef organisms; Gypsum geohazards*
- Newfoundland and Labrador Geological Survey:** *Geological mapping*
- Open University:** *Lithosphere generation in the South American mantle; Supervision of PhD*
- Oslo University (Norway):** *Uralides research*
- Oxford Brookes University:** *Co-supervisor to a student; Geology of 1:50k sheet 108E (Loch Naver); Stable and radiogenic isotope constraints, appinites; Stable and radiogenic isotope geochemistry of continental margin alkaline basalts; Structure of the Isle of Man*
- Oxford University:** *Timing of crustal melting and metamorphism in the Hindu Kush of Pakistan; Crustal melt granites of the western Himalaya;*
- Interaction of mantle-derived magmas and lower crust, N. Norway; Mantle involvement in compositionally evolved magmas in the Bolivian Eastern Cordillera; Provenance and dating of the Ordovician sequence, south Mayo trough; Timing and rates of metamorphism and melting, Karakoram Range, North Pakistan; Topological aspects of the magnetic field in the Earth's core*
- Perugia University (Italy):** *Jurassic palynology*
- Plymouth University:** *Foraminifera as environmental indicators*
- PNG University:** *Training*
- Polish Academy of Sciences:** *TESZ research*
- Polish Geological Institute:** *TESZ research*
- Portsmouth University:** *Llandovery graptolite biostratigraphy*
- Queen's University (Belfast):** *Movement of contaminated groundwater*
- Queens University (Canada):** *Geology of the Lizard Complex*
- Québec Université:** *Geological mapping*
- Queensland University (Australia):** *Carboniferous foraminiferal biostratigraphy*
- Reading University:** *Seismic properties of sea floor rocks and sediments; Sr-isotope composition of waters from Okstindan, Norway; Total atmospheric deposition of Pb, S and N in England and Wales*
- Rennes University (France):** *Geomechanical modelling and reservoir anisotropy*
- Royal Museum of Scotland:** *Archeometric petrology*
- Sao Paulo University (Brazil):** *Braslian magmatism, zinc mineralization.*
- Sheffield University:** *Crop storage practices in the Greek Bronze age; Hydrogeology course provider; Induced Polarization Tomography; Mapping of the Kendal Sheet, Windermere Supergroup; Movement of non aqueous phase liquids; Natural attenuation of organics in groundwater; Palynology*
- Snow College, Utah, USA:** *Carboniferous stratigraphy*
- South Pacific University:** *Hydrogeology tuition*
- Southampton Oceanography Centre:** *Margin studies*
- Southampton University:** *Palaeozoic palynology, Sediment drifts and contourites; Zircon geochronology and geochemistry of Zimbabwean Archaean granitoids; Zircon geochronology of a Precambrian megacrystic granite suite, Sierra Leone*
- St Andrews University:** *Determination of Sr isotopic ratio in apatite from Silurian Bentonites of Northern Europe.*
- Swansea University:** *Strontium, oxygen and carbon isotopes in Late Quaternary biogenic carbonates from Wallywash Great Pond, Jamaica.*
- Technical University of Delft (Holland):** *Geomechanical modelling and reservoir anisotropy*
- TNO Institute of Applied Geoscience (Holland):** *Geomechanical modelling and reservoir anisotropy*
- Trinity College, Dublin:** *Palaeozoic palynology*
- Tromsø University (Norway):** *Margin studies*
- Udine University (Italy):** *Uralides research*
- Universidad Autonoma de Yucatan (Mexico):** *Landfill research*
- Uppsala Univ. (Sweden):** *Uralides research*
- Wageningen University (Holland):** *External examiner*
- Wales (Aberystwyth):** *Abrupt Holocene arid intervals recorded in lake sediments from Ethiopia; Sea-level, environmental and climatic change in the Irish Sea Basin; Hydrology, water quality and solute transport in subglacial environments, Norway; Late Quaternary climatic history of the north-eastern coastal area of Argentina; Margin studies; Origins of Mid - Early Proterozoic stromatolite carbonate; Ostracod geochemistry as a record of abrupt holocene climatic change in Ethiopia; Characterization of the Port Askaig tillite; Inter-calibration of proxy indicators of late Holocene hydroclimatic change in Morocco; Timing of collision between the north and south China cratons; Bentonites from the Silurian Welsh Basin; X-ray diffraction analysis*
- Wales (Cardiff):** *PhD supervision; Late Quaternary climate change; Amazon fan provenance; BRIDGE drill; Paviland Cave Research Project*
- Windsor University (Ontario):** *Geological mapping*
- Wroclaw University (Poland):** *TESZ research*
- York University:** *Electrical Tomography*
- Zaragoza University (Spain):** *Geomechanical modelling and reservoir anisotropy; Gypsum geohazards*

# Appendix 6 Business collaboration

## COLLABORATION WITH UK AND INTERNATIONAL INDUSTRIES

The BGS maintains a wide range of links with industry. These involve co-funded projects, technology partnerships, strategic business alliances and advisory groups. The following include most of the companies who collaborated:

- AEA Technology plc, Harwell
- ABEM Instrument (Sweden)
- AeroService Corporation
- Allied Associates Geophysical Ltd
- Amerada Hess
- Anglesey Mining PLC
- ARK Geophysics
- BBC
- BG Technology plc
- British Antarctic Survey
- British Gypsum
- British Petroleum
- CCOP, Bangkok
- CMTC Environmental
- Coal Authority
- Conoco
- Durham University
- Edcon
- EEC
- Enterprise
- Esso
- Exxon
- European Union
- Fugro-Geoteam
- Geology Dept., Kuwait University
- Hydrographic Office
- Hydrocarbon Management International
- ICI Chemicals & Polymers Ltd
- IACR - Rothamsted
- International Mining Consultants Ltd.
- ITE, North
- ITGE, Madrid
- Joint Stock Company Ecogeya, Moscow
- Mackay Associates
- Minmet
- National Radiological Protection Board
- Natural History Museum
- Niedersächsisches Landesamt für Bodenforschung
- Nirex
- Norwegian University of Science and Technology
- Osservatorio Vesuviano, Naples
- Oxford Archaeological Associates Limited
- Peninsular
- Penspen
- Petroleum Exploration Computer Consultants (PECC)
- Petroleum Open Software Corporation (POSC)
- RTZ
- SCAE
- Saga
- Satellite Observation Systems (SOS)
- Schlumberger Geco-Prakla
- Shell
- Shell UK Exploration and Production

- Statens Kartverk (Norway)
- The British Museum
- VG Elemental Ltd
- Western Geophysical
- World Geoscience

## CLIENT LIST

### UK Government organisations

- Atomic Weapons Establishment
- Bristol City Council
- British Antarctic Survey
- British Waterways
- Calderdale District Council
- Carmarthen District Council
- CEFAS – Burnham-on-Crouch
- Ceredigion District Council
- City of Edinburgh Council
- Countryside Commission
- Cumbria County Council
- Darlington District Council
- Defence Evaluation and Research Agency
- Department of Economic Development (Northern Ireland)
- Department of the Environment (Northern Ireland)
- Department of the Environment, Transport and the Regions
- Department of the Environment: Wildlife and Heritage Service (Northern Ireland)
- Department of Trade and Industry
- Department for International Development
- DETR Minerals and Waste Planning Division
- DETR Radioactive Substances Division
- DOE Minerals
- Dyfed County Council
- Environment Agency
- European Development Fund
- European Union
- Foreign and Commonwealth Office
- Harrogate District Council
- Health and Safety Executive
- Historic Scotland
- Hydrographic Office
- Joint Nature Conservations Committee
- Metropolitan Police
- Midlothian District Council
- Ministry of Agriculture, Fisheries and Food
- Ministry of Defence
- National Grid
- Natural History Museum
- NERC Environmental Diagnostics thematic programme
- Ordnance Survey
- Preseli Pembroke District Council
- Royal Navy
- Scottish Borders Council
- Scottish Environment Protection Agency
- Scottish Natural Heritage
- Scottish Office
- Scottish Water Authorities
- South Lanarkshire Council

- SOAEFD
- The Scottish Office
- The Welsh Office
- Water Engineering and Development Centre
- West Lothian Council

### International and foreign organisations

- Asian Development Bank
- Australian Geological Survey Organisation
- ANDRA (France)
- Commonwealth Science Council
- Commission of the European Community (CEC)
- Coordinating Committee for Offshore Prospecting
- CSIRO, Australia
- Department of Mining and Petroleum, Papua New Guinea
- Empresa Colombiana de Carbon
- Environment Protection Agency (United States)
- EU BriteEuram Craft Programme
- European Commission (EC)
- EU SYSMIN
- Falkland Islands Government
- GeoAfrica Prospecting Services, Namibia
- Geological Survey of Finland
- Geotechnical Engineering Office, Hong Kong
- Government of Bangladesh
- GRS (Germany)
- Hong Kong Government
- Hong Kong Special Administration Region of China
- Hyundai Engineering & Construction, Singapore
- IPSN
- International Association for the Promotion of Co-operation with Scientists from the New Independent States of the Former Soviet Union
- Jordanian Natural Resources Authority
- Kevin Marshall, Trinidad
- Marine Research Division of CSIRO (Australia)
- Middle East Technical University, Turkey
- Mykobar Mining Co SA, Greece
- NAGRA
- Namibia Geological Survey
- National Water Commission of Mexico
- Natural Resources Authority, Jordan
- NEA
- Norwegian Crystallites AS
- Palestinian National Authority
- PNC
- Radiological Protection Institute of Ireland
- Russian Academy of Sciences
- SKB
- Secretariat of the South Pacific Applied Geoscience Commission
- Setco Services PTE Ltd, Singapore
- South Pacific Geoscience Commission (SOPAC)
- United States Navy
- United States Geological Survey (USGS)
- University of Pisa
- UNEP GPA (Global Programme of Action)
- World Bank
- Zambia Geological Survey

## Industry

- AA Associates
- ADAS, Jersey
- AEA Technology
- AES Ltd
- A F Budge (Holdings) Ltd
- Agip UK
- ATG Consultants
- Alex Stewart (Assayers) Ltd
- Allott & Lomax
- Amerada Hess
- Amerada Hess Denmark
- Amerada Hess Norge
- Amerada Hess UK
- Amoco
- Amoco (UK) Exploration
- Anadarko Petroleum Corporation
- Anadrill Schlumberger
- Analytical and Environmental Services Ltd
- ARCO International
- ARC Northern Ltd
- Aspen Burrow Crocker Ltd
- Babtie Group
- Baker Hughes INTEQ
- Bass Brewers Ltd
- BG Exploration & Production
- BG plc
- BGS Rockall Consortium
- Billiton International
- Blue Circle Cement
- B M Coope & Partner
- BP
- BP Australia
- BPB Gypsum Ltd
- BP/Conoco
- BP Exploration
- BP Norge
- Bridgewater Paper Company
- British Gas
- British Gypsum
- British Gypsum, R&D Dept
- British Nuclear Fuels plc
- British Petroleum Exploration
- Britsurvey
- Building Research Establishment
- Buxton Lime Industries Ltd
- CADW Welsh Historic Monuments
- Castle Cement Ltd
- Chevron
- Chevron Europe
- Chevron Nuigini
- Clyde Expro
- Conoco
- Conoco UK
- Crediton Gold Ltd
- Crediton Minerals, UK
- CSM Associates
- Cuthbertson Environmental Ltd
- D A Pelham
- Dames & Moore
- Deminex
- Deminex UK Oil & Gas
- Desire Petroleum
- Dunelm Drilling Ltd
- Dunlop Heywood
- East of Scotland Water
- Eaton Smith & Downey
- Edinburgh Petroleum Services
- Elf
- Elf Enterprise Caledonia
- Elf Exploration UK
- Entec
- Enterprise Oil
- Enterprise UK Ltd.
- Esso Exploration & Production UK
- Exploration Associates
- Falkland Islands Government
- Fina
- Fina Exploration
- Fugro
- Fugro-Geoteam
- Fugro UK Ltd
- GEC Alstom Engineering Systems Ltd
- Geochem Group Ltd
- GeoExploration (Italy)
- Geophysical Services International (UK) Ltd
- Gibb Ltd
- Greaves Welsh Slate Co Ltd
- Halcrow Waterman
- Halliburton Energy Services
- Hutten Jenkins & Titchmarsh
- IKU-Sintef Group
- Ifipco (Greece)
- IGES
- International Mining Consultants Ltd (IMCL)
- Jebco
- Jenkins Newell Dunford Ltd
- J G Associates
- Joynes Pike & Associates (JPA) Ltd
- JXX Oil & Gas
- Kerr McGee Oil & Gas
- Kirton Concrete Services
- Kuartrol Ltd
- Landmark
- Lasmo plc
- Lundin Oil AB
- Maersk Drilling
- Magnox Electric plc
- MAI
- Mercia
- Metal Bulletin plc
- Mobil
- Mobil North Sea
- Murphy Petroleum
- NAM
- National Grid Company
- Nirex
- Norsk Hydro ASA
- Norske Conoco
- Norwest Holst Soil Engineering Ltd
- Nuclear Electric plc
- Nuclear Installations Inspectorate
- Omya Croxton & Garry Ltd
- Oryx UK
- PanCanadian North Sea
- Petroleum Development Oman
- PGS
- Phillips Analytical X-ray (Cambridge)
- Phillips Petroleum
- Powergen
- Preussag Energie GMBH
- Quaternary TL Surveys
- Roxburgh & Partners
- Rugby Cement Ltd
- Rutter Johnson Partnership
- RWE-DEA
- Saga Petroleum ASA
- Samax Resources Ltd
- Santos Europe
- Saudi Arabian Oil Company
- Schlumberger
- Scottish Hydro-Electric plc
- Scottish Nuclear Ltd
- Severn Sands
- Sheffield University
- Shell
- Shell Norway
- Shell UK
- Shell Exploration & Production
- Simoniz International plc
- SOCAR
- Soil Mechanics
- Solmek Ltd
- Southern Water
- Southern Water Services
- Sperry Sun Drilling Services
- Statnett
- Statoil
- Statoil Exploration UK
- Sysdrill
- Talisman
- Talisman Energy
- Teikoku Oil Co
- Terradat (UK) Ltd
- Tertiary Gold Ltd
- Texaco
- Thorburn Colquhoun
- Total
- Total Oil Marine plc
- Ultra Electronics (Magnetics Division)
- Union Texas
- University of Newcastle
- UKWIR Ltd
- Wardell Armstrong
- Westminster Dredging Co Ltd
- Whitbread
- Wika Instruments Ltd.
- Yorkshire Water plc

# Appendix 7 Committees

- AAPG International Conference 1999 Birmingham: *Organising Committee*
- Arctic Ocean Sciences Board
- Atomic Spectrometry Updates: *Editorial Board of Journal of Analytical Atomic Spectrometry*
- British Micropalaeontological Society: *Treasurer, Committee Member*
- Camborne School of Mines: *Industrial Geology Liaison Panel*
- CBI Minerals Committee
- CIRIA Steering Group for remediation of VOC contamination
- Clay Minerals: *Editorial Board*
- Commission Internationale de Microflore du Paleozoique: *Vice President*
- Coordinating Committee for Offshore Prospecting
- Devonshire Association
- DTI committee on setting criteria for sustainable development — waste
- Edinburgh Geological Society: *Membership Secretary*
- Environmental Diagnostics: *Steering Group*
- Environmental and Engineering Geophysics Society (Europe): *Board Member and UK National Representative*
- Environment and Industrial Geophysics Group
- EPSRC Steering Committee for Waste and Pollution Management
- EuroGeosurveys Mineral Resources Topic Network
- EuroGeoSurveys Remote Sensing Topic Network: *Technical Secretary*
- European Journal of Environmental and Engineering Geophysics (EJEEG): *Editor-in-Chief, Editorial Board*
- European Seismological Commission: *various Working Groups*
- Foregs Task Group on Geochemical Inventory of Europe: *UK representative*
- Geological Society of London: *Marine Studies Group Secretary; Publications Committee; Stratigraphy Committee; Borehole Research Group Treasurer; Petroleum Group Secretary; Volcanic and Magmatic Studies Group; Working Group on Women in Geology; Remote Sensing Group Treasurer and Secretary*
- IEH, Leicester University: *Steering Group on Environmental sampling after a chemical accident.*
- International Association of Geomagnetism and Aeronomy (IAGA): *Executive Committee and various Working Groups*
- International Association of Seismology and Physics of the Earth's Interior (IASPEI): *Executive Committee and various Working Groups*
- International Consultative Group on Non-Ferrous Metal Statistics
- International Geographical Union Commission: *Sustainable Development and Management of Karst Terrains*
- International Strategic Minerals Issues
- International Standards Organisation Technical Committee
- International Society for Soil Mechanics and Geotechnical Engineering: *Sub-Committee on Classification of Carbonate Sediments and Ground Conditions*
- International Union of Geological Sciences
- International Union of Speleology: *Commission on Karst Hydrogeology and Speleogenesis*
- Institution of Mining and Metallurgy: *Council; Activities Committee; Editorial Committee; Executive; Applied Earth Science Editorial Board*
- IUGS International Working Group on Medical Geology: *Commission on Geological Sciences for Environmental Planning*
- IUGS Working Group on Global Geochemical Baselines: *Co-chairman*
- Joint Association for Geophysics (now British Geophysical Association): *Secretary*
- Journal of the Geological Society: *Editorial Board*
- Journal of Petrology: *Editorial Board*
- LITHOPROBE Scientific Committee of Canada
- Midlands Microanalysis Group: *Chairman*
- Minerals '98: *Organising Committee*
- Mineralium Deposita: *Editorial Board*
- Mineralogical Society: *Applied Mineralogy Group; Council*
- MIRO (Mineral Industry Research Organisation): *Research Executive Committee and Council*
- National Geospatial Data Framework: *Board and Working Group 2 – Metadata*
- National Marine Analytical Quality Control Scheme: *National Co-ordinating Committee*
- National Stone Centre: *Council*
- Nansen Arctic Drilling
- NERC Airborn Remote Sensing Facility: *Steering Committee*
- NERC Coordinating Group on Environmental Radioactivity
- NERC Environmental Diagnostics: *Steering Committee*
- NERC Earth Observation for Earth Sciences: *Working Group*
- Nuclear Energy Agency of the OECD: *Working Group on measurement and understanding of groundwater circulation in clay formations*
- Ocean Drilling Programme: *Technical Committee (Chairman); UK Steering Committee*
- Oersted International Science Team
- Oersted Science Advisory Committee
- Office of Science & Technology Energy Foresight Panel: *Liberalisation Task Force*
- OST NRE Foresight Challenge
- Palaeontographical Society: *Secretary, Council Member*
- Palaeontological Association: *Editor*
- Parliamentary Minerals Group
- Remote Sensing Society, Archaeology Special Interest Group: *Treasurer*
- Rivista Italiana di Paleontologia e Stratigrafia: *Editorial Board Member*
- Royal Astronomical Society: *Council*
- Royal Society: *Earth Resources Panel*
- Seafloor Sub-Commission for the Geological Map of the World: *President*
- Society for Underwater Technology: *Ocean Resources Committee; Offshore Site Investigation and Geotechnics Committee Secretary; Education and Training Committee; Research & Technology Policy Committee*
- South Pacific Applied Geoscience Commission
- South West Atlantic Hydrocarbon Commission
- Subcommission on Carboniferous Stratigraphy: *Titular Member*
- Subcommission on Jurassic Stratigraphy: *Triassic–Jurassic Boundary Working Group*
- Subcommission on Triassic Stratigraphy: *Secretary*
- Technical Advisory Group (SOPAC): *Chairman*
- Ussher Society
- URGENT: *Steering Group*
- Yorkshire Geological Society: *Editorial Board*

# Appendix 8 Acronyms

ADB	<i>Asian Development Bank</i>	IH	<i>Institute of Hydrology</i>
ANDRA	<i>Agence Nationale pour la gestion des Déchets Radioactifs</i>	IIFR	<i>Interpolation In-Field Referencing</i>
ARGOSS	<i>Assessing Risk to Groundwater from On-Site Sanitation</i>	IPT	<i>Induced Polarisation Tomography</i>
ASR	<i>Aquifer Storage Recovery</i>	IPR	<i>Intellectual Property Rights</i>
AWE	<i>Atomic Weapons Establishment</i>	IPSN	<i>Institut de Protection et de Sécurité Nucléaire</i>
BGGM	<i>BGS Global Geomagnetic Model</i>	ISDN	<i>Integrated Services Digital Network</i>
BGS	<i>British Geological Survey</i>	ISMI	<i>International Strategic Metals Issues</i>
BGSD	<i>Botswana Geological Survey Department</i>	KAR	<i>Knowledge &amp; Research Programme</i>
BRIDGE	<i>British Ridge</i>	LEMIGAS	<i>Indonesian Research &amp; Development Centre for Oil &amp; Gas Technology</i>
CASE	<i>Collaborative Awards in Science and Engineering</i>	LIDAR	<i>Laser Induced Detection And Range</i>
CEC	<i>Commission of the European Communities</i>	LOCS	<i>Land-Ocean Contaminant Study</i>
CEEC	<i>Central and East European Countries</i>	LOIS	<i>Land-Ocean Interaction Study</i>
CFTC	<i>Commonwealth Fund for Technical Cooperation</i>	MAFF	<i>Ministry of Agriculture, Fisheries and Food</i>
CIRIA	<i>Construction Industry Research and Information Association</i>	MINGOL	<i>Minerals GIS On-Line</i>
CCOP	<i>Intergovernmental Committee for the Coordination of Coastal and Offshore Geoscience Programmes in East and Southeast Asia</i>	MVO	<i>Montserrat Volcano Observatory</i>
CORSAIRES	<i>Coring Stable And Instable Realms In European Seas</i>	NAGRA	<i>Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle</i>
CSIRO	<i>Commonwealth Scientific &amp; Industrial Research Organisation</i>	NERC	<i>Natural Environment Research Council</i>
CTBT	<i>Comprehensive Test Ban Treaty</i>	NERS	<i>Natural Environmental Radioactivity Survey</i>
DED	<i>Department of Economic Development</i>	NDC	<i>National Data Centre</i>
DERA	<i>Defence Evaluation and Research Agency</i>	NDGD	<i>Nirex Digital Geoscience Database</i>
DETR	<i>Department of the Environment, Transport and the Regions</i>	NGO	<i>Non Government Organisation</i>
DFID	<i>Department for International Development</i>	NIGL	<i>NERC Isotope Geoscience Laboratory</i>
DOE-NI	<i>Department of the Environment, Northern Ireland</i>	N-MORB	<i>Normal-Mid Ocean Ridge Basalt</i>
DMQ	<i>Directory of Mines and Quarries</i>	NRA	<i>Natural Resources Authority of Jordan</i>
DRA	<i>Defence Research Agency</i>	NRPB	<i>National Radiological Protection Board</i>
DRGS	<i>Digital Report Generating System</i>	OBS	<i>Ocean Bed Seismometers</i>
DTI	<i>Department of Trade and Industry</i>	ODP	<i>Ocean Drilling Programme</i>
DTM	<i>Digital Terrain Model</i>	OSO	<i>Oil, gas and petrochemicals Supplies Office</i>
EA	<i>Environment Agency</i>	PACE	<i>Palaeozoic Amalgamation of Central Europe</i>
EC	<i>European Commission</i>	PC	<i>Personal Computer</i>
EC	<i>European Community</i>	PECC	<i>Petroleum Exploration Computer Consultants</i>
EAP	<i>Edinburgh Anisotropy Project</i>	PIMA	<i>Portable Infrared Mineral Analyser</i>
EGS	<i>European Geophysical Society</i>	PNC	<i>Power Reactor and Nuclear Fuel Development Corporation, Japan</i>
EMS	<i>European Macroseismic Scale</i>	PNG	<i>Papua New Guinea</i>
ENAM	<i>European-North Atlantic Margin</i>	POSC	<i>Petroleum Open Systems Corporation</i>
EU	<i>European Union</i>	PRIS	<i>Postgraduate Research Institute for Sedimentology</i>
EUG	<i>European Union of Geosciences</i>	PUS	<i>Public Understanding of Science</i>
EEZ	<i>Exclusive Economic Zone</i>	RGGE	<i>Rapid Global Geological Events</i>
EQUIP	<i>Evidence from Quaternary Infills for Palaeohydrology</i>	RESCAN	<i>Resistivity imaging technique</i>
FIG	<i>Falkland Islands Government</i>	SCRAN	<i>Scottish Cultural Resources Access Network</i>
G-BASE	<i>Geochemical Baseline Survey of the Environment</i>	SEDEX	<i>Sedimentary Exhalative</i>
GEIXS	<i>Geological Electronic Information Exchange System</i>	SEM	<i>Scanning Electron Microscope (Microscopy)</i>
GFZ	<i>GeoForschungsZentrum, Potsdam, Germany</i>	SEPA	<i>Scottish Environment Protection Agency</i>
GGMC	<i>Guyana Geology &amp; Mines Commission</i>	SERGEOMIN	<i>Servicio Geológico Minero de Bolivia</i>
GHASP	<i>Geo-Hazards Assessment and Susceptibility Programme</i>	SME	<i>Small and Medium Enterprises</i>
GIC	<i>Geometrically Induced Currents</i>	SOPAC	<i>South Pacific Geoscience Commission</i>
GIS	<i>Geographical Information System</i>	SOPAC	<i>South Pacific Applied Geoscience Commission</i>
GSNI	<i>Geological Survey of Northern Ireland</i>	SOS	<i>Satellite Observation Systems</i>
GPA	<i>Global Programme of Action</i>	TESZ	<i>Trans-European Suture Zone</i>
Hi-RES	<i>High-Resolution Resource and Environmental Survey</i>	TMR	<i>Training and Mobility of Researchers</i>
HSE	<i>Health and Safety Executive</i>	UKCS	<i>UK Continental Shelf</i>
HYACE	<i>Hydrate Autoclave Coring Equipment</i>	UKWIR	<i>United Kingdom Water Industry Research Ltd</i>
IAGA	<i>International Association of Geomagnetism and Aeronomy</i>	UNEP	<i>United Nations Environment Programme</i>
IASPEI	<i>International Association of Seismology and Physics of the Earth's Interior</i>	URO	<i>Urals Orogen</i>
ICAR	<i>Institute of Arable Crops Research</i>	VAR	<i>Value Added Resellers</i>
ICP	<i>Inductively Coupled Plasma</i>	VB	<i>Visual Basic</i>
ICP – AES	<i>– Atomic Absorption Emission Spectrometer</i>	VLf	<i>Very Low Frequency</i>
ICP – MC-MS	<i>– Multiple Collector Mass Spectrometer</i>	VMS	<i>Volcanogenic Massive Sulphide</i>
ICTJA	<i>Instituto de la Tierra “Jaume Almera”</i>	WAJ	<i>Water Authority of Jordan</i>
IDS	<i>Integrated Database System</i>	WWW	<i>World Wide Web</i>

# Appendix 9 Core Strategic Programme Achievements

At its meeting on 12 May 1998 the BGS Board was presented with a review of the 1997/98 Core Strategic Programme; a summary of its achievements follows:

## ONSHORE AND GEOPHYSICAL SURVEYS

### A1 — Multidisciplinary Regional Surveys

#### General

- 3303 km<sup>2</sup> resurveyed and revised.
- 275 1:10 000 standards (of which 24 are digital) approved for release.
- 6 1:25 000 standards approved for release.
- 53 technical reports written between 1 January and 30 June 1997.
- 20 1:50 000 sheets delivered to the Drawing Office:
  - Scotland: 53W, 55W, 63E, 76E, 83W, 107W, 114W
  - England and Wales: 29, 54, 153, 160, 268, 281, 343, 353, 355, 356
  - University collaboration
    - Scotland: 55W, Unst & Fetlar
    - England and Wales: 134
- 6 memoirs approved by Director; 5 with editors:
  - Scotland: 66W
  - England and Wales: 48, 78, 235, 297
- 8 boreholes drilled by BGS rig, with a total length drilled of 667m.

#### Co-funded Projects

- All draft maps and the report for the Afon Teifi area of west Wales sent to the consortia of local authorities for approval.
- Report 'The new stratigraphy – a guide' for CIRIA completed and approved.
- West Cumbria memoir published.
- Digital data delivered for Midland Valley Mineral Resources.
- Drafts of Fife and Angus booklets submitted to SNH.

### A2 — Continuous Revision

#### Data Acquisition and Map Revision, Scotland and Northern England

- 3 BGS boreholes, 30 commercial boreholes examined and data incorporated in correction copies.
- 22 non-coal mineplans captured digitally as Microstation design files; procedures trailed for display as Mapinfo tables.
- 3100 mine entries digitised from BGS published maps and incorporated in shafts database.
- 14000 records of former or active quarries captured and entered in Access database.

#### Data Acquisition and Map Revision, Central England and Wales

- Five 1:10 000 standards in Yorkshire coalfield approved for complex opencasted areas of Sheffield and Rotherham.

#### Data Acquisition and Map Revision, Southern and Eastern England

- 14 1:10 000 standards revised in Bristol/Bath and Beaconsfield/Reigate areas.
- 108 1:10 000 standards revised in the London area.

#### Digital Mapping Development

- Completion of prototype digital map compilation system for use by the Land Survey geologists. Land Survey groups will now commence field use of the system in selected project areas.
- Glasgow Project – data transfer protocol for Earthvision to Mapinfo developed.
- Microstation Field entry mapping system – report on field trials completed. Initial reaction unfavourable.
- Development of prototype system for delimiting areas of possible undermining from borehole data.
- Version 1 of Section Database completed.
- Automated enquiry answering service (ALGI) now functional and operating for Bristol area.

### A3 — Onshore Surveys Database

#### Database and Computing Support

- VAX conversion has been completed for the tasks identified as high priority. Work is progressing in collaboration with other Divisions on databases and applications that are under joint ownership.
- Installation of Lexicon applications and database within BGS and on WWW complete.
- Igneous rock classification scheme complete and available on WWW; other schemes in progress.
- Support for Land Survey applications via Help Desk now installed.

#### Onshore Geological Surveys University Contracts

- *Birmingham University* – project initiated to study palaeomagnetism of weathered Precambrian and Lower Cambrian at Nuneaton.
- *Birkbeck College* – Dr Roberts has completed on schedule an isocryst map of the Windermere Supergroup strata on the Kendal sheet.
- *Brighton University* – Chalk database of boreholes now 90% complete. Data placed in digital relational database linked to a GIS, and

now extended to link into BGS Wallingford Well log database.

- *Cambridge University* – Drs Woodcock and Rickards have submitted 1:10k maps of the southern Howgill Fells.
- *Durham University*
  - Dr Emeleus has resumed work on the Tertiary Regional Guide following his illness.
  - Dr Turner has nearly completed field studies on the Plennellor site in Northumbria; final report awaited.
  - Dr Holdsworth has completed all deliverables for the mapping contract on the Moine supergroup strata of the Eriboll sheet.
- *Edinburgh University*
  - Dr A Hall has submitted an internal report of drift geology of sheet 86 (Scotland).
  - Dr Clarkson is to study radiolaria in Southern Uplands chert.
  - Dr Fitton will be studying the geochemical characteristics of the Tayvallich Volcanics and Green Beds, Upper Dalradian, SW Highlands.
- *Glasgow University* – Dr Bell has delivered all 1:10k maps and other material for the 1:50K and 1:25k maps of Central Skye as well as a draft for the 1:25k explanation; work nearly complete.
- *Keele University* – Dr B Besley (now of Shell) continues his personal involvement with studies on the Upper Carboniferous/Lower Permian of the Pennine Basin.
- *Leicester University*
  - Revision of the Wenlock graptolite zones of the Builth Wells district is complete; new zonation of international significance.
  - Trias unconformity project is complete.
- *Leipzig University* – study visit carried out by BGS staff.
- *Liverpool University*
  - analysis of Ordovician glacioeustatic successions by Dr Brenchley has been postponed until BGS mapping resumes on the Builth Wells Sheet in central Wales.
  - New PhD project started on resolution of some problematic stratigraphical relationships in the Millstone Grit of northern England.
  - Dr Dagley has traced the Cleveland-Armathwaite dyke across the greater part of the Southern Uplands.
  - Dr Kokelaar has delivered the component material for the 1:25k Glencoe map.
  - Dr Flinn has delivered the marginalia, and component 1:10k maps and technical report for the 1:50k Unst-Fetlar sheet.
- *Manchester University* – Dr Treagus has delivered all material for the Schiehallion sheet, including, 1:10K maps, technical reports and a memoir script.
- *Newcastle University* – EU collaborative project to look at gypsum geohazards started in association with Universities of Zaragoza and Tübingen and the Ukraine Academy of Sciences.
- *Oxford Brookes University* – Dr Strachan is on schedule with a compilation of material for sheet 108E (Loch Naver).

- *Portsmouth University* – Dr Loydell has refined the lithostratigraphy at the junction of the Hawick and Gala groups in the central Southern Uplands.
- *Queens University* – Dr Leslie is to investigate shear zones in Highlands.
- *Royal Holloway/East Anglia* – Research, tied in with East Anglia mapping, now complete, resulting to date in two external published papers.
- *Sheffield University* – Dr Soper has almost completed mapping of Windermere Supergroup strata on the Kendal sheet.

## A5 — Regional Geophysical Surveys

### *Regional Crustal Structure*

- Modelling and imaging have been completed for the Southern Scotland and Northern England project.
- The Eastern and Southern England project has commenced with compilation of borehole and physical property data and production of gravity/magnetic images.

### *Geophysical Computing Support and Development*

- Further upgrades to *Gravmag* (release v1.7), *ARARAT* (IGRF, track-editing and improved line-splitting), *Wellog* (TIFF core photo displays and commencement of GUI development), and *Colmap*.
- Further major upgrades to the suite of 3D gravity/magnetic modelling programs (*Bmod/Gmod/Gridview*) including magnetic layer optimisation and GUI, improved display of fields and models, and prototype combined gravity/magnetic optimisation.
- Agreement with ARK Geophysics Ltd to use *Gmod/Bmod/Gridview* as the 3D component of ArkField, ARK's new integrated seismic/gravity/magnetic software for Landmark and GeoQuest workstations (*additional deliverable related to technology transfer*).
- Regional Geophysics Group Web pages have been developed and released (*additional deliverable*).

### *Refraction Studies*

- Minor software development, liaison with industry/academia with regard to possible new projects and review of paper on behalf of journals.
- Organisation of international conference on the Atlantic margin and production of a major publication on assessment of earthquake prediction.

### *National Geophysical Mapping and Data Management*

- Regional gravity survey of the Orkney Islands completed.
- Two 1:1M magnetic sheets publication (Shetland and Faeroes) prepared for publication.
- 1:1.5M gravity and magnetic shaded-relief maps (generated in previous years) printed and released, involving significant extra work to optimise display format of printed maps.
- Re-structured (line-format) GSGB aeromagnetic data and onshore gravity data loaded into the Oracle tables completed.
- Hydrographic Office gravity/magnetic data loaded into the BGS database.

- Prototype versions of new user interfaces to the physical properties database and geophysical survey index have been developed.
- Connection between the marine, onshore and airborne databases improved and *DBank* interface to the marine gravity/magnetic database has been updated to include adjusted data.
- Cataloguing of paper archive continued and connection with digital geophysical survey index commenced.
- Start made on cataloguing holdings of overseas geophysical data.
- Management of the marine gravity/ magnetic database has been transferred to Keyworth following the early retirement of the previous data manager in Murchison House.

### *ODP Research*

- Participation in core and wire-line logging research on leg 176 following request from ODP.

### *Co-funded Projects (including EU-TMR research networks)*

#### *High Resolution Airborne Resource and Environmental Survey*

- Co-funding secured from World Geoscience for the first survey (designated Hi-RES-1) over a 200x70km swathe across central England (including the Keyworth area). Data acquisition behind schedule.
- BGS has gained access to World Geoscience Irish Sea aeromagnetic surveys for core programme work and these have been delivered to BGS.

#### *FieldBank*

- Co-funded phase of the project completed (design and implementation). Four oil companies signed up for commercial phase (potential field data management service).

#### *URO Network*

- New magnetic images generated and analysed.
- Further integrated seismic/gravity/magnetic modelling of the trans-Urals URSEIS line carried out.
- Results have been presented at international conferences.

#### *PACE Network*

- New EU-TMR award (Palaeozoic Amalgamation of Central Europe) linked to Europrobe Trans-European Suture Zone project.
- Good start made on compiling European gravity and magnetic data (in collaboration with partners).
- Revised maps of the TESZ region presented at international meetings.

## **HYDROCARBONS, OFFSHORE SURVEYS AND GEOPHYSICAL MONITORING**

### **B1 — Offshore Surveys**

#### *Offshore Map Production*

- The 1:250 000 Shetland Sea Bed Sediment map is being printed.

- The Sula Sgeir solid Geology map is in the Drawing Office.
- The Shetland Quaternary map has been reviewed and is in its final editing stage.
- The UK elements of the Guernsey Solid Geology and Quaternary sheet have been completed for some time but still await input from the French.
- Work has started, in collaboration with the Irish Geological Survey and the Irish Petroleum Affairs Department on the St Georges Channel Solid Geology map which will revise the Cardigan Bay sheet and parts of Anglesey, Lundy and Nymph Bank sheets and include, for the first time, Irish areas in the Waterford sheet.

### *Rockall Consortium*

- Two additional companies have now joined the Rockall Consortium, bringing the total number of members to 14. Further members are being sought.
- The two-ship seismic experiment to image beneath the basalt was successfully completed and the data are now being processed.
- The consortium has agreed to support a major shallow drilling programme in 1998 and planning is in hand for the pre-site surveys and the drilling.
- Data from the Hatton-Rockall area has been acquired through a data exchange with the Danish Geological Survey and planning for the drilling programme includes potential sites on the Hatton-Rockall Bank.

### *Western Frontiers Association*

- The Western Frontiers Association has agreed to extend its area of interest to the areas west of the Hebrides and north of 62 degrees north.
- Projects undertaken include updating of a comprehensive computerised bibliography, studies of potential gas hydrate and shallow gas distribution, fluid seepage and geohazards.
- As part of the Association programme a major advance has been made in the imaging of the sea bed using the first signal return from 3D exploration seismic data.

### *Marine Operational Capability*

- Full scale trials of the MAST II Hammer Corer were successfully completed in the Indian Ocean.
- Development of the deep ocean NERC/BRIDGE one metre drill to take oriented rock cores has been completed and it is now awaiting full scale trials in the Indian Ocean.
- Refurbishment and development of equipment is in hand to support the Rockall Consortium funded drilling programme.

### *ODP Drilling Enhancement*

- The Tonga region proposal site survey has now been rated A1 and the scientific case strongly recommended. The proposal now awaits allocation within the programme.

### *North Atlantic 1:4M and European 1:5M Solid Geology maps*

- The UK data for these sheets have now been validated and compilation continues.

## B2 — Coastal Surveys

### *Coastal Estuarine Evolution/Land-Ocean Interaction Study (LOIS)*

- Comprehensive support has continued to be provided to the LOIS Special Topic community in respect of core curation and associated scientific services.
- As the designated data centre for the LOEPS component of LOIS, the Coastal Geology Group has completed its contribution to the initial phase of data compilation which has resulted in the production of a CD-ROM which provides an overview of the scientific achievements of LOIS.
- A series of conference presentations was made during the year at national and international conferences summarising one area of work which has combined coastal geology, remote sensing and GIS technology to the determination and prediction of sediment yields from coastal erosion in eastern England.
- The final LOIS conference was held in March 1998, at which 11 presentations were made summarising the scientific achievements of BGS staff involved with the project.

### *Strategic Nearshore Zone Survey*

- This project has continued, with co-funding from DETR, into its last full year and sets out to collate geoscientific data from sectors of the inshore zone of English waters into a digital framework.
- Three sectors of the co-funded Inshore Seabed Characterisation Project (East Anglia, Portland to Wight and Wight to Shoreham) have been completed along with the draft report. Presentation of the results on a CD-ROM for DETR is close to completion.

## B3 — Petroleum Geology

### *Stratigraphic Nomenclature*

- Work has started on the sequence stratigraphic nomenclature of the Neogene of the North-west Margin supported by sponsorship from six oil companies.

### *Database*

- Maintenance and development of petroleum and offshore databases continues.
- Work on the core archive continues including the transfer of offshore core from Keyworth to provide space for the land core being transferred from the DTI store.
- Data continues to be received and curated from the Hydrographic Office.
- A Confidentiality Agreement and process of acquiring seismic and well data from BP has been established and an important data set has been added to the BGS archive.

### *High Resolution Correlation*

- The final text of a digital report on Upper Silurian (Ludlow) stratigraphy was completed

during 1997/1998. It awaits completion of figures before being published on the BGS web site in 1998.

- Reports on Upper Triassic, Callovian and Thanetian stratigraphy are in progress. Reports on Llandovery, Oxfordian and Albian have been completed but await reformatting before following the Ludlow report onto the web site. Information is being compiled for the Bathonian, Kimmeridgian and Aptian stages.

### *UK Basin Analysis*

- Compilation datasets from a variety of sources gridded to produce regional contour maps at 1:1.5 million scale of:
  - Top Chalk/Base Tertiary entire UK (onshore and offshore).
  - Base Chalk North Sea (partial).
  - Base Cretaceous North Sea (partial).
- Trial production of GIS coverages of structural surfaces.
- Development of rudimentary procedures for generating cross sections and fault displacement statistics from GIS coverages.
- A preliminary 3D model of major crustal faults and Moho surfaces in southern England is nearing completion.
- Recovery and integration of data from the defunct East Midlands Coal Board borehole database (1985) into this database.
- Recovery and integration of data from database of boreholes from the defunct National Grid square SP (1986) into this database.
- Entry of data from significant boreholes in National Grid Squares ST, SU, SY, SZ, TQ, TR, TV.
- Trial integration of stratigraphic information from database with existing maps displayed in Earthvision and Locsec.
- Staffs subsurface mapping All seismic data interpreted except that to NE of Derbyshire and the Conoco data in the Welsh borders.
- Entry of stratigraphic information from boreholes in this area into stratigraphic surfaces database almost complete.
- 40% of interpreted seismic has been digitised and entered into the 'LOCSEC' seismic database.

### *Carboniferous Heavy Minerals*

- Work has continued on the development of a detailed heavy mineral stratigraphy of Upper Carboniferous sandstones in the northern Pennine region. Coverage for northern England has been extended to include several key sections in the Yorkshire and south Derbyshire areas. Dating of detrital zircons has been carried out as a means of identifying likely source terrains, and the results integrated with the heavy mineral data. Deliverables to end-March 1998:
  - Data from key sections in Yorkshire and south Derbyshire have been integrated with previously acquired data from the Bradford area and a provisional report prepared.
  - SHRIMP zircon-dating data have been integrated with the heavy mineral data and a draft report prepared.

## B4 — Geophysical Monitoring and Forecasting

### *Core Geomagnetism*

- GAUSS magnetic observatory systems commissioned on 1 January 1997 performed well with a noticeable improvement in baseline stability.
- GIFS and INTERMAGNET on-line database updated daily 7 days a week.
- UK magnetic observatory data sent weekly to the international agencies responsible for computing magnetic activity indices.
- Monthly bulletins for each of the UK magnetic observatories published within 7 days of the end of each month.
- 1996 UK Magnetic Observatories' Yearbook published in December 1997.
- Definitive data for the UK observatories supplied for the 1996 INTERMAGNET CD-ROM.
- Six repeat stations occupied in the UK Magnetic Survey network.
- 1996 Yearbooks for the BGS stations on Ascension Island and in the Falkland Islands published in October 1997.
- UK Regional main field model produced in October 1997.
- 1997 revision of the BGS Global Geomagnetic Model completed in May 1997.

### *Applied Seismology and Associated Engineering*

- New strong motion instruments installed in Anglesey and Leeds.
- Seismic data acquisition system transferred to QNX multi-tasking PC operating system.
- Instrumentation for field tests of data acquisition system response developed and trialled.
- Development of interfaces to integrate environmental sensors into seismic data acquisition systems completed.

### *Seismicity and Hazard Assessment*

- Immediate seismic event alerts issued for reported events.
- 251 earthquakes located during the period April 1997 to March 1998 (44 felt).
- Provisional monthly bulletin of seismic events published 6 weeks in arrears.
- UK earthquake bulletin for 1996 published in April 1997.
- Eighth Annual Monitoring Report (1996/97) published in June 1997.
- Macroseismic surveys for Devon/Jersey earthquakes.
- Publication of reports on individual UK seismic events and earthquake cluster activity in 1996, and hazard implications.
- Global seismicity database revised and operational.

### *Multi-component Seismics*

- Analysis of multi-component seafloor datasets.
- Application of innovative sub-basaltic imaging techniques using converted shear-waves.
- AVD processing using vertical cable and seabed seismics and walkaway VSPs applied to data from the marine environment.
- Demonstration of the ability of repeated 2-D azimuthal surveys to estimate fracturing in chalk fields.

- Software transferred to PROMAX for use by co-funding sponsors.
- Success in attracting co-funding to maintain the vigour of leading edge Research and Development.

## MINERALS AND GEOCHEMICAL SURVEYS

### C1 — Geochemical Surveys

#### *Geochemical Baseline Survey of the Environment (G-BASE)*

- *Regional geochemistry of parts of North-west England and North Wales*, in press.
- Release for sale of *Discovering geology: The Lake District. An interactive multimedia CD-ROM*.
- Systematic geochemical sampling over an area of 5200 km<sup>2</sup> of the East Midlands, with the collection of 1594 stream sediment, 1350 stream water and 2558 soil samples.
- Completion of computer-generated geochemical imagery and further progress on drafting the text for *Regional hydrogeochemistry of Wales*.
- Three scientific papers submitted to peer-reviewed journals.
- Use of G-BASE data in two projects in the NERC Environment Diagnostics Programme. These projects were completed and reported, and two further project proposals were prepared.
- Presentation on G-BASE field methods at FOREGS Field Workshop in Slovakia in May, in preparation for sample collection in 1998.
- Contribution to a FOREGS field manual on the collection of geochemical samples.

#### *Natural Environmental Radioactivity Survey (NERS)*

- Establishment of database for the East Midlands sheet and of classifications for draft radon-potential map.
- Development of streamlined database and GIS of natural radioactivity for Liverpool Bay and Lake District, including facility for incorporation of the large quantities of relevant Nirex data and back-calibration of Nirex airborne radiometric data against new ground truth measurements.
- Following reviewer's comments on the prototype Liverpool Bay radon-potential and gamma-ray exposure maps, a revised version of the radon map based on a classification including both solid and drift geology has been produced.

#### *Development of Capability in Analytical Geochemistry*

- *Determination of Cd in marine sediments by ICP-MS*. A detailed examination of interference effects related to sample dissolution.
- *Chemometric modelling to improve short-term precision and calibration procedures in ICP-AES*. Publication of paper; joint BGS studentship with Department of Environmental Sciences, Plymouth University started in September 1998.
- *Robust method for the determination of As, Sb, Se and Hg on a single digest*. Preliminary method development has been successfully applied.
- *Dissolution procedures for the determination of boron*. Several fusion techniques have been assessed and a method, based on sodium

peroxide, devised for the determination of boron in refractory samples.

- *ICP-AES procedure for iodine in rocks*. A gas-liquid separator has been assembled and the ICP-AES operating conditions have been optimised to maximise signal to background ratios for iodine determinations.
- *Simplified methodology for solid-phase speciation using chemometric data processing*. A novel approach to the determination of porewater composition in clay materials has been successfully developed.
- *Analysis and speciation of Se in soils*. Award of PhD to CASE student, working jointly with Postgraduate Research Institute for Sedimentology (PRIS), Reading University. A new PhD student from PRIS has carried out preliminary experiments on extraction methods for solid-phase speciation of Se in fresh and dried soil samples.
- *Laser ablation ICP-MS*. Selected as the only official NERC display at the Royal Society New Frontiers in Science Exhibition, June 1997, entitled *Aquatic life charts environmental change*.
- *Synthetic XRF standards*. A research programme, in conjunction with a leading equipment manufacturer, to develop synthetic XRF standards for the cement industry.
- *Halogens in geological materials*. Research on a method for the determination of chlorine and bromine in rocks by alkaline fusion with ion chromatography detection was published in early 1997.
- *Chemometric manipulation of analytical data*. A paper on methods for the integration, modelling and presentation of hydrochemical baseline data has been accepted for publication in *Journal of Geochemical Exploration*.
- *Polyaromatic Hydrocarbons (PAH)*. A method for the determination of PAH by gas chromatography, faster than the alternative HPLC method, was investigated and interferences from petroleum hydrocarbons in organic extract quantified.
- *Determination of cyanide*. In order to bid for work in the contaminated land sector it has been mandatory to participate in proficiency testing programmes using specified methods. Two such "preferred" methods for the determination of "easily-liberatable" and "total" cyanide have been investigated.
- *Laboratory Information Management System (LIMS)*. Transfer of the LIMS from its Informix database under Windows 3.11 to MS SQL Server running under Windows NT. A data entry routine has been assessed and purchased and a user-friendly interface written to provide unique identifiers for each analyte on data entry into the LIMS.
- *North West European Gas Atlas (co-funded)*. Final report submitted to Brussels in June 1997. Hard copy and interactive CD ROM versions are available for purchase. The scientific conclusions were presented at the 5th Conference on Petroleum Geology of NW Europe and at several other international meetings.
- *Tectonic Early Warning System (co-funded)*. The inaugural meeting of this two-year INCO Copernicus project to investigate the use of soil and groundwater gas geochemistry in relation to seismic activity was held in Athens in September 1997.

- *Development of Analytical Procedures to Guarantee Quality Assurance in International Environmental Monitoring (co-funded)*. Analytical geochemists from the 11 European Geological Surveys participating in this three-year INCO Copernicus project met in December in Budapest to discuss the analytical data from two rounds of inter-laboratory proficiency testing carried out during the first nine months of the project.

### C2 — Mineral Resources

#### *Minerals GIS On-Line (MINGOL)*

- Completion of the basic MINGOL system and preparation of CD-ROM copies for demonstration purposes.
- Incorporation of DETR-commissioned county Mineral Resource Planning map data for Warwickshire and South Wales.
- Incorporation of economic Planning Regions and associated production data.
- Completion of national index of mineral exploration data at 1:1M scale.
- Completion of the revision and updating of the BRITPITS dataset, on which the Directory of Mines and Quarries (DMQ) is based. The DMQ will be published in May 1998.
- *Mineral Resources of Britain publication* – digital location maps and diagrams, with plots of examples (gold, copper, lead and zinc) using a simplified background geology, designed; drafts prepared of further commodity chapters and completion of glossary of technical terms related to the definition of mineral resources and reserves.

#### *Sedimentary Basin Resources: Gold in Orogenic Extensional Basins — The Dalradian*

- Incorporation of multiple digital geoscience datasets for the Dalradian into ArcInfo GIS. Enhancement of system functionality for display and analysis of exploration data.
- Extensive suite of rock samples from known gold occurrences, with analyses for a wide range of trace and major elements. Polished thin sections and fluid inclusion wafers prepared for study.
- Completion of overview report on Dalradian gold to the stage of compiling in digital form (spreadsheet format) the results of more than 140 projects carried out by the commercial sector and BGS.
- Programmes for isotope studies of Caledonian intrusions associated with gold mineralisation and of Dalradian provenance, approved for 1998/99 start.
- Preparation for publication of *The Midas Project: multidataset analysis for the development of gold exploration models in western Europe*. (Printing funded by the EC.)

#### *Coal Map of Britain*

- Completion of borehole database for sub-surface reconstruction. The database of mine information is also well advanced.
- Decision on major design components; digital compilation of onshore linework (90% complete).
- Details of marginalia awaiting decisions from the Coal Authority.

### **Palaeofluid Flow in Resource Development**

- Successful completion of an evaluation study to determine the geochemistry of ore fluids associated with the world class Cu-Au Grasberg deposit, Indonesia (mining industry co-funded R&D). Results provide quantitative data on the metal content of the mineralising fluids for critical comparison with similar deposits elsewhere and the potential development of novel exploration methods.
- Completed installation of low temperature plasma and upgrade to ICP-MS. Preliminary results validate investment risk. Data used to underpin research proposal to DTI (LINK scheme) and stimulate CR work on high grade quartz materials for the semiconductor industry.
- Contribution to the modelling of high grade, low sulphidation Au-Ag deposits, Milos, Greece (British Council research grant with the University of Athens). Data used to prepare an industry co-funded R&D study of gold deposits elsewhere in Greece.
- Two scientific peer reviewed papers and two chapter contributions to text books (In press).
- Co-ordination of BGS input to NIGL-BGS-BAS new mass spectrometer initiative. Carried out acceptance tests on instrument at factory. Designed and drafted BGS isotope capability programme for 1998-99.

### **Development of Capability in Mineralogy and Petrology**

- *Mineralogical analysis of airborne particulates.* Reviews of sampling and preparation techniques have been prepared as technical reports; three frisbee-type deposition gauges have been deployed on the Keyworth site and samples from them are being monitored; publicity and demonstrations at the Society for Clean Air meeting (Keyworth, January 1998) has resulted in two commercial enquiries.
- *Mineralogical analysis of contaminated sediments.* Following contact with Nottingham University, a collaborative project using the BGS cryogenic SEM facility has been applied to heavy metal contaminated canal mud from the West Midlands.
- *Remediation and recycling of mining waste.* A technical report on testing of beneficiation of metalliferous waste from the Leadhills area is in draft, and a new sub-project dealing with recycling feldspar from granite waste is in progress.
- *Basin maturity indicators.* The international conference 'Clay Mineral Evolution, Basin Maturity and Mudrock Properties' was held at Keyworth in November 1997.
- *SEM CL fingerprinting of detrital minerals.* A novel technique for sandstone correlation and provenance based on growth patterns in zircon (and potentially other detrital minerals) is in progress and a first technical report drafted.
- *Gold database.* Data archives previously assembled as Excel tables have been assembled into a Microsoft Access™ database.
- *Fire retardant minerals.* With British Council co-funding, an Anglo-Greek investigation into potential use of huntite-magnesite, in relation to fire retardance performance of furniture fabrics, has been carried out and a technical report completed.
- *European zeolite resources.* A three year EU-co-funded (Brite-Euram) programme of evaluation of

European zeolite resources was completed during 1997 with submission of the project report.

- *BGS petrological classification scheme.* The scheme for igneous rocks has been adopted and those for the sedimentary, metamorphic and superficial groups are under final review. Interactive access and codification for the igneous scheme have also been undertaken.

### **C4 — Divisional Databases**

#### **Databases and Software Development**

- Further progress in the client-server model for the Geochemistry Database was achieved with the development of a user retrieval front-end and a field card data loading system using Microsoft Access on user's PC linked to the back-end ORACLE database. A user manual describing the procedures for loading data to the Geochemistry Database was completed (Technical Report WF/97/1) via UNIX and via Access.
- Data loading continued for the G-BASE program and a backlog of MRP data was loaded from staff taking early retirement. Lithochemical data was checked and loaded where available.
- A GIS system has been developed and fully tested which provides a graphical front-end to the Geochemistry Database (see below) and short description sheets produced detailing the Access and ArcView front-ends.
- Data loading to the BritRocks database from the old PetMin database was completed.
- A working ArcView GIS interface to the Geochemistry and BritRocks databases was developed and is undergoing trials.
- The database was linked to the Bibliographic Module used in the Mineral Occurrence Database, allowing detailed references to be made to literature sources.
- Review of the structure and design of the World Mineral Statistics database to determine and outline changes required to conform to BGS data architecture and revised user requirements.

### **HYDROGEOLOGICAL AND GEOTECHNICAL SURVEYS**

#### **D1 — National Groundwater Survey**

##### **Major Aquifer Studies**

- *Hydrogeology of the Chalk of the South Downs.* Comments made by reviewers and the updated section describing the management of the aquifers, contributed by Southern Water, were incorporated into the final report.
- *Hydrogeology of the Chalk of Yorkshire & Lincolnshire.* Integration of contributions to the reports and the results of co-funded activities continued and was nearing completion by the end of the year.
- *Hydrogeology of the Chalk of the Wessex Basin and the Chalk of the North Downs.* Initial reviews of information available have been undertaken and discussions have been held with water companies and regional Environmental Agency staff to describe the aims of the NGS and to identify issues to be addressed by the survey.

### **Effects of Old Chalk Landfills on Groundwater Quality**

- Five boreholes have been drilled in the landfill at Thriplow and 11 boreholes in the Chalk to define the contaminant plumes. Hydraulic testing has been carried out *in situ* and on core material from the middle Chalk and all existing boreholes have been sampled and fully analysed on 3 separate occasions.
- Modelling the plume using a dual porosity model has been started.
- Sampling of groundwaters, both close to the Thriplow landfill and regionally in order to determine to background concentrations, was completed and the samples analysed for a wide range of pesticides and radionuclides.
- A new contract, involving additional drilling to define the contaminant plume and provide permanent long term monitoring facilities, has been agreed with the EA to continue work at the site for another 2 years.

#### **Aquifer Process Research**

- The projects described below feed into the major aquifer studies and expand the scale of investigation through co-funding.
- *Transport and fate of pesticides.* Fieldwork in the winter 1997-98 was restricted to groundwater sampling. Laboratory studies of pesticide behaviour have been carried out.
- *Tracer Transport Tests.* The radial flow tests in the Sherwood Sandstone aquifer and regional tracer tests were completed.
- *Nitrate Trends in the Yorkshire Chalk.* Three cored boreholes were drilled to obtain unsaturated zone solute profiles. A new groundwater model, Multiple Analytical Pathways (MAP) has been developed.
- *Modelling.* Work has continued on the development of a UK Regional Model/ Modelling Test-bed linked to Chalk aquifer study areas.
- *Contaminant Migration in the Permo-Triassic Sandstone Aquifer.* A large fieldwork programme, including the core drilling of four boreholes, characterising rock core properties and obtaining detailed porewater profiles has been completed.
- *Permo-Triassic Sandstone Fractures.* The project report (Fracturing and the Hydrology of the Permo-Triassic Sandstones, BGS Technical Report WD/91/1) was produced on schedule in draft form.
- *Hydrogeological Map of Afon Teifi Catchment.* The hydrogeological map been prepared together with a conceptual model of the groundwater flow regime and a draft report written. The completed catchment map and report have enabled an exploratory drilling programme to be designed.
- PALAEAUX. The second annual report of the project was submitted to the EC on time.

#### **National Groundwater Archive**

- The 1996 Hydrological Data UK Yearbook was published on the Internet in December.
- Monthly summaries of groundwater levels continue to be published.
- The 1991-95 Hydrological Data UK Statistics volume has been sent to the printers.
- The long-term record of Water levels at Therfield Rectory was reviewed, with particular

attention paid to the interactions between groundwater level and climatic fluctuation.

- *Minor aquifer properties manual*. Field data collection was completed and a major restructuring of the database undertaken to cope with the broad range of minor aquifer data which has been encountered. A comprehensive literature search has been undertaken.
- *Major aquifer properties manual*. The project has been completed and the Aquifer Properties Manual and accompanying CD-ROM have been published.
- *Natural (Baseline) Quality of Groundwater in England and Wales*. Final reports on the seven areas selected for the first phase of this study were completed and submitted to the EA after review by EA regions. An interim version of the overview report was also prepared.

#### **Dissemination of Groundwater Data**

- The amalgamation of all water well and borehole records has been completed, finalising a process that took approximately 8 years.
- The index to all records was completed in March. Estimates of the number of records held at Wallingford have been revised down to slightly over 98,000.
- The new database structure, WellMaster, for hydrogeological data is now fully operational, and approximately 10,000 records have been digitised and entered onto the new system.
- Trials designed to match data held at Wallingford with data held at Keyworth were initiated.
- A report on the preparation of fully digital hydrogeological maps has been prepared.
- A database structure for managing geophysical logs has been included in the WellMaster database.
- A system for the compilation of databases of bibliographic material, linked spatially to maps of aquifers, from technical reports and monographs has been completed.
- A series of technical reports outlining the dissemination activity is nearing completion.

#### **D2 — Hydrogeotechnical Formation Properties and Hazards**

##### **Clay with Flints Monograph**

- The Clay with Flints Monograph has been published.

##### **Superficial Clays**

- Fracture mapping of Skipsea Till has been carried out on the Holderness coast.
- Nested piezometers have been installed in Skipsea Till at Yorkshire Water's Cottingham Pumping Station and will be tested once they have equilibrated.
- An 'Access' database of lithological information from an area surrounding Cottingham has been created.

##### **Clay Thermal Analogue Project**

- A total of six reports including the main deliverable, a report summarising the effects of heat upon

clays as determined from natural analogues, has been produced.

- An endnote database covering aspects relevant to this study has been released.

#### **GAMERS: Gas Migration in European Repository Systems. Gas Migration in Clay**

- Relationships between gas entry pressure, gas permeability and total stress have been established for various clay materials.
- Hydraulic characterisation of various natural and synthetic clay rich materials continues. Workshops in the UK and Europe have been attended to disseminate and discuss results.

#### **Fluid-Rock Reactions and Properties**

- A database of readily available sources of kinetic data for common minerals has been assembled and a methodology developed to handle such data.
- An experimental and computer modelling investigation into the leaching behaviour of fly ash from the incineration of municipal solid waste has been completed and produced excellent results.
- A draft technical report has been produced, cataloguing the gas entry properties obtained on laboratory specimens of selected clays.
- Experiments have been carried out to study the dissolution behaviour of calcite and dolomite under highly alkaline conditions.
- Construction of new temp./pressure controllers/monitors have been completed and tested successfully.
- Purchase of a high pressure (500 bar) pump.
- Construction of a large pressure vessel has been completed and pressure tested.
- Construction of a small recirculating reaction system has been completed and pressure tested to 600 bars, but high temperature seals are still awaited from the USA prior to final pressure testing.
- The rate of dissolution of zeolite minerals is being studied.

#### **Engineering Behaviour of UK Rocks and Soils**

- *Phase 2 Mercia Mudstone Group*. The completion of the first draft of the monograph on the Engineering Geology of the Mercia Mudstone Group is now complete.
- *Phase 3 Lambeth Group*. A literature search has been completed and reviewed. Samples have been collected from the Newbury and Isle of Wight areas; geotechnical testing will begin shortly.
- *Phase 4 Potentially collapsing soils*. Collaboration with Dr Ian Jefferson of Nottingham Trent University continues with joint supervision of two PhD student.
- Testing and reports on the shrink/swell behaviour of Gault clay are complete. Mercia Mudstone shrink/swell testing has been completed.

#### **D3 — Technology Foresight and Capability Development**

##### **Development of Geotechnical Capability**

- The report on the use of EKS for the remote estimation of permeability has been completed.

- Collaboration with Bristol University, regarding non-invasive subsurface imaging using 3D resistivity, has improved its accuracy to such a degree that geotechnical properties can be inferred in addition to geological structure.
- Numerical modelling of oil industry geophysical borehole logging tools has been successfully completed.
- BGS has underpinned the CIRIA/ Geological Society Working Party Report on 'Civil Engineering uses of Geophysics'.
- Collaboration between BGS, Leicester University and Shell & Mobil has demonstrated how high resolution geophysical imaging of core can improve the interpretation of downhole electrical images of the borehole wall.
- Connected fractures have been mapped in carbonate core (BGS, Leicester University, and LASMO).
- Work in collaboration with the US Navy has shown new insights into investigating sediment heterogeneity using non-seismic techniques which compliment established acoustic methods.

#### **Development of Hydrogeological Capability**

- There is an increasing demand for the analysis of high TDS waters, such as highly polluted waters and saline waters, making the analysis more time consuming and difficult.
- The laboratories are closely involved in two important arsenic projects (in Bangladesh and Argentina). The ability to speciate the arsenic into As(III) and As(V) is proving very valuable and earlier R&D is paying back dividends. Other important work involves analyses of polluted groundwaters from an ICI site (Project Pathway) and from other contaminated sites (EC FAMEST).

#### **Hydrochemical Research**

- Completion of paper on chemical residence time indicators in the East Midlands Triassic aquifer and one on thallium hydrogeochemistry.
- *Hydrogeochemistry of large sedimentary basins*. Investigation of Valley of Mexico aquifer, Great Artesian Basin Australia, Lake Chad Nigeria and Grand Erg Orientale Basin in Tunisia and Algeria.
- *Unsaturated zone studies*, including the investigation of the unsaturated zone as a climatic/environmental archive. Continuing interpretation of data from Senegal, Nigeria and Tunisia as well as Jordan and Mexico.
- Presentation and publication of research on INTAS supported project on geothermal waters in Kamchatka at the International meeting on Water-Rock Interaction in Taupo, New Zealand, March 1998.
- Research has continued on the use of stable (C, O, H) and radiogenic (Sr, Pb) isotopes in surface and groundwaters as indicators of flowpaths and weathering rates.

#### **Induced Polarisation Tomography**

- A prototype 4 channel IPT instrument has been designed, constructed and bench tested by our partners ABEM Instrument (Sweden).

- Software has been developed for 2.5D and 3D numerical modelling and image reconstruction using the finite element method. A full Gauss-Newton and Quasi-Newton solution has been implemented using smoothness constraints to remove the inherent instability of the IP/resistivity inverse problem.

#### ***Predicting the Potential for Natural Attenuation in Polluted Groundwater***

- All existing boreholes have been sampled and fully analysed.
- Laboratory microcosm experiments designed to follow degradation of the major pollutants under simulated *in situ* conditions have been completed.
- A detailed microbiological characterisation of the groundwater and sediments is being carried out at Windermere.

#### ***Geosphere Waste Containment***

- A review of fluid flow through mudrocks with particular reference to its significance to the oil industry has been produced.
- A successful series of gas injection tests was carried out in an instrumented borehole array in the Mercia Mudstone on the Keyworth site.
- An enhanced version of the BGS computer model BGSE, which predicts bacterial growths in subsurface geological environments has been written.
- The triaxial diffusion cell was loaded with a fractured rock core from the Borrowdale Volcanic Group for a tracer test using tritiated water.
- A 10 litre pressure vessel with an operating range up to 200°C and 500 bars pressure was constructed and tested to 515 bars.

#### ***UK Groundwater Forum***

- The Forum Internet site with the national database of current groundwater research has been maintained and an associated database of research contacts is nearing completion.
- A public meeting on "Risk assessment and management" was held jointly with the Geological Society. This attracted a capacity audience and provoked lively discussion. A second public meeting on "Uplands Groundwater" was held in Edinburgh.
- The book "Groundwater – our hidden asset" has been published in order to increase awareness of groundwater among the general public.
- A report prepared by an expert group of UK Groundwater Forum members on a UK perspective of the definition of good groundwater status in the draft EC Water Framework Directive has been prepared for the DETR.

#### ***ASR Development in England and Wales***

- Thirty copies of the draft final report were distributed to EA and Water company representatives prior to the dissemination seminar held on 29 January 1998.

#### ***EPSRC/NERC Landfill Gas Migration***

- Mechanisms of gas entry into natural and worked clays have been assessed.

- A resistivity apparatus to image real time propagation of dynamic gas fractures continues to be developed.
- A draft report (Preliminary review of gas migration in clay liners) covering the hydraulic properties of clays has been prepared.

### **NATIONAL GEOSCIENCES INFORMATION SERVICE**

#### **F1 — Information Services**

##### ***Collections Administration***

- All notifications and routine new accessions were acknowledged and databased within two working days of receipt.
- Borehole registration has been made a priority project with the target of eliminating the registration backlog over a 5 year period. This is the second year of the project for which the target is a 25% reduction in the backlog by 1 April 1998. On 1 April 1997 there was a backlog of 203,212 records. During this year 39,387 new records were received and a total of 117,949 records were registered. This corresponds to a 39% reduction in the backlog well in excess of the target. The average rate of borehole registration was 16,500 records per person year and borehole data entry was 78,700 records per person year, exceeding the targets of 15,000 and 60,000 respectively.

##### ***General Enquiries***

- The enquiry service has operated to performance targets.
- This year the total value of chargeable enquiries was £202k, a 19% increase over the figure of £170k for the previous year. This income represents a cost recovery of 55% of the FEC of the staff cost involved in answering the enquiries, which equals the target set for the year. This does not include the staff on the Keyworth and London general enquiries desks who only answer non-chargeable enquiries.

##### ***Customer Services***

- The mail order publications sales service has fully operated to performance targets.

##### ***Database Management***

- The BGS Rock Classification Scheme is now essentially complete, comprising four sections covering igneous, metamorphic, sedimentary and artificial deposits plus natural superficial rocks. Details of the igneous scheme are available for download from the World Wide Web.
- The Symbol and Ornament database is also accessible via the World Wide Web, and the contained information can be downloaded by potential users.
- Input of new data and revision of existing data in the BGS Lexicon, which can also be browsed via the World Wide Web, has continued. A number of new codes and definitions have also been added, and the Lexicon's content of codes and information verified as current has increased by more than 20%.

#### **F2 — Information Systems**

- *Lexicon delivery system* - System available on WWW.
- *Rock classification scheme database* – Designed and tested. Igneous Rock scheme entered; other 3 schemes prepared for entry but await validation by MEGS staff.
- *DIGMAPGB interface* – User requirement and index model finished.
- *Unified downhole database system* – Requirement defined and documented. System will be implemented as part of BGS-geoIDS.
- *Update data architecture* – Report prepared to guide BGS-geoIDS.
- *Re-design and implement World Wide Web pages* – Standards and procedures established. (Review and maintenance tasks required more resources than allocated.)
- *First stage investigation into text database system* – Work continues on the digital report generating system (DRGS) in 1998/99.
- *Review of Geoscience Data Index* – System reviewed and requirements documented. Future system development will be incorporated in BGS-geoIDS project.
- *Sections database* – New version of database produced and new GIS interface developed.
- *Field Notebook database* – Modifications required by Land Survey implemented and system delivered.
- *GELXS (50/50 EC co-funded project under ESPRIT)* – Contract signed late (29 April 1997). Project has successfully passed 2 scheduled reviews by EC. Project management requires significantly more effort than allocated.
- *Review of PC-based GIS used in BGS* – Report produced.
- *Database management* – Significant work done preparing for shut-down of Murchison House Vax.
- *Help and applications support* – Users supported within limits of allocated resources. Demand for service continues to increase in volume and sophistication.
- *BGS-geoIDS* – Project initiation completed; costed proposals and detailed plans documented and submitted.
- *BGS Intranet* – Scoping report and costed proposal prepared.
- *Management of BGS information systems* – Major achievement is effectiveness of Computer Management Group and agreement on Corporate Software Policy.

#### **F3 — Publication Services**

##### ***Published Maps***

- Seven 1:1M geophysics maps were targetted. None completed. Three are at proof stage. No priority given by authors so work held-up.
- Two 1:1.5M geophysical image maps were targetted and completed.
- The 1:1M Gold occurrence map was not completed. Initial proof completed and sent out for external review in June. Still not returned.
- One revised 1:250k map was completed. Shetland SBS final Versatec approved. Print preparation under way.
- The development of a prototype 1:250k lithostrat map to accompany regional guides was

partially completed. Design studies conducted. Will proceed in 1998/99 with release of new 250k litho-strat dataset early in the year.

- Sixteen new 1:50k maps (Advance copy Versatec release) were completed and 24 new printed maps were published where only plotted maps were previously available.
- A study was undertaken to redesign the map layout and marginalia to position 1:25k maps in the educational market. Design ideas were proposed and the educational sector was consulted. Results are inconclusive. A further idea of a more extensive teaching 'map book' has been proposed to CHUGD and dialogue is continuing.
- A new on-demand 1:10k plotted map delivery procedure was planned to be developed from the new integrated map production system (DMPS97). It was partially completed. A review of DMPS97 has been undertaken after nearly one year of trial operation. Porting of DMPS97 1:10k data into DMPS92 map production system has been tested and proved.
- 498 1:10 000 maps were digitised.

#### **Published Books**

- 11 memoirs were published. There were considerable problems with the privatised Stationery Office at the beginning of the year, but their performance improved markedly towards the end of the year.
- *Clay with Flints* and *Midas* special reports were published. *Cheshire Basin* in preparation. The co-funded *Major Aquifers* was completed but is

awaiting the accompanying data CDs before it can be released.

- The Annual Report was published. World Mineral Statistics, UK Mineral Year Book and Directory of Mines and Quarries books have been delayed until April 1998.

#### **F4 — Public understanding of science**

##### **Popular Publications**

- Nine new popular publications were completed. Six cards (three Holiday Geology Guides, two Holiday Geology Maps, one Discovering Geology: Fossil Focus); three books (*Fossils – the story of life*, *Earthquakes – our trembling planet* and *Groundwater – our hidden asset*. The latter was co-funded with the Groundwater Forum).

#### **F5 — Divisional Databases**

##### **DigMapGB**

- Trials to produce 1:250k drift data from 1:625k digital data were completed. The trial was conducted on Liverpool Bay area with drift data from 1:625k map and 100k hydrogeological maps. Results not satisfactory because of inconsistent drift aggregations on different maps.
- Version 1.1 of 1:250k digital lithostratigraphical map of GB was completed. Work was then extended to convert all lithostratigraphical codes to entries in the modern BGS Lexicon.
- The plan to restructure and attribute all existing 1:50k digital maps to comply with structure

(DMPS97) for DigMapGB was postponed until full evaluation of DMPS97 at end 97/98. Effort diverted to more work on 1:250k data (above) and digitisation of 1:50k analogue legacy maps (below).

- Twenty one 1:50k analogue legacy maps were digitised. 10 sheets in SE England (Sussex) and 11 in the Midlands (co-funded by DETR). Eight other sheets were partially completed.

#### **ADDITIONAL CORE ACTIVITIES**

##### **Remote Sensing**

- *Operational photogrammetric interpretation for mapping programme* - Work for Land Survey has now clearly established benefits of approach, but efficient system will require new hardware and software and distributed seats. Effort therefore concentrated on identifying replacement for ImageStation; summary report has been prepared and initial bid for funding submitted.
- *Hyperspectral remote sensing* - Thematic Programme proposal submitted to NERC Earth Observation Expert Group.
- *Digitising on perspectives* - Software development work done and user guide prepared.
- *PIMA* - Use extended to new geological situations.
- *New satellites and sensors* - Summary report produced.
- *Remote sensing and image analysis manual* - Revised edition produced.

# Appendix 10 The BGS Board

## Remit

As required in the Management Statement and Financial Memorandum agreed between the NERC and the BGS, the NERC has established the BGS Board to support the management and strategic direction of the Survey, taking into account the recommendations of Director, BGS. The Board was inaugurated in January 1998 as the successor body to the Programme Board after it was dissolved in December 1997. Whereas the Programme Board's remit was to determine the overall objectives and to set the priorities for the BGS Core Programme, the BGS Board has a much wider remit encompassing all the activities of the BGS. The Board will meet six times during 1998.

## Terms of Reference

The BGS Board will: advise and support the Director in the management and the furtherance of the Survey's mission, aims and objectives; specify the priorities, time-scales and detailed outputs of the core strategic programme in order to meet the overall objectives specified by Council; approve the annual business and operational plans for the Survey and submit these to Council's Chief Executive; review and monitor the quality and relevance of all aspects of the Survey's work; report, according to standards of review and at a frequency set by Council, to Council's Science and Technology Boards on the progress against milestones, achievements and quality of all the Survey's core strategic programmes funded by Council and make recommendations, as necessary, concerning the future of those programmes; monitor the Survey's management and administration and assist the Director in matters concerning efficiency, effectiveness and economy in the use of resources (funds and tangible and intangible assets); ensure an appropriate balance and synergy between the

core strategic, core partnership and commissioned research programmes; and report annually to Council.

## Membership

Board members are appointed by the NERC Chief Executive from nominations made by the Director and others, and approved by Council. Membership comprises: a non-executive, part-time Chairman; the Director, **Dr D A Falvey**; Council's Chief Executive or his nominee, currently the NERC Finance and Information Systems Director **Mr C M Read**; and between six and ten non-executive members. The latter are appointed by reason of their qualifications and experience and represent a broad cross-section of the BGS user community. They include senior representatives of industry, government agencies and academia as listed below. Members may be appointed for up to four years in the first instance and may be reappointed for up to a further four years. **Dr B R Marker** of the Department of the Environment, Transport and the Regions sits on the Board as an Observer. The Secretariat is provided by **Mr D Hackett** and **Dr S H Marsh** of the BGS.

## Board Chairman

**Dr E R Hassall** has been appointed Chairman of the BGS Board until 31st December 1999. He is also Deputy Chairman of the Coal Authority, a member of the Natural Environment Research Council and Keele University Court and Council. He was formerly the Chairman of Wardell Armstrong and the Crown Mineral Agent. He previously worked in the Production and Mining Departments of the National Coal Board. The Chairman of the BGS Board will report to Council through its Chief Executive and take particular responsibility for: developing, with the Board, the long-term vision for the Survey; providing leadership on strategic matters which are the col-

lective responsibility of Board members; supporting the Director in representing the views of the Survey to the public; ensuring that the Board observes high standards of corporate governance; and ensuring that the Board meets regularly throughout the year.

## Board Members

**Prof D J Blundell** is Professor of Environmental Geology at Royal Holloway, University of London. He has mainly researched in seismology and marine geophysics. He was a co-founder of the British Institutions Reflection Profiling Syndicate and took a leading role in the European Geotraverse supported by the European Science Foundation. He is a past President of the Geological Society.

**Dr J V Bramley** is a minerals consultant. He is the President of the Mining Association of the United Kingdom, a past President of the Institution of Mining and Metallurgy, and serves on the Council of the Mineral Industries Research Organisation. He was formerly the General Manager of Laporte Minerals in Derbyshire.

**Prof A L Harris** is Dean of the Science Faculty at Liverpool University, and former Head of its Earth Sciences Department. For twelve years a member of staff at the BGS, he joined Liverpool University in 1971. He is a member of RWMAC, a past President of the Geological Societies of London and Liverpool, and has served on NERC Committees dealing with studentships and grants.

**Dr J P B Lovell OBE** is a Senior Research Fellow in Earth Sciences at Cambridge University. Previously, he spent fifteen years with BP Exploration, joining as Chief Sedimentologist in 1981 and subsequently working mainly in international exploration. He remains a consultant to BP. In the 1970s he was a lecturer and consultant at Edinburgh University.

**Dr C J Morrissey** recently retired as Group Chief Geologist, Western Hemisphere, for Rio Tinto. He was previously Managing Director of RTZ Mining and Exploration in Europe and held several other senior positions in RTZ. Before this he was a Research Fellow at Imperial College London and Lecturer in Economic Geology at the Royal School of Mines.

**Mr J Mortimer** is Technical and External Affairs Director at ARC, for whom he has held a number of other positions in production management. He is Chairman of the CBI Minerals Committee, the Quarry Products Association Public Affairs Committee, and Minerals '98.

**Dr A C Skinner** is Environmental Protection Manager for the Midlands Region of the Environment Agency. He is the Secretary General of the International Association of Hydrogeologists and was formerly the Regional Technical Manager for the National Rivers Authority.

**Prof G Walton** is the Senior Partner at the Geoffrey Walton Practice and Visiting Professor of Mining at Leeds University. He was formerly the Headquarters Geotechnical Engineer for the National Coal Board's Opencast Executive, and was also seconded to the Rock Mechanics Research Group at the Royal School of Mines.



*The first BGS Board meeting, 20th January 1998. Back row: Mr D Hackett, Dr S H Marsh, Dr C J Morrissey, Dr A C Skinner, Dr J P B Lovell and Dr B R Marker. Front row: Prof G Walton, Mr C M Read, Dr E R Hassall, Dr D A Falvey, Dr J V Bramley and Prof D J Blundell. Insets: Mr J Mortimer (left) and Prof A L Harris (right).*

# Directors of the British Geological Survey

Sir Henry Thomas De la Beche  
1835–1855

Sir Roderick Impey Murchison  
1855–1871

Sir Andrew Crombie Ramsay  
1871–1881

Sir Archibald Geikie  
1882–1901

Sir Jethro Justinian Harris Teall  
1901–1914

Sir Aubrey Strahan  
1914–1920

Sir John Smith Flett  
1920–1935

Dr Bernard Smith  
1935–1936

Sir Edward Battersby Bailey  
1937–1945

Dr William Francis Porter McLintock  
1945–1950

Sir William John Pugh  
1950–1960

Sir Cyril James Stubblefield  
1960–1966

Sir Kingsley Charles Dunham  
1967–1976

Dr Austin William Woodland  
1976–1979

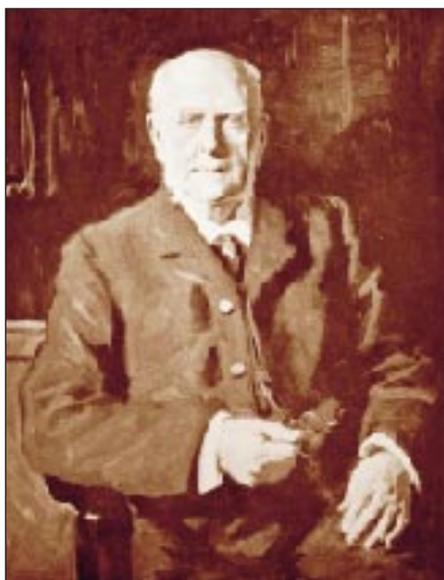
Sir George Malcolm Brown  
1979–1985

Mr George Innes Lumsden  
1985–1987

Mr Ferdinand Geoffrey Larminie  
1987–1990

Dr Peter John Cook  
1990–1998

Dr David Alan Falvey 1998–



Sir Archibald Geikie, Director of the Survey from 1882 to 1901.

Sir Archibald Geikie was the third of a trio of great Scottish directors. Born in Edinburgh in 1835 he became fascinated by the structure and history of the local crags and was soon befriended by the likes of Hugh Miller and James Forbes. After meeting Andrew Ramsay, he abandoned a banking career to study at Edinburgh University before joining the Geological Survey in 1855. For the next twelve years he learned his trade and earned geological fame in his mapping of the Lothians and Fife, particularly the ancient volcanic rocks and the Old Red Sandstone, in which he was able to recognise a long series of eruptions through Devonian and Carboniferous times. He was also a pioneer in the fields of glaciology and geomorphology.

Geikie was appointed director of the newly constituted Scottish branch of the Geological Survey in 1867, and in 1871 he combined these

duties with the chair of geology at Edinburgh University. In 1882 he moved to London as Director of the Geological Survey of Great Britain and spent the next 19 years directing the great national mapping programme including the exploration of the northwest Highlands of Scotland. Knighted in 1891, he remained active after retirement becoming, in 1908, the only geologist to be appointed President of the Royal Society.

Geikie was a prodigious writer. His works ranged from small geological treatises to great masterpieces such as *The Ancient Volcanoes of Great Britain*. He wrote biographies, belles-lettres and many early textbooks for his students; in *Scottish Reminiscences* he allowed free rein to his natural wit and humour. According to E B Bailey, his achievement of most permanent value was perhaps his successful demonstration that many of the profound lessons of geology can be accurately and effectively conveyed in simple, non-technical language.

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