



BRITISH GEOLOGICAL SURVEY  
International Division

# A decade of ODA/BGS international research and development 1981–1990



**BRITISH GEOLOGICAL SURVEY**  
Natural Environment Research Council

**TECHNICAL REPORT WC/91/15**

**A DECADE OF ODA/BGS INTERNATIONAL  
RESEARCH AND DEVELOPMENT**

**S J MATHERS (Compiler)**

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**Cover Illustration**

The cover depicts a satellite image of part of the Eastern Desert of Egypt adjacent to the Red Sea (top right). The processed image provides detailed geological information on the distribution of rock-types and structure. This enables cost-effective planning of follow-up ground exploration.

**Bibliographic reference**

British Geological Survey. 1991.  
A decade of ODA/BGS  
international research and  
development. British Geological  
Survey Technical Report WC/91/15



## ODA/BGS INTERNATIONAL RESEARCH AND DEVELOPMENT

This report summarizes all Overseas Development Administration (ODA)-funded international Research and Development (R & D) projects completed by British Geological Survey (BGS) before the end of the financial year 1990/91. The programme, funded by the Engineering Division of ODA, commenced in 1981 and during the following 3-4 years progressively replaced the "Subvention" programme, which had provided funding for short-term scientific and administrative support for Technical Cooperation (TC) projects.

The funding allocated by the ODA to this R & D programme since 1984 together with the levels of staffing deployed by BGS are shown below.

Financial Year	Budget £K	Man Years	Man Yrs vs, 84/85 base
84/85	1,097	28.0	100%
85/86	1,478	32.0	115%
86/87	1,375	30.7	110%
87/88	1,213	24.3	87%
88/89	1,255	23.0	82%
89/90	1,255	19.2	69%
90/91	1,400	21.3	76%

These figures indicate that over an eight year period the overall staffing level of the programme has been eroded by about a quarter, broadly reflecting a progressive shortfall in the funding as compared to increased staff costs. Annually about 15 - 20 % of the funding is earmarked for geological advisors as required by ODA and for international representation on various intergovernmental committees.

The R & D programme of projects and their budgets as reviewed annually by the ODA and project progress is monitored by the ODA at six monthly intervals. Financial statements are produced internally by BGS on a monthly basis.

The programme of topics studied has varied widely over the years and broadly reflects the changing priorities embodied in UK aid policy. For example in recent years there has been an increasing emphasis on environmental issues. Similarly the geographic emphasis changes from time to time.

In this review 42 completed R & D projects are covered accounting for total actual funding of about £6.5 million. A further 22 projects are currently in progress but are not included in this report. Where individual projects, which normally run for up to three years, have been extended or led directly to a continued line of investigation they have been treated here as a single entity. The average total cost of individual projects has been about £150,000 and, considering the levels of annual funding (£1.55 million at present), the programme has been impressively wide-ranging, both scientifically and geographically.

Since 1980 over 100 BGS scientists have contributed their expertise to the programme, collaborating with about 50 organizations in 45 Less Developed Countries (LDC's). The geographic distribution of projects is shown in Figure 1. The main emphasis has been in Africa, South-east Asia and the Andean Countries of Latin America. The individual countries are listed in an index at the back of this report, together with the numbers of the projects with which they were concerned.

The 42 completed projects are most easily grouped by scientific discipline and have included studies of mineral resources, hydrogeology, energy resources, geotechnical studies and natural hazards, geochemical exploration techniques, geophysics, remote sensing and computer applications. About half the projects have involved a strong "development of techniques" component.

The overall financial resources committed to R & D in these areas since 1981 are as follows:-

Scientific Discipline	No of Projects	Funding £ K	% of whole
Mineral Resources	8	1,996	30.6%
Hydrogeology	12	2,254	34.5%
Energy Resources	6	320	4.9%
Geotechnical / Natural Hazards	2	622	9.5%
Geochemical Studies	7	541	8.3%
Geophysical Studies	3	144	2.2%
Remote Sensing / Computing	4	655	10.0%
	42	6,532	100.0%

In 1987 the ODA held a "triennial" review of the ODA/BGS R & D programme which examined many of the projects summarized here. Their report highlighted the fact that "BGS had achieved a valuable worldwide reputation for sound professionalism and dispassionate advice" and that it contained "a highly professional team devoted to geological science and the developing world". The vast majority of the projects reviewed were found to be worthwhile and justified use of R & D funds; many should be replicable in other regions. In particular the report drew attention to the need for ODA to give BGS clearer overall guidance on their aid policy, and the need for the R & D programme to contain an increased element of poverty-related work, which most probably would be of a hydrogeological nature. The subsequent programme has benefitted from the implementation of these recommendations.

## REVIEW OF THE COMPLETED PROJECTS

The projects are reviewed under the disciplines outlined above.

### Mineral Resources

This group comprises eight projects; five relate to surveys aimed at providing an infrastructure of knowledge to guide exploration for metallic mineral deposits and three related with non-metallics/minerals.

The largest metallic minerals project undertaken involved a multidisciplinary study of **South East Asia Granites** and their associated tin mineralization over a vast region covering parts of Burma, Thailand, Malaysia and Indonesia. The study successfully subdivided large granite masses previously

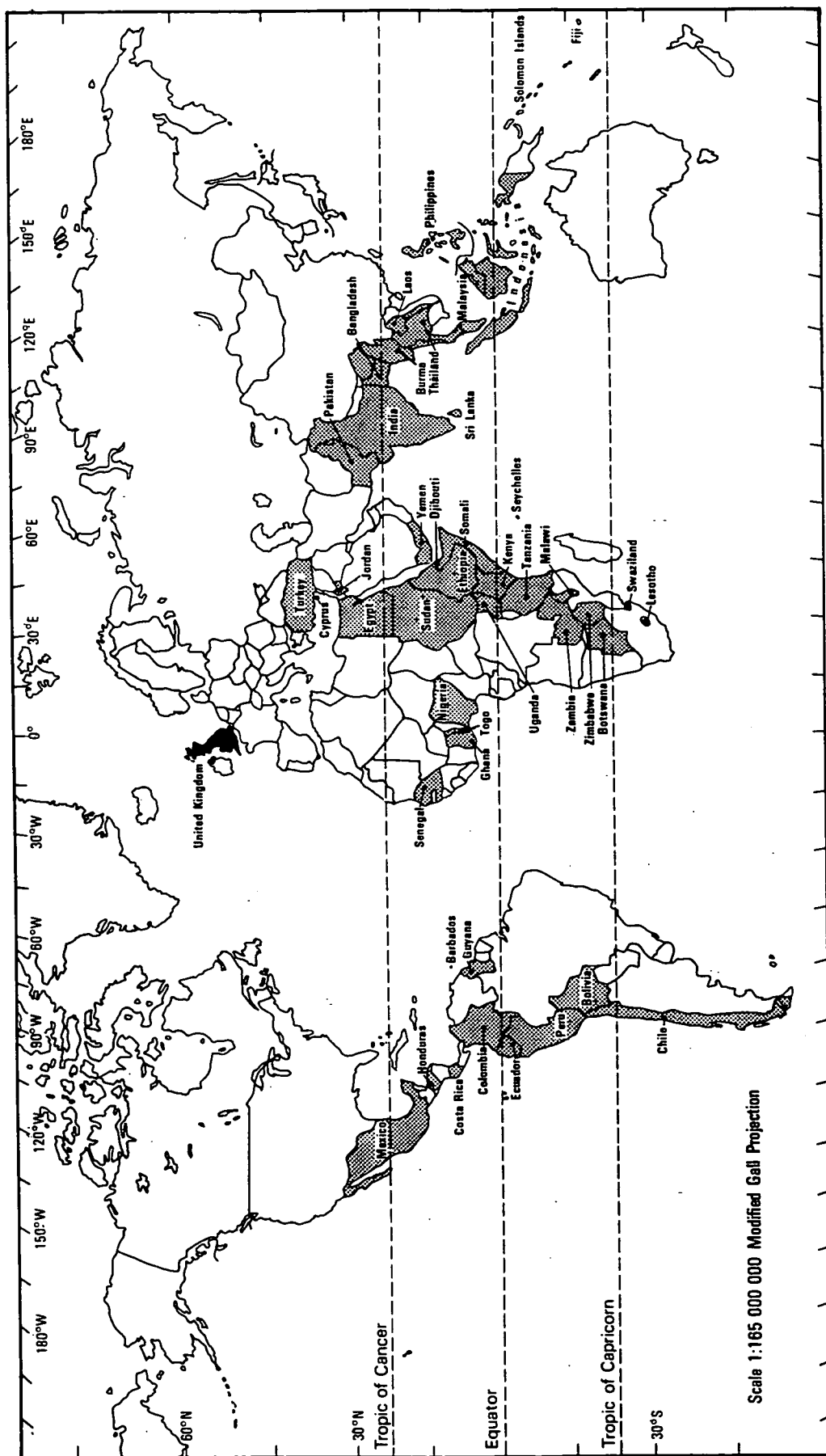


Figure 1. Distribution of less developed countries that have benefitted from the ODA/BGS R&D programme 1981-1990.

regarded as homogenous and established criteria for identifying those most likely to host tin mineralization. Having fully met its scientific objectives the results were widely disseminated at international conferences, in prestigious scientific and mining journals and through workshops. An Overseas Memoir of the British Geological Survey drawing together all the results of the study is currently in press. Application of the results has to date been somewhat delayed due mainly to the unforeseen withdrawal of support for the price of tin on the world market in the mid 1980's. Tin exploration has since been very limited due to overcapacity in the market.

Economically speaking the three studies of goldfields have been very timely. The 1980's saw considerable exploration effort for gold which is traditionally regarded by major multinational mining companies as a "safe bet" in times when many other metal prices have been unstable and depressed for several years.

The very practical approach adopted by the staff engaged on the **Archaean Goldfields of Africa** project focused on developing mineral processing techniques and disseminating skills to small-scale mining concerns in Zimbabwe and Ghana. The considerable interest in the project has resulted in an on-going TC project in Zimbabwe and further development of the techniques in other R & D projects.

The **Paragenesis of gold in Late Cenozoic sediments** study led to an important and novel reinterpretation of the geology and origin of the placer gold in southwest Costa Rica and has widespread implications for gold exploration in many other parts of the world. Considerable amounts of advice have been given to mining parastatals and private companies in Costa Rica where a strong resurgence of gold mining was evident towards the end of the 1980's stimulated in part by this study.

The **Precious and Base Metal Mineralization in Indonesia and Malaysia** study highlighted considerable gold mining potential in Sumatra, disappointingly, however, logistical problems curtailed planned work in Kalimantan and Sarawak.

Geological understanding of the origin and distribution of metallic mineralization in South America took a major step forward with the **Andean Geochronology, Petrogenesis and Metallogenesis** study. This project used isotopic abundances and fluid inclusions to define the age and source of mineral deposits on a regional scale. It also conducted a more detailed appraisal of a silver vein deposit in Peru and a gold prospect in Chile which have helped to guide their exploration strategies.

In the field of non-metallic (industrial) minerals the sustained success of the **Mineral Resource Development in the Third World** project owes much to its widespread applicability and sound philosophy. Despite a modest annual staff allocation, the studies of this and its two successor projects (here included as one project) have covered a dozen mineral commodities and benefitted some 16 LDC's, all within a seven year lifespan! A vast quantity of applications-related data and exploration advice has been provided to foreign governments on the basis of thorough UK-based laboratory testing. The success of this programme is reflected in the current funding by ODA of an on-going "daughter" R & D project.

The **African Carbonatites** are a rich source of industrial minerals. They represent the roots of ancient volcanoes and are characterized by their unusual chemistry. They were identified for study due to their potential as sources of phosphate rock and strategic rare earth elements. Detailed assessments of two carbonatite complexes from Malawi and Zambia have led to on-going field trials of ground carbonatite from Malawi as a fertilizer in the current ODA/BGS Agrogeology R and D project.



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A general study of **Dambo Stratigraphy** was also carried out. Dambos are swampy stream valleys common in the plateau of Central and East Africa. Previously neglected by geologists this study revealed their potential as sources of both groundwater and industrial minerals.

### **Hydrogeology**

The 12 Hydrogeological projects completed to date account for about a third of the funding for the ODA/BGS R & D programme and comprise four projects which principally examined water resources, four which developed new techniques, three which assessed groundwater quality and its pollution and a further project dedicated to providing hydrogeological training workshops.

Groundwater resources were examined by the **Basement Aquifer Project** which involved a major integrated study and is the largest ODA/BGS R & D programme mounted to date. 'Basement' comprises geologically stable areas of old, predominantly crystalline, rock which underlies large parts of many developing countries especially in Africa. The basement rocks, although of low permeability, frequently offer the only economic source of water in such areas. This study thoroughly investigated parts of Malawi, Zimbabwe and Sri Lanka and concluded that the basal part of the surficial weathered rock offers the best prospect for water abstraction and that the groundwater was adequately recharged by rainfall. Techniques for improving water recovery from such basement terrain were the principal focus of two separate R & D projects on **Hydraulic Fracturing** and **Collector Wells**.

To ensure maximum publicity and dissemination, the prodigious scientific output from both this study and from related technique development was presented to a large international audience at a prestigious two-day meeting at the Geological Society of London.

A further assessment of regional water potential was carried out in North Africa by the **Arid Zone Recharge Study** prompted by the Sahel droughts of the last two decades. The water resources of this area are finely balanced and the study indicated that replenishable sources are likely to be confined to a narrow corridor along the Nile valley and locally in wadi systems.

In the same area a study was involved with **Estimating availability of recharge for long-term support of forestry shelterbelts to protect against desert encroachment along the Nile**. It was concluded that adequate resources existed along the Nile to sustain shelterbelts but that water levels should be closely monitored during abstraction.

The **Hydrogeology of Qanats** project attempted for the first time to model the 'Qanats', or tunnels, that are driven into hillsides to intercept the watertable thus providing a perennial artificial spring. Such systems have been in use for at least 25,000 years and still represent the main water supply for vast parts of the Arab world and Continental Asia. The study identified that such systems commonly lose up to a quarter of their potential water through poor maintenance and seepage at their base. Discussions have been held with UK industry with a view to manufacturing lightweight layflat piping which could be used to minimise such losses.

Hydrogeological techniques investigated included the **Assessment of Hydraulic Fracturing in the basement aquifers of Zimbabwe** study which considerably improved the yield of several wells in Zimbabwe by inducing fractures in the bedrock under very high hydraulic pressure. This technique provides considerable cost-savings when compared to the current practice of drilling duplicate boreholes to obtain a similar quantity of additional water supply.

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The **Collector Well Project** successfully developed and operated a system for drilling horizontal radiating adits from the base of existing wide-diameter well shafts. Such modification was shown to improve yields up to threefold, with similar cost-saving characteristics to the Hydrofracking approach. Complete collector well systems and modifications to existing wells have been satisfactorily installed in Zimbabwe, Malawi and Sri Lanka. Subsequently an ODA/BGS TC project to convert 50 existing wells in Sri Lanka into collector wells resulted. This technique should be more widely adopted by international aid funding agencies in water supply projects.

A further study succeeded in **Developing a hollow auger drilling technique suitable for rapid, easy installation of handpumps in alluvial aquifers**. Such systems can be rapidly installed in a few hours and would be effective, for example, in provision of emergency water supplies for refugee camps situated in river valleys. ODA might wish to consider commissioning such a system which could be maintained on "stand by basis" for airlifting to help with such emergencies.

A small R & D project on **Well Design**, involving mathematical modelling and evaluation of well screens, was incorporated, after one year, into an ODA consultancy for the Deep Tubewells project conducted by BGS in Bangladesh.

The **Impact of tropical/sub-tropical agriculture on groundwater quality** has conducted research and given advice on pollution, water supplies and management in Mexico, Sri Lanka, India and Barbados. The **Appraisal and removal of iron problems in rural groundwater** has highlighted another groundwater quality problem and the production of a descriptive leaflet which has been circulated worldwide has generated expressions of interest in further research into the problem from several countries, though no further collaborative work has commenced to date. A study of **Saline Intrusion in Coastal Aquifers** has developed and tested mathematical models which will be of use in future programmes dealing with this widespread problem.

**Hydrogeological Workshops** have been held in Fiji, Honduras, Mexico and Zimbabwe, introducing over 250 delegates from 69 countries to various aspects of hydrogeology. A comprehensive course manual has been generated and is available in both English and Spanish.

### **Energy Resources**

Six energy resource projects have been completed, including four on geothermal energy systems which may, in geologically favourable areas, offer an environmentally-friendly and cheap source of energy.

The **Geothermal Research** project developed methods of investigating thermal anomalies using modelling techniques with the aim of defining more cost-effective programmes of geothermal exploration. Subsequent work led to a study of **Hydrothermal alteration in geothermal assessment** concentrating on the Miravalles field in Costa Rica, this further refined the mathematical models being applied and should optimise further development of this geothermal field within which construction of the power generating facilities has commenced.

The assessment of **Soil-Gas geochemistry** methods applied to geothermal exploration proved so successful in delineating geothermal zones that the technique was incorporated as a routine part of the ongoing ODA/BGS technical cooperation project exploring geothermal systems in Kenya. Additional studies in Costa Rica at the Miravalles Geothermal Field helped identify hazardous zones and recommendations were made for the safe location of buildings. The early termination of this project after one year aptly demonstrates responsible management of the R & D budget in immediately transferring successful results to projects funded from other sources rather than continuing research

for research's sake.

**The Evaluation of Gas Geothermometry** for geothermal exploration project has finished recently and has for the first time identified a gas geothermometer applicable to the East African Rift System. This is now being applied in the ODA/BGS TC programme in Kenya to identify new geothermal fields in this area.

**The Smaller Coal Basins in Africa** project produced a detailed review of all existing information on small coal basins in Malawi, Zambia, Zimbabwe and Botswana augmented by field studies in northern Malawi. Although present economics mitigate against large-scale exploitation of these areas, the governments of Malawi and Zambia have expressed their desire for further aid-backed evaluation including drilling and geophysical studies to quantify extractable reserves.

An investigation into the feasibility of using aquifers for seasonal storage of heat and/or chill in developing countries was thwarted, and the project suspended, when plans for field studies around Amman, Jordan had to be abandoned due to the recent "Gulf Crisis". The topic remains a valid research area for future consideration.

#### **Geotechnical Studies and Natural Hazards**

This group of projects includes two important studies which have brought considerable advances in our prediction and analysis of natural hazards. Studies such as these are expected to become increasingly required in the 1990's especially since the United Nations has designated it as the decade for improving our understanding and prediction of natural hazards.

**The Engineering Geology of cohesive soils associated with ophiolites** project studied landslips in Cyprus triggered by earthquakes and/or heavy rainfall and predominantly developed in clays characterized by their ability to shrink and expand (bentonites). Recommendations for planning future construction have been made which will help to avoid disasters like the £17.5 million damage caused in Cyprus in 1953 by landslips triggered by the Paphos earthquake. Widespread dissemination of this scientific work resulted in BGS being invited to contribute to an EC-EPOCH project on rainfall-induced landslides in the mountainous regions of Europe. The R & D project was singled out for praise by the ODA triennial review in 1987 as "a very good project by any standards" and it is unfortunate that the high cost of many geotechnical studies mean that this valuable field of geology has, to-date, been somewhat under-represented in the programme.

**The Earthquake Prediction Research** project utilized data gathered by an ODA/BGS installed seismograph network in the Marmara Sea, Turkey, to investigate the potential of measuring stress-induced cracks as a method of predicting earthquakes. It was quickly established that monitoring such cracks can warn of impending earthquakes; this represents a major breakthrough in the understanding of the physics of earthquakes and might be utilized routinely in future earthquake prediction. Again, the triennial review commented very favourably on this project.

#### **Geochemical Studies**

The closely related **Development of geochemical field methods** and subsequent **Development of a standard field kits for geochemical reconnaissance and publication of techniques handbooks** projects have been successful in providing on-going technical cooperation projects with rapid, cheap, field-based tests to save time and money in their exploration programmes. These TC projects have subsequently tested the methods and feedback has resulted in further refinement of techniques. This aptly illustrates the mutually beneficial relationships that should be developed between the ODA

R & D and TC programmes.

The **Regional Geochemical Studies: Precambrian Terrain** project enables the synthesis and publication of geochemical data gathered as part of the TC project "Proyecto Precambrico". This TC project is the largest completed ODA/BGS endeavour; over a nine-year lifespan it involved the geological surveying of the vast region of eastern Bolivia and identified considerable mineral potential. The resulting folio-size geochemical atlas has been widely consulted by the mining industry.

**Integration of geochemical data from ODA/BGS TC projects into a World Geochemical Map Series** successfully completed its objective of contributing information covering parts of Kenya, the Solomon Islands and Indonesia in formats developed so as to be suitable for integration into a worldwide series of geochemical maps.

In the field of geochemical exploration for metallic mineral deposits the **Gas and Vegetation Geochemistry in the search for buried ore bodies** and the **Application of Rock Geochemistry to mineral exploration** both demonstrated their potential when tested over known ore-bodies and now need to be applied in TC projects as exploration tools to fully justify their early promise. Both techniques have the potential to reduce exploration costs.

The final geochemical study reviewed **Seasonal variations in the trace metal content of stream sediments under different climatic regimes** and involved a reexamination of some of the methodology employed in geochemical surveys. Pronounced climate-induced changes in trace metal content were observed in Zimbabwe, where distinct wet-dry seasons occur, upsetting previously held assumptions and practices. Such results have important and obvious implications for future geochemical surveys, recommendations have been circulated to try and avoid the pitfalls highlighted by this study.

### **Geophysical Studies**

Two geophysical projects have involved the digitization and interpretation of data gathered prior to 1980 on ODA/BGS projects. The **Digitization and interpretation of BGS overseas gravity and aeromagnetic data** project processed data covering parts of 20 LDC's, the results were widely disseminated; the data has been in considerable demand by British Industry. The **Digitization and evaluation of selected BGS-held overseas airborne radiometric surveys** exercise included data from surveys covering parts of Swaziland, Ethiopia and Uganda. An interesting potential application of the data would be in monitoring the impact of a future Chernobyl-like disaster that might spread to the African continent. These data has been widely disseminated. The ODA triennial review of 1987 described the data organisation approach adopted by these two studies as "essential".

A third geophysical project the **Magnetic Susceptibility Study** examined the usefulness of pocket-sized magnetic susceptibility meters. These enable direct measurement on outcrops of this useful physical property and thereby assists field geologists in geological map-making and the on-site interpretation of aeromagnetic maps using portable computers. The meters were used successfully in several other ODA/BGS projects helping to identify metallic mineral exploration targets.

### **Remote Sensing and Computing**

The **Application of high resolution satellite data to mineral and geothermal resource evaluation** project has closely examined the potential of images from the Landsat Multi-Spectral Scanner and latterly the Thematic Mapper as a tool for delineating regional geology and identifying targets for



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mineral and energy resource exploration.

This state-of-the-art research has revealed that Landsat images have immense potential in structural geology enabling the identification of complex regional structure which is not always apparent from field studies and photogeology. In areas of limited vegetation cover carefully processed Landsat images, such as the one on the cover of this report, enable the sophisticated geological interpretation of large regions to be made very cost-effective. Such interpretations then require only limited checking on the ground before a reasonably reliable geological map can be published. In this research project Landsat images have, for example, been used successfully in delineating new target areas for mineral and energy exploration in Peru and Kenya.

To disseminate much of the experience gained in the project above a handbook on remote sensing together with course material has been prepared during the one year **Remote Sensing training for geologists in developing countries** topic. This will form the nucleus for future training courses. The handbook is currently in the press.

Microcomputer installation and back-up together with appropriate software development has been provided to about 15 distinct ODA/BGS projects in nine countries by the **Microcomputer applications in Geology** project. Explanatory notes on systems and software packages have been circulated to staff overseas and many systems subsequently donated to LDC's geological departments.

A small project involving **Development of an Analogue Computer for study of well hydraulics** made some progress but component failure and the inherent complexity of the task led to termination as short-term applicability proved doubtful.

## PROJECTS SUMMARIZED IN THIS REPORT

### MINERAL RESOURCES

1. South East Asia Granites
2. Archaean Goldfields of Africa
3. Paragenesis of gold in Late Cenozoic sediments
4. Precious and Base Metal Mineralization in Indonesia and Malaysia
5. Andean Geochronology, Petrogenesis and Metallogenesis (ANDCHRON)
6. Mineral Resource Development in the Third World
7. African Carbonatites
8. Dambo Stratigraphy

### HYDROGEOLOGY

9. The Basement Aquifer Project
10. Arid Zone Recharge Study
11. Estimating availability of recharge for long-term support of forestry shelterbelts to protect against desert encroachment along the Nile
12. Hydrogeology of Qanats
13. Assessment of Hydraulic Fracturing in the basement aquifers of Zimbabwe
14. The Collector Well Project
15. Development of a hollow auger drilling technique suitable for rapid, easy installation of handpumps in alluvial aquifers
16. Well Design
17. Impact of tropical/sub-tropical agriculture on groundwater quality
18. Appraisal and removal of iron problems in rural Groundwater
19. Saline Intrusion in Coastal Aquifers
20. Hydrogeological Workshops

### ENERGY RESOURCES

21. Geothermal Research
22. Hydrothermal alteration in geothermal assessment
23. Soil Gas geochemistry methods applied to geothermal exploration
24. Evaluation of Gas Geothermometry for geothermal exploration
25. Smaller Coal Basins in Africa
26. An investigation into the feasibility of using aquifers for seasonal storage of heat and/or chill in developing countries

### GEOTECHNICAL STUDIES OF NATURAL HAZARDS

27. Engineering Geology of cohesive soils associated with ophiolites
28. Earthquake Prediction Research

### GEOCHEMICAL STUDIES

29. Development of geochemical field methods
30. Development of standard field kits for geochemical reconnaissance and publication of techniques handbooks
31. Regional Geochemical Studies: Precambrian Terrain

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32. Integration of geochemical data from ODA TC projects into a World Geochemical Map Series
  33. Gas and Vegetation Geochemistry in the search for buried ore bodies
  34. Application of Rock Geochemistry to mineral exploration
  35. Seasonal variations in the trace metal content of stream sediments under different climatic regimes

#### **GEOPHYSICAL STUDIES**

36. Digitization and interpretation of BGS overseas gravity and aeromagnetic data
37. Digitization and evaluation of selected BGS held overseas airborne radiometric surveys
38. Magnetic Susceptibility Study

#### **REMOTE SENSING AND COMPUTING**

39. Application of high resolution satellite data to mineral and geothermal resource evaluation
40. Remote Sensing training for geologists in developing countries
41. Microcomputer applications in Geology
42. Development of an Analogue Computer for study of well hydraulics

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**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 1**

**TITLE:** SOUTH EAST ASIA GRANITES

**LOCATIONS:** Burma, Indonesia, Malaysia,  
Thailand

**LENGTH OF PROJECT:** 6 Years

**STARTING DATE:** 1981

**COLLABORATING ORGANISATIONS**

Geological Research and Development Centre of Indonesia  
Geological Survey of Malaysia  
Department of Mineral Resources Thailand

**PROJECT OBJECTIVES**

To establish whether the large previously undifferentiated masses of granite in the mountainous jungle terrain of SE Asia could be resolved into component intrusions.

To make a regional geological survey of the granites in the South-east Asian Tin Belt in order to establish the patterns of tin mineralization, in the hope of finding new resources.

To establish criteria to recognise which granitic masses were most likely to contain mineralization.

**PROJECT RESULTS**

Detailed maps and reports have been published classifying the masses of granite into their constituent intrusions, the patterns of tin mineralization were established and will be used to help make future discoveries.

Unfortunately the withdrawal of support for the price of tin in the mid 1980's coupled with world surpluses has resulted in little exploration for tin being undertaken since, hence the valuable results of this project have not as yet been fully applied.



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Pitfield, P E J, Teoh, L H and Cobbing, E J. 1990. Textural variation and tin mineralization in granites from the Main Range Province to the southeast Asian Tin Belt Geological Journal Vol.25, 419-429.

Cobbing, E J. 1990. A comparison of granites and their tectonic settings from the South American Andes and the southeast Asian tin belt Geological Society of America Special Paper 241.

Cobbing, E J, Mallick, D I J, Pitfield, P E J and Darbyshire, D P F. In Press. The geology of the granites of Peninsula Malaysia, Indonesia, Burma and Thailand. Overseas Memoir, BGS.

Contribution made to 1:2,000,000 Geological map of the granites of southeast Asia. USGS In Preparation.

## WORKSHOPS AND PRESENTATIONS

Workshops at:

1. Kuala Lumpur, Malaysia 1987
2. Trondheim, Norway 1989
3. Geological Survey of Sweden, Uppsala, Sweden 1989

## PROJECT STAFF

Dr E J Cobbing (Project Manager)  
Dr D I J Mallick  
P E J Pitfield  
D P F Darbyshire

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K	61	70	92	96	106	72					497K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 2**

**TITLE:** ARCHAEOAN GOLDFIELDS OF AFRICA

**LOCATIONS:** Ghana, Zimbabwe

**LENGTH OF PROJECT:** 3 Years

**STARTING DATE:** 1986

**COLLABORATING ORGANISATIONS**

Ashanti Goldfields Corporation (Ghana) LTD  
Geological Survey of Ghana  
Geological Survey of Zimbabwe  
Falcon Mines (Pty) LTD Zimbabwe  
Small Scale Miners Association Zimbabwe  
Southampton University

**PROJECT OBJECTIVES**

To provide practical solutions to exploration, processing and geological problems encountered by small-scale, hard-rock gold miners; thereby stimulating production and where possible sustaining operations currently experiencing difficulties.

To mount practical training courses for miners in conjunction with local geological survey staff

**PROJECT RESULTS**

A low-cost integrated exploration system combining several simple techniques has been developed; it allows certain important types of gold mineralization to be delineated without recourse to laboratory facilities. The system also incorporates techniques developed by the ODA/BGS "Geochemical Field Methods R&D Project" (No. 29 this volume).

Further development of this work is incorporated in the ODA/BGS R&D project "Gas & Vegetation Geochemistry" in the search for buried ore deposits (No. 33 this volume) and the on-going UK/Zimbabwe 'Midlands Goldfields' TC project.

A very successful training workshop was given by BGS staff at Shamva, Zimbabwe for local miners in conjunction with the Geological Survey Department of Zimbabwe.

Information and techniques have been disseminated to over twenty important mining and exploration companies and government surveys worldwide.

One of the project officers subsequently took a senior position within Ashanti Goldfields Corporation (Ghana) Ltd thus contributing further to development in that country.

## **OUTPUT (Reports, Papers, & etc)**

Crow, M J 1986. Report on a visit to Ghana and proposals for orientation surveys. BGS Technical Report, MP/86/27R.

Crow, M J & Laffoley, N d'A. 1987. Visit report and an account of orientation surveys for gold exploration conducted in Ghana between 8 March - May 1987, with proposals for future work. BGS Technical Report, MP/87/15R

Crow, M J & Laffoley, N d'A. 1987. Report on a visit to Kenya between 24-26 June 1987, with proposals for integrated gold exploration using residual soils. BGS Technical Report, MP/87/25R

Crow, M J & Laffoley, N d'A. 1987. Report on a visit to Zimbabwe between 26 June - 17 August 1987 with an account of methods and results of orientation surveys for gold exploration, and proposals for future work. BGS Technical Report, MP/87/29R.

Crow, M J & Laffoley, N d'A. 1987. A summary of gold exploration trials conducted in the Chakari mining lease area of Falcon Mines Ltd., Zimbabwe. BGS Technical Report, MP/87/38R.

Crow, M J & Piper, D P. 1988. Report on gold exploration trials carried out at the Ashanti mine, Ghana 1 February - 15 March 1988. BGS Technical Report WC/88/19R.

Crow, M J & Piper, D P. 1988. Gold exploration trials at the Ashanti mine, Ghana. BGS Technical Report, WC/88/23.

Crow, M J & Laffoley, N d'A. 1988. Orientation studies of gold exploration methods at the Ashanti mine, Ghana. BGS Technical Report, WC/88/25.

Laffoley, N d'A & Crow, M J. 1988. Evaluation of an improved loaming techniques for gold exploration. BGS Technical Report WC/88/31.

Laffoley, N d'A & Crow, M J. 1988. A Preliminary study of geochemical patterns in soils overlying gold mineralisation at the Ashanti mine, Ghana, West Africa. BGS Technical Report, WC/88/32.

Crow, M J & Laffoley, N d'A. 1988. Summary of trials of an integrated gold exploration system at Chakari, Zimbabwe. BGS Technical Report, WC/88/33.

Piper, D P. 1988. Training workshop in simple gold prospecting techniques for the Small-Scale Miners Association of Zimbabwe: Report on a visit to Zimbabwe 30/8/88-23/9/88. BGS Technical Report, WC/88/41R.

Piper, D P. 1988. report on a visit to Ghana 7/10/88-17/10/88; International conference on the geology of Ghana. BGS Technical Report, WC/88/42R.

Piper, D P, Crow, M J & Laffoley, N d'A. 1989. Simple exploration techniques for sulphide-hosted, shear-zone related gold deposits in Ghana. BGS Technical Report WC/89/3.

Piper, D P 1989. Archean goldfields of Africa Project, Final Report BGS Technical Report WC/89/5.



## OUTPUT (Reports, Papers, & etc)

Crow, M J, Laffoley, N d'A & Piper, D P. 1990. Simple exploration techniques for sulphide-hosted, and shear-zone related gold deposits. IN "Geosciences in Development". A.A. Balkema, Rotterdam.

Ball, T K, Crow, M J, Laffoley, N d'A, Piper, D P & Ridgway, J. 1990. Application of soil gas geochemistry to mineral exploration in Africa. Journal of Geochemical Exploration Vol. 38, 103-115.

Foster, R P & Piper, D P. (in prep). Archean lode gold deposits in Africa. (for Ore Geology reviews).

Piper, D P & Crow, M J. (in prep). Surface soil geochemistry at the Rusty Monkey prospect, Ashanti mine, Ghana. BGS Technical Report.

## WORKSHOPS AND PRESENTATIONS

Training workshop for local miners. Shamva, Zimbabwe. 1988

Presentations on project work at

Southampton University 1987

Leicester University (Mineral Exploration MSc) 1987

'Geosciences in Development' meeting Association of Geoscientists for International Development (AGID) Nottingham 1988.

International Conference on the Geology of Ghana, Accra, Ghana 1988.

## PROJECT STAFF

Dr M J Crow (Project Manager 86-88)

D P Piper (Project Manager 88-89)

N d'A Laffoley

Dr R P Foster (Southampton University)

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K						43	73	71			187K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**  
**PROJECT NO: 3**

**TITLE:** PARAGENESIS OF GOLD IN LATE CENOZOIC SEDIMENTS

**LOCATIONS:** Costa Rica

**LENGTH OF PROJECT:** 3 YEARS

**STARTING DATE:** 1983

**COLLABORATING ORGANISATIONS**

Corporacion de Desarrollo SA (CODESA) Costa Rica  
Minera Nacional SA (MINASA) Costa Rica  
Open University, UK  
British Museum Natural History (BMNH)

**PROJECT OBJECTIVES**

To investigate the distribution, source and genesis of alluvial placer gold in Tertiary and Quaternary sediments in southern Costa Rica.

To provide exploration guidelines for similar gold deposits worldwide.

**PROJECT RESULTS**

The work has led to an important reinterpretation of the geology and tectonics of southwest Costa Rica; the studies suggest a different source for the gold deposits than that hitherto assumed.

A 1:100,000 geological map based on field observations and aerial photointerpretation of the Osa Peninsula of southern Costa Rica has been drafted and this together with the reinterpretation of the gold's source will prove invaluable in predicting and discovering further gold reserves in Costa Rica and in other geologically similar environments.

A considerable amount of advice and guidance has been given to the Costa Rican Government and many private companies exploring for and extracting gold in the region.

## OUTPUT (Reports, Papers, & etc)

- Beddoe-Stephens, B. 1985. Electron-probe micronanalysis of Costa Rican gold. BGS, Mineralogy & Petrology Report.
- Bland, D J. 1985. Electron microprobe examination of gold grains from the Osa Peninsula, Costa Rica. BGS Mineralogy and Petrology. Report No.85/23.
- Nuttal, C P. 1985. Report on of Neogene marine molluscs from the Osa Group of Costa Rica. British Museum (Natural History), Dept. of Palaeontology, Reports BMNH/OGS 1984/4 and 1985/4.
- Shepherd, T J. 1985. Assessment of fluid inclusions as provenance tracers for gold placer deposits, Costa Rica. BGS Isotope Geochemistry Research Group Report No.85/15.
- Whittaker, J E. 1985. Micropalaeontological report on samples from the Osa Group, Costa Rica. British Museum (Natural History), Dept. of Palaeontology Rept. BMNH/OGS 1984/4 and 1985/3.
- Basham, I R. 1986. Mineralogical examination of heavy mineral concentrates from the Osa Peninsula, Costa Rica BGS Mineralogy and Petrology Report No.86/4
- Berrangé, J P. 1986. Paragenesis of gold in late Cenozoic Sediments, Costa Rica. BGS Technical Report MP/86/14.
- Bland, D. 1986. XRF of gold flakes and nuggets from the Osa Peninsula, Costa Rica. Mineralogy and Petrology Report No.86/3.
- Bradley, D R and Snelling, N J. 1986. K:Ar age determinations on basic rocks of the Nicoya Complex, western Costa Rica. Isotope Geology Unit Report No 86/6.
- Barritt, S and Berrangé, J P. 1987. An interpretation of a gravity survey of the Osa Peninsula and environs, southern Costa Rica. Overseas Geology and Mineral Resources, No.64, 18p.
- Berrangé, J P. 1987. Gold in Costa Rica. Mining Magazine, p.402-407.
- Berrangé, J P. 1987. Gas seeps on the margins of the Golfo Dulce pull-apart basin, southern Costa Rica. Revista Geológica de América Central, No.6, p.103-107.
- Berrangé, J P and Thorpe, R S. 1988. The geology, geochemistry and emplacement of the Cretaceous/Tertiary ophiolitic Nicoya Complex of the Osa Peninsula, southern Costa Rica. Tectonophysics, Vol.147, p.193-220.
- Berrangé, J P. 1989. The Osa Group: an auriferous Pliocene sedimentary unit from the Osa Peninsula, southern Costa Rica. Revista Geológica de América Central, No.10, p.67-93.
- Berrangé, J P, Bradley, D R and Snelling, N J. 1989. K:Ar age dating of the ophiolitic Nicoya Complex of the Osa Peninsula, southern Costa Rica. Journal of South American Earth Sciences, Vol.2. No.1, p.49-59.
- Berrangé, J P. 1991. Geological maps of the Osa Peninsula, southern Costa Rica sheets Sierpe, Rincón, Llorona, Golfo Dulce, Madrigal and Carate; explanatory notes. BGS Technical Report WC/91/35.

## OUTPUT (Reports, Papers, & etc)

Berrangé, J P. in press. Origin of gold from the Golfo Dulce Placer Province, southern Costa Rica. Transactions of 'Symposium on Energy and Mineral Potential of the Central American - Caribbean region'. Circum Pacific Council for Energy and Mineral Resources San Jose 1989.

Berrangé, J P. in press. Gold from the Golfo Dulce Placer Province, southern Costa Rica. Revista Geológica de América Central.

## WORKSHOPS AND PRESENTATIONS

Poster presentation at Geological Society Mineral Deposits Studies Group Meeting 1985

Presentation at Circum-Pacific Council "Energy and Mineral Resources of Central America - Caribbean Region" meeting, San José, Costa Rica 1989

## PROJECT STAFF

Dr J P Berrangé (Principal Investigator)  
Dr I R Basham  
Dr S Beddoe-Stephens  
D Bland  
Dr N J Snelling  
D R Bradley  
S Barritt (Open University)  
J Whittaker (BMNH)

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			31	59	59						149K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 4**

**TITLE:** PRECIOUS AND BASE METAL MINERALIZATION IN INDONESIA AND MALAYSIA

**LOCATIONS:** Indonesia, Malaysia

**LENGTH OF PROJECT:** 3 Years

**STARTING DATE:** 1982

**COLLABORATING ORGANISATIONS**

Directorate of Mineral Resources, Indonesia

**PROJECT OBJECTIVES**

To study distinct gold and platinum and associated base-metal mineralization in Sumatra and Malaysia.

To determine the source of distinct heavy mineral assemblages found in river sediments in the hope of encountering new ore bodies.

To design exploration techniques to identify such ore-bodies.

**PROJECT RESULTS**

New mineralogical, chemical and geochronological data on several (now largely abandoned) mining areas in Sumatra. Particularly native gold composition and in relation to the type of host deposit.

Detailed study, and published account, of one auriferous skarn deposit. A proposal was also submitted to the Indonesian Department of Mines for redevelopment of this mine area based on re-discovered archival documents detailing the pre-War mine working.

Reconnaissance geochemical mineral data from one remote area of high gold potential. Field Survey in collaboration with the ODA/BGS TC Northern Sumatra Geological and Mineral Exploration Project (NSGMEP). Results are in a series of NSGMEP reports.

General evaluation of the styles of mineralization and potential of Sumatra for gold, based on new data and literature surveys. Also of geologically related terrains throughout Indonesia and E Malaysia.

## OUTPUT (Reports, Papers, & etc)

Beddoe-Stephen, B et al. 1983. Initial data on gold mineralization in the Magani and Muara Sipongi areas. Applied Mineralogy Unit Report No 309.

Beddoe-Stephen, B. 1984. Dolok Pinapan area N Sumatra. Applied Mineralogy Unit Report No 320.

Beddoe-Stephen, B. 1984. Muara Soma area, N Sumatra. Applied Mineralogy Unit Report No 321.

Beddoe-Stephen, B. 1985. New data on gold prospects in N Sumatra. Mineralogy and Petrology Report No 85/9.

Bowles, J F W. 1985. Final Report. Mineralogy and Petrology Report No 85/14.

Beddoe-Stephen, B. 1986. Gold mineralization and potential of the Anu-Reunguet area of Aceh, Sumatra. NSGMEP Report No 10.

Bowles, J F W et al. 1985. Precious metal mining prospects in N Sumatra Asian Mining '85' IMM.

Beddoe-Stephens, B. et al. 1987. Gold mineralization and skarn development near Maura Sipongi, W Sumatra, Indonesia. Economic Geology Vol 82, 1732-49.

## WORKSHOPS AND PRESENTATIONS

Papers presented at:

Asian Mining '85' Institute of Mining and Metallurgy, 1985

Mineralogical Society Meeting, 1986

Annual (13th) commodity meeting of Institute of Mining and Metallurgy, 1989

## PROJECT STAFF

Dr J F W Bowles

Dr B Beddoe-Stephens

Dr T J Shepherd

M Brook

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K		31	62	61							154K

ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM

FORM A3  
PROJECT NO: 5

**TITLE:** ANDEAN GEOCHRONOLOGY, PETROGENESIS AND METALLOGENESIS (ANDCHRON)

**LOCATIONS:** UK Chile Peru

**LENGTH OF PROJECT:** 4 Years

**STARTING DATE:** 1983

**COLLABORATING ORGANISATIONS**

British Antarctic Survey (BAS)  
Servicio Nacional de Geologia y Minería, Santiago, Chile  
Departamento de Geologia y Geofísica, Universidad de Chile  
Corporación Chilena Del Cobre  
Compañía de Minas Buenaventura  
Instituto Geológico Minero y Metallúrgico, Lima, Peru  
Corporación Minera Nor Peru SA

**PROJECT OBJECTIVES**

To investigate the mineralization, igneous and basement geology of the Andes using radiogenic isotopes as time-dependant tracers, and stable isotopes and fluid inclusions as temperature and process-dependant tracers.

**PROJECT RESULTS**

Genetic models of the evolution of the Andes have been developed which contribute significantly to our understanding of the timing and origin of metallic mineral deposits in the region. These models will enable the prediction of further mineral deposits.

Detailed studies of a silver deposit at Quiruvilca, Peru and a gold prospect at Silica del Hueso, Chile have been undertaken and should help improve the exploration strategies for these concessions. The report initiated several further studies, one of which was funded wholly by industry.

## OUTPUT (Reports, Papers, & etc)

Brook, M, Pankhurst, R J, Shepherd, T J & Spiro, B. 1986. ANCHRON - Andean geochronology and metallogenesis BGS Isotope Geology Unit Report.

Bussell, M A, Alpers, C N, Petersen, U, Shepherd, T J, Bermudez, C and Baxter, A N. 1990. The Ag-Mn-Pb-Zn vein, replacement and skarn deposits of Uchucchacua, Peru: studies of structure mineralogy, metal zoning, strontium isotopes and fluid inclusions. Economic Geology, 85, 1348-1383.

## WORKSHOPS AND PRESENTATIONS

International Geological Correlation Programme (IUGC/UNESCO)

Project 120 Contribution to Final Meeting

Project 249 Contribution to Andean Magmatism Topic

Fluid Inclusion Workshops: Santiago, Chile 1984  
Lima, Peru 1985

## PROJECT STAFF

M Brook  
Dr T J Shepherd  
Dr B Spiro  
Dr N J Snelling  
I G Swainbank  
Dr R J Pankhurst (BAS)

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			21	76	70	32					199K



ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM

FORM A3

PROJECT NO: 6

**TITLE:** MINERAL RESOURCE DEVELOPMENT IN THIRD WORLD

**LOCATIONS:** UK, Bolivia Costa Rica, Egypt,  
Indonesia, Kenya, Malawi, Malaysia, Nigeria,  
Philippines, Senegal, Sudan, Tanzania, Thailand,  
Togo, Zambia, Zimbabwe

**LENGTH OF PROJECT:** 7 Years - including  
extensions

**STARTING DATE:** 1984

**COLLABORATING ORGANISATIONS**

Costa Rica	-	Ministerio de Recursos Naturales, Energia y Minas (through PACOMI)
Egypt	-	Egyptian Geological Survey and Mining Authority
Indonesia	-	Mineral Technology Development Centre, Bandung
Indonesia	-	Directorate of Mineral Resources, Bandung
Kenya	-	Department of Mines and Geological Survey
Malawi	-	Geological Survey Department, Zomba
Malaysia	-	Geology Survey (Ipoh Laboratories)
Malaysia	-	Geological Survey (Sabah)
Malaysia	-	Geological Survey (Sarawak)
Philippines	-	Industrial Technology Development Centre, Manila
Philippines	-	Bureau of Mines and Geosciences, Quezon City
Tanzania	-	State Mining Corporation (STAMICO), Dar es Salaam
Thailand	-	Department of Mineral Resources, Bangkok
Zambia	-	Geological Survey of Zambia
Zambia	-	Mineral Exploration Department (Zambia Industrial and Mining Corporation Ltd)
Zimbabwe	-	Zimbabwe Mining Development Corporation (ZMDC)
Zimbabwe	-	G & W Industrial Minerals (subsidiary of the Industrial Development Corporation)
Other Organisations	-	CEC (DG3), Brussels

**PROJECT OBJECTIVES**

To provide assistance to developing countries in the small-scale exploitation of their indigenous mineral resources, with particular reference to industrial minerals.

Providing training and advice to foreign governmental institutions; in particular National Geological Surveys; together with private companies; in the development and expansion of their mineral industries.

To identify and characterise economically valuable mineral deposits.

To encourage the establishment of small-scale mineral-based industries thus promoting import substitution, generating exports and local employment.

## PROJECT RESULTS

Detailed laboratory evaluation of mineral deposits in 16 countries has been achieved, up to a dozen individual commodities have been assessed.

Applications data have been provided on these industrial minerals to geological surveys, parastatal organisations and potential users in Africa, SE Asia and Central America.

Techniques developed have subsequently been applied in TC and commercial repayment work, notably on graphite resources in Malawi, Tanzania and Kenya.

Advice through project has contributed to mineral exploitation in many areas, particularly of bentonite in Malaysia, and to the development of an Egyptian strategy for mineral evaluation.

A training advisor was temporarily seconded to Malawi and two project staff took part in an EC-funded training course in Malaysia.

High Technology Laboratory support and training of counterpart staff was provided for a 3 year ODA/BGS TC Project on Industrial Minerals in Costa Rica.

The sustained success of this project has led to a further on-going R & D project "Minerals for Development".

## OUTPUT (Reports, Papers, & etc)

Briggs, D A. 1985. Visit to Kenya to investigate scope of new mineral initiatives on behalf of Intermediate Technology. BGS Technical Report WG/85/13R.

Briggs, D A, Bloodworth, A J and Morgan D J. 1985. Mineralogical support for the development of small-scale mining. BGS Technical Report WG/85/15.

Bloodworth, A J and Bernard, D A W and Morgan, D J. 1985. Mineralogy and beneficiation of kaolinite-bearing rocks from Bolivia. BGS Technical Report WG/85/25R

Morgan, D J, Bloodworth, A J and Bernard, D A W. 1985. Mineralogy and technical appraisal of kaolins from Kenya. BGS Technical Report WG/85/30R.

Morgan, D J, Bloodworth, A J and Bernard, D A W. 1985. Mineralogy and technical appraisal of montmorillonite-bearing clays from Kenya. BGS Technical Report WG/85/31R.

Bloodworth, A J. 1985. A practical guide to the technical testing of clay raw materials for ceramics. BGS Technical Report WG/85/37.

Bloodworth, A J, Vickers, B P, George, I A and Morgan D J. 1986. Examination of absorbent clays from Senegal and Togo. BGS Technical Report WG/86/13C.

Morgan, D J. 1986. Report to Stevens Agencies: pre-feasibility study of china clay occurrence, Kaduna State, Nigeria. BGS Technical Report WG/86/17C.

## OUTPUT (Reports, Papers, & etc)

- Bloodworth, A J, Briggs, D A, Morgan, D J and Bernard, D A W. 1986. Processing trials and property modification of kaolin-bearing rocks from Pugu, Tanzania, using conventional and new hydrocyclone bodies. BGS Technical Report WG/86/25R.
- Briggs, D A, Bernard, D A W, Inglethorpe, S D J, Fortey N J and Morgan D J. 1986. Air classification for on-site dry pre-concentration of minerals: 1. Application of the Alpine zig-zag classifier to the separation of graphite from schist. BGS Technical Report WG/86/26R.
- Bloodworth, A J. 1986. Mineralogy and technical appraisal of further samples of smectite-bearing clay and kaolin and Kenya. BGS Technical Report WG/86/28R.
- Bloodworth, A J, Bernard, D A W, Briggs, D A and Morgan D J. 1986. Mineralogy and technical appraisal of a suite of industrial minerals from Zimbabwe. BGS Technical Report WG/86/29C.
- Briggs, D A. 1987 Processing of graphite samples from Kenya for Veitscher Magnesitwerke AG, Vienna, Austria. BGS Technical Report WG/87/8C.
- Briggs, D A. 1987. Mineralogical appraisal of graphite prospects in Tanzania. BGS Technical Report WG/87/9C
- Bloodworth, A J, Inglethorpe, S D J and Morgan D J. 1987. Composition and lime-burning performance of limestones, Early Worm mine, Zimbabwe. BGS Technical Report WG/87/16R.
- Inglethorpe, S D J, Bloodworth, A J and Morgan, D J. 1987. Chirundu diatomite, Zimbabwe: air classification trials and product evaluation. BGS Technical Report WG/87/17R.
- Bloodworth, A J, Morgan, D J and Inglethorpe, S D J. 1987. Mineralogy and properties of bentonitic clays from Minjingu and Sinya, Tanzania. BGS Technical Report WG/87/18R.
- Bloodworth, A J, Inglethorpe, S D J and Morgan, D J. 1987. Characterization of miscellaneous industrial minerals, Zimbabwe. BGS Technical Report WG/87/19R.
- Kemp, S J, Bloodworth, A J and Morgan, D J. 1987. Clay mineralogy of Karroo samples from Malawi. BGS Technical Report WG/87/28.
- Morgan, D J. 1988. Laboratory assessment of bentonite deposits. BGS Technical Report WG/88/3R.
- Briggs, D A, Bloodworth, A J and Morgan D J. 1988. Mineralogical support for the development of small-scale mining. Geological Society of London. Miscellaneous Paper No 18.
- Morgan, D J, Inglethorpe, S D J and Highley, D E. 1988. Mineralogical and chemical examination of bentonite samples from Karangnunggal miners, West Java, Indonesia. BGS Technical Report WG/88/12R.
- Briggs, D A. 1988. Malawi: Graphite Research Project. BGS Technical Report WG/88/13R.
- Morgan, D J and Inglethorpe, S D J. 1988. Mineralogical examination of bentonites from Thailand. BGS Technical Report WG/88/14R.
- Bloodworth, A J and Inglethorpe, S D J. 1988. Mineralogical and technical appraisal of clay sample from Zimbabwe. BGS Technical Report WG/89/21R.
- Bloodworth, A J, Morgan, D J and Briggs, D A. 1989. Laboratory processing trials on kaolin-bearing sandstones from Pugu, Tanzania, using conventional and new hydrocyclone bodies clay minerals Vol. 24, 539-48.

## **OUTPUT (Reports, Papers, & etc)**

Inglethorpe, S D J and Bloodworth, A J. 1989. Preliminary assessment of diatomites from Costa Rica as raw materials for filter aids. BGS Technical Report WG/89/4R.

Briggs, D A. 1989. Graphite in Tanzania. BGS Technical Report WG/89/8C.

Mitchell, C J and Bloodworth, A J. 1989. Evaluation of pumice from Costa Rica as lightweight aggregate. BGS Technical Report WG/89/10R

Bloodworth, A J. Report on a visit to Costa Rica, March, 1989.

Inglethorpe, S D J and Bloodworth, A J. 1989. Mineralogy and technical appraisal of common clays and limestones from Costa Rica. BGS Technical Report WG/89/16R.

Briggs, D A and Mitchell, C J. 1989. Beneficiation testing of three samples of graphite-bearing rock from Ancuabe, Mozambique. BGS Technical Report WG/89/17C.

Bloodworth, A J. 1989. A manual of basic procedures for the laboratory investigation of industrial minerals. BGS Technical Report WG/89/20R.

Briggs, D A and Mitchell, C J. 1989. The recovery of Ti-rich garnets from alkaline rocks by magnetic and gravity separation. BGS Technical Report WG/89/31R.

Briggs, D A and Mitchell, C J. 1990. Mineral beneficiation tests on apatite-bearing carbonatite, Tundulu, Malawi. BGS Technical Report WG/90/4.

Inglethorpe, S D J. 1990. Mineralogical composition and filtration properties of a sample of diatomite from Loma Camastro, Costa Rica. BGS Technical Report WG/90/13C.

Mitchell, C J, Briggs, D A and Morgan, D J. 1990. Air classification of feldspar pegmatite from Thailand. BGS Technical Report WG/90/21C.

Inglethorpe, S D J. 1990. Visit to San Jose, Costa Rica, to demonstrate laboratory methods for assessing bentonites (13 August - 2 September, 1990). BGS Technical Report WG/90/22R.

Inglethorpe, S D J, Bloodworth, A J and Razak, M A. 1990. Evaluation of clays from the environs of Cairo, Egypt, for brick manufacture and use as bentonites. BGS Technical Report WG/90/38.

Mathers, S J, Chavez, L, Alvarado, F & Inglethorpe S D J. 1990. Detailed Investigations of Selected Costa Rican Diatomites. BGS Technical Report WC/90/35.

Berrange J P, Mathers, S J, Morales N M and Alvarado F. 1990. The Non-metallic Industrial Minerals and Rocks of Costa Rica. BGS Technical Report WC/90/22.

Briggs, D A and Mitchell, C J. 1991. Mineralogical appraisal and beneficiation tests on some industrial minerals from Zambia. BGS Technical Report WG/91/4R.

Mitchell, C J, Briggs, D A and Bloodworth, A J. 1991. Mineralogy and technical appraisal of kaolinite-bearing rocks from Zambia. BGS Technical Report WG/91/5R.

## WORKSHOPS AND PRESENTATIONS

Extractive Industries Geology Meeting, Nottingham UK 1985.

Commonwealth Science Council Meeting on Mineral processing Lusaka, Zambia, 1985.

C.E.C/ASEAN Workshop on Industrial Minerals, 1988. 4 Volume Course Documentation published.

"Geosciences in Development" Association of Geoscientists for International Development (AGID), Nottingham, UK, 1988.

Circum-Pacific Council "Energy and Mineral Potential of Central American-Caribbean Region, San Jose, Costa Rica, 1989.

EC Funded Training Course on Clays and Ceramics, Ipoh, Malaysia. 1990. 4 Volume Course Documentation Published.

## PROJECT STAFF

Dr D J Morgan (Project Manager)

D A W Bernard

A J Bloodworth

D A Briggs

A E Davis

D E Highley

S D J Inglethorpe

C J Mitchell

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K				22	25	75	78	104	96	103	£503K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 7**

**TITLE:** AFRICAN CARBONATITES

**LOCATIONS:** Kenya, Malawi, Zambia,  
Zimbabwe

**LENGTH OF PROJECT:** 4 Years

**STARTING DATE:** 1986

**COLLABORATING ORGANISATIONS**

Geological Survey of Kenya  
Forestry Research Institute, Malawi  
Geological Survey of Malawi  
Geological Survey of Zambia  
Zambia Industrial and Mining Corporation  
Geological Survey of Zimbabwe  
Tea Research Foundation (Central Africa)  
Oxford Forestry Institute  
University of Newcastle-Upon-Tyne

**PROJECT OBJECTIVES**

Carbonatite-complexes, the roots of certain ancient volcanoes and characterised by unusual mineralogy and geochemistry, are an important source of several industrial minerals, notably phosphate - rich rocks which are in some cases used as the primary raw material for phosphatic fertilizers.

This study examines the economic potential of selected carbonatite-complexes with particular attention to the potential use of phosphate rocks as direct application fertilizers.

The work was planned in conjunction with several national geological surveys with the results to be widely disseminated to interested parties.

**PROJECT RESULTS**

A rapid field method for determining the phosphate content of rocks was developed.

Detailed geochemical and mineral processing studies were carried out on rocks from the Tundulu Complex, Malawi and Nkombwa Hill, Zambia with a view to their use as sources of phosphate rock, potassium and rare earth elements.

Agronomic evaluation of the phosphate and potassic rocks as direct application fertilizer in Malawi was started in collaboration with Newcastle University; the on-going field trials and studies are a component of the new ODA/BGS "Agrogeology" R & D Project, and an NRED/ODA R & D Project "Agronomic evaluation of phosphate resources from African Carbonatites as direct application fertilizers" (1988-1992).

The studies to-date are written-up and include an article in the journal Appropriate Technology to publicise the potential of rock fertilizers.

## OUTPUT (Reports, Papers, & etc)

Appleton, J D. 1988. Phosphate Resources of African Carbonatites: Potential use as low cost direct application fertilizers BGS Technical Report WC/88/34 R.

Styles, M T. 1989. A preliminary report on the Mineralogy of the Tundulu and Songwe carbonatite complexes, Malawi. BGS Technical Report WG/88/6.

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Sandon, P T S, Peachey, D and Vickers B P. 1989. Assessment of methods for the determination of chemical reactivity, and hence the agronomic potential, of African phosphate rocks. BGS Technical Report WI/89/5.

Appleton, J D, Chisdale, R T K, Hardcastle, P D, Styles, M T, Situabe, L A and Syers, J K. 1990. Potential use of Phosphate Resources from African Carbonatites as low cost direct application fertilizers In. 'Geosciences in Development' p 181-190. A.A. Balkema Rotterdam.

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Appleton, J D. 1990. Rock and Mineral Fertilizers. Appropriate Technology Vol. 17/2, 25-27.

Briggs, D A and Mitchell, C J. 1990. Mineral beneficiation tests on apatite-bearing carbonatite Tundulu, Malawi. BGS Technical Report WG/90/4R.

Appleton, J D, Bland, D, Mambwe, S, Nancarrow, P, Styles, M T and Zambezi, P. In press. The occurrence of daqingshanite (Ce) in the Nkombwa Hill Carbonatite, Zambia. Mineralogical Magazine.

## WORKSHOPS AND PRESENTATIONS

Presentation at Geosciences in Development International Conference Nottingham AGID, 1988

## PROJECT STAFF

Dr J D Appleton (Project Manager)  
Dr M T Styles  
D A Briggs  
C J Mitchell  
D Bland  
P Nancarrow

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K						45	61	74	10		190K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 8**

**TITLE:** DAMBO STRATIGRAPHY

**LOCATIONS:** Malawi

**LENGTH OF PROJECT:** 2 Years

**STARTING DATE:** 1985

**COLLABORATING ORGANISATIONS**

Geological Survey of Malawi

**PROJECT OBJECTIVES**

Dambos are seasonally swampy stream valleys, widely distributed in the plateau of Central and East Africa. They are known to contain valuable aquifers and industrial minerals but a lack of knowledge of their geology has thus far hampered development.

This project involves compiling the limited existing information on Dambos and undertaking detailed field investigations in order to remedy the perceived deficiency in knowledge.

A summary report will describe the study.

**PROJECT RESULTS**

The Dambos examined are in Central Malawi are a potential source of groundwater and three industrial minerals, gypsum, bentonite and silica sand.

Detailed descriptions of Dambo stratigraphy plus a thorough discussion of their probable origin and evolution are contained in the report referenced below.

This study has considerably extended knowledge about Dambos and has potential future application in the fields of mineral resources, engineering geology and geohydrology.



24

## OUTPUT (Reports, Papers, & etc)

Freshney E C. 1987. Stratigraphy and origin of selected Dambos from the Central Region of Malawi. BGS Technical Report MP/87/39R

## WORKSHOPS AND PRESENTATIONS

## PROJECT STAFF

Dr E C Freshney  
J R Hallam

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K					75	42					117K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 9**

**TITLE:** THE BASEMENT AQUIFER PROJECT

**LOCATIONS:** Malawi, Sri Lanka, Zimbabwe

**LENGTH OF PROJECT:** 5 Years

**STARTING DATE:** 1984

**COLLABORATING ORGANISATIONS**

Public Works Department, Malawi. Institute of Hydrology  
Sri Lanka Water Resource Board  
Ministry of Energy, Water Resources and Development, Zimbabwe

**PROJECT OBJECTIVES**

In large parts of Africa and SE Asia crystalline basement is widely exposed and offers the only foreseeable economic source of water.

This project attempted to evaluate the hydrogeology of such terrains and assessed their potential for water supply.

**PROJECT RESULTS**

State-of-the-art reviews on hydrochemistry, geophysical methods, remote sensing and weathering processes were prepared.

Questionnaires on occurrence and development of basement aquifers were circulated and replies collated.

Field studies were concentrated in Malawi, Zimbabwe & Sri Lanka to assess groundwater potential; The estimates made of recharge (8-16% of rainfall), easily exceeded likely abstraction needs.

The findings were widely disseminated via meetings and publications.

This project ran in close association with the 'Hydraulic Fracturing' and 'Collector Well' ODA/BGS R&D projects which together have generated further on-going TC and R&D projects.

## OUTPUT (Reports, Papers, & etc)

- Carruthers, R M. 1985. Review of geophysical techniques for groundwater exploration in crystalline basement terrain. British Geological Survey, Regional Geophysics Research Group Report No. RGRG 85/3.
- Greenbaum, D. 1985. Review of remote sensing applications to groundwater exploration in basement and regolith. British Geological Survey Overseas Directorate Report No. 85/8.
- Kay, R L F. 1985. Review of the application of hydrogeochemistry to groundwater in tropical basement and regolith. British Geological Survey, Overseas Hydrogeology Report ED/OS/85/4.
- Carruthers, R M, 1986. Report on application of geophysical surveys to groundwater exploration in crystalline basement terrain, 1985. British Geological Survey, Regional Geophysics Research Group Report No. RGRG 85/12.
- Greenbaum, D. 1986. Tectonic investigation of Masvingo Province, Zimbabwe: Preliminary report. British Geological Survey, Overseas Directorate Report MP/86/2R.
- Greenbaum, D. 1986. Comments on the 1986 field structural investigations in masvingo Province, Zimbabwe and notes on follow-up geophysical surveys. British Geological Survey, Overseas Directorate Report.
- Kay, R L F. 1986. Basement Aquifer Project. Preliminary account of the hydrogeochemical investigations in Southern Africa. British Geological Survey, Overseas Hydrogeology Report.
- Kay, R L F and McFarlane, M J. 1986. Preliminary account of the BH2, Chikobwe dambo. British Geological Survey, Overseas Hydrogeology Report.
- Lewis, M A. 1986. Interim report on data analysis for the basement aquifer project. British geological Survey, unpublished report.
- McFarlane, M J. 1986. Hydrogeology of regolith. Interpretation of weathering profiles. End of year report, March 1986.
- Allen, D J. 1987. Hydrogeological investigations using peizometers at Chimimbe and Chikobwe Dambo sites, Malawi, in August-September 1986. British Geological Survey Technical Report EGARP/WL/87/4.
- Amos, B J. 1987. Report on lineament analysis of Livulezi, Dowa and Lilongwe areas, malawi. British Geological Survey Report NO. MP/87/21R.
- Greenbaum, D. 1987. Lineament studies in Masvingo Province, Zimbabwe. British Geological Survey, Overseas Directorate Report MP/87/7R.
- Lewis, M A and Orzel, M J. 1987. Basement Aquifer Project. Data collection and analysis 1986/87. British Geological Survey, Overseas Hydrogeology Report WD/OS/87/6.
- Smith, I F and Raines, M G. 1987. Geophysical studies on the basement aquifer in masvingo Province, Zimbabwe. British Geological Survey, Regional Geophysics Research Group Project Note 88/4.
- Wright, E P. 1988. Basement Aquifer Project. Report on June-July 1987 field investigations in Masvingo Project Area. British Geological Survey, Overseas Hydrogeology Report, April 1986.

## OUTPUT (Reports, Papers, & etc)

- Allen, D J. 1988. Hydrogeological investigations at Chimimbe Dambo, Malawi, in May-June 1987. British Geological Survey Technical Report WN/88/3.
- Allen, D J. 1988. Hydrogeological investigations at Chimimbe Dambo, Malawi, in March-April 1988. British Geological Survey Technical Report WD/88/29R.
- Bird, M J, McFarlane, M J and Neal, M. 1988. Porosity and density results from Chikobwe borehole ALI, Malawi. British Geological Survey unpublished report.
- Carruthers, R M. 1988. Basement Aquifer Project. Geophysical studies to evaluate groundwater resources in crystalline bedrock terrains in Malawi, Sri Lanka and Zimbabwe, 1986-1988. British Geological Survey Technical Report WK/88/10.
- Carruthers, R M and Smith, I F. 1988. Basement Aquifer Project 1984-1988. Summary report on surface geophysical studies. British Geological Survey Technical Report WK/88/23.
- Greenbaum, D. 1988. Basement Aquifer Project. Report on structural studies 1987/88. British Geological Survey Technical Report WC/88/17.
- McFarlane, M J. 1988. Basement Aquifer Project. SEM of clay glaebules in Malawi.
- McFarlane, M J. 1988. Some aspects of the chemical characteristics of the Chimimbe interfluvial core (B3), Malawi.
- McFarlane, M J. 1988. Basement Aquifer Project. Digitisation of geomorphological features in the 'Malawi Strip'.
- McFarlane, M J, Miles, D L and Cook, J M. 1988. Preliminary investigation of water characteristics from a selection of crescent springs in dambos, dambo peripheral seepage zones and a palaeodambo interfluvial profile in Malawi.
- McFarlane, M J and Shedlock, S L. 1988. Correlation of regolith stratigraphy, mineralogy and chemistry with gamma logs in an interfluvial profile (B3) in Malawi.
- Oliver, D. 1988. Interim report on borehole logging in Masvingo area, Zimbabwe.
- Smith, I F and Raines, M G. 1988. Further geophysical studies on the basement aquifer in Masvingo Province, Zimbabwe. British Geological Survey, Regional Geophysics Research Group Project Note 88/4.
- Wright, E P. 1988. Basement Aquifer Project. Progress Report for 1987-1988 (includes discussion on Radon Surveys and BGS Drilling Programme in Masvingo Project area, 1987). British Geological Survey Overseas Hydrogeology Report, April 1988.
- Wright, E P, Herbert, R, Murray, K, Ball, D F, Carruthers, R M, McFarlane, M J and Kitching, R. 1988. Final Report of the Collector Well Project 1983-1988. British Geological Survey Technical Report No WD/88/31.
- Allen, D J. 1989. Summary of hydrogeological investigations using piezometers at Chimimbe and Chikobwe Dambos, Malawi, 1986-1988. British Geological Survey Technical Report WD/89/2.

## OUTPUT (Reports, Papers, & etc)

Bullock, A, McFarlane, M J and Meigh, J R. 1989. Hydrogeological studies in Zimbabwe and Malawi. Institute of Hydrology Report, Wallingford.

McFarlane, M J 1989. Chikobwe dambo core (Bh A1L) - profile features, mineralogy, chemistry, age of the infill and stratigraphic context.

McFarlane, M J 1989. Chimimbe dambo core - the profile features, mineralogy, chemistry and stratigraphic context.

McFarlane, M J 1989. Some aspects of the chemistry of the Chikobwe palaeodambo core (B2).

McFarlane, M J and Neal, M 1989. Mineralogy of selected profiles from Masvingo, Zimbabwe.

Shedlock, S L 1989. Borehole geophysics in crystalline rocks. British Geological Survey Report WK/89/14.

Stewart, J B 1989. Estimation of areal evaporation from dambos in Zimbabwe. Institute of Hydrology, unpublished report.

BGS. 1989. The Basement Aquifer Research Project 1984-9. Final Report to the Overseas Development Administration. BGS Technical Report WD 89/15.

## WORKSHOPS AND PRESENTATIONS

A Workshop on Project findings was held in Harare, Zimbabwe in June 1987, there was considerable international representation and the proceedings have been published.

A 2-day meeting to discuss the final project results was held at the Geological Society of London in April 1989 and a special publication detailing the studies will be published.

## PROJECT STAFF

Dr E P Wright	J C Talbot	M G Raines
Dr R Herbert	M J Orzel	Dr J B Stewart (IH)
Dr D Greenbaum	M A Lewis	Dr A Bullock (IH)
Dr B Amos	Dr R L F Kay	J R Meigh (IH)
R M Carruthers	S L Shedlock	Dr M J McFarlane (Independent Consultant)
I F Smith	P J Chilton	
D J Allen	K H Murray	
T R Shearer	M G Raines	

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K				64	157	255	218	82			776K



# GROUNDWATER RESOURCES IN WEATHERED BASEMENT

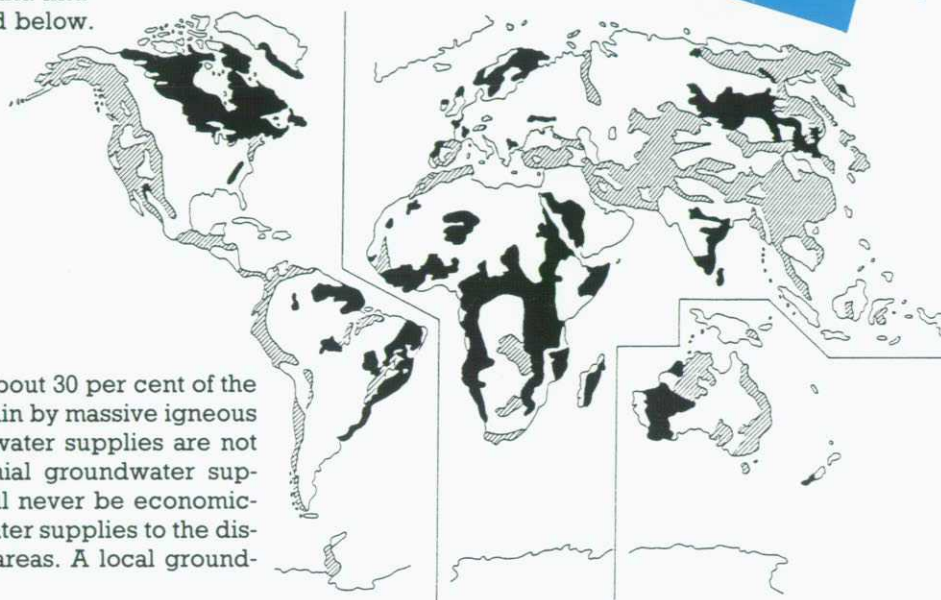
## The Project

In 1988 BGS completed a five year multi-disciplinary study of the groundwater resources of the weathered basement aquifers. The project was financed by ODA, and was intended to help improve the water supply for millions of villagers who live over such rocks throughout the developing world. Key features and findings of this study are summarised below.

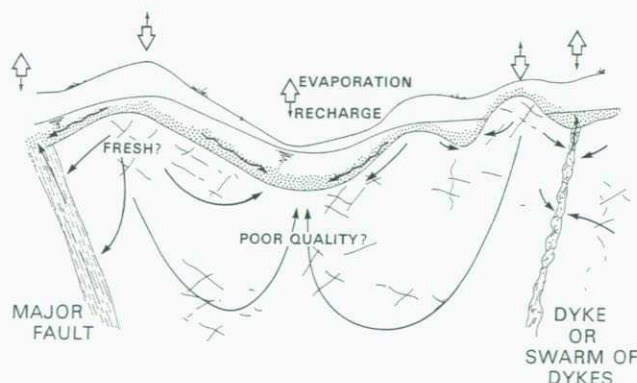
## The Need

In the arid to semi-arid regions about 30 per cent of the developing countries are underlain by massive igneous or metamorphic rocks. Surface water supplies are not available and significant perennial groundwater supplies are difficult to locate. It will never be economically possible to provide piped water supplies to the disperse villages situated in these areas. A local groundwater supply is essential.

■ Areas of intrusive rocks  
▨ Areas with significant metamorphic rocks



*World-wide distribution of basement rocks  
(after Uhl and Atobrah, 1987)*



## The System

The diagram opposite contains all the essential features of the groundwater system in the hard rock areas. There is a superficial weathered layer. Where rainfall is greater than c. 300 mm there will be a widespread groundwater reservoir perched on the hard rock below. The interface between the weathered and hard rock zones is rugged. The most likely locations for a perennial supply are in valley bottoms, especially when wet season irrigation is practised there.

## Exploration

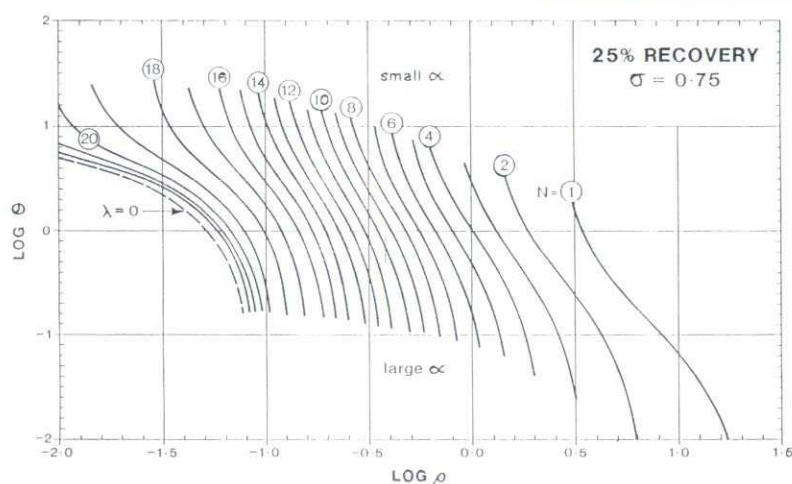
Geophysical techniques—Resistivity, Electromagnetics, Magnetics and Seismic—can rapidly identify zones of this weathering which will not provide a perennial water supply from the weathered zone. New techniques are being developed which will assist with identifying the most deeply weathered parts of the valley bottoms.





## Dug Well Construction

Large diameter wells, hand-dug through the weathered zone, are the traditional way of exploiting the perched aquifer. The photograph shows a prototype 2 m diameter reverse circulation well drilling-bit, which was used to construct such large diameter wells in three days. Brick, concrete masonry and galvanised iron have been used as lining materials. Different methods of construction are appropriate for different countries.



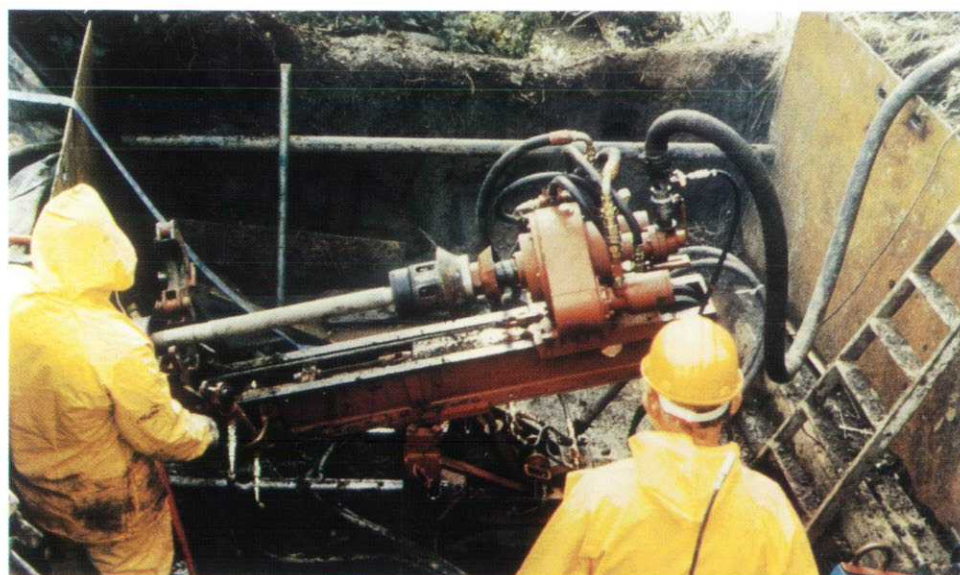
## Testing

Three different pumping test techniques have been developed to help determine aquifer hydraulic properties and type for weathered basement. The print shows one of six nomograms used to determine transmissivity from a short-term pumping test on a farmer's dug well. These tests allow predictions to be made of the long-term safe abstraction rates of the dug wells.

## Collector Well Construction

To date, four special drilling rigs have been constructed which can drill out 120 mm diameter holes horizontally to a distance of 40 m from the centre of the dug well. About 50 collector wells, each having four adits, have been constructed in Malaysia, Sri Lanka, Zimbabwe and Malawi. The photograph shows one rig

undergoing development trials. At 32 locations in Sri Lanka the conversion from dug wells to collector wells more than doubled the dug well yield. Tests on these wells showed sustainable yields of 2 litres/second, assuming 100 days of drought, were obtainable. The median yield of a deep slim borehole in such locations is 0.3 litres/second.



Further enquiries:  
British Geological Survey  
Overseas Hydrogeology  
Maclean Building  
Crowmarsh Gifford  
Wallingford  
Oxon OX10 8BB  
☎ 0491 38800

**TITLE:** ARID ZONE RECHARGE STUDY

**LOCATIONS:** Sudan

**LENGTH OF PROJECT:** 5 Years with extension

**STARTING DATE:** 1981

**COLLABORATING ORGANISATIONS**

Arab Centre for Semi Arid Zones Development (ACSAD), Damascus, Syria  
National Administration for Water (NAW) Khartoum, Sudan

**PROJECT OBJECTIVES**

The Sahel droughts of the past two decades have drawn attention to scarce water resources in N. Africa where groundwater is the only available source of supply. The water balance (extraction versus recharge) is critical and sensitive to climatic changes.

The study posed the following key questions

- a) To what extent does rainfall infiltrate directly into the soil?
- b) During floods how much infiltration occurs via the beds of Wadis
- c) Does the Nile recharge the aquifers, and if so where?
- d) What is the origin of the groundwater in the key Nubian Sandstone aquifer, what is its potential?

**PROJECT RESULTS**

The conclusions fully answer the objectives and are as follows:-

Recharge from the land surface is very low ( $< 1\text{mm/yr}$ ) except in sand dune areas which may offer a highly permeable substrate for rapid infiltration.

Wadi beds act as important routes for recharge to shallow aquifers providing the replenishment that has been traditionally relied on to balance extraction.

The Nile is locally recharging the Nubian Sandstone for about 10km on either side of the river, elsewhere the Nubian Sandstone is not being recharged and is not a secure source for long-term extraction.

The only renewable groundwater resources are adjacent to the Nile Valley and in Wadi systems.

Any development and conservation schemes must rely on these sources not on regional recharge



## OUTPUT (Reports, Papers, & etc)

Edmunds, W M, Darling, W G and Kinniburgh, D G 1987. Estimation of aquifer recharge using geochemical techniques. BGS Technical Report WD/OS/87/1.

Darling, W G, Edmunds, W M, Kinniburgh, D G and Kotoub, S. 1987. Sources of recharge to the basal Nubian Sandstone aquifer, Butana region, Sudan. pp.205-224, in Isotope techniques in water resources development, AEA Vienna.

Edmunds, W M, Darling W G and Kinniburgh, D G. 1987. Solute profile techniques for recharge estimation in semi-arid and arid terrane. pp.139-157 in 'Estimation of Natural Groundwater Recharge' Nato Asi Series (c) 222 ed. I Simmers. Reidel. Dordrecht.

Edmunds, W M, Darling, W G, Kinniburgh, D G, Kotoub, S and Mahgoub, S. 1991. Sources of recharge at Abu Delaig, Sudan. J Hydrology.

## WORKSHOPS AND PRESENTATIONS

1) International Symposium on the use of isotope techniques in water resources development. IAEA (UNESCO) Vienna 1987.

2) Nato Advanced Research Workshop 'Estimates of Natural Recharge of Groundwater with special reference to arid and semi and zones 1987 Antalya, Turkey.

## PROJECT STAFF

Dr W M Edmunds  
Dr D G Kinniburgh  
W G Darling

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K	9	41	16	19	7						92K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 11**

**TITLE:** ESTIMATING AVAILABILITY OF RECHARGE FOR LONG-TERM SUPPORT OF FORESTRY SHELTERBELTS TO PROTECT AGAINST DESERT ENCROACHMENT ALONG THE NILE

**LOCATIONS:** UK, Sudan

**LENGTH OF PROJECT:** 1 Year

**STARTING DATE:** 1989

**COLLABORATING ORGANISATIONS**

SOS Sahel

**PROJECT OBJECTIVES**

To establish if long-term groundwater supplies are available to irrigate the forestry shelterbelts that are needed to protect fertile agricultural land bordering the Nile from encroaching desert sands.

BGS will rely on the SOS Sahel organization to collect field data (to save costs) with equipment provided by ODA/BGS. The results will be analysed and interpreted.

**PROJECT RESULTS**

The study concludes that groundwater resources are adequate to irrigate shelterbelts. The river Nile is the only significant source of the existing groundwater supplies.

The extraction will cause small falls in existing groundwater levels which should be monitored closely and which should not seriously affect the present day riverside irrigation of cash crops.

In the event of a significant drop in water levels a fuller hydrogeological study will be required to establish safe extraction rates.

## OUTPUT (Reports, Papers, & etc)

**Herbert, R and Edmunds, W M. 1990. Estimating the availability of recharge for long-term support of forestry shelterbelts to protect against desert encroachment along the Nile. Final Report BGS Technical Report WD/90/17.**

## WORKSHOPS AND PRESENTATIONS

## PROJECT STAFF

Dr R Herbert  
Dr W M Edmunds

## PROJECT EXPENDITURE

[illegible]

PROJECT NO: 12

**TITLE:** HYDROGEOLOGY OF QANATS

**LOCATIONS:** UK, Pakistan

**LENGTH OF PROJECT:** 2 Years

**STARTING DATE:** 1986

**COLLABORATING ORGANISATIONS**

Arab Centre for Studies in Arid and Dry Lands (ACSAD) Damascus, Syria

Wimpey Laboratories, UK

**PROJECT OBJECTIVES**

A Qanat is a long tunnel driven into a hillside to intercept the groundwater table and so act as a permanent spring. They provide essential water supplies in large parts of the arab world and continental Asia, such systems have been used for about 25,000 years.

This project attempted to develop a 3-D model of a Qanat which would enable analysis of its performance and indicate how such systems can be used most efficiently. Very little rigorous study of Qanats has been previously attempted.

**PROJECT RESULTS**

A model of typical Qanat was developed utilizing data from Qanats in the Mastung Valley, Pakistan.

The study indicates that a Qanat may well lose 25% of its potential yield whilst flowing underground and lining of the tunnel base with an impermeable material would in many cases be very beneficial. Many Qanats are also badly in need of maintenance to optimise performance.

Discussions have been held with Wimpey Laboratories, UK concerning Qanat maintenance and the development of layflat lightweight pipe to convey the water along the underground section and so maximise output.

## OUTPUT (Reports, Papers, & etc)

Kitching, R. 1988. Hydrogeology of Qanats. BGS Technical Report WD/88/6.

Shearer, T R. 1989. A computer model of the Mastung Valley Aquifer System (Baluchistan). BGS Technical Report WD/89/4.

## WORKSHOPS AND PRESENTATIONS

## PROJECT STAFF

Dr R Kitching  
Dr W M Edmunds  
Dr R Herbert  
T R Shearer

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K						19	21				40K

ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM

PROJECT NO: 13

FORM A3

**TITLE:** ASSESSMENT OF HYDRAULIC FRACTURING IN THE BASEMENT AQUIFERS OF ZIMBABWE

**LOCATIONS:** Zimbabwe

**LENGTH OF PROJECT:** 1 Year

**STARTING DATE:** 1990

**COLLABORATING ORGANISATIONS**

Ministry of Energy and Water Resources Development (MEWRD), Zimbabwe

**PROJECT OBJECTIVES**

To assess the application and use of the hydraulic fracturing technique to improve the water supply from low yielding boreholes in rural areas of Zimbabwe.

**PROJECT RESULTS**

In the Masvingo area of Zimbabwe; an area noted for difficulty in obtaining groundwater; twelve wells were treated with hydraulic fracturing and six showed increased yields averaging 80%.

Hydraulic fracturing is a cheap and simple technique and should be used routinely on low-yielding wells this would reduce the costs compared with the redrilling option by about 50%

Post project analysis of the results with experts from the oil and geothermal industry suggest that the method may be improved and so increase the success rate further.

## OUTPUT (Reports, Papers, & etc)

Herbert, R, Talbot, J C, Shedlock, S L, Rastall, P, Sinnott-Jones, P and Nhunhama G. 1991. A Pilot Study of Hydraulic Fracturing used on Low Yielding Wells in the basement rocks of Masvingo, Zimbabwe. BGS Technical Report WD/91/4.

## WORKSHOPS AND PRESENTATIONS

**A factsheet has been produced and widely circulated.**

## PROJECT STAFF

Dr R Herbert  
S L Shedlock  
J C Talbot

## PROJECT EXPENDITURE

[illegible]

# HYDRAULIC FRACTURING

## HYDRAULIC FRACTURING TO ENHANCE YIELD IN THE HARD BASEMENT ROCKS OF MASVINGO PROVINCE, ZIMBABWE

### ● The Project

In 1990, the British Geological Survey (BGS) and the Ministry of Energy and Water Resources Development (MEWRD), Zimbabwe, completed a study of the potential of Hydraulic Fracturing (HF) for increasing the yields of low-yielding boreholes drilled into the hard basement rocks of Masvingo Province, Zimbabwe. The Overseas Development Administration (ODA) provided funds for the BGS involvement and the MEWRD provided a hydraulic fracturing unit, the Atlas Copco HFU-140, and technical staff to operate the system.

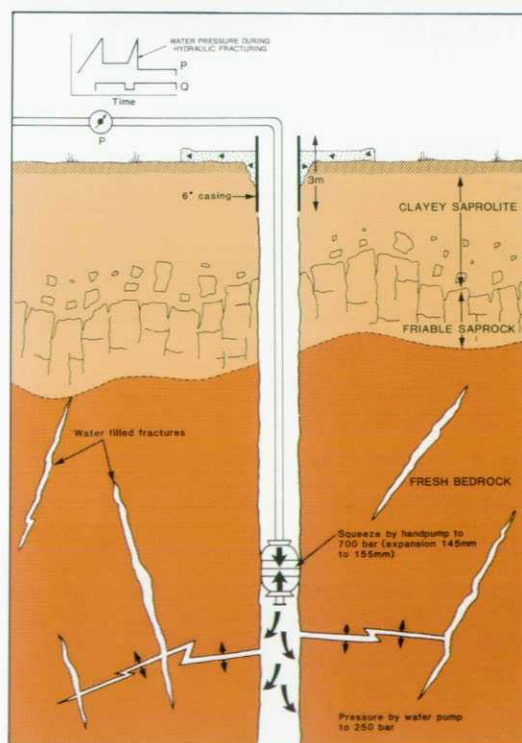
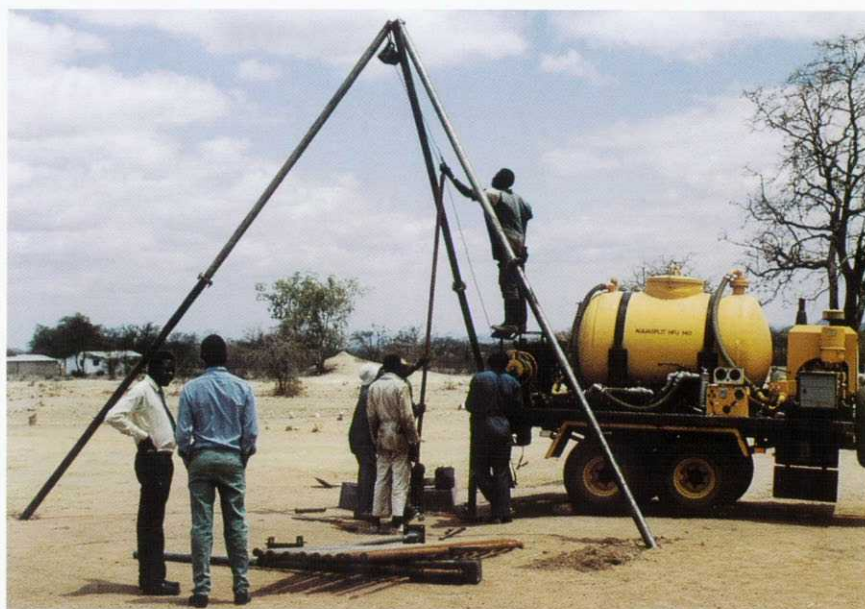
### ● Needs, aims and objectives

Basement aquifers are important in the arid and semi-arid regions of the world because of their wide extent in areas where alternative water sources are limited. Usually, slim (100–200 mm diameter) boreholes are drilled to c.40 m in the hope that water-filled fissures will be struck and a handpump can be installed. Almost 30% of all holes drilled are dry and low yielding i.e.  $c < 0.11$  l/sec. The aim of the project was to determine how effective Hydraulic Fracturing can be in increasing the yields of low-yielding boreholes drilled into basement rocks.

### ● Hydraulic Fracturing

In reality, little is known about the distribution and geometry of fissuring in basement rocks but HF (illustrated opposite) requires a packer to be set near the base of the borehole; thereafter water is injected beneath it at pressures great enough to crack the ground near the well. The figure shows how the pressure of the injected water varies during HF. The aim is to either connect the well to the rock's fissure system or increase the permeability of the zone around the well, so thereby increasing well yield.

*The winch of the HF Unit being used to remove a handpump*



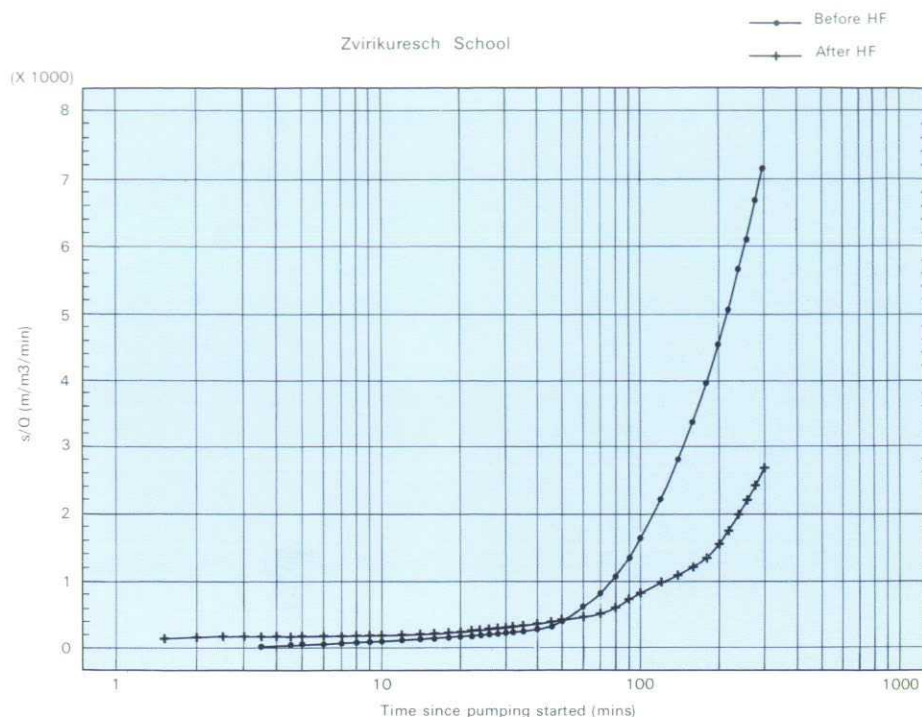


## Testing Programme

Three days were spent at each site. On the first day, the handpump was pulled, and the borehole was logged using caliper, resistivity, temperature and SP sondes. The test pump was installed and the throttle in the delivery main was set to such a rate that a long-term pumping test could be carried out. On the second day, the borehole was pumped for five hours and the well performance monitored. The pump was then removed HF was carried out; this took about 2 hours. The test pump was then reinstalled and the pumping rate reset. On the third day, the pumping test was re-run before the handpump was reinstalled. The figure opposite shows the results of the pumping tests before and after HF for one of the sites. The figure is typical of most of the improved wells in that HF delays the onset of a relatively rapid period of drawdown in the well, thus increasing the total volume of water that can be pumped.

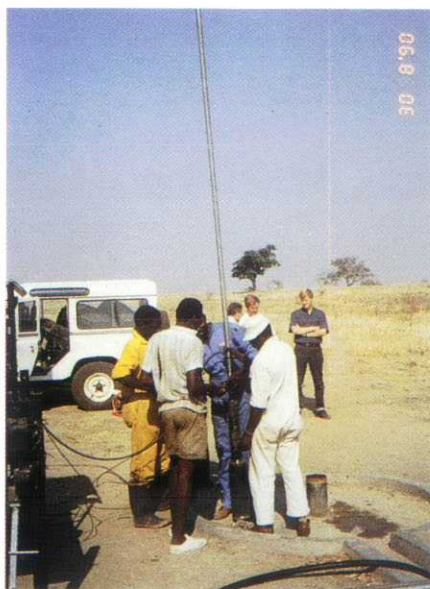
## Results

Twelve wells were subjected to HF. The yields of six were improved by an average of 80% in the range 10 to 240%. Costs of HF are low and the technique is simple to use. It is **recommended** that HF is used as a matter of routine on low-yielding wells as this will reduce the average cost of redrilling by 50%. Masvingo Province has one of the highest rates of drilling failures in Zimbabwe. Evidence from earlier pilot projects carried out in Australia, West Africa and America suggests it is likely that HF will be even **more successful** in basement rocks which are less prone to producing low-yielding wells.



Day 1: Discharge during the long pumping test. Rate set at 2 l/min

Day 2: Extracting the packer after hydraulic fracturing



Day 3: Logging the well after the second pump test.

For further information contact:  
The Hydrogeology Advisor to ODA  
British Geological Survey  
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OXON OX10 8BB  
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Telex 849365 HYDROL G

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 14**

**TITLE:** THE COLLECTOR WELL PROJECT

**LOCATIONS:** Malawi, Sri Lanka, Zimbabwe

**LENGTH OF PROJECT:** 6 years including extensions

**STARTING DATE:** 1982

**COLLABORATING ORGANISATIONS**

Public Works Department, Malawi  
Sri Lanka Water Resource Board  
Ministry of Energy & Water Resources Development, Zimbabwe  
Drilling and Geosciences Ltd, Zimbabwe  
Hatcliffe Agricultural Engineering College, Zimbabwe

**PROJECT OBJECTIVES**

To design, build and test a horizontal drilling rig which can be used to drill radial collecting adits in to the sides of existing large diameter hand-dug wells sited in crystalline basement.

The radial collectors will tap the relatively permeable basal zone of the weathered overburden.

Using this method yields of existing wells should be substantially increased enabling more people to depend on the wells for drinking water, village gardens or livestock development and also to promote better long-term aquifer management.

**PROJECT RESULTS**

Four horizontal drilling rigs have been fabricated.

In a pilot programme some 11 collector wells have been constructed in Zimbabwe and two in Malawi.

Yields of existing wells have been improved, some up to threefold.

The method is extremely cost effective compared with drilling several individual boreholes or dug wells and benefits from a much lower failure rate.

This research has resulted in

a) an on-going ODA/BGS R&D project "Development of a horizontal drilling rig for alluvial aquifers of high permeability".

b) an ODA/BGS TC project which converted 50 existing wells in Sri Lanka into collector wells.

## OUTPUT (Reports, Papers, & etc)

Wright, E P, Herbert, R, Murray, K H, Ball, D K, Carruthers, R M, McFarlane, M J & Kitching, R. 1988. BGS/ODA Collector Well Project. BGS Technical Report WD/88/1.

Herbert, R, Ball, D F, Rodrigo, I D P & Wright, E P. 1989. Collector wells for Exploiting the Regolith Aquifer for small scale irrigation in Sri Lanka, Irrigation Theory and Practice, Pentech Press, London, pp.317-328

Ball, D F & Herbert, R. (In Press). The Use and Performance of Collector Wells within the Regolith Aquifer of Sri Lanka. Groundwater.

## WORKSHOPS AND PRESENTATIONS

Presentations at Irrigation Theory and Practice, International Conference, University of Southampton 1989.

Groundwater Exploration and Development in Crystalline Basement Aquifers, Zimbabwe, 1987.

The Hydrogeology of Crystalline Basement Aquifers in Africa, Geological Society London and Association of Geoscientists for International Development (AGID) 1989.

## PROJECT STAFF

Dr E P Wright  
Dr R Herbert  
K H Murray  
Dr R Kitching  
D K Ball  
R M Carruthers  
Dr M J McFarlane

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K		22	74	72	244	130	37				579K

ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM

FORM A3

PROJECT NO: 15

**TITLE:** DEVELOPMENT OF A HOLLOW AUGER DRILLING TECHNIQUE SUITABLE FOR RAPID, EASY INSTALLATION OF HANDPUMPS IN ALLUVIAL AQUIFERS

**LOCATIONS:** UK

**LENGTH OF PROJECT:** 1 Year

**STARTING DATE:** 1989

**COLLABORATING ORGANISATIONS**

Institute of Hydrology, Wallingford

**PROJECT OBJECTIVES**

To design and construct a prototype hollow stem auger drilling system suitable for the rapid installation of handpumps in alluvial aquifers.

Such equipment would be particularly valuable for provision of emergency water supplies for refugee camps situated on alluvial plains.

**PROJECT RESULTS**

Field trials have shown that hollow stem auger drilling is an effective method of installing handpumped wells, although several technical difficulties were encountered, most have been satisfactorily overcome.

It is recommended that a pilot project to install handpumped wells overseas is now funded and that the design criteria defined in this study be circulated to drilling rig manufacturers in order to identify suitable equipment currently in production and/or invite proposals for a purpose-built system.

Dixon, A J, Adams, B and Herbert, R. 1990. Development of a Hollow Stem Auger Drilling Technique for Rapid, Easy Installation of Handpumps in Alluvial Aquifers BGS Technical Report WD/90/15.

**Bradford, R. 1990. Hollow Stem Augering: Results of Initial Field Trials. Institute of Hydrology Internal Report.**

## PROJECT STAFF

Dr R Herbert  
B Adams  
R Bradford  
A J Dixon (IH)

## PROJECT EXPENDITURE

[illegible]

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**  
**PROJECT NO: 16**

**TITLE:** WELL DESIGN

**LOCATIONS:** Bangladesh

**LENGTH OF PROJECT:** 1 Year

**STARTING DATE:** 1982

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To construct digital mathematical models of flow to wells.

To construct a test rig to study the hydraulics of different well screens.

To monitor performance of wells of varied design in Bangladesh and model their behaviour

To meet the Terms of Reference of the pilot study of the ODA consultancy for the Deep Tubewells (II) Project in Bangladesh

**PROJECT RESULTS**

Incorporated into the Deep Tubewells ODA Consultancy Project in Bangladesh after achieving satisfactory progress

**OUTPUT (Reports, Papers, & etc)**

## WORKSHOPS AND PRESENTATIONS

**PROJECT STAFF**

Dr R Herbert  
J Davies  
S L Shedlock  
Dr J A Barker

**PROJECT STAFF**

Dr R Herbert  
J Davies  
S L Shedlock  
Dr J A Barker

PROJECT EXPENDITURE	
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[illegible]



ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM

FORM A3

PROJECT NO: 17

**TITLE:** IMPACT OF TROPICAL/SUB-TROPICAL AGRICULTURE ON GROUNDWATER QUALITY

**LOCATIONS:** Barbados, India  
Mexico, Sri Lanka

**LENGTH OF PROJECT:** 6 Years with  
extensions

**STARTING DATE:** 1985

**COLLABORATING ORGANISATIONS**

Barbados - Environmental Engineering  
Divison, (MoH)  
- Government Laboratory  
- Pan American Health Organisation (PAHO)

India - Anna University, Madras  
- Frederick Institute of Plant Protection and  
Toxicology, Madras (FIPPAT)

Mexico - Instituto Tecnológico de Sonora  
- Comision Nacional del Agua

Sri Lanka - Ceylon Institute of Scientific & Industrial Research  
- Water Resources Board  
- Agriculture Department, Kalpitiya Research Station

**PROJECT OBJECTIVES**

To provide appropriate authorities in each country with data on the quality of potable groundwater supplies and indicate the need to protect these supplies.

To suggest ways in which excessive and unnecessary nutrient leaching can be stopped; hence improving crop yields.

To try to recommend measures for improved agriculture and water management thereby reducing the risk of pollution in shallow groundwater.

To train local organizations to carry out similar assessments.

**PROJECT RESULTS**

Low to moderate nitrate concentrations were observed in India, Barbados and Mexico. The low concentrations under rice cultivation in India are attributed to denitrification in the anaerobic conditions beneath paddy fields. In Barbados and Mexico, low nitrate leaching reflects generally modest fertilisers applications and efficient use of nitrogen (from sugarcane).

In both case, local higher nitrate concentrations can be attributed to the impact of unsewered sanitation. High nitrate leaching from heavy fertiliser use in horticulture in Sri Lanka on permeable soils is producing a general rise in nitrate concentrations in groundwater under irrigated land.

In Sri Lanka, carbofuron is extensively leached to groundwater, but the degradation products are not persistent. In India, the anaerobic conditions produce a different degradation pathway and the persistant metabolite carbofuron phenol is found. Atrazine is widely observed in groundwater in the limestone aquifer of Barbados from usage in sugarcane cultivation.



## OUTPUT (Reports, Papers, & etc)

Foster, S S D. 1986. Groundwater contamination threats in Mexico BGS Technical Report WD/OS/86/8.

Lawrence, A R, Chilton, P J and Kuruppuarachchi, D S P. 1988. Review of the pollution threat of groundwater in Sri Lanka. J. Geol. Soc. Sri Lanka, Vol.1, 85-92.

BGS and others 1989. Groundwater pollution risk assessment for Belle Public Water Supply Catchment, Barbados, pp.52.

Lawrence, A R, Kuruppuarachchi, D S P, Fernando, N and Mubarak, A M. 1989. Impact of Agriculture on Groundwater Quality: An interim Report on Progress of Investigations at Kalpitiya, Sri Lanka BGS Technical Report WD/89/59R.

Chilton, P J, Vlugman, A A and Foster, S S D. 1990. A groundwater pollution risk assessment for public water supply sources in Barbados Proceedings of the International Symposium of Tropical Hydrology and Fourth Caribbean Islands Water Resources Congress, Puerto Rico, July 1990, AWRA p.279-289.

BGS and others. 1991. Groundwater pollution risk assessment for the Hampton catchment, Barbados, pp.55.

Chilton, P J. 1991. Groundwater quality studies for pollution risk assessment in Barbados: Results of monitoring in the Belle and Hampton Catchments 1987-1990. BGS Technical Report WD/OS/91

Reports on Mexico, India, Sri Lanka in preparation. Summary report to be prepared for ODA.

## WORKSHOPS AND PRESENTATIONS

International Symposium of Tropical Hydrology and Fourth Caribbean Islands Water Resources Congress, Puerto Rico 1990, paper presented (see above).

Proposed workshop on the Impact of Agriculture on Groundwater Quality to be held in Venezuela, October/November 1992, in collaboration with PAHO and FAO, and supported by ODA Engineering Division dissemination funds.

## PROJECT STAFF

P J Chilton (Project Manager)  
A R Lawrence  
L R Bridge  
J Talbot

Dr S S D Foster  
J M Cook  
M E Stuart

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K					23	36	48	68	74	68	317K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 18**

**TITLE:** APPRAISAL AND REMOVAL OF IRON PROBLEMS IN RURAL GROUNDWATER

**LOCATIONS:** UK, Ghana, India, Sri Lanka

**LENGTH OF PROJECT:** 3 Years

**STARTING DATE:** 1988

**COLLABORATING ORGANISATIONS**

Water Resources Research Institute, Ghana

Danida Water Research Centre, India

Water Resources Board. Celan Institute of Scientific and Industrial Reserch, Sir Lanka

**PROJECT OBJECTIVES**

To compile a report on the nature, extent and methods of removal of iron from groundwater.

To publish a leaflet explaining the problem simply, for worldwide distribution.

Identify countries, particularly in Africa, where iron in groundwater is a problem, establish research initiatives with local organizations and develop pilot iron-removal plants.

**PROJECT RESULTS**

The report and leaflet were produced and given widespread circulation.

Positive responses were received from Sri Lanka and Ghana, although discussions about co-operation projects took place no project materialised before the project was terminated. A project proposal for work in Sri Lanka had been formulated but was cancelled due to lack of financial support.

An advisory visit to the Orissa Region of India was undertaken and a report compiled. There is potential for further advisory input.

## OUTPUT (Reports, Papers, & etc)

Gale, I N and Smedley, P L. 1989. Iron in Groundwater - A Summary of the Nature and Extent of the problem and the methods of removal. BGS Technical Report WD/89/29.

BGS Leaflet. Iron in Rural Groundwater.

## WORKSHOPS AND PRESENTATIONS

## PROJECT STAFF

I N Gale  
Dr P L Smedley

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K								20	7	18	45K

# IRON IN RURAL GROUNDWATER

## The problem

Iron-rich groundwater poses a serious problem in rural supplies from boreholes. Although these sources provide small supplies, usually equipped with hand pumps, large numbers are in use and consequently large rural populations depend upon them. Iron precipitates cause water discolouration and can impart an unpleasant metallic taste and odour to water as well as causing the staining of food and laundry and the clogging of well screens and pipework. Iron is not known to have any directly detrimental effects on human health, but in many places it is indirectly responsible for the spreading of disease, since iron-rich groundwaters are frequently abandoned in favour of surface sources which may be polluted and bacteriologically infected.

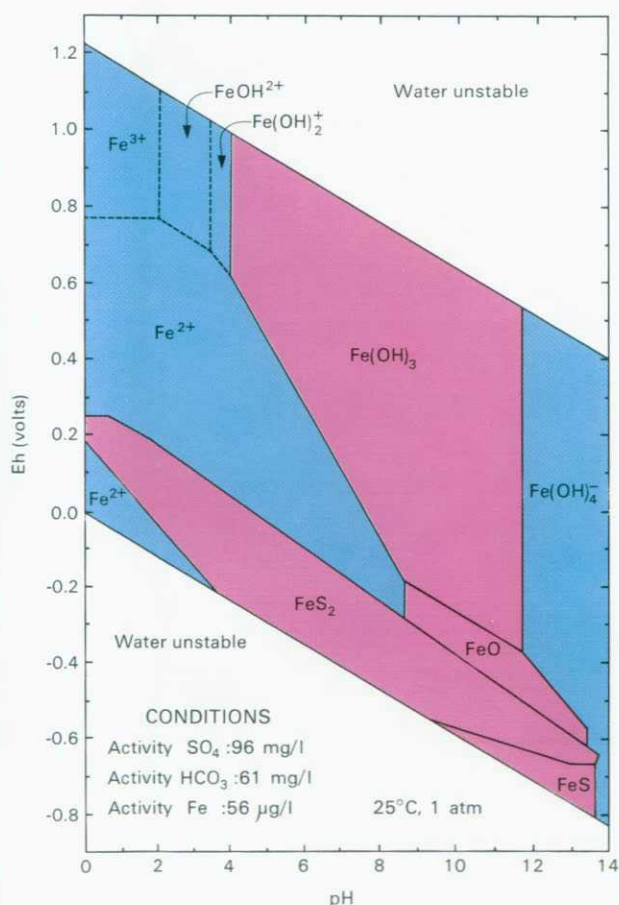
## Benefits of iron removal

WHO and US Public Health Service guidelines recommend 0.3 mg/l as the acceptable limit of iron in potable water, although in rural areas of developing nations an upper limit of 1 mg/l may be acceptable for most purposes. Many natural groundwaters contain iron in excess of these limits and require treatment prior to use. Treatment methods are relatively simple, being based principally on aeration and filtration, and are common practice in many parts of the world. If the use of treated groundwater can be encouraged in place of contaminated surface-water sources, incidences of water-transmitted disease can be greatly diminished in many places and water availability can be increased in arid climates where water supplies are otherwise limited.

## Hydrochemistry of iron

Iron is an abundant element in most rocks and soils and is present in ferrous casings, pumps and pipework. It can therefore be derived from many potential sources in aquifers and wells.

The concentrations of iron in natural waters are controlled by both physico-chemical and microbiological factors. The major physico-chemical controls are Eh (redox) and pH, although the activity of other ions is also important. The concentration of dissolved iron is generally high at low pH where, under reducing conditions the dominant form is aqueous ferrous iron,  $\text{Fe}^{2+}$ , or under oxidizing conditions it is in the ferric form as  $\text{Fe}^{3+}$  or minor  $\text{FeOH}^{2+}$  or  $\text{Fe(OH)}_2^+$ . Under oxidizing conditions at near-neutral pH, iron precipitates as iron hydroxide:  $\text{Fe(OH)}_3$ . It is this red-brown precipitate which is responsible for the problems of water discolouration, taste, staining and clogging inherent in iron-rich waters. The presence of other ions such as sulphur or carbon can have an important impact on iron mobility since these can promote the formation of pyrite ( $\text{FeS}_2$ ) or siderite ( $\text{FeCO}_3$ ) under reducing conditions.



Eh-pH diagram showing that under reducing conditions and at low pH, iron is predominantly in solution. In the presence of sulphur at low Eh, pyrite ( $\text{FeS}_2$ ) may be stable. Under oxidizing conditions at higher pH, iron hydroxide:  $\text{Fe(OH)}_3$  precipitates.

## Influence of organic compounds and bacteria

The presence of organic compounds in groundwater can on the other hand, significantly increase the concentration of iron held in solution since both ferrous and ferric iron will readily form complexes with organic matter, particularly fulvic and humic acids. Organic-rich water can therefore contain dissolved iron over a large range of redox conditions and the stability field of iron hydroxide will be significantly diminished. Organic



compounds can also indirectly affect iron mobility since organic matter may reduce the levels of oxygen in water, hence lowering Eh and may produce carbon dioxide which reduces pH.

An important additional factor involved in the mobility of iron in groundwater is the presence of bacteria. The group of so-called 'iron-bacteria', such as *Gallionella*, *Leptothrix* and *Thiobacillus* are particularly problematic. These gain energy for metabolism from the oxidation of  $Fe^{2+}$  and act as catalysts for the oxidation process. Bacterial oxidation of iron leads to the production of a red-brown slime on well casings and pipework and to subsequent clogging. Decay of these bacteria also produces unpleasant odours.

### Measuring iron concentrations in groundwater

Many problems are apparent in the sampling of groundwater for iron. Since the solubility of iron minerals is so strongly influenced by pH and redox variations, any changes in environmental conditions during sampling can rapidly change the sample composition. Measurement of pH, Eh, temperature and dissolved oxygen (which greatly affect iron mobility) should therefore be carried out immediately on site. Representative samples of groundwater are best taken after a period of well pumping such that stagnant water is purged prior to sample collection.

Differing sampling techniques can discriminate varying between total iron, particulate iron and dissolved iron, thus leading to potential interlaboratory discrepancies. For this reason, immediate on-site filtration of water samples is important and although the filter used is somewhat arbitrary, it has become conventional to use a  $0.45\mu m$  membrane filter to discriminate between dissolved and particulate forms of iron. The sample should be collected using an in-line filter which utilizes the pressure of the pump or by using a syringe with a filter attached.

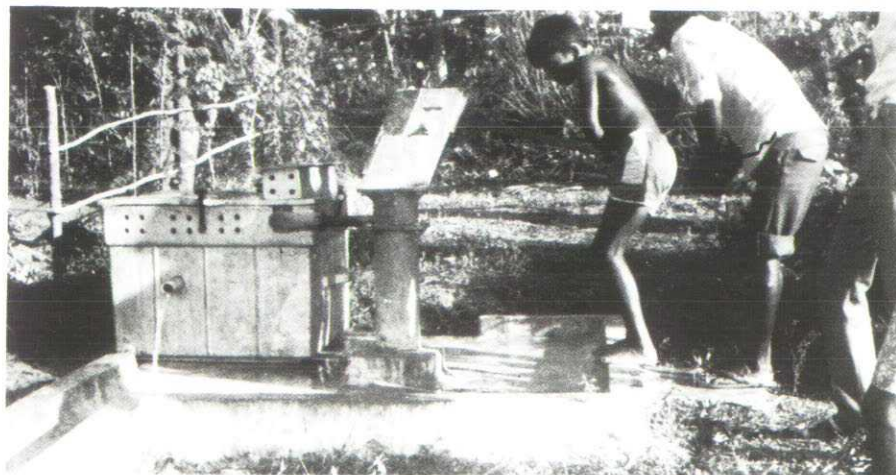
Samples must also be preserved by the addition of hydrochloric or nitric acid to reduce pH to  $<2$ . This is important because aeration of the sample both during sampling and subsequently could lead to the rapid precipitation of iron hydroxide. This reaction would result in analysed iron concentrations being much lower than true in-situ values.

### The occurrence of iron in groundwater

In countries where water resources are scarce and/or surface waters are polluted, the use of available groundwater supplies should be encouraged. Optimum water quality is best achieved by careful evaluation of accessible groundwater resources prior to the installation of wells and pumps. In areas where high-iron groundwaters are prevalent, an understanding of the redox and pH conditions of the aquifer, as well as aquifer composition, can help in locating potential sources of low-iron water. Knowledge of the hydrogeological regime is also important as generally, groundwater in unconfined, oxygenated aquifers contains little aqueous iron whilst that in confined aquifers may be reducing and hence iron-rich. In areas where groundwater has low pH and is aggressive, iron levels can be kept at a minimum by the installation of corrosion-resistant pumps and pipework rather than ferrous materials. In the absence of alternative low-iron sources of groundwater, low-cost iron-removal plants (IRP's) can be installed at well outlets. Such systems require regular cleaning and maintenance, without which their performance will rapidly decline. Involvement of the local community in the planning and construction of the iron-removal plant and training in maintenance methods is vital if the systems are to continue to provide potable water with acceptable levels of iron.

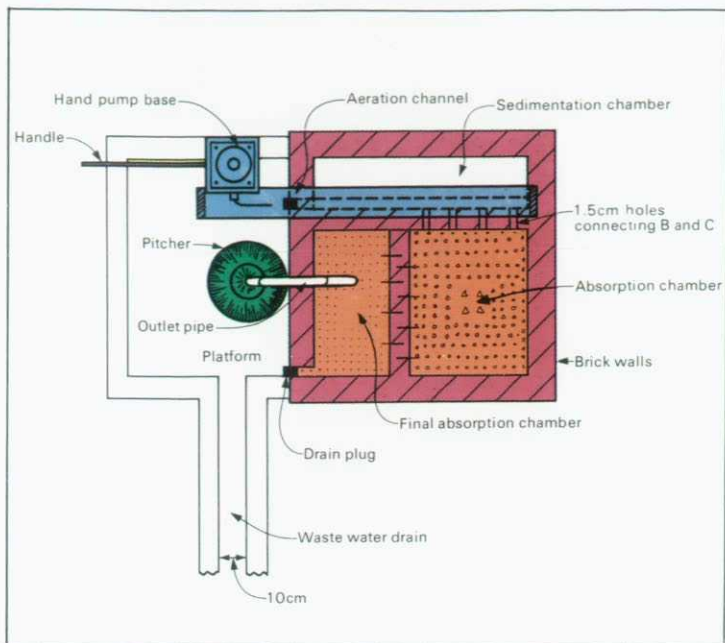
### Iron-removal plants

Many successful methods of removal of iron from groundwaters have been developed and vary in degree of sophistication with socio-economic factors. Methods generally take advantage of the fact that iron readily precipitates as hydroxide under oxidizing conditions, at least in organic-poor waters, and principally involve water aeration and subsequent filtration to remove precipitates. Iron-removal plants in developing nations need to be simple, low-cost, low-maintenance systems. One example developed for Bangladesh under UNICEF and Department of Public Health Engineering (DPHE) sponsorship involves aeration of water in an aeration



UNICEF iron-removal plant operating in Sri Lanka.

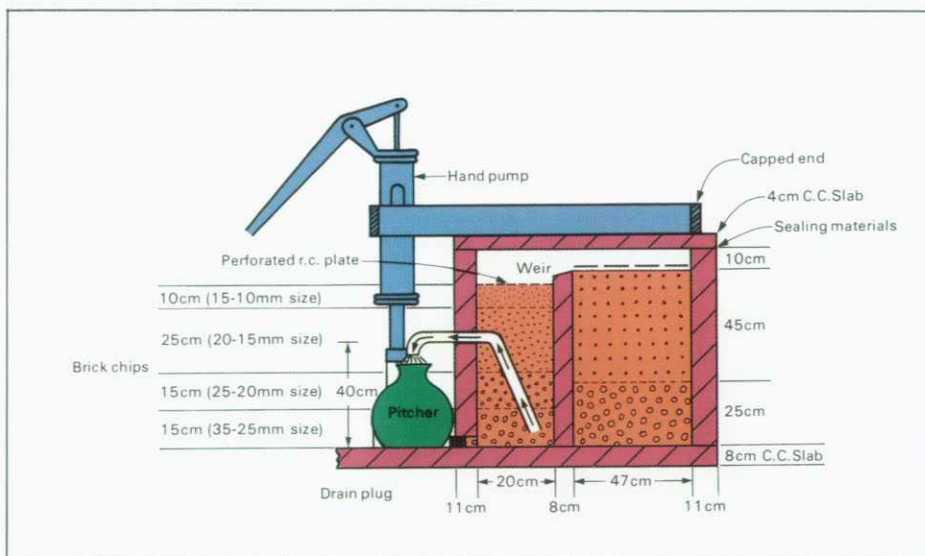




channel attached directly to the outlet pipe from a community tubewell. Precipitated iron hydroxide is then removed, firstly in a sedimentation chamber, followed by two filtration/adsorption chambers filled with graded brick chippings (Ahmed and Smith, 1987). After implementation of the system in Bangladesh, a survey of 180 plants showed a decrease in iron content from 13–15 mg/l to between 0.4 and 0.7 mg/l. Similar UNICEF-funded plants have been developed in Sri Lanka using fibre glass to construct the tanks instead of bricks or concrete.

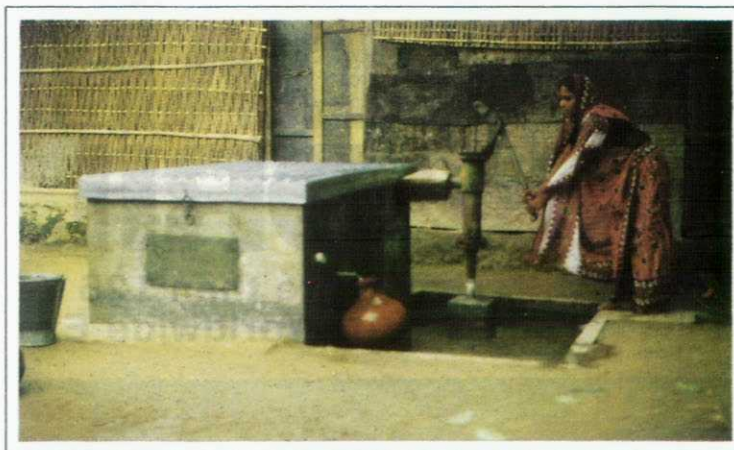
In Bangladesh, the original design developed problems with construction materials and maintenance, and consequently a revised version was developed (World Water, 1988). This simplified version has the advantage of cheaper construction and easier maintenance but is less effective than the original design at decreasing iron concentrations.

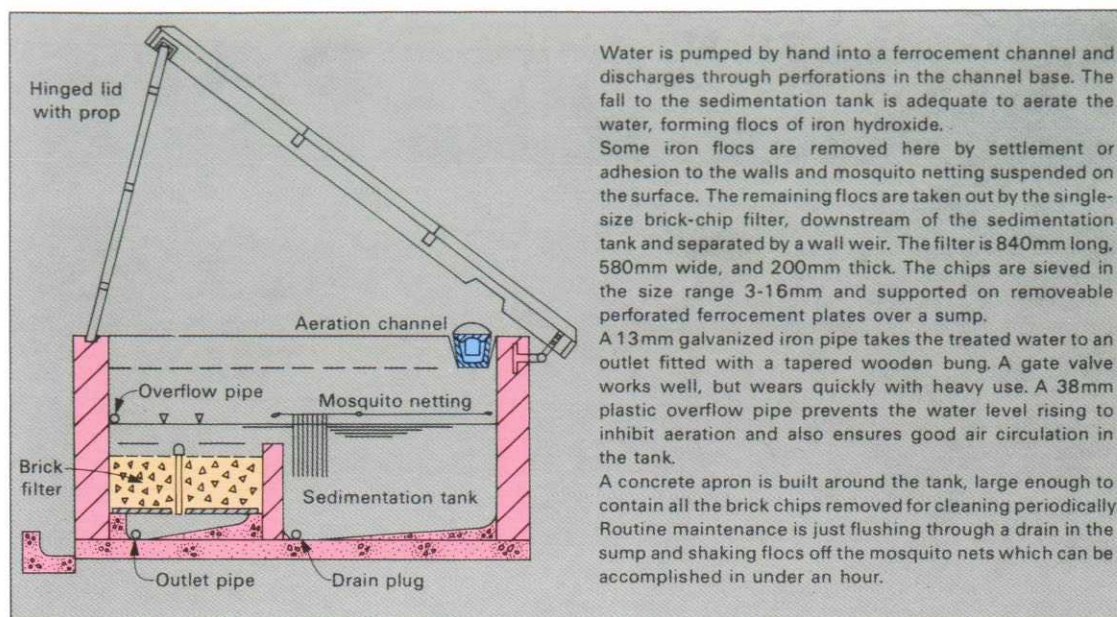
Plan of an iron-removal plant, Bangladesh (Ahmed and Smith, 1987).



Section of iron-removal plant, Bangladesh (Ahmed and Smith, 1987).

Iron-removal plant in Bangladesh (from World Water, 1988).





Revised design of iron-removal plant  
(from World Water, 1988).

Water is pumped by hand into a ferrocement channel and discharges through perforations in the channel base. The fall to the sedimentation tank is adequate to aerate the water, forming flocs of iron hydroxide.

Some iron flocs are removed here by settlement or adhesion to the walls and mosquito netting suspended on the surface. The remaining flocs are taken out by the single-size brick-chip filter, downstream of the sedimentation tank and separated by a wall weir. The filter is 840mm long, 580mm wide, and 200mm thick. The chips are sieved in the size range 3-16mm and supported on removeable perforated ferrocement plates over a sump.

A 13mm galvanized iron pipe takes the treated water to an outlet fitted with a tapered wooden bung. A gate valve works well, but wears quickly with heavy use. A 38mm plastic overflow pipe prevents the water level rising to inhibit aeration and also ensures good air circulation in the tank.

A concrete apron is built around the tank, large enough to contain all the brick chips removed for cleaning periodically. Routine maintenance is just flushing through a drain in the sump and shaking flocs off the mosquito nets which can be accomplished in under an hour.

#### Useful references

**Ahmed, F, and Smith, P G.** 1987. Design and performance of a community type iron-removal plant for hand pump tubewells. *Journal of the Institution of Water Engineers and Scientists*, Vol. 41, 167-172.

**Gale, I N, and Smedley, P L.** 1989. Iron in groundwater—a survey of the extent and nature of the problem and methods of removal. *Unpublished technical report WD/89/29, British Geological Survey, UK.*

**UNICEF.** 1987. Iron removal plant. Installation and maintenance manual. *Water and Sanitation Section, UNICEF, Colombo.*

**World Water.** 1988. Bangladesh remedies rusty water. *World Water*, September 1988, p.19.

#### Further enquiries:

Hydrogeological Research Group  
British Geological Survey  
Macleans Building  
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Funding for British Geological Survey (BGS) research into iron in groundwaters is provided by the Overseas Development Administration (ODA). BGS is a component body of the Natural Environment Research Council (NERC).

PROJECT NO: 19

**TITLE:** SALINE INTRUSION IN COASTAL AQUIFERS

**LOCATIONS:** UK

**LENGTH OF PROJECT:** 4 Years

**STARTING DATE:** 1981

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To develop 2D mathematical models of saline intrusion in aquifers to allow engineering decisions to be made as to optimum development of coastal and saline/fresh aquifers.

**PROJECT RESULTS**

The models were developed and tested using a case-history from Anguilla.

The areal model was concentrated on as it had more immediate and relevant application.

The model developed has been applied to problems in Kenya and Pakistan.



## OUTPUT (Reports, Papers, & etc)

Computer models as mentioned above

Barker, J A. 1985. Freshwater-Saltwater relations in Water Resources of Small Islands, Commonwealth Science Council Technical Publication No 154, p124-130.

Barker, J A. 1985. Coastal aquifer modelling in Water Resources of Small Islands, Commonwealth Science Council Technical Publication No 154, p243-254.

Barker, J A, Williams, A T and Adams, B. 1985. CAM: A finite-difference model for coastal aquifers. BGS Technical Report WD/OS/85/27. 82pp.

Barker, J A and Williams, A T. 1985. Experiences in modelling the freshwater lens of Anguilla. BGS Technical Report WD/OS/85/26. 21pp.

## WORKSHOPS AND PRESENTATIONS

Presentations at Water Resources of Small Islands Conference, Suva, Fiji 1984.

## PROJECT STAFF

Dr J A Barker  
A T Williams  
B Adams

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K	4	10	15	8							37k

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 20**

**TITLE:** HYDROGEOLOGICAL WORKSHOPS

**LOCATIONS:** Fiji, Honduras, Mexico,  
Zimbabwe

**LENGTH OF PROJECT:** 9 Years

**STARTING DATE:** 1981

**COLLABORATING ORGANISATIONS**

Commonwealth Science Council.

**PROJECT OBJECTIVES**

To introduce Hydrogeology to representatives from a region through a 1-2 week long workshop.

These workshops should stimulate groundwater studies in the region concerned and the better use of modern investigation and analytical techniques.

**PROJECT RESULTS**

Four Workshops covering the Pacific, Africa and Central America have been held introducing over 200 delegates from 69 countries to hydrogeology.

A training manual available in English and Spanish was produced for the Honduras workshop, and has subsequently been reprinted. Proceedings of the workshops in Fiji and Zimbabwe were published by the Commonwealth Science Council.

## OUTPUT (Reports, Papers, & etc)

Cook, J M, Edmunds, W M, Kinniburgh, D G and Lloyd, B, Course Manual Tegucigalpa, Honduras 1990. Field Techniques in Ground Water Quality Investigations. BGS Technical Report WD89/56.

Commonwealth Science Council. 1989. Groundwater Exploration and Development in Crystalline Basement Aquifer. CSC (89) WMR-13. Technical Publication 273 Volumes I and II. (Proceedings of Harare Workshop).

Commonwealth Science Council. 1985. Water Resources of Small Islands. CSC (85) WMR 2. Technical Publication No 154. Volumes I and 2.

Wright E P. 1984. Preliminary Report on the Workshop on Water Resources of Small Islands, Suva, Fiji, 1984. BGS Technical Report WD/OS/84/9.

## WORKSHOPS AND PRESENTATIONS

Workshops held in :

Location	Date	Participants	Countries	Topic
Fiji	1984	62	24	Water Resources of Small Islands
Mexico	1985	60	8	Development and Admin of Groundwater Resources
Zimbabwe	1987	71	29	Hydrogeology of Crystalline Basement
Honduras	1990	34	8	Groundwater Chemistry - A Practical Guide

## PROJECT STAFF

Dr W M Edmunds	Dr M J McFarlane
Dr D G Kinniburgh	Dr E P Wright
Dr D Greenbaum	Dr R L F Kay
Dr J A Barker	Dr R Herbert
Dr S S D Foster	
J M Cook	
B L Morris	
R Marks	

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K	17	15	7	40	35	30	61	29	39		273K

PROJECT NO: 21

**TITLE:** GEOTHERMAL RESEARCH

**LOCATIONS:** UK

**LENGTH OF PROJECT:** 4 Years

**STARTING DATE:** 1981

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To develop methods to investigate thermal anomalies using modelling techniques which can be used to design more cost-effective programmes of geothermal exploration.

To review electrical resistivity methods in geothermal exploration.

**PROJECT RESULTS**

The mathematical basis and the computational approach for determining anomalies caused by conductively cooling rectilinear and spherical bodies were examined. Hypothetical examples were considered and one real case (Vanuatu) was examined. It was suggested that further work should consider the effects of convective heat flow.

The relative merits of the various electrical methods used in geothermal exploration were reviewed. No single method emerged as superior to the others in all conditions. In many cases a combination of two or more methods was found to be desirable and integration with other exploration methods was considered to be important. An important limitation was found to be the depth of exploration. The methods often detect shallow conduits but not deep reservoirs.

## OUTPUT (Reports, Papers, & etc)

Burgess, W G and Barker, J A. 1984. Modelling thermal anomalies: conductive cooling of simple intrusions. BGS Technical Report WD/OS/84/18.

Burley, A J. 1985. Review of electrical methods in geothermal exploration. BGS Regional Geophysics Research Group Report 85/1.

## WORKSHOPS AND PRESENTATIONS

New Zealand Geothermal Workshop 1982

## PROJECT STAFF

W G Burgess  
J A Barker  
A J Burley

## PROJECT EXPENDITURE

YR	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K	8	15	18	21							62K

**TITLE:** HYDROTHERMAL ALTERATION IN GEOTHERMAL ASSESSMENT

**LOCATIONS:** Costa Rica

**LENGTH OF PROJECT:** 2 Years

**STARTING DATE:** 1985

**COLLABORATING ORGANISATIONS**

Instituto Costarricense de Electricidad (ICE)

**PROJECT OBJECTIVES**

To assess the use of alteration mineralogy as a guide to the characteristics of a geothermal field through field and analytical studies coupled with laboratory simulation experiments.

If successful the results will help plan geothermal exploration/exploitation programmes efficiently, yielding savings.

Studies will be based on the Miravalles Geothermal Field in Costa Rica.

**PROJECT RESULTS**

A detailed study of the mineralogy of drillcores from the Miravalles Geothermal Field, Costa Rica was undertaken.

The data give an improved insight into the evolution of this geothermal field in time and space. Modelling of these results will ensure optimal development of the Miravalles and neighbouring geothermal fields in Costa Rica.

## OUTPUT (Reports, Papers, & etc)

Burgess, W G and Milodowski, A E. 1985. Background notes for samples from Miravalles Field, Costa Rica. BGS Technical Report.

Milodowski, A E, Savage, D, Bath, A H, Fortey, N J, Nancarrow, P H A and Shepherd T. In Press. Hydrothermal Mineralogy in Geothermal Assessment: Studies of Miravalles Field, Costa Rica and Experimental Simulations of Hydrothermal Alteration BGS Technical Report No WE/89/63.

## WORKSHOPS AND PRESENTATIONS

## PROJECT STAFF

Dr W G Burgess  
Dr A H Bath  
A E Milodowski  
Dr N J Fortey  
Dr D Savage

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K.					49	64					113K

ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM

FORM A3

PROJECT NO: 23

**TITLE:** SOIL GAS GEOCHEMISTRY METHODS APPLIED TO GEOTHERMAL EXPLORATION

**LOCATIONS:** Costa Rica, Kenya

**LENGTH OF PROJECT:** planned for 2 years  
So successful stopped prematurely after 1 year

**STARTING DATE:** 1987

**COLLABORATING ORGANISATIONS**

Instituto Costarricense de Electricidad, Costa Rica (ICE)  
Ministry of Energy and Rural Development, Kenya (MERD)

**PROJECT OBJECTIVES**

To assess a recently developed portable soil-gas detection system as a reconnaissance tool for geothermal prospecting in conjunction with on-going TC studies in Kenya, and with ICE at their Miravalles Geothermal Field in Costa Rica.

**PROJECT RESULTS**

The techniques proved to be so successful in delineating geothermal zones that this R&D project was stopped after one year and the technique was incorporated as a routine exploration tool in the on-going TC studies in Kenya.

In Costa Rica at the Miravalles Geothermal Field four zones with copious dangerous gas emissions of CO<sub>2</sub>, Radon and Thoron were identified. These constitute a major health risk and recommendations were made for the safer siting of the power generating facility for the ICE geothermal energy project.

A further geothermal prospect at nearby Rincon de la Vieja Volcano was written-off on the basis of preliminary gas geochemistry studies thus providing substantial savings for ICE in terms of exploration costs.



## OUTPUT (Reports, Papers, & etc)

Ball, T K. 1987. Soil-gas geochemical methods applied to geothermal exploration. BGS Technical Report.

Ball, T K and Stuart M E. 1988. Soil-gas geochemical methods applied to geothermal exploration. Distribution of volatile elements in soils surrounding fumaroles.

Ball, T K. 1988. Soil-gas geochemical methods applied to geothermal exploration. Report on a visit to Costa Rica. BGS Technical Report WC/88/15R.

Ball, T K and Clarke M C G. 1991. Gas geochemistry in exploration for geothermal energy sources. Proceedings International Colloquium on Gas Geochemistry, Mons, Belgium (1990).

## WORKSHOPS AND PRESENTATIONS

Field Demonstrations to MERD Scientists in Kenya of soil gas geochemistry techniques.

## PROJECT STAFF

Dr T K Ball  
R A Nicholson

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K							25				25K

PROJECT NO: 24

**TITLE:** EVALUATION OF GAS GEOTHERMOMETRY FOR GEOTHERMAL EXPLORATION

**LOCATIONS:** Djibouti, Ethiopia, Kenya

**LENGTH OF PROJECT:** 1 Year

**STARTING DATE:** 1990

**COLLABORATING ORGANISATIONS**

Institut Supérieur D'Etudes et des Recherches Scientifiques et Techniques, Djibouti.

Ethiopian Institute of Geological Surveys.

Kenya Power and Light Company

**PROJECT OBJECTIVES**

To develop a system of gas geothermometry applicable to the East African Rift and to evaluate its use as a geothermal exploration tool

This project seeks to build on existing ODA/BGS TC and R&D work in Kenya and extend its application to Ethiopia and Djibouti

**PROJECT RESULTS**

All analyses are now on a database with the exception of some total carbon concentrations which are required to calculate gas/steam ratios. These results are expected shortly. Once they are received, all gas analyses can be run through the installed geothermometry equations and the results evaluated. Any other emerging relationships with known downhole temperatures will also be analysed.

## OUTPUT (Reports, Papers, & etc)

Gas Geothermometry in the East African Rift System, in preparation. BGS Technical Report.

## WORKSHOPS AND PRESENTATIONS

International Conference On Geochronology, Cosmochronology and Isotope Geology 1990.

## PROJECT STAFF

W G Darling  
J C Talbot

## PROJECT EXPENDITURE

[illegible]

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 25**

**TITLE:** SMALLER COAL BASINS IN AFRICA

**LOCATIONS:** Botswana, Malawi, Tanzania,  
Zambia, Zimbabwe

**LENGTH OF PROJECT:** 2 Years

**STARTING DATE:** 1986

**COLLABORATING ORGANISATIONS**

Geological Survey of Botswana  
Geological Survey of Malawi  
Mining Investment Development Corporation, Malawi  
State Mining Corporation of Tanzania  
Geological Survey of Zambia  
Geological Survey of Zimbabwe  
British Mining Consultants Ltd

**PROJECT OBJECTIVES**

To acquire and synthesize available basic geological information related to the resources of the smaller coal basins of Botswana, Malawi, Tanzania, Zambia and Zimbabwe.

To review this information and undertake field studies, leading to the compilation of an authoritative account to guide future exploration efforts and to assess the economic and strategic importance of the coal resources.

**PROJECT RESULTS**

The thorough review article listed overleaf meets the project objectives and provides background for future planning and development.

A key finding however is that at present economics militate against any large-scale exportation of these coal resources due primarily to the high overland transport costs to markets and ports from these landlocked countries. Local demand is largely catered for by existing operations.

Nevertheless Malawi and Zambia have expressed interest in further evaluation of their coal resources including drilling programmes through TC projects.

## **OUTPUT (Reports, Papers, & etc)**

Bennett, J D. 1987. Smaller Coal Basins In Africa - Malawi Field Report BGS Technical Report MP/87/36R.

Bennett, J D. 1989. Review of Lower Karoo coal basins and coal resource development in parts of central and southern Africa with particular reference to northern Malawi. BGS Technical Report WC/89/21.

## **WORKSHOPS AND PRESENTATIONS**

## **PROJECT STAFF**

Dr J D Bennett

## **PROJECT EXPENDITURE**

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K						22	64				86K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 26**

**TITLE:** AN INVESTIGATION INTO THE FEASIBILITY OF USING AQUIFERS FOR SEASONAL STORAGE OF HEAT AND/OR CHILL IN DEVELOPING COUNTRIES

**LOCATIONS:** Jordan (Proposed)

**LENGTH OF PROJECT:** 1 Year

**STARTING DATE:** 1990

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To investigate the feasibility of using aquifers for the seasonal storage of heat and chill.

To develop computer models to simulate storage and recovery of energy at promising locations. Jordan was selected for initial study.

**PROJECT RESULTS**

A literature survey was undertaken

Field studies in Jordan were cancelled due to the 'Gulf Crisis' and the project was abandoned. The topic remains valid for future consideration.

## OUTPUT (Reports, Papers, & etc)

Kitching, R. An investigation into the feasibility of using Aquifers for Seasonal Storage of Heat and/or Chill in developing countries. BGS Technical Report WD/91/19. .

Kitching, R. In Press Groundwater Heat Pumps and Aquifer Heat Storage. BGS Technical Report.

## WORKSHOPS AND PRESENTATIONS

## PROJECT STAFF

**Dr R Kitching**

## PROJECT EXPENDITURE

[illegible]

**TITLE:** ENGINEERING GEOLOGY OF COHESIVE SOILS ASSOCIATED WITH OPHIOLITES

**LOCATIONS:** UK Cyprus

**LENGTH OF PROJECT:** 4 Years

**STARTING DATE:** 1983

**COLLABORATING ORGANISATIONS**

Geological Survey Department, Cyprus  
Public Works Department, Cyprus  
Water Development Department of Cyprus

**PROJECT OBJECTIVES**

Cohesive soils especially those rich in bentonite can cause considerable engineering problems due to their shrinkage/swelling properties. In ophiolite terrains, these problems are exacerbated as the clay formations are often extensively sheared as a result of their complex tectonic stress history.

In Cyprus, clays of this type failed causing widespread landslippage and £17.5 million of damage associated with the 1953 Paphos earthquake and abnormally high winter rainfalls in ensuing years.

This project investigated such problems in Cyprus in order to:

- a) Classify the soils geotechnically enabling mapping and prediction of their engineering behaviour
- b) Establish the extent and type of landslipping and formations most prone to failure, and identify the factors controlling slope instability.
- c) Guide planners especially in siting key engineering structures and villages threatened by out-going shore movements.

**PROJECT RESULTS**

Over 5000 tests have been performed on cohesive soil samples from Cyprus; databased and analysed, enabling them to be classified in engineering terms.

Practical recommendations and guidelines for future construction have been issued. The Engineering geology maps produced are being used by Cypriot authorities to plan infrastructure development (roads, powerlines resiting villages).

The results have been widely disseminated.

Based on this work, BGS was invited to contribute to the CEC - Epoch (European Programme on Climatology and Natural Hazards) programme studying rainfall - induced landslips in the mountainous regions of Europe in collaboration with 2 Italian and 1 Greek Universities.

A CASE studentship supervised by BGS and Imperial College, London is extending the work further, the study includes utilization of satellite imagery.



## **OUTPUT (Reports, Papers, & etc)**

- Charalambous, M, Hobbs P R N and Northmore, K J. 1986. Supplementary geotechnical and mineralogical data for cohesive soil samples from selected sites across Cyprus. BGS Report No EGARP-KW/86/5.
- Gostelow, T P and Loucaides, G. 1986. Investigation of a landslide in the Moni Formation, Pendakomo, Cyprus. BGS Report No EGARP-KW/86/2.
- Hobbs, P R N. 1986. Preliminary geotechnical investigation of the Pliocene marl in the Polis area, Cyprus. BGS Report No EGARP-KW/86/3.
- Hobbs, P R N, Loucaides, G and Petrides G. 1986. Geotechnical properties and behaviour of the Pliocene marls in Nicosia, Cyprus. BGS Report No EGARP-KW/86/1
- Northmore, K J, Charalambous, M, Hobbs, P R N and Petrides, G. 1986. Engineering geology of the Kannaviou, Melange and Mamonia Complex Formations in the Phiti/Statos areas, SW Cyprus. BGS Report No EGARP-KW/86/4.
- Northmore, K J. 1987. Engineering geology of cohesive soils associated with the ophiolites project 1982-7 Final Report to ODA BGS Technical Report EGARP KW/86/6.
- Northmore, K J, Charalambous, M and Hobbs, P R N. 1987. Engineering geological map of the Phiti area, S W Cyprus (1:10 000 scale). Colour printed, showing landslide distribution and classification, hydrological and erosional details on geological/topographical base for 40 km<sup>2</sup> area in geologically-complex landslide-prone terrain.
- Northmore, K J, Charalambous, M, Hobbs, P R N and Kyriakou, E. 1987. Engineering geological map of the Statos area, SW Cyprus (1:10 000 scale). Colour printed, showing landslide distribution and classification, hydrological and erosional details on geological/topographical base for 63 km<sup>2</sup> area in geologically complex landslide-prone terrain.
- Gostelow, T P and Loucaides, G. 1988. A first-time landslide in Moni Melange, Cyprus. Proceedings of the V<sup>th</sup> Int. Symposium on Landslides, Lausanne, Switzerland.
- Northmore K J. 1988. Report on the Seminar presentation of Project Results Paphos-Nicosia, October 1988. BGS Technical Report WN/88/21.
- Northmore K J, Hobbs, P R N, Charalambous, M and Petrides, G. 1988. Complex landslides in the Kannaviou, Melange and Mamonia Formations of SW Cyprus. Proceedings of the V<sup>th</sup> Int. Symposium on Landslides, Lausanne, Switzerland. Ed C Bonnard A A Balkema.

## **WORKSHOPS AND PRESENTATIONS**

V<sup>th</sup> International Symposium on Landslides, Lausanne, Switzerland 1988.

Seminar to present and discuss project results to engineers and planners, Paphos-Nicosia, Cyprus 1988.

## PROJECT STAFF

C R Cratchley  
D C Entwisle  
P R N Hobbs  
K J Northmore

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			53	43	56	14					166K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 28**

**TITLE:** EARTHQUAKE PREDICTION RESEARCH

**LOCATIONS:** Turkey

**LENGTH OF PROJECT:** 3 Years

**STARTING DATE:** 1983

**COLLABORATING ORGANISATIONS**

Kandilli Observatory, Turkey  
Istanbul Technical University, Turkey

**PROJECT OBJECTIVES**

To investigate the potential of measuring stress-induced cracks as a method of predicting earthquakes.

This project utilizes data gathered from the Marmara Sea Seismograph Network installed by ODA/BGS Technical Assistance Programme 1976-1981.

**PROJECT RESULTS**

It was established that the crust around the site of the seismic network is predated by stress-aligned water-filled microcracks, probably to a depth of at least 10km. This internal structure controls the behaviour of seismic shear waves recorded at the surface. If the stress changes before an earthquake, the most immediate effect would be to modify the geometry of these microcracks, which would be expected to modify the behaviour of the shear waves. We could not find any changes with time in the Turkish data (there were no large earthquakes nearby), but changes are believed to have been identified before and after one medium sized earthquake in California, and one small earthquake in Arkansas. Thus, although not successful in Turkey, the ideas from Turkey have been confirmed elsewhere, and the research begun in Turkey continues.

This was the first time that such behaviour of shear waves had been correctly interpreted, and these ideas have now been more or less thoroughly incorporated into seismological knowledge. The largest effect was in the oil industry where many groups now investigate such shear-wave propagation. It has been the most fundamental advance in seismology for several decades, and this experiment in Turkey started it off.

There were several publications directly deriving from this work, but now probably a hundred or more by BGS and others, directly stimulated by this work. There have been many sessions at meetings and several international workshops devoted to the subject. This was a pioneering project which has opened a new area (shear waves) to seismological investigation.

## **OUTPUT (Reports, Papers, & etc)**

- Crampin, S, Evans, R and Üçer, S B. 1985. Analysis of records of local earthquakes: the Turkish Dilatancy Projects (TDP1 and TDP2), *Geophys. J. R. astr. Soc.*, 83, 1-16.
- Üçer, S B, Crampin, S, Evans, R, Miller, A and Kafadar, N. 1985. The MARNET radiolinked seismometer network spanning the Marmara Sea and the seismicity of Western Turkey, *Geophys. J. R. astr. Soc.*, 83, 17-30
- Booth, D C and Crampin, S. 1985. Shear-wave polarizations on a curved wavefront at an isotropic free-surface, *Geophys. J. R. astr. Soc.*, 83, 31-45.
- Doyle, M, Crampin, S, McGonigle, R and Evans, R. 1985. Joint inversion of arrival times in a region of dilatancy anisotropy, *Pure App. Geophys.*, 123, 375-387.
- Evans, R, Asudeh, I, Crampin, S and Üçer, S. 1985. Tectonics of the Marmara Sea region of Turkey: new evidence from micro-earthquake fault plane solutions, *Geophys. J. R. astr. Soc.*, 83, 47-60.
- Booth, D C, Crampin, S, Evans, R and Roberts, G. 1985. Shear-wave polarizations near the North Anatolian Fault - I. Evidence for anisotropy-induced shear-wave splitting, *Geophys. J. R. astr. Soc.*, 83, 61-73
- Crampin, S and Booth, D C. 1985. Shear-wave polarizations near the North Anatolian Fault - II. Interpretation in terms of crack- induced anisotropy, *Geophys. J. R. astr. Soc.* 83.75-92.
- Crampin, S and Evans, E. 1986. Neotectonics of the Marmara Sea region of Turkey, *J. geol. Soc.* 143, 343-348.
- Evans, R, Beamish, D, Crampin, S and Üçer, S B. 1987. The Turkish Dilatancy Project (TDP3): multidisciplinary studies of a potential earthquake source region, in *Proc. Second Int. Workshop on Seismic Anisotropy, Moscow, 1986*, editors D C Booth, S Crampin and E M Chesnokov, *Geophys. J. R. astr. Soc.*, 91, 265-286.
- Chen, T-C, Booth, D C and Crampin, S. 1987. Shear-wave polarizations near the North Anatolian Fault - III. Observations of temporal changes, in *Proc. Second Int. Workshop on Seismic Anisotropy, Moscow, 1986*, editors D C Booth, S Crampin and E M Chesnokov, *Geophys. J. R. astr. Soc.*, 91, 287-311.
- Lovell, J, Crampin, S, Evans, R and Üçer, B. 1987. Microearthquakes in the TDP swarm, Turkey: clustering in time and space, in *Proc. Second Int. Workshop on Seismic Anisotropy, Moscow, 1986*, ed. D C Booth, S Crampin and E M Chesnokov, *Geophys. J. R. astr. Soc.*, 91, 313-330.

## **WORKSHOPS AND PRESENTATIONS**

Numerous presentations at:

IASPEI meeting Tokyo 1985

2nd International Workshop on Seismic Anisotropy, Moscow, USSR, 1986

3rd International Workshop on Seismic Anisotropy, Berkeley, USA, 1988

4th International Workshop on Seismic Anisotropy, Edinburgh, UK, 1990

5th International Workshop on Seismic Anisotropy, Bamff, Canada, 1992

## PROJECT STAFF

Dr S Crampin  
Dr R Evans  
Dr D Beamish  
A Miller  
J H Lovell  
Dr D Booth

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			165	166	125						456K

ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM

FORM A3

PROJECT NO: 29

**TITLE:** DEVELOPMENT OF GEOCHEMICAL FIELD METHODS

**LOCATIONS:** UK

**LENGTH OF PROJECT:** 7 Years with extensions

**STARTING DATE:** 1983

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To develop rapid chemical tests for use by exploration geologists and geochemists on-site or in a field laboratory. This facilitates rapid recognition of target areas for more detailed exploration.

The work benefits geologists by providing immediate information in the field, central analytical laboratories by reducing the number of barren samples to be handled, and host countries by reducing survey time and costs. The range of geochemical exploration techniques is thus enhanced, without the need for equipment that is either expensive or inappropriate in a developing country.

**PROJECT RESULTS**

Over a dozen reports and handbooks (overleaf) have been produced describing rapid detection methods for key elements, compounds and minerals.

These have been distributed to BGS staff working worldwide.

Field kits and summary handbooks were prepared as part of a subsequent ODA/BGS R&D project.

## OUTPUT (Reports, Papers, & etc)

Peachey, D, Vickers, B P and Roberts, J L. 1982. Field Methods Project 1. A rapid field test for copper in soils. Analytical Chemistry Unit Report, Institute of Geological Sciences, No.130.

Peachey, D, Vickers, B P, Haslem, H W and Roberts, J L. 1983. Field Methods Project. 2. Rapid field test for molybdenum in sediments and soils. Analytical Chemistry Unit Report, Institute of Geological Sciences, No.131.

Roberts, J L, Vickers, B P and Peachey, D. 1984. Field Methods Project. 3. Rapid turbidimetric determination of water-soluble sulphate. Analytical Chemistry Research Group Report, British Geological Survey, No.84/2.

Peachey, D, Vickers, B P and Roberts, J L. 1984. Field Methods Project. 4. A new rapid method for estimating levels of extractable heavy metals in geochemical survey samples. Analytical Chemistry Research Group Report, British Geological Survey, No.84/4.

Peachey, D, Vickers, B P and Roberts, J L. 1985. Field Methods Project. 5. Acid attack of geochemical survey samples: a chemical phase analysis approach. Analytical Chemistry Research Group Report, British Geological Survey, No.85/5.

Roberts, J L and Peachey, D. 1985. Field Methods Project. 6. Staining tests for mineral grains; sphalerite, galena and their secondary minerals. Analytical Chemistry Research Report, British Geological Survey, No.85/6.

Peachey, D, Roberts, J L and Vickers, B P. 1985. Field Methods Project. 7. Tests for molybdenum and copper in mineral grains. Analytical Chemistry Group Report, British Geological Survey, No.85/10.

Peachey, D, Aucott, J W, Roberts, J L, Vickers, B P and Bloodworth, A J. 1986. Rapid colorimetric test to differentiate between bauxite-rich material and clay in exploration samples. Applied Geochemistry, Vol.1, no.4.

Peachey, D, Roberts, J L and Vickers, B P. 1986. Field Methods Project. 8. The background to chemical field methods. Analytical Chemistry Research Group Report, British Geological Survey, No.86/1.

Vickers, B P, Peachey, D and Roberts, J L. 1986. Field Methods Project. 9. An investigation into the determination of ammonium in rocks. Analytical Chemistry Research Group Report, British Geological Survey, No.86/6.

Peachey, D, Roberts, J L and Vickers, B P. 1986. Development of geochemical field methods, Technical Information Report No 1. Application of soil organic matter to geochemical exploration. Analytical Chemistry Report, British Geological Survey.

Roberts, J L, Peachey, D and Vickers, B P. 1987. Rapid chemical methods for use in geochemical surveys overseas. Overseas Directorate Report, British Geological Survey MP/87/22.

Roberts, J L, Peachey, D and Vickers, B P. 1988. Rapid chemical methods for use in geochemical surveys overseas. Part 2. Industrial or bulk minerals. British Geological Survey Technical Survey Technical Report WE/88/26R.

## OUTPUT (Reports, Papers, & etc)

Vickers, B P. 1988. Development of geochemical field methods, Technical Information Report No 2. Health and safety aspects for a rapid method for the estimation of arsenic. Analytical Chemistry Report, British Geological Survey.

Ball, T K, Peachey, D and Vickers, B P. 1989. Soil gas techniques for use in geochemical surveys overseas. British Geological Survey Technical Report WI/89/8.

Sandon, P T S, Peachey, D and Vickers, B P. 1989. Field Methods Project. 10. Assessment of methods for the determination of the chemical reactivity, and hence the agronomic potential, of African phosphate rocks. British Geological Survey Technical Report WI/89/5.

Ridgway, J, Peachey, D, Vickers, B P and Midobatu, C. 1989. Pometia pinnata: A possible biogeochemical indicator species in tropical rainforest environments. British Geological Survey Technical Report WC/89/14.

Bradley, A D, Vickers, B P, Peachey, D and Levinson, A A. 1990. The geochemical significance of two different chemical attacks used in ammonium geochemistry. Applied Geochemistry, Vol.5, No.4.

Piper, D, Vickers, B P and Peachey, D. (In preparation). Field testing of gold exploration samples: rapid As determination and Au gain counting.

## WORKSHOPS AND PRESENTATIONS

## PROJECT STAFF

D Peachey  
B P Vickers  
J L Roberts

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			13	19	24	23	24	26	24		153K



**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**  
**PROJECT NO: 30**

**TITLE:** DEVELOPMENT OF STANDARD FIELD KITS FOR GEOCHEMICAL RECONNAISSANCE AND PUBLICATION OF TECHNIQUES HANDBOOKS

**LOCATIONS:** UK

**LENGTH OF PROJECT:** 1 Year

**STARTING DATE:** 1990

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To develop standard field kits for use in geochemical reconnaissance surveys, this continues the work of an earlier BGS/ODA R&D Project on chemical field methods. (No 29, this volume).

To publish three complementary handbooks describing chemical field methods developed by BGS/ODA R&D projects in recent years.

**PROJECT RESULTS**

Prototype field kits for copper and arsenic have been constructed, and will undergo field trials when a suitable opportunity arises. Field kits for other chemical tests can be provided as and when required. A field-laboratory test for tungsten is being evaluated as part of the BGS/ODA TC Midland Goldfields Project, Zimbabwe, with a view to a suitable kit being produced.

The 3 handbooks are written and will all be published shortly.

Roberts, J L, Peachey, D and Vickers, B P. 1987. Rapid Chemical Methods for use in geochemical surveys overseas Part 1 BGS Technical Report MP/87/22.

Roberts, J L, Peachey, D and Vickers, B P. 1988. Rapid Chemical Methods for use in geochemical surveys overseas Part 2 Industrial or Bulk minerals BGS Technical Report WE/88/26R.

Ball, T K, Peachey D and Vickers, B P. 1989. Soil-Gas techniques for use in geochemical surveys BGS Technical Report W1/89/8.

**Peachey, D and Vickers, B P. 1990. Discussion on the development of a general field kit for geochemical exploration. BGS Technical Report W1/90/2.**

**The Three Handbooks are:-**

Vickers, B P, Peachey, D and Roberts, J L. 1991. Geochemical Methods Handbook 1. Rapid chemical methods for use in geochemical surveys overseas.

Vickers, B P, Peachey, D and Roberts, J L. 1991. Geochemical Methods Handbook 2. Rapid chemical methods for use in geochemical surveys overseas: Industrial or bulk minerals.

Ball, T K, Peachey D and Vickers, B P. 1991. Geochemical Methods Handbook 3. Soil-gas techniques for use in geochemical surveys overseas.

## PROJECT STAFF

R A Nicholson  
B P Vickers  
Dr T K Ball

## PROJECT EXPENDITURE

[illegible]

ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM

FORM A3

PROJECT NO: 31

**TITLE:** REGIONAL GEOCHEMICAL STUDIES: PRECAMBRIAN TERRAIN

**LOCATIONS:** Bolivia

**LENGTH OF PROJECT:** 2 Years

**STARTING DATE:** 1983

**COLLABORATING ORGANISATIONS**

Servicio Geologico de Bolivia (GEOBOL)  
Corporacion Minera de Bolivia (COMIBOL)

**PROJECT OBJECTIVES**

To synthesize geochemical information gathered during the ODA/BGS TC "Proyecto Precambrico" (1976-1983) project and produce a geochemical atlas of the data.

To develop techniques for geochemical atlas production.

**PROJECT RESULTS**

The folio-size atlas was produced in 1985 and it's availability widely advertised, there has been considerable interest in the atlas from industry.

The methods developed in producing the atlas have been applied to other ODA/BGS geochemical atlas publications.

## OUTPUT (Reports, Papers, & etc)

Appleton, J D, and Llanos A. 1985. Atlas Geoquimico de Bolivia Oriental. BGS.

Appleton, J D and Ridgway J. In Press. Drainage geochemistry in Tropical Rain Forest areas in Handbook of Exploration Geochemistry.

Appleton, J D and Llanas, A. In Press. The Importance of Fe and LoI for the interpretation of Cu, Pb, U and Zn in stream sediments: some examples from the Precambrian Shield area of Eastern Bolivia. Proceedings of AGID workshop on Geochemical Exploration in Tropical Rain Forests, Manaus, Brazil 1985.

Appleton, J D, Jones, R C and Ridgway J. In Press. Spatial representation of geochemical data - examples from eastern Bolivia and the Solomon Islands. Proceedings of AGID Workshop on Geochemical Exploration in Tropical Rain Forests, Manaus, Brazil 1985.

## WORKSHOPS AND PRESENTATIONS

Poster Presentation at

"Spatial Representation of Geochemical Data" International Geochemical Exploration Symposium, Toronto, Canada 1985.

Two papers presented at

AGID's Conference "Geochemical Exploration in Tropical Rain Forests" Manaus Brazil 1985.

## PROJECT STAFF

Dr J D Appleton

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			18	7							25K

**TITLE:** INTEGRATION OF GEOCHEMICAL DATA FROM ODA TC PROJECTS INTO A WORLD GEOCHEMICAL MAP SERIES

**LOCATIONS:** UK

**LENGTH OF PROJECT:** 2 Years

**STARTING DATE:** 1989

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To process ODA/BGS Geochemical data into a format suitable for incorporation into a worldwide series of superficial geochemical maps being organized by the International Geological Correlation Programme (IGCP).

Using existing ODA/BGS regional geochemical datasets, to produce a comparative series of geochemical maps by means of different data processing algorithms and from this make recommendation on ways of incorporating existing datasets into a world geochemical map series. Particular attention to be paid to the effects of widely spaced sampling.

**PROJECT RESULTS**

Geochemical maps of E. Bolivia, N.E. Zimbabwe and parts of Kenya, Solomon Islands and Indonesia have been produced using two different algorithms to simulate a series of decreasing sample densities. Results show that meaningful geochemical patterns can persist to densities as low as 1 sample per 500 km<sup>2</sup> but the scale of geological features and original density of the dataset are important factors in limiting the amount of data reduction which is feasible.

## OUTPUT (Reports, Papers, & etc)

Ridgway J, Appleton, J D and Greally, K. In Press. Variations in regional geochemical patterns - effects of site selection and data processing algorithms. Transaction of Institute of Mining and Metallurgy.

## WORKSHOPS AND PRESENTATIONS

## Presentations at

**International Geological Congress, Washington, USA 1989**

14th International Geochemical Exploration Symposium Prague, Czechoslovakia 1990

## PROJECT STAFF

**Dr J Ridgway**

Dr J D Appleton

**K Greally**

## PROJECT EXPENDITURE

[illegible]

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 33**

**TITLE: GAS AND VEGETATION GEOCHEMISTRY IN THE SEARCH FOR BURIED ORE BODIES**

**LOCATIONS:** Botswana

**LENGTH OF PROJECT:** 2 Years

**STARTING DATE:** 1988

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To examine the potential of gas and vegetation geochemistry as a tool for buried ore bodies.

If successful gas and vegetation geochemistry would considerably reduce initial exploration costs compared with the traditional geophysics and drilling programmes.

Little has been done in this field so the techniques will be first tried over known buried ore-bodies in NW Botswana to gauge their effectiveness.

**PROJECT RESULTS**

The project demonstrated that gas geochemistry can be used successfully to indicate the presence of buried ore bodies under at least 12m of overburden. A new microbial technique based on the use of *Bacillus Cereus* also showed promise. Results from the use of vegetation were more difficult to interpret, largely because the arid environment made it difficult to find a uniform distribution of a single plant species at a constant stage of growth.



### OUTPUT (Reports, Papers, & etc)

Ball, T K, Graw, M J, Laffoley, N, Piper, D and Ridgway J. 1990. Application of soil-gas geochemistry to mineral exploration in Africa Journal of Geochemical Exploration 38, 103-115.

Parduhn, N. 1991. Bacillus cereus and soil geochemical results from Soil Traverses. Botswana, Africa. Cereus Exploration Technologies Inc 5p + 4 pp + Appendice..

Final report in preparation.

### WORKSHOPS AND PRESENTATIONS

### PROJECT STAFF

Dr J Ridgway

Dr T K Ball

K Greally

### PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K								45	55		100K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 34**

**TITLE:** APPLICATION OF ROCK GEOCHEMISTRY TO MINERAL EXPLORATION

**LOCATIONS:** Bolivia Peru

**LENGTH OF PROJECT:** 2 Years

**STARTING DATE:** 1985

**COLLABORATING ORGANISATIONS**

Corporacion Minera de Bolivia (COMIBOL)  
Servicio Geologico de Bolivia (GEOBOL)  
Instituto Geologico Minero Metalurgico (INGEMMET), Peru

**PROJECT OBJECTIVES**

Detection of 'Haloes' associated with tin and polymetallic provinces in the Andean Chain of Bolivia and Peru.

Formulation of zonation models which will be useful in rock geochemical exploration surveys.

Establish new guidelines for litho-geochemical exploration in tin and polymetallic provinces of Bolivia and Peru.

**PROJECT RESULTS**

Rock geochemical data, which is quicker and cheaper to collect than mineralogical data, is a reliable guide to the identification of Ag-Au-Pb-Zn vein deposits in the Andes.

The alteration effects associated with these veins can, in some cases, be detected 100m from the vein although visible evidence extends only 10m; hence veins will be more easily detected.

The chemical data also enable distinction of the hanging and footwall sides of the vein indicating its inclination.

K<sub>2</sub>O/Na<sub>2</sub>O ratios are useful in detecting alteration near ore-bodies.

## **OUTPUT (Reports, Papers, & etc)**

- Appleton, J D and Claros, J. 1985. Comparison of rock geochemistry and mineralogical alteration as exploration guides for andean epithermal precious and base-metal vein-type deposits. Abstracts, Geological Society Mineral Deposits Studies Group Meeting, Glasgow, 1985.
- Appleton, J D. 1985. Application of rock geochemistry to mineral exploration: Progress report for 1984-1985. BGS Overseas Directorate Report.
- Claros, J and Fernandez, V. 1985. Estudio geoquímico preliminar: Sector Iranuta. Informe GQ-1/85, Subgerencia de Geología, Sección Geoquímica, COMIBOL, Oruro.
- Claros, J. 1986. Geoquímica de rocas en la cordillera intersalar, sector Iranuta. Congreso Geológico de Bolivia.
- Appleton, J D. 1987. Application of Rock Geochemistry to Mineral Exploration in Bolivia and Peru. BGS Technical Report MP/87/14R.
- Appleton, J D, Claros, J and Rodriguez, W. 1987. Comparison of rock geochemistry and mineralogical alteration as exploration guides for cordilleran epithermal precious and base metal vein-type deposits in Bolivia and Peru. In: Exploration in the North American Cordillera, eds. I Elliot and B Smee. p 83-93.
- Appleton, J D, Claros, J and Rodriguez, W. 1987. Geoquímica y alteración mineralógica de rocas como guías de exploración para yacimientos filonianos en la cordillera andina de Perú y Bolivia. CEDOMIN: Revista del Ministerio de Minería y Metalurgia, Bolivia.
- Appleton, J D, Claros, J and Rodriguez, W. 1987. Indicadores litogeoquímicos de mineralización filoniana polimetálica en el Perú. VI Congreso Peruano de Geología, Lima, Perú.
- Claros, J and Appleton, J D. 1987. Report on visit of Ing. Jorge Claros to the British Geological Survey, 6-28 April 1987. BGS Overseas Directorate Report.
- Appleton, J D, Claros, J and Rodriguez, W. 1988. Lithogeochemical and mineralogical indicators of Andean precious metal and polymetallic vein mineralization. Journal of Geochemical Exploration, Vol.32, 359-368.
- Appleton, J D, Ridgway, J, Claros, J, Gomez-Caballero, A, Rodriguez, W and Villaseñor, M G. 1988. Lithogeochemical exploration for silver mineralization in Bolivia, Mexico and Peru. In Silver: Exploration Mining and Treatment. Institute of Mining and Metallurgy Conference Proceedings, Mexico, 1988 p 57-72.
- Appleton, J D, Ridgway, J, Claros, J, Gomez Caballero, A, Rodriguez, W and Villaseñor, M G. 1989. Lithogeochemical exploration for silver mineralization in Bolivia, Mexico and Peru. Transactions Institution of Mining and Metallurgy 1398 201-212.

## **WORKSHOPS AND PRESENTATIONS**

### **Presentations**

- GEOEXPO/86 Vancouver, Canada 1986
- 12th International Geochemical Exploration Symposium, Orleans, France 1987
- VI Congreso Peruano de Geología, Lima, Peru 1987
- Silver: Exploration Mining and Treatment Conference, Mexico, 1988

**PROJECT STAFF**

Dr J D Appleton

**PROJECT EXPENDITURE**

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K					52	25					77K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3  
PROJECT NO: 35**

**TITLE:** SEASONAL VARIATIONS IN THE TRACE METAL CONTENT OF STREAM SEDIMENTS  
UNDER DIFFERENT CLIMATIC REGIMES

**LOCATIONS:** Solomon Islands, Zimbabwe

**LENGTH OF PROJECT:** 4 Years

**STARTING DATE:** 1983

**COLLABORATING ORGANISATIONS**

Solomon Islands Geology Division, Ministry of Natural Resources  
Geological Survey Department, Zimbabwe  
Midland Earth Science Associates, Zimbabwe

**PROJECT OBJECTIVES**

To investigate seasonal variations in the trace element content of stream sediments due to climatic factors and to assess their importance in geochemical exploration programmes.

Two contrasting areas were studied: in Zimbabwe there are distinct wet and dry seasons whereas in the Solomon Islands rain of varying intensity falls nearly every day.

**PROJECT RESULTS**

Pronounced changes in the trace metal content of fine sediments were observed at both locations showing that apparent geochemical anomalies can be controlled by climate as much as source region.

The results have important implications for mineral exploration programmes and question the validity of commonly accepted practices. Recommendations have been disseminated which should help to improve the reliability of geochemical surveys. This in turn should increase the chances of locating valuable mineral reserves.

## OUTPUT (Reports, Papers, & etc)

Ridgway, J. 1987. Seasonal variations in the trace metal content of stream sediments under different climatic regimes. BGS Technical Report MP/87/20.

Ridgway, J and Dunkley, P N. 1988. Temporal variations in the trace element content of stream sediments: examples from Zimbabwe. Applied Geochemistry Vol.3 609-621.

Ridgway, J and Midobatu, C. 1991. Temporal variations in the trace element content of stream sediments: an example from a tropical rain forest regime, Solomon Islands. Applied Geochemistry Vol.6 185-193.

## WORKSHOPS AND PRESENTATIONS

Presentations at

12th International Geochemical Exploration Symposium, Orleans, France 1987

"Exploration 87" Symposium Toronto, Canada 1987

## PROJECT STAFF

Dr J Ridgway (Principal Investigator)

D Peachey

B P Vickers

M E Stuart

D Bradley

K Greally

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			21	35	51	29					136K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 36**

**TITLE:** DIGITIZATION AND INTERPRETATION OF BGS OVERSEAS GRAVITY AND AEROMAGNETIC DATA

**LOCATIONS:** Bangladesh, Bolivia, Botswana, Colombia, Ethiopia, Fiji, Guyana, Indonesia, Kenya, Lesotho, Malawi, Malaysia, Nigeria, Peru, Seychelles, Somalia, Swaziland, Tanzania, Uganda, Yemen, Zimbabwe

**LENGTH OF PROJECT:** 2 Years

**STARTING DATE:** 1986

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

Computerization of BGS overseas gravity and aeromagnetic data collected over the past 3 decades.

Cataloguing details of individual surveys covering over 20 countries.

Production of colour-enhanced images of the processed information, analysis and identification of structures of economic interest.

Presentation of results, dissemination of output as tapes and maps to interested parties.

**PROJECT RESULTS**

The data were computerized and the output generated as proposed.

The information was widely disseminated through presentations and publications, there has been considerable demand from British industry for the data.

Some examples of the application of the data include

- a) providing + 10,000 gravity data points from nine African countries to the African gravity project of Leeds University (this DTI-commended project is funded by a consortium of major oil companies).
- b) advice given to BP on coal exploration in Bangladesh
- c) aeromagnetic data supplied to Goldfields for mineral exploration in Botswana
- d) processing programme supplied to ODA/BGS TC project in Malaysia
- e) gravity data supplied to ARC geophysics, UK for surveys in the Indian Ocean.

In all over 15, mainly UK, companies have benefitted from this project.

## **OUTPUT (Reports, Papers, & etc)**

Many colour - enhanced computer plots.

Annells, R N, Fletcher, C J N, Styles, M T, Burton, C C J, Evans, R B and Harding, R R. 1986. The Rincon del Tigre Igneous Complex: a major layered ultramafic intrusion of Proterozoic age in the Precambrian shield of eastern Bolivia. Overseas Geology and Mineral Resources Report No. 63, 64 pages and map.

Annells, R N, Fletcher, C J N, Styles, M T, Appleton, J D, Burton, C C J, Evans, R B and Harding, R R. 1986. Mineral potential of the Rincon del Tigre Igneous Complex: a major Upper Proterozoic layered intrusion in the shield of eastern Bolivia. In Metallogeny of Basic and Ultrabasic rocks. Institute of Mining and Metallurgy, London

Gould, D, Rathbone, P A, Kimbell, G S and Burley, A J. 1986. The Molopo Farms Complex, Botswana - a possible target for Bushveld-type mineralisation. Metallogeny of Basic and Ultrabasic rocks. Institute of Mining and Metallurgy, London.

Burley, A J. 1986. Electrical and gravity surveys for groundwater assessment in Fiji. Regional Geophysics Research Group Report NO. 86/6.

Kimbell, G S and Turnbull, G. 1986. BGS regional gravity digital data of Lesotho. Regional Geophysics Technical Report No. 86/11.

Busby, J P and Evans, R B. 1986. Geophysics surveys for auriferous moraine in the Ananea concession, SE Peru. Prospecting in Areas of Glaciated Terrain, Institute of Mining and Metallurgy, London.

Busby, J P. 1987. Land Gravity Data Reduction: A computational method for a worldwide application. BGS Technical Report No. RG/87/17

Kimbell, S F, Self, S J and Evans, R B. 1987. BGS digital aeromagnetic data of the Molopo Farms area, southern Botswana. BGS Technical Report No. RG/87/21.

Baldock, J W, Evans, R B and Zhou, P P. 1987. Integrated geological, geochemical and geophysical surveys at Selby Prospect, Harare Greenstone Belt, Zimbabwe: an exploration case history of massive sulphide zones in Archean Black Shales. African Mining, Institute of Mining and Metallurgy, London

Self, S J and Evans, R B. 1988. Catalogue of BGS overseas applied geophysics reports and publications. Report WK/88/26R.

Busby, J P and Evans, R B. 1988. Depth to magnetic basement in north-west Bangladesh from digital aeromagnetic data. Technical Report WK/88/3.

Evans, R B and Jones, M E. 1988. Digital gravity from NE Kenya and SW Somalia. BGS Technical Report No. WK/88/4.

Johnson, R L and Evans, R B. 1988. Review of Malawi Geophysical Data for United Nations BGS Technical Report No. WC/88/77/R.

Busby, J P. 1988. Geophysical visit to the Geological Survey of Malaysia to provide geophysical software. BGS Technical Report WR/88/24.



## OUTPUT (Reports, Papers, & etc)

Evans, R B and Gibberd, A J. 1988. Gravity measurements of Seychelles BGS Technical Report No. WK/88/20.

Carruthers, R M. 1988. The reprocessing and interpretation of regional geophysical data for Swaziland. BGS Technical Report No. WK/88/11.

Evans, R B. 1989. Summary Report on ODA Project for digitization of BGS Overseas Gravity and Magnetic Data 1986-8 BGS Regional Geophysics Project Note 89/3.

## WORKSHOPS AND PRESENTATIONS

IMM Conference on Glacial Prospecting in Kuopio, Finland. September 1986

IMM Conference of African Mining. Paper presented on ODA/BGS Zimbabwe geophysics. August 1987

IMM Conference on Asian Mining. Paper presented on ODA/BGS magnetic susceptibility work in S E Asia. March 1988

Geosciences in International Development Conference at Nottingham UK, sponsored in AGID, Geol. Soc. IMM and ODA Paper presented on BGS Geophysical work overseas. September 1988

## PROJECT STAFF

J Busby  
R M Carruthers  
R B Evans  
S Self

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K						35	47				82K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 37**

**TITLE: DIGITIZATION AND EVALUATION OF SELECTED BGS HELD OVERSEAS AIRBORNE  
RADIOMETRIC SURVEYS**

**LOCATIONS: UK, Ethiopia, Swaziland, Uganda      LENGTH OF PROJECT: 2 Years**

**STARTING DATE: 1988**

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To computerize pre-1980 airborne radiometric data sets of several diverse areas in developing countries with the object of:

- a) identifying mineral occurrences of uranium and possibly rare earth elements.
- b) provide a very important background-level data set against which the impact of any future nuclear accidents like Chernobyl can be monitored.

**PROJECT RESULTS**

Computer-plotted maps of about 61.000 digital radiometric data points of Swaziland, parts of Ethiopia (Eritrea, Tigre) and Uganda.

The Swaziland data distinguish between individual bodies of granite in a previously undifferentiated mass whereas some of the Ethiopian plots have important findings for agriculture and water resource development.

The data have been widely presented and disseminated to amongst others, the National Radiological Protection Board, BP, (British) Directorate of Military Surveys, Swaziland Government and the East and South African Mineral Resources Development Centre.

## OUTPUT (Reports, Papers, & etc)

Carruthers, R M. 1988. The reprocessing and interpretation of regional geophysical data for Swaziland. Technical Report No WK/88/11.

Carruthers, R M, Evans, R B and Self, S J. 1990. Digital airborne radiometric data of part of Northern Ethiopia. Technical Report No WK/90/14.

Carruthers, R M, Self, S J and Evans, R B. 1990. Digital airborne radiometric data from Swaziland. Technical Report No WK/90/12.

Self, S J, Carruthers, R M and Evans, R B. 1990. Digital airborne radiometric data for part of Western Uganda. Technical Report No WK/90/13.

## WORKSHOPS AND PRESENTATIONS

Geosciences in International Development Conferences at Nottingham, UK, sponsored by AGID, Geol. Soc., IMM and ODA. Paper presented on BGS geophysical work overseas. 1988.

Local Government Conference on Radon in Sheffield was attended to assess the significance of radon for gamma ray spectrometer work overseas. 1988.

Geol. Soc. of London Conference on Geoscience voluntary service in the Third World on 27th March 1990. Paper presented on Ethiopia which included the Northern Ethiopia digital airborne radiometric data set. 1990.

Institution of Geologist Meeting in Manchester on hazardous gases including radon where contact made with the National Radiological Protection Board (NRPB) and discussions held on implications of our digitization of BGS overseas airborne radiometric data for radiological protection overseas. 1990.

## PROJECT STAFF

R M Carruthers  
R B Evans  
A J Gibberd  
S J Self

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K								33	17		50K

**ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM**

**FORM A3**

**PROJECT NO: 38**

**TITLE: MAGNETIC SUSCEPTIBILITY STUDY**

**LOCATIONS:** UK, Bolivia, Botswana,  
Burma, Indonesia, Malaysia, Thailand

**LENGTH OF PROJECT:** 1 Year

**STARTING DATE:** 1983

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To undertake a pilot study of the use of new pocket-sized magnetic susceptibility meters which enable exploration geologists to measure directly this useful property of rocks in the field.

The results should aid mapping, mineral location and the interpretation of aeromagnetic maps using portable computers

**PROJECT RESULTS**

The meters have been tested and proved extremely useful in several geological settings.

They must have been utilized to help elucidate geology and mineral potential in conjunction with ODA/BGS TC and R&D projects in SE Asia, Botswana and Bolivia

### OUTPUT (Reports, Papers, & etc)

Evans, R B and Greenwood, P G 1988. Outcrop magnetic susceptibility measurements as a means of differentiating rock types and their mineralization. In Asian Mining 1988 p.45-57 Institute of Mining and Metallurgy.

### WORKSHOPS AND PRESENTATIONS

### PROJECT STAFF

R B Evans  
P G Greenwood

### PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			12								12K

ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM

FORM A3

PROJECT NO: 39

**TITLE:** APPLICATION OF HIGH RESOLUTION SATELLITE DATA TO MINERAL AND GEOTHERMAL RESOURCE EVALUATION

**LOCATIONS:** UK, Kenya, Peru

**LENGTH OF PROJECT:** 7 Years with extensions

**STARTING DATE:** 1983

**COLLABORATING ORGANISATIONS**

Department of Mines and Geology, Nairobi, Kenya

INGEMMET Lima Peru

Southern Peru Copper Corporation

Ministry of Energy and Regional Development (Geothermal Section), Nairobi, Kenya

**PROJECT OBJECTIVES**

To assess recently-derived high-resolution satellite imagery as a tool for identifying area of hydrothermal alteration which may contain valuable mineral deposits and/or geothermal systems.

If the approach proves useful the technique should produce substantial savings in exploration costs.

**PROJECT RESULTS**

The evaluation of the LANDSAT TM Imagery for Mineral Exploration has resulted in

- a) Areas of hydrothermal alteration with mineralization have been identified in Southern Peru and Kenya and confirmed by field inspection. Some of the areas in Peru are related with Porphyry Copper style mineralization and this potential has been disseminated to mining enterprises interested in the region.
- b) The image-processing techniques involved have been developed and refined, specific algorithms have been devised to distinguish the effects due to alteration and vegetation in the imagery.

## OUTPUT (Reports, Papers, & etc)

Amos, B J and Greenbaum, D. 1989. Alteration detection using TM Imagery. The effects of supergene weathering in an arid climate. International Journal of Remote Sensing Vol 10/3 515-27.

## WORKSHOPS AND PRESENTATIONS

Poster Display of Peru work at 21st International Symposium on Remote Sensing of the Environment, ERIM, Ann Arbor, 1987.

## PROJECT STAFF

Dr B J Amos  
Dr D Greenbaum  
Dr D I J Mallick  
Dr A J McDonald

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			14	49	53	73	81	90	31		391K

ODA/BRITISH GEOLOGICAL SURVEY  
R & D PROJECT COMPLETION FORM

FORM A3

PROJECT NO: 40

**TITLE:** REMOTE SENSING TRAINING FOR GEOLOGISTS IN DEVELOPING COUNTRIES

**LOCATIONS:** UK

**LENGTH OF PROJECT:** 1 Year

**STARTING DATE:** 1990

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To develop and expand previous training materials into a more comprehensive package suitable for training foreign students in all aspects of remote sensing.

To produce a comprehensive text on remote sensing which will be used as a training manual and reference text.

**PROJECT RESULTS**

The manual and training package have been completed and will act as the basis for future BGS courses in remote sensing.



## OUTPUT (Reports, Papers, & etc)

An introduction to Geological Remote Sensing. In Preparation, to be published by Cambridge University Press

## WORKSHOPS AND PRESENTATIONS

Short course "Applications of image analysis in the Earth Sciences", UKGA, Leicester 1991.

## PROJECT STAFF

Dr D Greenbaum  
Dr B Amos

## PROJECT EXPENDITURE

[illegible]

**TITLE:** MICROCOMPUTER APPLICATIONS IN GEOLOGY

**LOCATIONS:** UK

**LENGTH OF PROJECT:** 7 Years including extensions

**STARTING DATE:** 1983

**COLLABORATING ORGANISATIONS**

**PROJECT OBJECTIVES**

To develop a microcomputer system for the management, editing and processing of data in wide variety of geological applications.

The provision of sophisticated word processing and plotting facilities to enable desk-top publication of reports.

The system will be installed with ODA/BGS teams abroad and will ultimately be transferred to the governments of developing countries.

**PROJECT RESULTS**

Microcomputer systems have been installed for 15 ODA/BGS projects in 9 countries, support and advice has also been given to many UK-based ODA/BGS R&D projects.

Reports and manuals describing options within the system such as map plotting and digitizing and desk-top publishing have been written and circulated (a full list appears below).

Courses in the use of the system have been presented in SE Asia, South America and Africa and several short consultancies have been generated.

## OUTPUT (Reports, Papers, & etc)

### Overseas Microcomputer System Series:

- 1) The Cifer 1887 microcomputer and commercial software packages.
- 2) Programs for the analysis and graphical display of geochemical data.
- 3) The configuration of IBM type PCs and their utility software.
- 4) Introduction to MS-DOS 3.3.
- 5) Programs for map plotting and digitising.
- 6) Programs for whole rock geochemistry.
- 7) Notes on desk top publishing.
- 8) Notes on the construction of databases and the use of database software.
- 9) Notes on the use of Autocad.

### Course manuals:

Use of microcomputers in applied geochemistry (Bandung, Indonesia, 1985).

Use of microcomputers in placer gold exploration (Cali, Columbia, 1987).

### Other:

Ridgway, J R. 1986. Computerisation of geological records in Vanuatu and the Solomon Islands. BGS Technical Report MD/86/13R.

Jones, R C, Johnson, C C, Ghazali, S A, Widjana, H and Suganda, E. 1988. Computer-aided geochemical mapping and mineral exploration in Sumatra, Indonesia. In Asian Mining '88, 83-92 (IMM, London).

## WORKSHOPS AND PRESENTATIONS

- 1) Use of microcomputers in applied geochemistry. Directorate of Mineral Resources, Bandung, Indonesia, 1985.
- 2) Use of microcomputers in placer gold exploration. INGEOMINAS, Cali, Colombia, January-February 1987 and November-December 1987.
- 3) Use of microcomputers in applied geochemistry. Geological Survey Department, Zomba, Malawi, 1989.
- 4) Desk Top Publishing. Geological Survey of Malaysia, Ipoh, Malaysia, 1989.

## PROJECT STAFF

Dr J Ridgway  
R C Jones  
K Greally

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			29	10	15	21	28	29	28		160K

417

## OUTPUT (Reports, Papers, & etc)

## WORKSHOPS AND PRESENTATIONS

## PROJECT STAFF

Dr R Herbert  
S L Shedlock

## PROJECT EXPENDITURE

	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	TOTAL
£K			20	19	18						57K

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BRITISH GEOLOGICAL SURVEY  
International Division

# A decade of ODA/BGS international research and development 1981–1990



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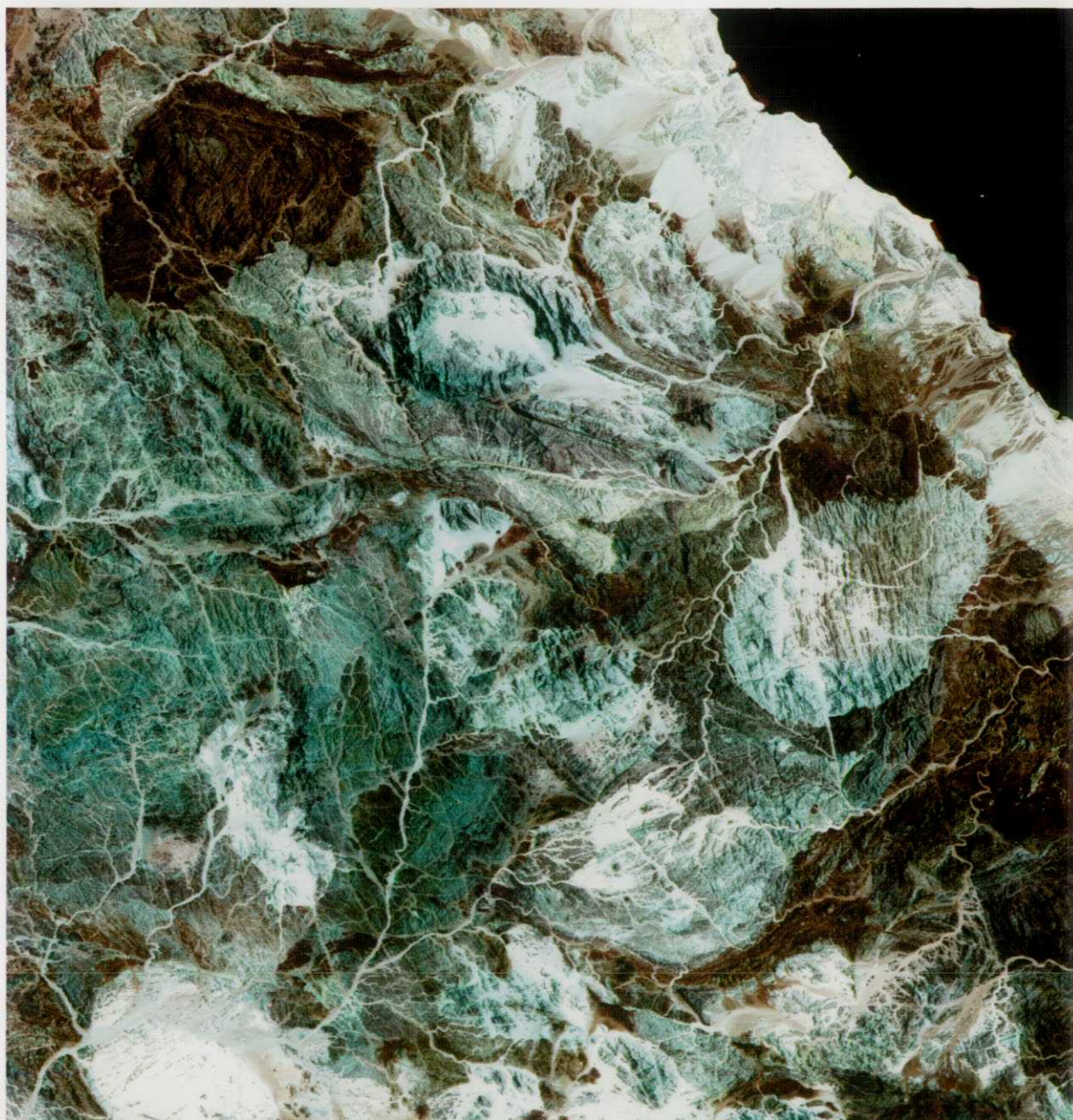






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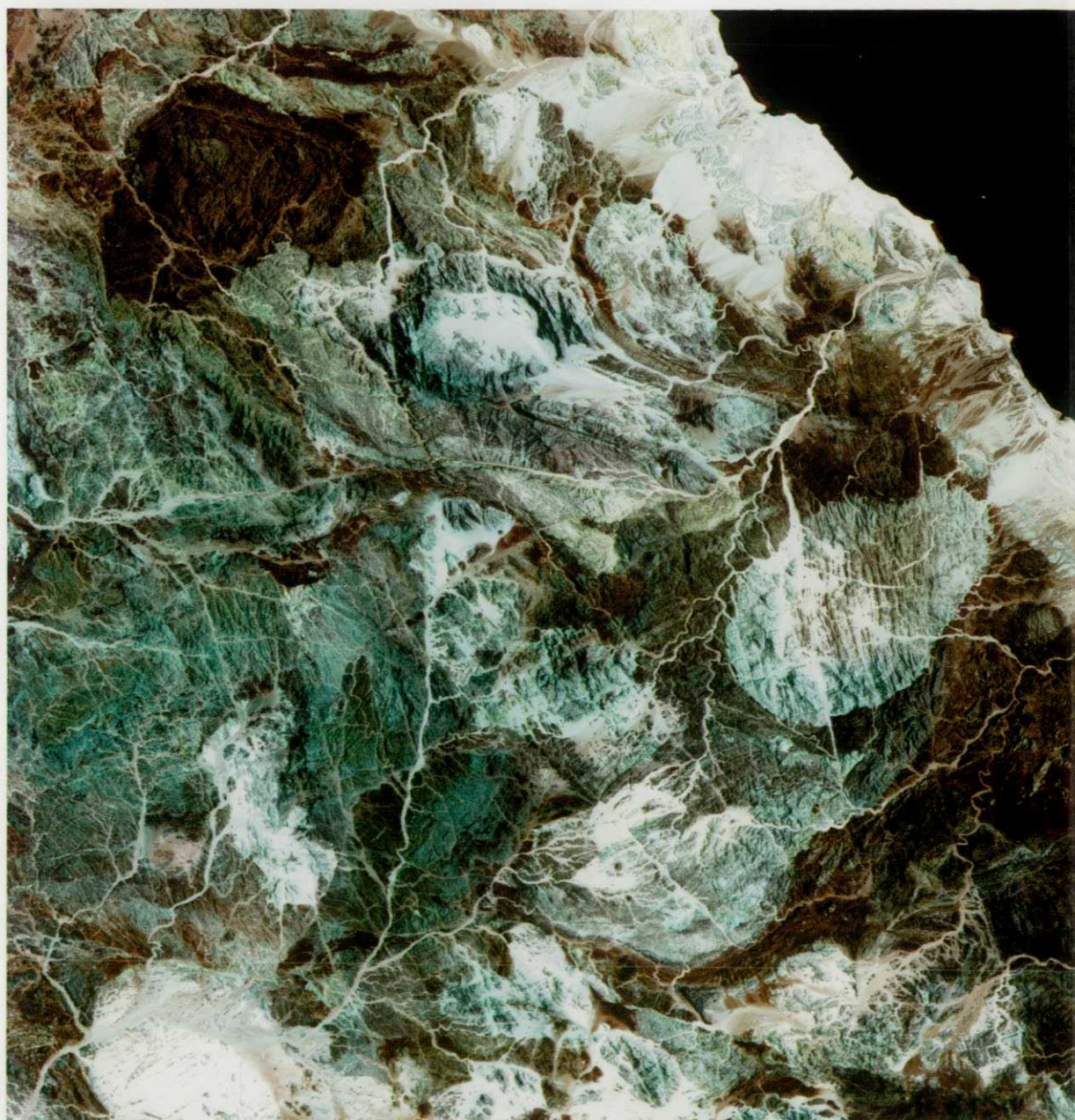
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