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38. Geoscience and development – The 1990s and beyond

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Abstract: The role of geosciences in the development of nations is unquestionable, but our understanding of that role has changed and expanded dramatically in recent years. As the 120 or so nation states that make up the Less Developed Countries move through similar stages of development as experienced by the industrialised countries, there is an ever-increasing need for energy and mineral resources, and hence for geoscientists to find and exploit them. However, real development means improving the quality of life for all a nation's people and involves far more than simple economic growth based on exploitation of traditional natural resources.

The geosciences have an essential role to play in all aspects of development. Hydrogeologists are concerned with the search for groundwater for drinking and for irrigation, agrogeologists with the search for rock and mineral products to improve soil quality. Industrial geologists look for materials appropriate for building and construction in widely differing conditions. Economic geologists concerned with energy and mineral deposits must consider the use of small-scale and alternative resources. Engineering geologists must work with environmentalists and land planners towards rational land use, as well as the prediction and mitigation of natural and human-made disasters.

These are some of the topics addressed in this paper. In addition, three important questions must be posed: Is the education and training provision adequate for the new generation of geoscientists required to tackle these issues? Are we communicating these needs satisfactorily to policy planners and decision makers? Geology is a global science - is our perspective sufficiently global?

INTRODUCTION

Just as geology is a global science, so development is a global concern. As human beings, we share the same basic requirements for food, water, shelter, good health, a safe environment, good education and fulfilling employment. As geologists, no matter the continent, we talk the same language, walk in the same time frame and work with the same geological principles. Furthermore, I believe that whatever type of geologist we are, whether concerned with mega-plate-tectonic reconstructions or the growth of illite clays in sandstone pore spaces, we all share the knowledge that geology has an important contribution to make to society as a whole and to the process of world development.

It is no longer - nor has it ever been - a matter of us and them, or them and us, for the world has grown too small and too interdependent to allow any one part to develop at the expense of another without sharing the consequences. This is just as true of climate, the environment, dwindling oil reserves and other natural resources, as it is of national economies and even national politics.

If we look at the recent history of the North - the Industrialised Countries, the Developed World - then the role of geoscience in development is unquestionable. Coal fired the industrial revolution early in the 18th century. Metals and industrial minerals then provided the framework for rapid development. Oil and gas injected a major boost to 'progress' early in the 20th century, revolutionising transport and bringing us into the age of plastics. There is still debate as to whether the nuclear age has truly dawned and whether or not we can prevent it from blowing up in our faces. But there is no doubting the dramatic influence on all our lives of the silicon chip, purified from almost pure quartz sandstone and coated with substances such as phosphorus, boron and aluminium.

That the earth's natural resources have provided for major economic advances in some parts of the world is not debated. But, that this 'development' has caused very serious environmental problems and led to the dramatically unequal distribution of wealth in the world, must be of profound concern to us all.

As the 120 of so nations of the South - the Less Developed Countries, the Third World - now move through similar stages of development, there is ever-increasing demand for natural resources of all kinds and, of course, for geoscientists to find and exploit them. However, more gold and more oil does not necessarily lead to development, especially not for the majority. Real development means improving the quality of life for all, achieving those same basic requirements that we all have. Geoscientists have an essential, if more subtle, role to play in all these aspects of development.

It is that role of geoscientists in development that is explored further in this paper, focussing first on the main areas of concern and, second, on the principal ways and means of achieving these objectives. It is difficult adequately to acknowledge or refer to all the various sources for many of the concepts and ideas expressed, and so I list the following as some of the more influential sources: Lanning and Mueller (1979), Brandt Commission (1980, 1983), Tanzer (1980), Cooray (1988a, b), McLaren and Skinner (1987), Stow (1986, 1989a, b) and Berger (1990). In addition, I have drawn heavily on papers presented at the 1988 Nottingham Geosciences in Development Conference, both those that are published in this volume (Stow and Laming, 1990) and those that have yet to be published, other than by reference in the conference summary (Stow and Notholt, 1989). Where possible the source of specific facts are referenced in the text.

THE AIMS

If geology and geoscientists are to concern themselves more and more with development issues in the last decade of the present century, then just what are the crucial areas that require geological attention? It is important to identify clearly these topics and just what needs to be achieved within them, because they are in most instances very different from the areas we would select as requiring particular scientific attention in the future. Certainly, we will not solve the problems of development in just ten years, so that the broad areas of focus will remain the same as we enter the 21st century.

Water Resources

By far the greater proportion of the water used by humans is used for irrigated agriculture, although most of that water never reaches a plant but is lost to seepage or evaporation. Common industrial practices are also major water consumers and very wasteful, with almost no effort at recycling. Domestic water use in highly developed economies is typically 100 times per capita that found in populations living near subsistence level (Laurence and others, 1987). Despite completion of the UN Water Decade, which aimed to provide safe water to all by the year 1990, we are still very far from achieving this ambitious goal. Inevitably, development will result in growing demands for domestic, industrial and agricultural water. This fact, coupled with serious problems of desertification in parts of the world, has sharply focussed attention on the location and management of water resources.

Tremendous advances have been made in the past three decades with the greater use of remote sensing techniques, improved groundwater modelling and cheap, effective drilling. Many parts of the developing world do now have adequate, safe water supplies for present needs. But many others do not. Some of key areas for future focus include:

- increasing efficiency in agricultural and industrial usage;
- improving groundwater quality management;
- developing conjunctive use of groundwater and surface water resources;
- modelling of basin water budgets, with special reference to soil moisture contents, evapotranspiration and the role of afforestation; and
- modifying institutional structures to cope better with water resource management.

Agrogeology

There is an ever-growing pressure on agricultural land caused, on the one hand, by increasing populations and the need in many parts of the world for improved diets and, on the other hand, by decreasing land fertility coupled with land-use transformation for urban and industrial purposes. In the recent past, this has led to greater demand for natural resources such as phosphate and potassium-rich rocks to feed a flourishing chemical fertiliser industry. More recently still, there has been a resurgence of interest in the use of locally available agromineral resources for soil improvement. Direct application of limestone, phosphate rock, volcanic scoria, malachite, pyrite and other rock and mineral substances (see Appleton and others, this volume) has been found to be very successful in treating a range of common soil problems.

There is considerable scope for further development in the field of agrogeology, in particular through:

- targeted research and development projects to assess fully the effects of different types and amounts of agrominerals on soil conditions and crop productivity; and
- development of simple and practical agromineral assessment procedures in relation to local soil conditions and agricultural demand.

Industrial Minerals

Aptly named because of their critical importance to all aspects of development or, more specifically, industrial development, are the industrial minerals. They include a wide range of non-metal

and non-fuel minerals and rocks, which can be grouped according to their usage in the construction, glass/ceramics-refactory, drilling, chemical-refinery, fertiliser and gem industries (Table 1).

Many of these minerals are widely distributed throughout the world and are not generally in danger of being in short supply, at least not in the medium-term future. The commercial viability of deposits is mainly a function of location and transportation costs with respect to market areas, and only secondarily a function of mining and processing costs. However, local shortages can develop due to rapid urban expansion coupled with poor planning, or an absence of the required industrial mineral. It is also difficult to generalise because of the maze of diverse and disordered markets involved.

Particularly, but not exclusively, the field of industrial mineral development lends itself to:

- multiple local small-scale initiatives that utilise readily available materials, often quite different from those used in another region for the same purpose (e.g. in construction or road-building);
- exchange of information and experience between regions and countries on the type of materials to use and on simple cost-effective processing techniques; and
- research into the properties of different industrial minerals.

Metallic Mineral Resources

The variety of metallic mineral resources that we use is even more diverse than the spectrum of industrial minerals. They can be differently grouped according to economic value, strategic importance, how widely used they are, and so on. To a geologist, perhaps the most logical grouping is according to their geochemical abundance in the earth's crust. A slight refinement of this was proposed by Erickson (1973) who defined geochemically abundant metals as those that are present in the continental crust at levels of 0.01% by weight or greater, whereas geochemically scarce metals all have crustal abundances below 0.01% (Table 2).

If we include the next three most abundant metals (nickel, zinc, copper) with the top seven then, with the exception of lead and tin, this is also the list of the most widely used metals in the world today.

The concentration of the different metals in ore bodies, their modes of occurrence and their geographical distribution are further geological variables that influence the complex web of mineral exploitation and trading patterns that have developed. Certain well-endowed industrialised countries (USA, Canada, Australia, South Africa, USSR and, more recently, Brazil) have become both major world producers of a variety of metals

Table 1. Common Industrial Minerals (from Sheldon, 1987)

Construction Materials:	asbestos, clay, construction stone, diatomite, gypsum, lightweight aggregate, sand, gravel, limestone, dolomite
Refractory, Ceramics and Glass-Making Materials:	barytes, clay, sodium carbonate, boron minerals, feldspar, kyanite, magnesium refractory minerals, selenium, silica sand, talc
Drilling Materials:	barytes, clay, abrasives
Chemical, Metal and Refinery Materials:	asbestos, diatomite, sodium carbonate, fluorite, graphite, limestone, sulphur, zeolites, silica sand, sodium chloride
Fertiliser Minerals:	potassium salts, gypsum, limestone, dolomite, phosphate rock, zeolites, selenium

as well as key processing and manufacturing centres. Many developing countries, on the other hand, have grown up and have largely remained as mineral producers feeding the processing centres of North America, western Europe, Japan and, most recently, South Korea. In many cases, a nation's export earnings have become highly dependent on only one or two commodities, such as bauxite for Jamaica and Guinea, cobalt and copper for Zambia, tin for Malaysia and Thailand.

These factors, coupled with very unstable markets for metals and the firm control still exerted by multinational corporations across the whole of the minerals industry, have contributed very significantly to underdevelopment in the South as well as the continued struggling of these economies (e.g. Lanning and Mueller, 1979). It is clear that the role of metallic mineral resources in development of the South is a very important one, and that the areas requiring particularly careful consideration are the following:

- routine and detailed exploration for and assessment of a nation's metallic mineral resources;
- careful management of these non-renewable resources as an insurance policy for the future, especially in the case of the geochemically scarce metals;
- the planned development of indigenous mineral processing and downstream manufacturing capabilities;

Table 2. Geochemical abundance of selected metals in the crust. Geochemically abundant metals are present in amounts greater than 0.01% by weight; geochemically scarce metals have abundances below 0.01% by weight (data from Skinner, 1987).

Geochemically abundant metals

Element	Weight % in: oceanic crust	Weight % in: continental crust	Amount in continental crust in kg x 10^{18}
Aluminum	8.40	8.30	1240
Iron	7.50	4.80	725
Titanium	0.81	0.53	81.5
Manganese	0.18	0.10	15.2
Barium	0.037	0.040	6.1
Vanadium	0.017	0.012	1.8
Chromium	0.016	0.008	1.2

Geochemically scarce metals

Element	Weight % in: oceanic crust	Weight % in: continental crust	Amount in continental crust in kg x 10^{15}
Zinc	1.2×10^{-2}	8.1×10^{-3}	1220
Nickel	1.4×10^{-2}	6.1×10^{-3}	920
Copper	8.5×10^{-3}	5.0×10^{-3}	760
Lithium	2.0×10^{-3}	2.2×10^{-3}	320
Niobium	1.8×10^{-3}	2.0×10^{-3}	300
Cobalt	3.7×10^{-3}	1.8×10^{-3}	270
Lead	1.0×10^{-3}	1.3×10^{-3}	200
Tantalum	4.3×10^{-5}	2.3×10^{-4}	35
Uranium	1.0×10^{-4}	2.2×10^{-4}	33
Beryllium	8.3×10^{-5}	1.5×10^{-4}	24
Tin	1.9×10^{-4}	1.6×10^{-4}	24
Tungsten	9.4×10^{-5}	1.2×10^{-4}	18
Molybdenum	1.5×10^{-4}	1.1×10^{-4}	17
Antimony	9.1×10^{-5}	4.5×10^{-5}	6.8
Mercury	1.1×10^{-5}	8.0×10^{-6}	1.2
Silver	9.1×10^{-6}	6.5×10^{-6}	0.98
Selenium	1.0×10^{-5}	5.9×10^{-6}	0.91
Platinum	7.5×10^{-6}	2.8×10^{-6}	0.43
Gold	3.5×10^{-7}	3.5×10^{-7}	0.052
Bismuth	6.6×10^{-7}	2.9×10^{-7}	0.041
Tellurium	8.8×10^{-8}	3.6×10^{-8}	0.005

- encouragement of small-scale initiatives in exploration, production and processing operations, as a means of more rapidly and effectively distributing the effects of development where it is most needed; and
- the careful mixing of multiple small-scale operations with large-scale state-run and other schemes, and the adoption of firm codes of practice in all types of operation.

Energy Resources

Amongst the plethora of energy resources available for use on the earth, we are very largely dependent on the non-renewable conventional fossil fuels: oil accounts for about 35% of current usage, gas for 17% and coal for about 27%. In addition, hydroelectric schemes contribute nearly 6% of the world total, nuclear power generates less than 4%, while the collective use of biomass (principally wood and animal dung in the South) accounts for some 12.5%. Wind, waves, solar power, geothermal and various other renewable energy options provide an insignificant proportion of the whole, although they may be very important locally, such as geothermal power in Iceland or peat in Eire. Some figures on current usage, proven reserves and estimated resources are given in Table 3.

As with other natural resources, the energy minerals are very unevenly distributed across the world on account of geological chance. Nearly 60% of oil reserves occur in the Middle East, some 70% of the natural gas occurs in the Middle East and Soviet Union, and over 70% of coal reserves are found in just three countries - the USA, China and the Soviet Union. Of course, many parts of the world have not yet been very thoroughly explored in this regard, including large areas of the South, so that the ultimate distribution of resources will be somewhat different. The control of these resources, however, is only partly in the hands of the producers, for the expansion of the giant oil corporations, both horizontally across the range of energy resources and vertically through exploration, production, distribution and marketing, has left these multinationals very firmly in the driving seat.

Such an uneven distribution of resources, when taken together with the marked disparities in energy consumption between North and South has lead to the very reasonable conclusion that an indigenous energy-resource base and increased energy consumption are two key ingredients of successful development. The recent success of geological exploration in finding oil and gas in particular, has contributed to our remarkably wasteful usage of fossil fuels in the North (i.e. the low efficiency of the internal combustion engine, waste heat loss from conventional power stations, and the flaring of 'unwanted' gas at the well site, etc.). Current rates of consumption have led to doomsday predictions for energy resource lifetimes, although even the apparently 'reasonable' estimates must give some cause for concern in the long term.

Without speculating on whether or not there is an energy crisis facing the world, it is abundant-

Table 3. World energy use in 1984 (expressed as primary energy equivalent). Current use data from *BP Statistical Review of World Energy* (BP Oil Company, London, 1985). Table from Hall, Slesser and others (1987).

Stocks Fuel Source	Current use (EJ/y)	Proven reserves (EJ)	Resources (EJ)	Resource uncertainty
Coal	97.6	21,500	238,000	±20%
Oil	127.3	4,300	10,000	-30% to +60%
Gas	63.1	3,700	10,000	-40% to +70%
Uranium	12.6	813	1,324	±50% - resource figure assumes < \$130/kg (reserves ±20%)
Tar sands and oil shale	-	550+	1,600	highly uncertain
Approximate total	300.6	30,850+	260,900+	
Fluxes	(EJ/y)	Practical	Ultimate potential	Resource uncertainty
Hydropower	21.7	100	200	little uncertainty
Biomass	46	80	720	highly uncertain
Wind	very small	30	100	speculative
Photovoltaic	very small	infinite	infinite	rapidly reducing price
Geothermal	0.1	large	large	
Approximate total	67.8	210+	1,020+	

1 barrel of oil = 6.3 gigajoules (GJ, 10^9 joules)
1 tonne coal equivalent = 29.3 gigajoules
1 tonne oil equivalent = 44.0 gigajoules
EJ = Exajoule = 10^{18} joules

ly clear that the developing countries have several serious problems to surmount in this regard, but that the 'solutions' involve action by North and South alike. In particular, there must be:

- concerted efforts towards the development of a variety of appropriate renewable energy resources, including the major investment of funds in these areas;
- careful management and conservation of non-renewable resources, including the introduction of serious conservation measures as well as refined techniques for the recovery of existing resources (e.g. tertiary recovery methods, etc):
- encouragement of local and small-scale energy resource initiatives; and
- a shift in the focus of energy planning away from expansion in exploration and supply, and towards the development of improved end-use technologies.

Planning and the Environment

When a nation undergoes development, there are necessary major changes to the whole infrastructure of that society. These changes, for example large-scale urbanisation, the introduction of water management and waste-disposal schemes, an improved transportation network, and so on, either take place in a planned or an unplanned manner. For many reasons and, more importantly, for the preservation of the global environment, it is essential that planned changes are made that involve geologists, engineers, ecologists, sociologists, planners and politicians, as well as the local community directly involved in any one area.

There is already a long list of blunders that have been made in the past, mainly by the industrialised nations on their way to development, others by the newly industrialising nations, and yet others that are still being made.

Urban sprawls are typically quite unplanned, and then are later found to have covered the best source of construction material for their own improvement or some other economically valuable resource. There is considerable problem at present with the progressive 'sinking' of large Third World cities (e.g. Bangkok) due to enhanced compaction of unconsolidated substrate and the withdrawal of excessive amounts of water to support the overlying urbanisation (see Figure 3 in Berger, this volume). Increased concentrations of population together with attendant industrialisation lead to an ever-worsening problem of waste disposal - human, chemical, radioactive, etc. Pollutants entering the atmosphere appear to be having a significant effect on the global climate, although the knock-on effects of this on such things as sea-level rise and the inundation of low-lying, heavily populated coastal areas, are by no means fully understood. The rapid depletion of non-renewable resources in a frenzied or unplanned manner is an irreversible process.

The whole area of planning and the environment is even more complex than some of the other issues discussed previously, mainly because it involves so many disparate disciplines, each with their own language and interests. Clearly there is an important role for the geosciences in:

- focussing attention of politicians, planners and the public on the problems and issues involved;
- working cooperatively with other disciplines towards favourable solutions, and bringing the experience gained in one region or country to bear on the problem in another; and
- developing a record of base-line conditions against which we can measure the environmental impact of various human activities.

Natural Hazards

Closely related to the environmental concerns outlined above, but often more dramatic and immediate in their effect, are the sudden, unexpected and violent volcanic eruptions, major earthquakes and resultant tsunamis, devastating floods and hurricanes, catastrophic landslides and avalanches. Then there are the more insidious hazards - the health risks of rising groundwater in Saudi Arabia, and the widespread effects of soil erosion, which may cause many more deaths per year, from malnutrition, than all the other natural disasters together.

As recently as 1976, a major earthquake measuring 6.9 on the Richter scale claimed an estimated 242,000 lives in the Tianjin region of China. An equally severe earthquake in the heart of Tokyo, or along the heavily populated parts of the San Andreas Fault in California, would shake buildings and their occupants, maybe even disrupt gas supplies and communications for a short while, but would pass without much loss of life. The difference is the long-established codes of structural design that have ensured that buildings are quake-resistant; in other words, the effects of natural disasters can be mitigated by engineering.

Perhaps little could be done if there were a repetition of the giant tsunamis that battered the shores of Java and Sumatra following the eruption of Krakatao some hundred years ago, when 36,000 people perished. But, much more recently, many lives have been lost and livelihoods destroyed as a result of unpredicted volcanic eruptions in Third World countries; contrast this with the careful monitoring of Mount St Helens in the western USA, that minimised the loss of life when she finally blew in May 1980.

The vagaries of the earth's climate are felt by us all the world over. But, whereas record-breaking heat and droughts in North America in 1988 were inconvenient, they did not translate into a major disaster. The same was not true of the long-continuing drought in the Sahel region of northern Africa, nor the severe flooding in Bangladesh in the same year, where major catastrophes are ever threatening. Of course, there is nothing new in the hazard of living close to climatic extremes and in the disasters that are a regular feature of certain parts of the world. Many countries have neither the economic resources nor the political will to do much about such natural phenomena. Other countries have been able to fight back - Israel and Saudi Arabia in the greening of their deserts for agriculture, Nigeria to some extent with its very active flood control programme, and so on.

Recent publicity about the greenhouse effect and the possible long-term consequences of global warming, coupled with growing public concern over the environmental hazards of nuclear waste disposal, the traffic in toxic chemicals and the effects of major oil spillages have further focussed attention on hazards resulting from human activity and negligence and their possible disastrous consequences. At the same time, earthquake monitoring and volcano watching have become more and more global in scope, particularly with the advent of sophisticated satellite-borne remote-sensing devices. Suddenly, we have a public much more aware of the issues involved, and politicians beginning to take more seriously our ability and responsibility to mitigate the effects of both natural and human-made hazards.

There is no doubt that it is the developing countries that are most seriously affected by natural disasters and therefore stand to gain most

by well-directed efforts over the coming decades. What is needed from geoscientists is to:

- ensure the active and effective participation of Third World scientists in a truly international and interdisciplinary effort towards understanding natural hazards and combating the effects of disasters;
- respond to public and political awareness, help guide and direct the programmes designed to meet the global challenges, and to develop new initiatives that focus our priorities for action where they are most urgently needed.

WAYS AND MEANS

As individual geoscientists, or as part of a university or high-school department, a government institute, a private company, a local or national geological society, what are the ways and means by which we can participate in the application of geosciences to development? How can we begin to address some of the 'aims' outlined in the previous section?

In a way the answer is not surprising, it is the same as it has always been - begin by creating a sound educational base, continue with fundamental and applied research and, ultimately, seek to apply that geological knowledge effectively. In another way, though, it is perhaps not as simple as all that. The geosciences have not had the impact on development in the past that they should, and so we need to reassess where the focus for most effective action should lie within these broad areas, where it is most crucial to direct our efforts.

Geoscience Education

Vital to all the aims discussed is the need for adequate geoscience education and training at all levels. Within a broadly defined perspective of education, we can highlight the following as particularly important:

1. Geology must be introduced in all schools, as a separate subject at secondary level, and also at primary level, where it can form part of a general introduction to science, environmental or resource issues. This will inevitably require significant in-service training provision for existing teachers.
2. More appropriate geology needs to be taught in universities and other higher education institutes. This does not, of course, mean abandoning the basics, but it does mean developing the applied teaching, including mapping, hydrogeology, engineering geology, urban geology, industrial mineral development, natural resources management, etc.
3. Various appropriate and imaginative schemes for sharing and exchange in education can be developed, for example, international training centres, institution twinning and outreach continuing education (Baker and Stow, this volume), with particular focus on building up good indigenous geoscience education capabilities in all countries.
4. Professional in-service training, for practicing geologists in government surveys, private exploration/production companies, universities and schools, needs considerable expansion in many countries. There should be available a wide range of specialist and up-to-date courses of different lengths, given in different places to varied groups. Very important amongst these are training courses for geoscience technicians.
5. It is equally important not to neglect geoscience public relations work, including communication of both the fascination and relevance of geology to the public at large, and the essential role of geosciences in society to planners, policy makers and decision takers at every level. We may know how critical a good geological understanding is to resource management, urban development, environmental protection, etc, but most politicians do not! In my opinion, this is one of the most critical areas of concern within the broader framework of geoscience education.

Geoscience Research

We do not know it all! In fact, we have barely scratched the surface, literally, of a small part of the globe. Without fundamental and applied research in all areas we will simply not progress. Especially important for Third World development is research in the areas outlined in the previous section, and significant to achieving those aims, we can highlight the following:

1. Programmes that encourage and support research collaboration between individual scientists from both North and South need to be expanded and increased in number. Whether the research topic is of a local and very applied nature, more broadly regional or fundamental in scope, such collaboration is an excellent way of improving communication, enhancing training opportunities and achieving tangible research results.
2. At the same time, we must ensure that the global research initiatives that are becoming more and more widespread (e.g. the IUGS Geological Correlation Programmes - IGCP, the Ocean Drilling Program - ODP, the Global Sedimentary Geology Programme - GSGP, the International Geosphere-Biosphere Program on Geological Change - IGBP, Climatic Change programmes - CLIMAP), involve a full cross-section of the world's geoscientists from the South as well as the North, in order to be truly global (Berger, this volume). There

is a need for more such programmes that emphasise applied geoscientific research - resource management, coping with natural hazards, water supplies and urban geology, for example - as these must remain priorities until basic living standards are raised everywhere.

3. Geoscientists must push to become fully involved themselves and to incorporate other relevant sciences into interdisciplinary research programmes. This type of collaboration is essential for resolving some of the complex problems of natural disaster mitigation, environmental safeguards, land-use planning, and so on.

Geoscience Application

In parallel, and closely interwoven with geoscience education and research, must be the continued, on-the-ground application of geology in all the various ways outlined previously: the sinking of a well in Sudan to tap clean drinking water from a sandstone aquifer; a test bore for the development of local geothermal energy in West Yunnan, China; the direct application of volcanic scoria to improve soil fertility in Tanzania; the testing of different local substances for use in the manufacture of construction materials in Senegal; retroactive planning to ameliorate conditions and manage future development of the urban sprawl around Recife in northeastern Brazil; studies of mobility of heavy metals and sinks for them in the rivers and coastal zone of South America; the introduction of legislation to encourage, and codes of practice to control, the spread of small-scale mining operations in Southeast Asia; and so on.

There is no need to repeat here the numerous priority areas for the application of geoscience to aid development; a number of these have been highlighted in the earlier section on 'Aims' in this paper, and some of them featured as recommendations of the Geosciences in Development Conference in the Preface to this volume.

One area that has not yet been mentioned, but that underpins the whole of geoscience education, research and application, is the development of new or modernisation and improvement of existing institutes in Third World countries, at which and from which all the various aspects of geoscience are carried out. Such institutes may include geological surveys, national minerals or energy-resource bodies, universities, technical colleges, water authorities, national disaster centres, etc., and are in very variable states of 'development' in different countries or areas. In many cases, there is need for the introduction of advanced information technology and data handling techniques, modernisation of laboratories, equipment, methodologies, improvement of teaching materials and methods, increase of library stocks, and a whole range of other requirements.

Particular efforts and expenditure need to be made in this regard, although with careful attention to the purpose for, and the appropriateness of, such development.

SOURCE OF FUNDS

As with all development, the bottom line is funding. Any increase in the activity of geoscientists in applying their subject to the problems of international development will require additional funds, and considerable funds indeed, if even a part of the ambitious plans outlined above are to be realised. However, I suggest that it is really a matter of demonstrating the important role the geosciences have to play, and of convincing those with the purse strings of the rationale for spending more on the geosciences in development.

The various sources of funds can be itemised as follows:

1. Education Council funds, both central and local, for improvements in education, including continuing education and distance learning schemes.
2. Research Councils and other research funding bodies for collaboration between individuals and institutes from North and South.
3. State funds, either indigenous to the South (e.g. Departments of Energy, Environment, Natural Resources, Minerals, or equivalents) or via bilateral co-operation/aid with the North (e.g. Departments of Aid or Foreign Affairs), typically for regional surveys, mapping, exploration and basic research. Such funds may be administered also by quasi-governmental organisations (e.g. the British Council in the UK).
4. Private funds, from multinational corporations or other large transnational companies, mainly targeted at specific exploration and development schemes or applied research.
5. Private funds, from small-scale collaboration and consultancy contracts: these may be commissioned by the state and paid for by a multilateral donor agency.
6. Voluntary sector funds, including a wide range of trusts and organisations that have interest in development work in the South, and the 'volunteer' agencies (such as Voluntary Service Overseas in the UK) that undertake the supply of trained personnel for specific projects.
7. Multilateral donor organisations, such as the World Bank, UN Development Programme, UNESCO, that commonly give to major projects at a national or regional level.
8. International research programmes, such as those under the IUGS umbrella and those listed earlier, which have limited funds for collaborative research ventures involving both North and South.

CONCLUSIONS

Geology is a global subject, both scientifically and environmentally, and problems, large or small, are best tackled with this broader perspective. The really important advances in the subject are likely to come from the numerous global programmes that are now being put into effect. Geoscientists from both North and South are essential to this process. It is very important, however, that global programmes of a directly applied nature are also developed.

Geoscientists must take their position, alongside others, as custodians of the Planet Earth. We must share responsibility for its management and play our full role in caring for its environment. Geological knowledge about the earth and its workings must be used to monitor and understand slow changes (e.g. sea level, climate) as well as very rapid changes (earthquakes, eruptions, etc), and so to combat both environmental pollution and natural disasters wherever they may threaten.

Natural resources have always figured high on the list of priorities for any nation's viability and security. However, the fact must be recognised that the resource base is of global concern, and that the continuing need for a supply of energy is a common denominator of all societies. A geologist's role must include locating and managing supplies as well as assessing global needs now and for the future.

The resources that are of major importance to many countries are more than just the fossil fuels and metals. They include water, agrominerals, industrial minerals and the land itself. Geoscientists must be equally concerned with these resources, and with the rational and planned use of land for urban development, agriculture, tourism, etc.

At the very root of progress in development and, more specifically, of increasing the effectiveness of geoscience in playing a part in that progress through the 1990s and into the next century, is *effective communication*. That communication is manifold: first, there must be provision of a good grounding in geoscience education; second, there has to be understanding and agreement amongst practising geoscientists throughout the world of the priorities for development; third, we must be able to inter-relate efficiently with other disciplines necessary for tackling various multi-faceted problems that face the world; and, finally, there is a clear need for us to simplify and share our subject and concerns with both politicians and the public, with the policy makers as well as those affected by these policies.

In such a role, we cannot escape the responsibility of insisting that *the wasteful use of precious raw materials and pollution of the common global environment are immoral*, and that *continuing excessive expenditure on weapons and warfare is totally unjustified*.

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