NATURAL RESOURCES FORUM

TRIBUNE DES RESSOURCES NATURELLES

FORO DE RECURSOS NATURALES

Vol. I
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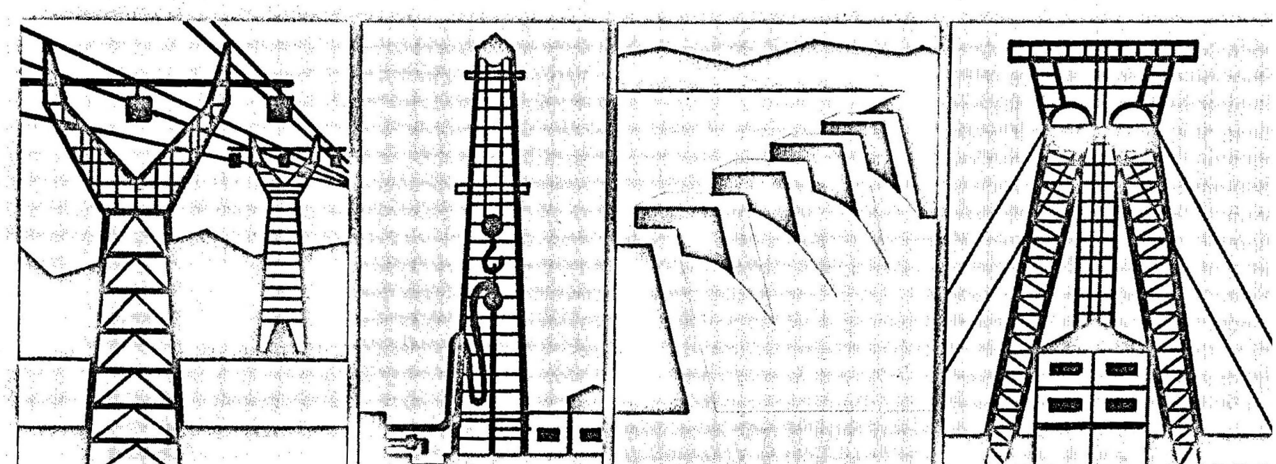

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Department of Economic and Social Affairs
Département des affaires économiques et sociales
Departamento de Asuntos Económicos y Sociales

NATURAL RESOURCES FORUM
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* The panel is composed of international specialists and members of the United Nations Secretariat who may be requested to review articles in their respective fields in order to ensure high technical quality.

FOREWORD

There is today an increasing understanding of the role of natural resources within the framework of economic development, either as the driving force of development—as may be said of petroleum and other minerals—or as an indispensable element of infrastructure—as may be said of water and energy resources.

Opportunities for development brought about by the foreseen demand for key minerals in the years to come, and the challenge posed by the infrastructural needs associated with population and economic growth, have made the tasks of natural resources development among the foremost efforts required for rapid self-sustained growth. That such opportunities and challenges are now well understood by Member States of the United Nations is reflected in the emphasis placed in recent years by the General Assembly and other United Nations bodies on international rivers and marine resources; and of course in the recent establishment by the Economic and Social Council of a standing Committee on Natural Resources.

It is the conviction within the United Nations that the challenges of the future can be successfully met by the use of modern technology and by a high calibre of expertise. Accordingly, the United Nations, through technical co-operation activities, as well as through studies, seminars and symposia places considerable emphasis on assisting developing countries in their efforts to explore and develop their natural resources.

The storehouse of experience gathered by United Nations experts over the past twenty years and the similar knowledge acquired by professionals all over the world; the ever-growing complexity of technology; the need for information among experts in national and international organizations, enterprises and institutions of applied research; the necessity for creating common approaches between technical specialists and policy makers: these considerations have led the Economic and Social Council to approve the publication of the *Natural Resources Forum*, a journal devoted to the exchange and dissemination of information and experience in the natural resources field.

Philippe de Seynes

Philippe DE SEYNES
Under-Secretary-General
for Economic and Social Affairs

AVANT-PROPOS

L'opinion mondiale prend aujourd'hui une conscience de plus en plus nette du rôle que jouent les ressources naturelles dans le processus du développement économique, que ce soit à titre d'élément moteur du développement — comme c'est le cas du pétrole et d'autres ressources minérales — ou à titre d'élément indispensable d'infrastructure — comme c'est le cas de l'eau et des ressources énergétiques.

Les possibilités de développement que laisse entrevoir la demande prévisible de minéraux clefs dans les années à venir et les problèmes posés par les besoins d'infrastructures qu'entraîne la croissance démographique et économique ont placé la mise en valeur des ressources naturelles au premier plan des efforts à accomplir pour réaliser une croissance rapide et autonome. Les Etats Membres de l'Organisation des Nations Unies l'ont bien compris : la preuve en est l'attention soutenue que l'Assemblée générale et d'autres organes des Nations Unies ont portée aux fleuves internationaux et aux ressources de la mer au cours des dernières années et aussi, évidemment, la création récente par le Conseil économique et social d'un Comité permanent des ressources naturelles.

L'Organisation des Nations Unies est convaincue que le recours aux techniques modernes et l'emploi d'experts hautement qualifiés permettront de vaincre les obstacles qui se dressent sur les chemins de l'avenir; en conséquence, par le biais de ses activités de coopération technique ainsi que par des études, des séminaires et des colloques, elle s'attache particulièrement à aider les pays en voie de développement dans les efforts qu'ils déploient pour explorer et mettre en valeur leurs ressources naturelles.

La vaste expérience accumulée par les experts des Nations Unies au cours des 20 dernières années et la masse de connaissances acquises par les spécialistes du monde entier, la complexité toujours croissante de la technologie, la nécessité d'établir un courant d'information entre les experts des organisations nationales et internationales, les entreprises et les institutions de recherche appliquée et celle de rapprocher les points de vue des experts et des responsables de la formulation des politiques sont autant de considérations qui ont conduit le Conseil économique et social à approuver la création d'un périodique qui, sous le nom de *Tribune des ressources naturelles*, visera à assurer l'échange et la diffusion de l'information et des données d'expérience dans le domaine des ressources naturelles.

Philippe de Seynes

Philippe DE SEYNES
Secrétaire général adjoint aux affaires économiques et sociales

PROLOGO

En la actualidad se comprende cada vez mejor el papel de los recursos naturales en el ámbito del desarrollo económico, ya sea como factor dinámico del desarrollo, en el caso del petróleo y otros minerales, o bien como elemento indispensable de la infraestructura, tratándose de los recursos hidráulicos y energéticos.

Las oportunidades para el desarrollo creadas por la demanda prevista de minerales esenciales en los próximos años y las cuestiones que suscitan las necesidades infraestructurales inherentes al crecimiento demográfico y económico han determinado que la tarea del desarrollo de los recursos naturales constituya uno de los principales esfuerzos necesarios para un progreso rápido y autosostenido. El hecho de que ahora los Estados Miembros de las Naciones Unidas comprendan bien estas oportunidades y cuestiones se refleja en la importancia atribuida en los últimos años por la Asamblea General y otros órganos de las Naciones Unidas a los ríos internacionales y los recursos del mar; claro está, en la reciente creación de un Comité permanente de recursos naturales por parte del Consejo Económico y Social.

En las Naciones Unidas existe la convicción de que los problemas del futuro se pueden afrontar con éxito recurriendo a la tecnología moderna y al saber altamente especializado. En consecuencia, las Naciones Unidas, por conducto de las actividades de cooperación técnica y de estudios, seminarios y simposios, asignan gran importancia a la prestación de asistencia a los países en desarrollo en sus esfuerzos por explorar y aprovechar sus recursos naturales.

El acopio de la experiencia adquirida por los expertos de las Naciones Unidas en los últimos veinte años y los conocimientos similares obtenidos por profesionales en todo el mundo, la creciente complejidad de la tecnología, la necesidad de información entre los expertos de organizaciones nacionales e internacionales, empresas e instituciones de investigación aplicada y el imperativo de crear enfoques comunes entre los especialistas técnicos y los que formulan las políticas han sido las consideraciones que han llevado al Consejo Económico y Social a aprobar la publicación del *Foro de Recursos Naturales*, revista dedicada al intercambio y la difusión de información y experiencia en la esfera de los recursos naturales.

Philippe DE SEYNES
Secretario General Adjunto
de Asuntos Económicos y Sociales

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Reference to "dollars" indicates United States dollars unless otherwise stated.

The term "billion" signifies a thousand million.

Sauf indication contraire le terme "dollar" s'entend du dollar des Etats-Unis d'Amérique.

Le terme "milliard" signifie 1 000 millions.

El término "dólares" se refiere a dólares de los Estados Unidos, salvo que se indique lo contrario.

El término "billón" significa millar de millones.

STATEMENT BY PHILIPPE DE SEYNES, UNDER-SECRETARY-GENERAL FOR ECONOMIC AND SOCIAL AFFAIRS, AT THE OPENING MEETING OF THE FIRST SESSION OF THE COMMITTEE ON NATURAL RESOURCES

It is a great privilege for me, on behalf of the Secretary-General and the Organization as a whole, to thank you for attending this first session of the Committee on Natural Resources. I should first like to welcome the delegations present here and to convey our friendly greetings to those who have not arrived in time for this first meeting and to those for whom a place has not yet been assigned here. A glance at the list of participants, many of whom are among the most eminent authorities in the field of natural resources, shows that rhetoric would be out of place. Nevertheless, a few words should be said to mark the significance of the occasion in which we are participating today.

United Nations work in natural resources has been influenced essentially, if not exclusively, by a certain practical or pragmatic internationalism directed mainly or exclusively—perhaps too exclusively—at achieving the most immediate results. On this level, the Organization can take pride in its appreciable success. Given the importance to developing countries of foreign earnings from the exploitation and sale of raw materials, United Nations technical assistance and pre-investment activities are surely among the most productive in the sphere of international co-operation, whether bilateral or multilateral.

We must recognize, however, that even these practical activities are marginal by comparison with the needs of the developing countries and perhaps also of the industrial countries, and with the known and foreseeable possibilities of new technology in the exploitation of natural resources. For example, geological surveys have certainly not been proceeding at the pace which is desirable in view of the current situation of the international market for certain primary commodities. Existing activities are also marginal by comparison with the project executing capacity which has been gradually built up by the United Nations family of organisations. This executing capacity, which has been acquired through fairly long experience in extremely diverse conditions, has naturally produced a store of economic and technical expertise which in my opinion is far from being put to full use for lack of adequate financial resources.

Even if it is argued, in the light of the principles of pragmatic internationalism to which I have referred, that United Nations activity in the field of natural resources should be restricted to individual projects in programmes of practical action, the existence of a Committee like this one would be justified and extremely useful. The technical problems needing to be solved at the practical action level are numerous, and the effectiveness of future operations is directly dependent on their solution. These problems relate to the rational utilization and management of resources, particularly in developing countries; the co-ordination of resource exploitation with the implementation of national plans—we know what crucial problems arise when heavy investment is carried out in small-scale economies; the accurate assessment of the practical possibilities offered by new technological methods—the use of satellites, to cite only one example; the methodological difficulties of cost-benefit analysis for the alternative courses of action open to countries in the exploitation of their resources. Even if the approach is confined to individual projects, some research is essential, some technical and economic discussion is necessary, and the existence of a Committee like this one can provide a most valuable instrument for the promotion as well as the guidance of such research and discussion. There are complex and controversial questions in this area. There is, furthermore, knowledge which must without fail be spread and disseminated. There is also a need to determine what are the most appropriate organizational arrangements for activities in different circumstances.

Yet I must confess that I do not think that the Economic and Social Council and the General Assembly would have taken the bold decision to establish a new organ in contravention of one of their most persistently stated articles of faith if it had been solely to guide the administrations of the United Nations family of organizations in their practical activities and in the execution of specific projects, I think that it relates to a question of growing urgency about the exploitation and disposal of natural resources. I think it indicates that the international community is questioning whether the exploitation and disposal of natural resources can continue, indefinitely, on the basis of current patterns, procedures and criteria or, whether the new circumstances do not require even now, and increasingly in the future, a degree of organization and, if not planning, at least guide-lines on a world scale. For in the field of natural resources, activities in one small part of the globe directly affect vast regions of the world. The work of the Sea-Bed Committee, for example, and the prospect of an international régime which might make some planning obligatory for a great portion of the reserves of certain resources; recent concern for environmental protection, which is putting a new light on technical options in the exploitation of natural resources; other very recent developments which show the influence of temporary or even chance factors on the world supply of certain commodities important for development: all these would indicate that somewhere—and it can hardly be elsewhere than in the United Nations—a start should be made in formulating a world natural resources policy.

At the present time, natural resources exploitation is carried out mainly on the basis of short-term governmental policies, but very rarely by international considerations. This situation is not essentially new, but I think that in the present circumstances there are various considerations favouring a different attitude, and the time has come to examine whether certain elements of an international policy on raw materials should not now be considered and explored.

The first problem is the possible exhaustion of raw materials. This problem is not new either, and has arisen from time to time in connexion with certain surveys and projections on natural resources as a whole or certain individual ones. But it seems to be receiving more attention now that we tend to compare our planet to a space ship—one of the most popular images of the day—a space ship whose existing or foreseeable resources require infinitely more conscious and prudent management than they now receive. The population/resources relationship, which is a restatement or reformulation of the Malthusian dilemma of the nineteenth century, is causing disquiet in its global ramifications within a segment of public opinion that is still small, but quite influential, and interested in the future—or various possible futures—of our planet, and in the interplay of what appear to be the determining factors for this future or futures. It must be recognized that speculations regarding this problem of resource exhaustion are often purely intuitive. They are sometimes even presented in the form of an absolute postulate based on an extrapolation of recent trends which stresses certain factors while taking no account of others, such as, for example, technological innovation. With regard to the possible or impending exhaustion of natural resources, there is no consensus on which to base political action unless it is agreement as to the probable long-term shortage of water resources, which appears to be generally recognized by all those involved in these matters. But in other cases, speculations range from zero to infinity. In my view we must be wary of these extrapolations, which are generally made in order to avoid the introduction of too many variables in forecast models. However, account must clearly be taken not only of the exhaustion process already noted but of technological innovation, its impact on costs, and on substitution prospects and the extremely complex interplay of demand, cost, and the changing uses of resources. Consideration must be given to certain new concepts such as the recycling of natural resources. Still, we cannot ignore the fact that certain theories hold that the exhaustion of some resources is inevitable or almost inevitable and that rigorous restrictions should therefore be imposed on their use. If that is true we should know it, and if it is not true we should prepare, having reached basic scientific and political agreement, to combat trends and opinions which might adversely affect the growth of developing countries and the future of the world in general.

The second problem is the relationship between the use of natural resources and the protection of the environment. The deterioration of the human environment through pollution resulting from the exploitation and utilization of natural resources has, as you know, received considerable attention recently and is at present the subject or one of the subjects to be dealt with by a conference being planned at this very moment at Geneva. The international community has only recently become aware of the problem, and there is still no organized body of opinion, and therefore no consensus, relating to it. This is true both for the purely scientific and for the economic aspects of the question. Moreover, both in government circles and in academic circles, a fair amount of confusion still exists and even a certain remissness with regard to basic intellectual discipline. In the statements made by political figures it is sometimes difficult to distinguish between reflections of fear of toxic and dangerous substances and reflections of primarily aesthetic or hedonistic concerns. But we do have here a factor which is influencing —and may influence more in the future—the pattern of natural resources production and consumption. Again it is essential to ensure that the problem is not dominated by intuitive speculations. I believe we must take care in this matter to bring out the importance and necessity of rational management of natural resources, including efforts to find alternative solutions, and not only the penalizing of pollution sources. The developing countries' need for growth must be borne in mind. If there are to be no harmful repercussions, regulation must advance at more or less the same speed as promotion of natural resources exploitation.

Finally, there is a third problem, that of equity. Our view of natural resources has changed since the theory, developed at the end of the eighteenth and beginning of the nineteenth centuries, that the soil is the sole source of wealth. Our understanding of natural resources today covers many varied elements, solid and volatile, tangible and invisible. But the situations are still approximately those of monopolies based on geography or geology or special advantages deriving from the economic environment. Thus for example at the present time two thirds of the most important mining activities are to be found in a small number of industrialized countries. Clearly, without a more equitable system of international relations, without a world-wide arrangement for the more balanced development of different parts of the world, it is almost inevitable that these situations of geographical monopoly or advantages deriving from the economic environment will be exploited to the full. The principle of national sovereignty over natural resources has been proclaimed so frequently and solemnly that it has by now acquired the weight of a Charter principle. But we here know that this principle is not a substitute for the political and philosophical reality into which we must fit a natural resources policy ensuring some degree of organization in the exploitation and utilization of natural resources. The principle of national sovereignty should be considered in conjunction with another principle, that of world solidarity. It is the combination of these two principles that should gradually find expression in the definition of economic arrangements for the exploitation and distribution of natural resources, be it in the area of trade conditions, division of profits from exploitation, organization of exploration activities or limited planning of production, suggested more recently by the prospect of a world regulatory authority for the sea-bed.

Gentlemen, what I have just said shows that the United Nations should consider the problem of natural resources from the standpoint of the most far-reaching economic, social and political co-operation possible and with as universal as possible an approach to the interests and objectives involved. The outlook for international co-operation in the field of natural resources is extremely satisfying and promising. Some of the documents before you outline, for instance, the possibility of long-range electric power transmission and construction of intercontinental lines, the possibility of developing a world-wide network with its enormous advantages in terms of electric power costs, and the further possibility, for example, of promoting the use of satellites, an undertaking which entails not only many technical problems but also problems in the political relations between States, and even military problems. There are the more immediate possibilities, already suggested in the United Nations, of more systematic exploration of natural resources to prevent over-concentration in certain economically favoured countries or areas. Lastly there is the possibility of comprehensive and coherent regulations which take account of all the various aspects of the problems and not just one or two. All of this suggests that somewhere in this system, in the United Nations system of collective consideration, we must have a central organ capable of taking a global view of these different problems and of formulating the necessary guidelines. An organ is needed which can bring to light the practical possibilities offered by the use of modern technology and secure the greatest possible political consensus on them. A central organ is needed which can alert the world to certain dangers and open its eyes to certain possibilities, an organ which can outline plans for institutional arrangements combining effectively, and in a politically acceptable way, national control over natural resources with a sense of world solidarity.

I think that the creation of such an organ, which you are in the process of constituting at this time, is most appropriate in the context of the global strategy which the international community has now accepted and adopted for the Second Development Decade, a strategy which is endeavouring to insert into the development problem an embryonic element of collective management reflecting better than in the past a sense of joint responsibility. The effort you are beginning today is an important factor in this development strategy, and so the Organization places great hopes in the work of this Committee.

The Resources and Transport Division

It may be appropriate in the first issue of the *Natural Resources Forum* to describe the history and activities of the Resources and Transport Division of the Department of Economic and Social Affairs, which will supervise the substantive matter of this journal, emphasizing the work carried out in the field of natural resources.

A Unit for natural resources within the United Nations Secretariat was first formed about twenty years ago, consisting of the late Emmanuel de Breuvery, a resources economist with long experience in the Far East, a young economist, and the present Director, Joseph Barnea. The Unit gradually developed into a Section, then into a Branch, and about seven years ago it became a Division with Emmanuel de Breuvery as its first Director. He was succeeded by Roberto Arce, a mining engineer who for many years had worked as a United Nations technical adviser in a number of developing countries and had been transferred to Headquarters when the Special Fund activities began. Mr. Barnea succeeded Mr. Arce. All three directors have had a background in three interrelated fields, namely, resource economics, resource technology and working experience in developing countries.

ORGANIZATION OF THE DIVISION

Today the Resources and Transport Division, headed by its Director with the aid of two Assistant Directors (for Research and Studies and for Co-ordination of Operations respectively) and several other staff members, comprises, in addition, an Ocean Economics and Technology Branch, and five sections: Cartography, Energy, Geology and Mining, Water, and Transport. The Division operates as a closely-knit unit, an interdisciplinary approach being ensured through the office of the Director.

Though large in terms of work programme and operational activities, the Division has only forty-six professional staff members and about twenty-seven interregional advisers. These include personnel of widely differing international background, representing the economic and technical specialties essential to the broad field of natural resources and transport. Among them are economists specialized in water, energy, minerals and transport; civil engineers expert in water, roads and bridges; a variety of specialists in various geological fields such as exploration geology, geochemistry, geophysics, geothermal resources, hydrogeology, volcanology and petroleum. In addition to civil engineers, the Division has mining, mechanical and chemical engineers. It also has two experienced drilling engineers, cartographic and marine engineers and a variety of other technical specialists. This professional staff has been brought from all over the world, including Canada, the United States of America, the Union of Soviet Socialist Republics, Japan and various European countries; and there are a number of members from developing countries.

THE ROLE OF NATURAL RESOURCES IN DEVELOPMENT

From the first setting up of the Unit, an attempt was made, through studies, seminars and reports to the Economic and Social Council, to foster an understanding of the significance of natural resources as one of the most important elements in economic development for developing countries. In the beginning, there was little appreciation of this fact within the United Nations or among policy-makers, and this was only a reflection of the limited attention given to natural resources in economic literature or among economists generally. In time, however, an understanding of the material importance of natural resources development prevailed and began to exercise weight in the decisions of the Council and in those of policy-makers in developing countries. Whereas two decades ago representatives from Member States seated at the Economic and Social Council doubted the necessity of the United Nations dealing with problems of water and other resources, today the position has changed radically, again a reflection of a change that has come about in a general point of view. The most recent concrete expression of this change was the decision of the Council in 1970 to establish a Committee on Natural Resources.

In the immediate future, as world-wide public concern for questions of the human environment increases, interest in the related basic problems of natural resources is bound to follow in step, and indeed some of these considerations have already become major political issues in the United Nations, particularly as regards the resources of the sea, international rivers, and questions of sovereignty.

Apart from those aspects which have acquired political interest, it is important to note that in the field of natural resources, technology has moved fast. Since the end of the Second World War, changes have taken place almost constantly, and these changes have involved not only the search for new resources but the discovery of ways to make better use of known resources. A case in point is that of brackish water which in many countries is now moving from the category of worthless, low-grade water to a resource of economic significance. Natural gas, which in most countries was flared twenty years ago is now becoming, through liquefaction, an important item of international trade. Geothermal energy which was once regarded as a freak of nature is now being recognized as a new, important resource with many applications.

The list of such examples is considerable. These technological changes—one might refer to a technological revolution—have so vastly increased our capability to discover natural resources that a gloomy Malthusian outlook can no longer be maintained. By means of such modern techniques as geochemistry and geophysics, we are now able to uncover hidden wealth, to explore for resources in neglected areas, inland and in the sea; to delve deeper into the earth and go farther afield into areas previously considered unproductive. Thus, given the experienced staff to work with, the beliefs of decision-makers in many developing countries concerning their lack of natural resources could no doubt be proved wrong in a few years, and therefore whenever possible we have encouraged developing countries to think in terms of their natural resources potential.

Special Fund projects

When the Special Fund was established in 1959 making it possible to carry out large-scale pre-investment projects in developing countries, the Division was given the opportunity through projects executed by the United Nations to test in the field the validity of this belief. We are now in a position to state with no exaggeration that natural resources are far more widely available than earlier generations had believed and that in fact they can be found in almost every developing country, even those which the mining industry, and very often the local population as well, have considered to be barren of resources on the basis of exploration carried out a generation ago with less advanced techniques. Examples of such cases are the porphyry-copper discoveries in Sabah (Malaysia), Panama, Argentina, Ecuador and Northern Mexico.

To some extent, the sudden need for mineral surveys and other Special Fund projects in some developing countries was due to the vacuum created by the abandonment of the colonial system. The geological and other services connected with natural resources in newly independent countries had been previously staffed by expatriates, and with their departure technically experienced personnel were lacking to carry on activities in the field of natural resources or to develop new ones. Some of the colonial geological services had traditionally restricted their activities to mapping, whereas mineral exploration was left to private companies, and with the withdrawal of the colonial administrations, the readiness of private companies to enter into geological exploration, in the absence of clear mineral indications, also declined. The United Nations, with its limited funds, tried to fill the breach, not only with exploration projects but in the training of local personnel and the rendering of assistance in setting up geological, hydrological, and other natural resources services where they did not exist before.

With the establishment of so many new countries, a new function has developed over the last few years; that of an advisory service in matters concerning concessions, the modernization of mining laws and other laws, and assistance with urgent problems, such as dam construction. Furthermore, through United Nations activities, many new technologies have been introduced to developing countries, leading among other things to the establishment of more than fifty laboratories, and the provision of geophysical and drilling equipment.

Principles of work

We have learned that knowledge and application of technology are not alone sufficient. Equally important are the judgement and experience of resource specialists with long-term practical field experience and an integrated approach, maintaining full contact with related fields so that technological breakthroughs in one field may be appropriately applied in other fields. Thus, a trace metal analysis of underground water is significant not only from the point of view of water quality, but as a source of important information on possible mineral deposits. Research in geothermal energy has stimulated a realization of the relationship between geothermal energy and certain minerals, and the significance of minerals in areas of hydrothermal alteration is widely recognized. It is not an accident, for example, that the areas of geothermal belts and areas of porphyry-copper are almost everywhere in the same mountain range, even though we may not yet possess the full geological interpretation of this phenomenon.

One of the working principles of the Resources and Transport Division is to maximize information gathered through new technologies in developing countries, irrespective of geological concepts, provided that such maximization does not add materially to the cost of the exploration project. As an example, where we undertake airborne geophysics, additional equipment is supplied—if this can be done at reasonable cost—in order to obtain maximum information. For a survey of an iron ore body in Somalia, radiometric gathering of information was added, and in this way uranium and thorium-bearing areas were discovered, even though there had been no previous indication in the geological literature or elsewhere of the occurrence of radioactive material. Similarly, bauxite was found in the Solomon Islands on a coral reef in a marine environment, although accepted geological theory would exclude the existence of bauxite in a marine environment.[1]

Based on the same principle of maximization of information gathering, the personnel of projects are urged in their geochemical surveys to test their samples not only for the two or three elements they expect to find, based on their geological understanding of the area of the survey, but for as many elements as their laboratory facilities will allow.

In geochemistry, which the Division finds to be a useful tool, especially in tropical areas, the United Nations is now collecting annually vast quantities of information. Our experience has indicated that we still lack technologies in a number of fields. We have found that geochemistry is of little use in areas covered by lava, and as lava-covered areas are widespread in developing countries, we are searching for new technologies which, at relatively low cost, would help us to explore the mineral, geothermal and water potential of lava-covered areas.

Another guideline which the Division has tried to follow has been to consider at every stage of exploration and exploitation the economic position of a country, so that Government or United Nations funds may be used in the most efficient way, maximizing the contribution of natural resources development to economic

[1] This type of bauxite has the lowest silica content of any bauxite so far known, that is, 0.2 per cent.

development. Economic justification is particularly important in the field of water resources, where a country usually has alternative sources of water for development. The Division has tried to follow the principle that the first task is to determine the water needs by quantity, quality and location, and governed by those needs, the most economic water sources are then evaluated. Where water needs are relatively small, groundwater is often the most economic source of supply; where large quantities of water are needed for irrigation, surface-water is the normal answer, and desalination, in which the Division has done extensive work, is recommended only where no cheaper alternative sources of water supply are available. The Division, through its studies and field operations, has come to the conclusion also that a water-supply system based on desalination alone should be avoided wherever possible, and that a combined system of desalinated water and groundwater is probably the most economic in water-short areas, with the desalination plants operating on base load and the limited groundwater being used for peak demand in summer.

A field in which the Division has, over the years, tried to improve efficiency is that of drilling. Drilling is very often the most expensive item in a field project. We have found that with our own drilling engineer in control of operations in the field better results can be obtained in ore recovery and lower costs, and in better standardization and utilization of equipment. The workload has now increased; we have two drilling engineers on the Headquarters staff. Costs have been considerably reduced, and it appears that our drilling costs are well below the prices charged by private contractors in developing countries.

The Division has also encouraged the use of outside consultants. Indeed, Project Managers are encouraged to request specialized advice immediately when problems are encountered which would benefit by consultations. Such advice may be provided from among the Headquarters specialists with the assistance of outside consultants who are outstanding in their fields.

As a matter of course in our field projects we train local personnel, and, in practically every area, we send international personnel into the field. Not only is on-the-job training carried on, but almost every field project includes fellowships by means of which appropriate instruction is provided to local personnel.

Achievements in the field

The extent of operations in which the Resources and Transport Division is concerned is perhaps not always realized. Actually, the Division has been responsible for executing 156 Special Fund projects in developing countries—a figure which exceeds those executed by most of the specialized agencies within the United Nations system[2]—as well as for United Nations technical assistance activities in the field of natural resources and transport. The Division has carried out a number of projects under the West Irian Programme; it works from time to time with the World Food Programme in developing countries; it has a trust fund from the Government of the United Kingdom for activities in the field of desalination; and it carries out a number of field operations financed under funds-in-trust.

The total international personnel on field operations in developing countries for which the Resources and Transport Division has substantive responsibility numbers about five hundred (excluding the personnel of consulting firms); in effect, one professional at Headquarters corresponds to fourteen professionals in the field, a relationship which is much lower than in any other United Nations body and in any other substantive division in the United Nations Secretariat. This figure can be interpreted in a variety of ways: it may be interpreted as a figure indicating the comparatively limited number and perhaps insufficient number of Headquarters personnel; it may also indicate a high proportion of operational activities to the total activities of the Division; and it may indicate high performance, at least in financial terms.

The United Nations is well aware of the need, in all projects, of working for positive results which will lead to follow-up development. The Division adheres to the principle that the success of a given project is to be found in the achievement of the practical goals set forth at the outset; and the performance of the technical personnel is measured accordingly.

Reporting services

Apart from operational activities, the Division has a number of other functions and has carried out many of them, I believe, satisfactorily. It has its own research and studies programme, based largely on resolutions of the Economic and Social Council, submitting to the Council (and now to the Committee on Natural Resources) studies and reports as required. It provides reports and material to a variety of bodies which during the last few years have been established within the United Nations system, and which may require to be informed on certain aspects of resources or transport.

Such activities include services to the Advisory Committee on the Application of Science and Technology to Development and to any of the agencies of the United Nations system under the programme for inter-agency co-operation; the preparation of papers for meetings held by a United Nations body; research in matters concerning the connexions between natural resources and the human environment; and provision of the informational needs of the newly established Committee on Natural Resources. The Division also co-operates with the Committee on the Peaceful Uses of the Sea-bed and the Ocean Floor beyond the Limits of National Jurisdiction and with the Committee on the Peaceful Uses of Outer Space. A number of studies have been produced on marine affairs and marine resources, and one on the use of resource satellites for the benefit of developing countries.

In addition to these reporting services, the Division has the work of preparing seminars and conferences. At least two seminars are organized each year—in some years the number is higher—and these are designed to train policy-making officials from developing countries in specific fields of resources and transport. Each seminar requires careful review of known

[2] A Special Fund project is a large-scale field project financed by the United Nations Development Programme (UNDP) and by the Government or Governments concerned, in which, through a Project Manager, the executing agency carries out the management of the project.

technologies and other relevant data, the preparation of outlines for each lecture and the discussion of subject-matter with outside and inside specialists. Such seminars, apart from their value as a medium of training, have two consequences: they establish personal contact between Headquarters staff and corresponding specialists in developing countries, and through this contact they enable our staff to keep abreast of developments on a world-wide scale. Seminars, therefore, contribute to the easy availability of international know-how, not only theoretically, but in terms of practical operation.

Among the significant international symposia or conferences organized by the Division were the Conference on New Sources of Energy[3] held in Rome in 1961, the Interregional Symposium on the Development and Utilization of Oil Shale Resources held in Tallin, Estonian SSR, in 1968, and in September 1970, the Symposium on Development and Utilization of Geothermal Resources, in Pisa, Italy.

To provide guidance in fields of special interest, the Division frequently organizes studies, through international panels of experts. A panel on integrated river basin development produced a now famous report, which has become standard and has recently been re-issued in its second edition.[4] A Panel of Experts also wrote the first report on large-scale groundwater exploration;[5] and another panel wrote on the relationship of desalination and storage, a report which has given to desalination a totally new direction.[6]

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[3] *Proceedings of the United Nations Conference on New Sources of Energy (Solar Energy, Wind Power and Geothermal Energy)*, Rome, 1961, vols. 1-7 (United Nations publication, Sales No.: 63.I.2, 63.I.36-41).

[4] *Integrated River Basin Development* (United Nations publication, Sales No.: E.70.II.A.4).

[5] *Large-scale Ground-water Development* (United Nations publication, Sales No.: 60.II.B.3).

[6] *The Design of Water Supply Systems Based on Desalination* (United Nations publication, Sales No.: E.68.II.B.20).

In the field of iron ore, through a Panel of Experts in 1954, the Division carried out its first survey of the world's iron ore resources,[7] and recently, at the request of the Economic and Social Council, in its resolution 1033C (XXXVII), carried out the second world-wide survey.[8] The new report, recently published, reflects an increase on a very large scale of known iron ore resources as a result of the application of new technology, indicating that in the foreseeable future the world will not suffer from a shortage of iron ore.

The growth and diverse activities of the Resources and Transport Division are to some extent a demonstration of the usefulness of the United Nations in the field of economic development and the effectiveness of putting into practice the international expertise the United Nations has at its disposal, not only in the field, but in the development of new concepts that can be applied in some of the industrialized countries. The United Nations, being composed of many Member States, cannot perhaps apply the speed of decision-making habitual to private companies or individual Governments; it is bound to act within a circumscribed framework. Yet, within these limits, much can be accomplished, provided effective use is made of the United Nations' unique access to an international storehouse of expertise, both in experience and in personnel.

As long as the staff of the United Nations, at Headquarters and in the field, believe in United Nations principles, believe in the principle of effective performance and are intellectually alert and devoted to the work they are carrying out, the co-operative approach we have developed over the years and the feeling of pride in working for the United Nations will ensure that our efforts will continue to meet with success.

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[7] *Survey of World Iron Ore Resources: Occurrence, Appraisal and Use* (United Nations publication, Sales No.: 54.II.D.5).

[8] *Survey of World Iron Ore Resources: Occurrence and Appraisal* (United Nations publication, Sales No.: E.69.II.C.4.).

SUMMARY — RESUME — RESUMEN

The Resources and Transport Division

The article traces the history of the Resources and Transport Division (which will supervise the substantive matter of the *Forum*) from its inception as a Unit about two decades ago to its present organization with an international staff of specialists representing the economic and technical fields connected with natural resources. During that time it has played a primary role in establishing the material importance of natural resources in economic development.

After the creation of the Special Fund in 1959 there was increased opportunity to engage actively in the search for new resources, and in finding ways of making better use of old ones. As a result it can be stated today that natural resources are far more widely available than was hitherto supposed, and this fact now plays a weighty part in the decisions of policy makers as well as in those of the Economic and Social Council.

Over the years, through projects of the United Nations Development Programme (UNDP), the Division has assisted developing countries in conducting exploration projects, establishing training programmes, founding laboratories and setting up geological, hydrological and other resource services, at all times with emphasis upon the training of local personnel, both on the job and by means of fellowships abroad. In recent years it has offered advisory services in matters of mining law or in urgent projects such as dam construction. Not only does it provide the expertise of its own staff at Headquarters, but where desirable it engages the services of consultants in every field.

Certain working principles have emerged, guiding the activities of the Division. The new technologies are brought to bear on the work of exploration; an integrated approach is fostered in which contact between related fields is maintained; on every project as much information as possible is collected, so as to establish a generally useful bank of information; and care is taken to ensure that all work shall be economically justified within the context of total development.

Apart from its field operations, the Division is responsible for providing reports and material to a variety of United Nations bodies, and it has organized seminars, conferences and special studies. A concrete expression of the importance of the Division's work has been the recent decision by the Economic and Social Council to establish a standing Committee on Natural Resources.

La Division des ressources et des transports

L'article retrace l'histoire de la Division des ressources et des transports (qui assurera la supervision des matériaux publiés dans la *Tribune des ressources naturelles*) depuis ses débuts en tant que service distinct, il y a quelque 20 ans, jusqu'à son organisation présente, avec son personnel international composé de spécialistes représentant l'ensemble des domaines économiques et techniques se rapportant aux ressources naturelles. Durant cette période, elle a joué un rôle de premier plan dans la reconnaissance de l'importance matérielle des ressources naturelles dans le développement économique.

Après la création du Fonds spécial en 1959, des moyens sans cesse accrus ont permis d'entreprendre activement la recherche de nouvelles ressources ainsi que des méthodes permettant de faire meilleur usage de celles déjà connues. Les résultats montrent que les ressources naturelles sont beaucoup plus largement disponibles qu'on ne l'avait cru jusqu'à présent, et cette considération est maintenant de poids dans les décisions des responsables de la politique des ressources naturelles comme dans celles du Conseil économique et social.

Au cours des années, par l'intermédiaire des projets du Programme des Nations Unies pour le développement, la Division a aidé les pays en voie de développement en exécutant des projets de recherche, en établissant des programmes de formation, en créant des laboratoires et en organisant des services spécialisés dans le domaine des ressources naturelles : géologiques, hydrologiques et autres. Dans tous les cas une attention particulière a été donnée à la formation de personnel local, à la fois à l'occasion de l'exécution du projet même et au moyen de bourses de formation à l'étranger. Dans les dernières années, les services de conseillers spécialisés ont été fournis dans des domaines divers allant de la législation minière à la construction de barrages. La Division non seulement prête les services spécialisés de son personnel au Siège, mais aussi, s'il est nécessaire, a recours à des consultants dans tous les domaines.

Certains principes d'action ont pu être dégagés pour guider les activités de la Division. Les nouvelles techniques sont appliquées aux activités de prospection; on cherche à favoriser une approche intégrée qui tienne compte des domaines connexes; on recueille le maximum d'information sur chaque projet pour constituer une banque des données généralement utiles; enfin, on veille à faire en sorte que tous les travaux soient justifiés sur le plan économique dans le cadre du développement général.

Outre les travaux sur le terrain, la Division a dans ses attributions l'établissement de rapports et autres matériaux destinés à divers organes des Nations Unies, et l'organisation de séminaires, de conférences et de groupes d'études spécialisées. Une expression concrète de l'importance du travail de la Division a été la récente décision du Conseil économique et social d'établir un Comité des ressources naturelles.

División de Recursos y Transportes

El artículo hace la historia de la División de Recursos y Transportes (la cual supervisará la temática esencial del *Foro*) desde que se creó como dependencia hace unos veinte años hasta su organización actual con una plantilla de funcionarios internacionales especializados en los campos económicos y técnicos relacionados con los recursos naturales. Durante ese lapso ha desempeñado un papel destacado para cristalizar la importancia material de los recursos naturales en el desarrollo económico.

Desde que se organizó el Fondo Especial en 1959, ha habido cada vez más oportunidades de iniciar la búsqueda de nuevos recursos y encontrar métodos para aprovechar mejor los recursos conocidos. Como consecuencia, puede afirmarse ahora que existen muchos más recursos naturales disponibles que lo que se suponía, y este hecho constituye un factor determinante en las decisiones de los encargados de establecer políticas, así como en las del Consejo Económico y Social.

Con el transcurso de los años y mediante los proyectos del Programa de las Naciones Unidas para el Desarrollo (PNUD), la División ha ayudado a los países en desarrollo a realizar proyectos de exploración, organizar programas de capacitación, crear laboratorios y establecer servicios para los recursos geológicos, hidrológicos, etc., destacando siempre la capacitación de personal nacional en el empleo y mediante becas en el extranjero. En los últimos años ha ofrecido servicios de asesoramiento sobre leyes de minería o en proyectos urgentes, tales como construcción de presas. No sólo proporciona los conocimientos especiales de su propio personal en Nueva York, sino que contrata consultores en todas las esferas de actividad cuando es necesario.

Se han creado algunos principios generales de trabajo que orientan las actividades de la División. Se aplican nuevas técnicas en los trabajos de exploración; se estimula el enfoque integrado, por el cual se mantiene contacto entre las esferas de actividad conexas; se reúne toda la información posible de cada proyecto, a fin de establecer un banco informativo útil en general, y se cuida de que todo el trabajo esté económicamente justificado dentro del contexto del desarrollo global.

Aparte de sus operaciones en los países, la División se encarga de proporcionar informes y material a una serie de órganos de las Naciones Unidas, y ha convocado seminarios y conferencias y preparado estudios especiales. Una expresión concreta de la importancia de la labor de la División ha sido la reciente decisión del Consejo Económico y Social de crear un Comité permanente de Recursos Naturales.

GEOCHEMICAL EXPLORATION IN UNITED NATIONS MINERAL SURVEYS

by Claude LEPELTIER

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The first United Nations mineral survey became operational at the end of 1960. Since that time, sixty-six major mineral projects, financed jointly by the United Nations Development Programme (Special Fund) and by a requesting Government have been entrusted to the United Nations as executing agency. The scope of the projects covers economic and industrial studies and the establishment of educational and research institutes, but they are directed mainly towards the search for exploitable minerals, including the training of counterpart personnel in the various modern methods of mineral exploration.

Apart from purely airborne or off-shore surveys, there have been fifty-four ground exploration projects for metallic minerals, of which forty-eight have used geochemical techniques ranging from ancillary analyses to full-scale reconnaissance and follow-up programmes that is, 73 per cent of the total, and if we consider ground exploration projects alone, 89 per cent. The present review is based on data collected from forty-one projects, conducted over almost a decade (1961-1969). During this period, about 437,000 samples were collected and analysed by colorimetric, atomic absorption or spectrographic techniques, and more than 1,940,000 determinations for a wide range of elements carried out in laboratories, many of which were completely set up by the United Nations; others were made available by the counterpart organizations. The yearly average, over a period of nine years, was 49,000 samples collected and 215,000 geochemical determinations made, but these figures were increasing steadily over the period covered.

At the beginning of 1970 there were nineteen projects in operation carrying out geochemical exploration, and it was supposed there would be twenty-five by the end of the year: fifteen in Africa, seven in Latin America, two in the Middle East and one in Asia.

From these twenty-five projects, it is expected that about 100,000 samples will have been collected and 600,000 determinations carried out. It is not possible to make a long-range forecast for future geochemical activity because the trend of UNDP involvement in the field of natural resources is not clear at present, but it is fair conjecture that given the present level of activity, the relative importance of geochemistry in each project will continue to increase for some time to come, particularly with regard to the number of analyses carried out on each sample; it follows then that the volume of analytical data available for interpretation will probably increase considerably, posing new problems of treatment and interpretation.

EVOLUTION IN TECHNIQUES

During the first decade of operation, the trend has been towards greater refinement of analytical and interpretation techniques. Five years ago there was a bottleneck of slow analytical determinations. This was overcome by the introduction to the laboratory of atomic absorption spectrophotometry. There are twenty-one AA facilities now in operation in project laboratories, predominantly those of Perkin Elmer, Jarrell Ash and Techtron. Greater use is progressively being made of emission spectrography and in some cases of X-ray fluorescence. After the completion of a project, such equipment is usually turned over to the Government counterpart organization.

In the field of interpretation, we have passed from a purely empirical stage to statistical analysis and computer treatment of data.

Simultaneously with the technical evolution, a specialization of personnel has come about. In the early 1960s, many projects had a small geochemical exploration component—if any—which was usually the responsibility of one of the staff geologists: a Jack-of-all-trades, geologist and geochemist combined, if not also topographer and draftsman. The system worked well enough—but nowadays the species is becoming rare, and I daresay is disappearing (at least in the kind of integrated programmes we are considering) before the advance of a new breed of exploration man, the geochemist, whose definition I will leave discreetly aside.

Geochemical exploration is now an affair of specialists and team-work. Besides the geochemist, who is primarily responsible for orientation of the programme and supervision of its execution, a chemist is ordinarily in charge of the laboratory. Short-term consultants are also called in for difficult or particularly important operations, or at critical stages, such as the orientation phase and the laying-out of the programme, and for the interpretation of data.

MAIN FEATURES OF GEOCHEMICAL SURVEYS

Geochemistry is at its best in reconnaissance. Stream sediment reconnaissance surveys represent the bulk of our geochemical operations. They have the great advantage of contributing to the understanding of the regional geology, an enormous asset especially in rugged tropical or equatorial country where the geology is little known, which compensates for the relatively slow pace of the survey and the need for numerous personnel.

The method is employed either as the initial reconnaissance technique or after an area has already been outlined by photogeological, geological or airborne geophysical survey. The subsequent detailed surveys are usually done in close association with large-scale geological mapping and ground geophysics.

So far, neither hydrogeochemical nor biogeochemical surveys have been carried out in UNDP projects.

The main characteristic of United Nations surveys is their diversity: they vary in the type of operation, in size and geographical distribution and in the internationally recruited staff which carries them out. While the great majority of surveys are purely exploration-oriented—either reconnaissance or follow-up—there are also such operations as the establishment of geological institutes, for example in Iran, the Philippines,[1] and Jordan, which are oriented towards training and education.

Small ancillary surveys might involve perhaps some hundreds of samples and thousands of analyses (as in Nigeria); full-scale programmes with reconnaissance and follow-up might reach 10,000 samples and about 60,000 determinations per year, as in Panama, Guatemala or Malaysia (Sabah). Material means and logistical support vary accordingly. Sampling is made by parties on foot, horse-back, mule-back, four-wheel drive vehicles, boats or helicopters. Analytical work may be carried out on the spot, or in field-based laboratories, or in a central laboratory. The degree of sophistication of interpretation varies in the same measure, from simple profile drawing to—for example—trend surface analyses.

The surveys are world-wide, with a distribution south of latitude 40° N. The United Nations has had projects—to cite only a few—in Asia and the Far East (British Solomons, India, Malaysia) the Middle East (Cyprus, Iran and Turkey), Africa (Ethiopia, Senegal, Zambia), Central America (Guatemala, Honduras, Nicaragua) and South America (Bolivia, Chile, Ecuador).

Such far-flung distribution entails operations under all topographical and climatical conditions, from the Bolivian Altiplano to the hills of Senegal, from the swamps of Panama to the deserts of Sudan. Climate is a very influential factor in geochemical prospecting, and surveys have been carried out in the most deserts, such as Atacama in Chile, in the semi-arid savannahs of the Niger, in the tropical hills of Nicaragua and in the equatorial jungle of Congo or Guyana.

Unlike geophysical operations which draw heavily on contractors, geochemical surveys are carried out by United Nations personnel, the only outside contribution consisting of short-term consultant geochemists at critical stages of operations; sub-contracts with private or public laboratories for control analyses or special determinations; and automatic data processing through consultants or sub-contracts.

The United Nations personnel represents a wide range of nationalities. Since 1961 we have engaged the services of 20 geochemists, 16 chemists and 7 short-term consultants. It is interesting to note the distribution of their countries of origin. The 20 geochemists came from twelve different countries—14 from Europe, 2 from Latin America, 2 from the United States and Canada, and one each from Asia and Africa. Of the 14 European geochemists, 9 (that is 45 per cent of the total) came from the USSR, Czechoslovakia and Poland. Even more striking were the figures at the beginning of 1970: of 13 geochemists on duty, 9 came from Eastern Europe—a proportion of 70 per cent. This trend seems firmly established.

The national distribution for the 16 analytical chemists (11 of them still on duty) is more even. They come from thirteen different countries, 10 from Europe, 4 from North America, and one each from Asia and Africa. Only three are from Eastern Europe.

Seven consultants have assisted in United Nations programmes from five different countries; but here the situation is the reverse of that of the geochemists: 4 were from the United States and Canada and the remaining 3 from Western Europe.

The heterogeneity of professional background and experience of the people engaged in our geochemical exploration programmes resulted, at first, in difficulties in operational co-ordination, each individual having particular approach to the problems to be treated. But with the years, as experience was exchanged, this very variety of professional background turned out to be beneficial, and a kind of unity has been forged throughout all United Nations projects. The main remaining inconvenience is the high turnover of project personnel and the difficulty in recruiting qualified professionals for relatively short-term assignments —one to three years. This has been offset by efforts, generally successful, to retain the services of particularly competent people by reassigning them to a new project after the completion of their assignment.

Figures for field productivity vary from one project to another; for example in detailed surveys, the samples collected per party per day may be anywhere between twenty and a hundred, depending on topography and sampling pattern. In reconnaissance surveys the range is somewhat narrower: three to fifteen stream sediment samples may be collected per party per day, with an average of ten samples considered as fairly representative in average conditions (as in Ecuador and Guatemala). Soil sampling done in Senegal (on grids of 2,000 × 500 metres and 1,000 × 500 metres) gave the same average rate of sampling.

The average monthly output of some of our field laboratories, calculated over one year, vary by 1 to 10 ratio approximately, from a monthly 600 determinations in the case of small operations to 6,000 for full-scale programmes. These results are obtained in relatively small and simple laboratories, usually staffed by one United Nations chemist assisted by local counterparts.

Considering the inherent characteristics of our projects, their short-life and relatively long warm-up period, and the problems of counterpart personnel training, the productivity figures may be considered reasonably good.

The cost per area unit in detailed surveys is directly proportional to sampling density; figures vary between $50 and more than $1,000 per square kilometre.

[1] W. E. Hale and G. J. S. Govett, "An experiment in mineral exploration and training in the Philippines"; *Canadian Inst. Mining Metallurgy* (March 1968).

For example, the cost of a follow-up soil survey in Senegal carried out along a 100 × 200-metre grid (that is, 48 samples per square kilometre) was $175 per square kilometre.

In the case of reconnaissance surveys, which comprise the bulk of United Nations geochemical exploration programmes, in spite of their diversity the costs per unit of stream sediment reconnaissance fall within a relatively narrow range of $5-14 per square kilometre, the average being $10. These figures have been obtained from surveys with a sampling density ranging from one sample per half a square kilometre to one sample per 10 square kilometres, an average being one sample for one or two square kilometres.

Case histories

Two particularly successful operations where geochemistry played a major role were carried out in Malaysia and Panama.

Integrated survey in Malaysia (Sabah)

From 1961 to 1965, an integrated survey, including hydrology, sylviculture, pedology and mineral exploration, was carried out in Sabah, the northern part of Borneo, at a total cost of $1,560,000. The mineral exploration component lasted two and a half years and was concentrated in the valley of the Labuk River, an area largely underlain by ultrabasic intrusive rocks, but there are few outcrops and the geology is little known. A geochemical drainage survey was planned and supervised by a consulting geochemist and carried out under the guidance of a United Nations geologist over approximately 3,500 square kilometres in difficult conditions: rough topography, heavy forest and bad weather.

Stream sediment samples were often collected by boat. The sampling interval was usually one-half mile and the over-all sampling density about two samples per square kilometre. Samples were analysed for cold-extractable copper in the field and for Cu and Ni (hot extraction) in a central laboratory in Jesselton. The results for nickel were negative. Copper backgrounds were established at 10 ppm for cxCu and at 80 ppm for total Cu. On a total of 119 copper anomalies, 21 were selected for detailed follow-up investigations: ridge and spurs soil-sampling, grid-sampling, trenching and pitting.

The most promising anomaly was outlined in the head-waters of the Mamut River: anomalous cxCu values (four times the threshold) extend over five miles downstream. Follow-up investigation disclosed a principal zone of sulphide mineralization of 34 acres with soil Cu values ranging from 400 to 6,000 ppm. The geology is complex, strongly folded and faulted; weakly metamorphosed sedimentary rocks are intruded by large masses of ultrabasic rocks and smaller intrusions of porphyry, dolerite and serpentinite.

Further work by the Borneo Geological Survey[2] revealed the presence of porphyry copper mineralization, and the Government invited proposals for detailed exploration and development. Evaluation studies indicated reserves of about 100 million tons averaging 0.7 per cent copper.

Panama mineral survey

A more recent example where geochemistry was the backbone of the exploration programme was the mineral survey carried out from 1965 to 1968 over 17,000 square kilometres of the Azuero Peninsula in Panama. This is a difficult area for exploration because of the climatic conditions which are humid-tropical with 200 inches of rainfall annually. The region is virtually uninhabited and covered by unbroken primary forest. Geochemical drainage reconnaissance was considered the best approach to general exploration and an important programme was set up by the United Nations team, which included, among others, a geochemist and a chemist, with the assistance of a consultant.

Attention was first attracted to the northern part of the project area by clear, if not very strong, anomalies in cold-extractable heavy metals and copper in stream sediment (anomalous values of 200-225 ppm Cu against a high regional background of 80 ppm). A more detailed stream sediment survey outlined two areas, Botija and Petaquila, with high copper-molybdenum anomalies (up to 2,000 ppm Cu and 125 ppm Mo). They could be traced downstream for 10 and 17 km respectively.

The regional geology consists of andesitic and basaltic lavas, probably Miocene, with three younger main intrusives composed largely of quartz monzonite, granadiorite and dacite. Follow-up work included soil sampling (Cu, Pb, Zn, Mo), geophysics (EM-magnetometry) and scout drilling, which intersected porphyry-copper-type mineralization and confirmed the existence of orebodies of possible economic interest. The Government of Panama then sent out invitations for proposals for detailed evaluation and possible development. Another result of this discovery was that several mining companies started prospecting activities in other areas of Panama and elsewhere in Central America.

Miscellaneous projects

Other projects where geochemistry was one of the main components of the exploration programme took place in the following countries:

Senegal. A general reconnaissance was carried out by soil sampling along 2,000 × 500-metre grid. The problem of lateritic cover made the sampling difficult in some parts of the area.

British Solomon Islands. Regional reconnaissance was carried out by boat, sampling the river-mouth sediment around the islands;

Chile. Detailed surveys were made of hydrothermal alteration zones;

Argentina. A general reconnaissance was made of 130,000 km^2 in the Andes for the purpose of selecting follow-up areas rapidly;

El Salvador. Regional reconnaissance was carried out in areas covered with thick Quaternary post-mineral volcanics.

[2] H. J. C. Kirk, "Porphyry-copper deposits in northern Sabah, Malaysia", London, *Inst. Mining Metallurgy Trans.*, vol. 76 (1967), p. B 212-13.

Guatemala. Stream sediment sampling and spring sampling were done and statistical interpretation made of geochemical data.

Swaziland. Reconnaissance and follow-up surveys were made for gold by tracing As and Sb in stream sediment.

Cyprus. Orientation surveys and research were done on the primary dispersion of base metal sulphides in volcanic rocks and very complete mathematical interpretation made of the data.

Recording of data

The development of geochemistry in the decade under review and the results achieved have been spectacular. In United Nations survey projects, geochemical exploration is now a key technique. A cumulative problem has been generated, however, of the recording, storage and treatment of the ever-increasing mass of data. At present there is a lack of homogeneity in the recording and presentation of field results: efforts are being made towards standardization, so that the vast amount of information collected throughout the world may not be lost in dusty files but be recorded in computer-recoverable form and made easily available for further analysis. Ordinarily, use is made of only the most obvious geochemical features in a given survey; however, the "raw data" alone have great potential value, and they should be easily retrievable for interpretation or re-interpretation by computerized methods in order to extract the maximum information in the light of the latest development in this field.

This problem should be tackled before too vast and unmanageable a volume of figures will have accumulated, making it tedious to go back through the data and recast them for computer assimilation. This is the only way geochemical material can become available for interproject correlations and provide mineral exploration guidance on a fully regional scale.

SUMMARY — RESUME — RESUMEN

Geochemical exploration in United Nations mineral surveys: *Claude Lepeltier*

Since 1960, sixty-six mineral projects sponsored by the United Nations Development Programme have been entrusted to the United Nations as executing agency, and forty-eight of them have carried out geochemical exploration programmes. Data collected from forty-one projects reflect the growing importance of geochemical prospecting among the various exploration techniques. During nine years of operation (1961-1970), about 437,000 samples were collected and 1,940,000 determinations carried out, and these figures are expected to increase steadily in the future. The data show also the evolution towards greater specialization and sophistication in personnel and techniques; since 1966, the bottleneck in analytical determinations has been overcome by the introduction in the laboratory of the atomic absorption spectrophotometer; and geochemists today are usually assisted by chemists.

United Nations geochemical surveys are extremely diversified as to personnel, type of operation, size, organization and geographical distribution. Nevertheless, the costs of reconnaissance stream-sediment surveys (which make the bulk of the programmes) are relatively steady, varying from $US 5 to 14 per square kilometre with an average of $10 per square kilometre. The costs of detailed follow-up (soil-surveys) are more variable, varying from $50 to $1,000, depending upon sampling density and local conditions. In the laboratory, the cost per determination of usual base metals is, in large operations, as low as $0.50; the average is below one dollar per determination. Some typical case histories are briefly reviewed.

The main drawback of such a variety of exploration programmes is a lack of uniformity in the recording and presentation of data; this is to some extent correlated with incomplete exploitation of results. An immediate aim should be to establish a system of recording and presenting data in computer-recoverable form.

La prospection géochimique dans les programmes d'exploration minière de l'Organisation des Nations Unies: *Claude Lepeltier*

Depuis 1960, 66 projets miniers financés par le Programme des Nations Unies pour le développement ont été confiés à l'Organisation des Nations Unies, en tant qu'agent d'exécution, et 48 d'entre eux comportaient ou comportent des programmes d'exploration géochimique. Les informations recueillies au sujet de 41 projets attestent l'importance de la prospection géochimique [en neuf ans (1961-1970), 437 000 échantillons prélevés et 1 940 000 analyses géochimiques effectuées] et la place croissante qu'elle occupe parmi les techniques d'exploration. On s'attend que ces chiffres augmenteront régulièrement à l'avenir. Les données indiquent également que le personnel s'est spécialisé et les méthodes se sont perfectionnées; l'introduction, en 1966, de spectrophotomètres d'absorption atomique dans les laboratoires a permis de résorber l'excédent d'analyses géochimiques à entreprendre; aujourd'hui, les géochimistes sont d'ordinaire assistés par des chimistes.

L'un des traits principaux des prospections géochimiques entreprises par l'Organisation des Nations Unies est leur extrême diversité quant au personnel, au type et à l'échelle des opérations, à l'organisation et à la répartition géographique. Malgré cette diversité, les coûts des prospections de reconnaissance dans les alluvions de rivière, qui représentent l'essentiel des opérations, sont relativement constants: ils varient de 5 à 14 dollars des Etats-Unis par km^2, la moyenne se situant à 10 dollars par km^2. Le coût des prospections de détail (dans les sols) est beaucoup plus sujet à fluctuations et peut varier de 50 à 1 000 dollars par km^2 en fonction de la densité d'échantillonnage et des conditions locales. Au laboratoire, le coût de la détermination d'un élément courant peut être ramené à 0,50 dollar, la moyenne étant inférieure à 1 dollar. Quelques exemples de prospection sont passés en revue.

Le point faible de ces programmes est qu'en raison même de leur diversité il y a manque d'uniformité dans l'enregistre-

ment et la présentation des données; jusqu'à un certain point cela conduit aussi à une exploitation incomplète des résultats. Une des tâches immédiates est d'établir une standardisation dans ce domaine, permettant de traiter les résultats géochimiques sur ordinateur.

La exploración geoquímica en las investigaciones de minerales de las Naciones Unidas: *Claude Lepeltier*

Desde 1960, sesenta y seis proyectos de minerales auspiciados por el Programa de las Naciones Unidas para el Desarrollo han sido encomendados a las Naciones Unidas como organismo de ejecución, y en 48 de ellos se han llevado a cabo programas de exploración geoquímica. Los datos recogidos de 41 proyectos reflejan la importancia creciente de la prospección geoquímica entre las diversas técnicas de exploración geoquímica. En nueve años de operaciones, se tomaron cerca de 437.000 muestras y se efectuaron 1.940.000 determinaciones; se calcula que estas cifras aumentarán sistemáticamente en el futuro. La información acumulada también demuestra la evolución del personal y de las técnicas hacia una especialización y un perfeccionamiento mayor; el embotellamiento de las determinaciones analíticas ha sido superado desde 1966 con la introducción en el laboratorio del espectómetro de absorción atómica; además, los geoquímicos cuentan usualmente con la asistencia de químicos.

Las investigaciones geoquímicas de las Naciones Unidas presentan una extrema diversificación en cuanto a personal, tipo de operación, magnitud, organización y distribución geográfica. A pesar de ella, los costos de las investigaciones de reconocimiento de los sedimentos de río, que forman el grueso de los programas, son relativamente constantes: varían de 5 a 14 dólares por Km^2, con un promedio de 10 dólares por Km^2. Los costos de prospección detallada (investigaciones edafológicas) son menos constantes y varían de 50 a 1.000 dólares, según la densidad del muestreo y las condiciones locales. En el laboratorio, el costo por determinación de un metal corriente es de apenas 0,50 dólares, en el caso de grandes operaciones; el promedio es inferior a un dólar por determinación. Se analizan brevemente algunos ejemplos típicos de prospección.

La desventaja principal de tal variedad de programas de exploración es la falta de uniformidad en la compilación y presentación de los datos; ésta, hasta cierto punto, se relaciona con una explotación incompleta de los resultados.

Una meta inmediata debe ser la institución de un sistema de compilación y presentación de los datos en forma utilizable por computadoras.

AN APPROACH TO MINERAL POLICY FORMULATION

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In any nation, whether it has a centrally planned and controlled economy or a private enterprise economy, or a mixture of the two, or whether it has a developed or a developing economy, mineral policy comprises only one element of the total national policy. Mineral policy must be such that it enables mineral exploitation[1] to contribute to over-all national objectives. Indeed, it is only in the light of national objectives that mineral policy can be formulated (or modified) and implemented. In this context, the discipline of mineral economics can provide an essential tool in the formulation, modification, implementation and evaluation of mineral policy in relation to over-all national objectives.

Expressing the foregoing more directly, mineral exploitation should not be carried out merely for the sake of mineral exploitation itself but rather as an important aid in the attainment of national objectives.

What might be a nation's objectives towards which mineral policy could contribute? In the case of Canada, which has elements of both developed and developing economies and which is essentially a private enterprise economy with a measure of indicative planning, general national policy seeks rising levels of *per capita* real income with minimum unemployment, inflation, cyclical instability, and environmental destruction; rising absolute levels of population and output to maintain and improve Canada's position in the world community; a favourable balance of payments; and a measure of equitable distribution of income among the population and equitable development among regions. Notwithstanding the necessity of compromise among these general objectives—because some are to an extent incompatible—they represent an interrelated package. They reflect not only economic but non-economic objectives (that is social, cultural and political goals and matters relating to sovereignty and defence). Hence, desirable rates of efficient national and regional economic growth must be considered in "optimum" rather than "maximum" terms because of the utility gained in realizing the non-economic objectives.

The objectives of other nations, particularly those with developing economies, may differ from the objectives ascribed to Canada. Whatever they may be, however, mineral policy must be formulated in the light of them, not only for idealistic reasons but for realistic ones. At the national budget level, for instance, the planning of public expenditures involves a continuous process of choice. National legislatures exercise their choice of priorities by limiting or expanding expenditures in one area or another of government activity to meet specific national objectives or to fit particular budget levels. It is important to realize and accept that governmental activities in support of mineral resource exploitation must compete for funds with activities that support other sectors of the economy. Budget proposals for expenditures in support of mineral resource exploitation must, therefore, be prepared in the light of, and couched in terms of, the attainment of national objectives. It is at this critical level that the application of mineral economics can play a key role.

Factors influencing the development of mineral resource objectives

The development of national mineral resource objectives and of specific mineral policies to attain these objectives should, therefore, reflect the analysis, evaluation and interrelationship of the following:

(*a*) General national policies and objectives;

(*b*) The political, economic, social and physiographic character of the nation;

(*c*) The known or potential mineral resource base;

(*d*) The unique characteristics of mineral resources and the mineral industry.

Having considered the first, let us now turn to the second of their points, that is the political, economic, social and physiographic character of the nation and the implications of these factors in mineral policy.

[1] The term "exploitation", as employed in this paper, covers the full process of mineral exploration, development and production.

Whether a nation has a centrally planned and controlled economy, a private enterprise economy, or a mixed economy, the nature and stability of its Government will have a profound effect on its mineral policy and the attainment of mineral resource objectives. Mineral resource exploitation is risky, capital intensive and, in the case of most nations, necessarily oriented towards external markets. These three characteristics have implications for the political environment in developing countries, in which it is desired to encourage mineral resource exploitation. Generally, there is insufficient capital for resource exploitation within the nation itself, and such capital as does exist is not oriented to risky enterprises; also, there are generally insufficient domestic markets for the products of the mineral enterprise. It is necessary, therefore, to attract foreign capital investment in competition with other nations, both developed and developing—foreign investment which carefully weighs the terms of entry into the seeking nation in comparison with the terms of entry into other nations and the attendant risks. Both the nature and the stability of the Government are, therefore, factors to be considered in the formulation of a mineral policy designed to encourage mineral resource exploitation.

The state of a nation's economic development has implications for mineral policy. Consideration must be given to the level of sophistication of existing primary, secondary and tertiary industry, and to the existence, quantity and distribution of infrastructure such as power plants, railroads, roads, airstrips, harbours, hospitals, schools, communication facilities and financial institutions. The level of social development must be considered also—in particular, the aptitudes and attitudes of the population as they pertain to the level of education and technical and managerial skills needed for mineral enterprises. The physiography of the nation is an important consideration in the formulation of mineral policy, particularly in nations of large physical size or with difficult terrain or for regions distant from tide-water.

Essential characteristics of mineral resources

Mineral policy must also take into consideration the essential characteristics and problems of mineral resources, in many ways unique compared with other economic goods. Some of these characteristics are:

(*a*) A mineral deposit that can be economically used is unusual, relative to the volume and areal extent of the earth's crust. The complexity of geological processes does not provide all mineral occurrences with the same technical characteristics to facilitate discovery, exploitation and evaluation. Mineral deposits usually vary in chemical and physical characteristics, both horizontally and at depth; the necessity of probing below the earth's surface adds considerably to problems of discovery, exploitation and evaluation. Thus, mineral deposits vary widely as to location, size, quality, complexity, proximity to surface, and, therefore, economic potential. Thus, also, there is an inherent time lag of from a few years to decades between the time of the discovery of a mineral deposit and the time of first production;

(*b*) Unlike other natural resources, minerals are a non-renewable resource, with each deposit subject to technical and economic depletion. The aggregate supply of mineral resources can be considered generally continuous through time as technology and capital utilization are allocated to seek new deposits, mineral and non-mineral substitutes, and more efficient exploitation and utilization. However, with disaggregation of analysis to individual industries, commodities and producing regions, the known resource base is fixed and depletable. For an economic unit such as a company, the depletion factor, the risk of uncertainty about the deposit, and the very wide probability range about the predictability of another discovery all help to explain firm behaviour and certain government programmes;

(*c*) Mineral resources are unequally distributed among regions, countries, and continents by types of deposits and by economic usefulness. In turn, the demand for mineral resources is not homogeneous throughout regions, countries or continents. Depending on particular supply-demand conditions, minerals vary in the extent to which they enter regional, national and international trade. Many, however, are the subject of international agreements, the focus of trade policy, the source of economic growth for regional and national economies, and the basis for national and international disputes;

(*d*) The long-term demand for minerals is expected to continue to grow at a rapid rate so that adequate supplies will continue to remain a major challenge. Nevertheless, short-term over-supply of specific minerals will continue to present challenges to Governments;

(*e*) A major part of the mineral industry is international in character so that multinational firms, foreign ownership and the international mobility of capital are important considerations for Governments;

(*f*) Change in conditions of demand and supply, including such uncertain variables as new discoveries and technological innovation, affect the competitive position and trade patterns of individual establishments, regions, nations and continents. Such changes give rise to problems of cyclical instability, dislocation by industry and region, and mineral shortages for industry;

(*g*) Since mineral resources occur in proximity to other natural resources, individual resource developments should optimize the economic usefulness of all resources within areas of multiple resource conflict;

(*h*) Finally, mineral resource exploitation activities can have socially undesirable environmental effects;[2] conversely, socially-based governmental regulations can inadvertently impose excessive measures, so that mineral resource utilization is sub-optimal, relative to potential net benefits to the nation.

Potential benefits of a national mineral policy

A positive and dynamic mineral policy can be highly beneficial to the economic development of a nation. In Canada, for instance, the nation's positive mineral

[2] *See also* David B. Brooks and G. W. Tough, "Conservation of mineral and environmental resources", paper delivered at the United Nations Interregional Seminar on Mineral Economics, Ankara, Turkey, 12-24 October 1970.

policy during the past quarter of a century has contributed significantly to its present economic development and to the attainment of a high standard of living. During the past twenty years, the value of Canadian mineral production has grown from 5.8 per cent of GNP to 7.1 per cent of GNP and now amounts to nearly $5 billion annually, of which 50 per cent originates in the metallic sector, 20 per cent in the fuels sector and 21 per cent in the industrial minerals sector of the industry. Since the end of the Second World War, the annual rate of growth of mining, at 8.5 per cent, has been five times that of agriculture, nearly four times that of forestry and nearly double that for the country's total real domestic product. Minerals and mineral products account for about one third of the country's total export trade, 43 per cent of all revenue freight traffic and more than 12 per cent of total annual capital investment. Mineral exploitation has been in large part responsible for the development of that vast part of Canada which lies above the populated area just north of the Canada-United States border.

In considering the traditional economic factors of production—land, labour and capital—minerals are unique in that they comprise two of these factors—the "land" factor in the traditional sense, and the "capital" factor in the sense of new wealth. Minerals are of little or no value to a nation lying in the ground, unexploited; they can be of great value to a nation in meeting national objectives, when exploited.

Elements of a national mineral policy[3]

The general objective of a nation's mineral policy could conceivably be expressed in the following terms: "To develop and utilize the nation's mineral resources to optimize through time their net contribution to the attainment of national objectives". Individual components of mineral policy must be formulated so that the policy, in total, is applicable or adaptable to a wide range of specific problems or classes of problems. For example, some classes might involve a certain aspect common to most if not all mineral commodities (such as degree of processing before export). Others might involve problems related to a specific mineral commodity (for example, pricing of copper for domestic sales). Similarly, certain components of a national mineral policy may evolve slowly, so that change over a relatively long period may be fairly predictable (as in the case of policy with respect to foreign capital). Other components may change rapidly without complete predictability (for instance, rapid price changes or unexpected interruptions in supply). Thus, although a national mineral policy may be based on a number of fundamental concepts that evolve slowly, application of the policy to specific areas is a highly dynamic process.

In terms of the foregoing general mineral policy objective, consideration could appropriately be given to the following elements in the formulation of a nation's mineral policy (these elements are not listed in any order of priority; their importance will vary with the circumstances existing both within and without the nation):

1. To maintain an adequate domestic supply, whether from domestic or imported sources, of all minerals at reasonable prices, so that shortages or uneconomic prices do not impede development of secondary industry in the nation. This element is less applicable to developing nations than to developed nations but, in appropriate circumstances, it should be taken into consideration in a nation's mineral policy;

2. To establish standards within which both the public and private sectors, whether domestically or foreign-owned, are expected to operate with respect to land tenure, pricing and other marketing practices, operating and safety practices, further processing, degree of domestic ownership and control, employment practices, land conservation and reclamation, and integration of land or resource exploitation. Security of land tenure, for instance, is fundamental to the encouragement of mineral exploration and development and to the attraction of private capital. It has been a cornerstone of Canadian mineral policy. Without security of land tenure, other inducements or incentives for private investment can be rendered meaningless;

3. To encourage increasing degrees of domestic mineral processing and mineral-based manufacturing rather than exporting crude or lightly-processed mineral products, and to optimize return to the nation from minerals exported in terms of price and value added in relation to volume. One of the continuing elements of Canadian mineral policy relates to further processing. It derives from a desire in Canada, shared by most nations of the world including even the most highly industrialized nations, to process its mineral production to the highest manufactured form possible, prior to export. This desire, natural and pressing as it may be, must be tempered by the realities of the international market place;

4. To encourage and expand domestic ownership and control of mineral resource industries, taking appropriate account of the continuing need for foreign capital, while optimizing benefits derived from foreign capital invested in the nation's mineral industry. This is probably one of the most sensitive elements of a nation's mineral policy, yet it is an element with which every nation must come to grips, not emotionally, but through careful, objective analytical study and evaluation, in relation to both mineral resource objectives and national objectives. In Canada, where there is a high degree of foreign ownership, a number of studies have suggested that, in most respects, foreign-owned companies perform little differently from domestically-owned companies. The advantages that foreign investment have brought to Canada are also well known —necessary investment capital, particularly risk capital; assured markets; management know-how; and sometimes new technology. Nevertheless, there are certain key domestic sectors of the economy, including the uranium sector of the mineral industry, where the Government of Canada has placed specific limits on the degree of foreign ownership. In general, however, Canada continues its historic encouragement of foreign investment in the Canadian economy;

[3] For a description of the elements of Canadian mineral policy, reference can be made to W. Keith Buck, "Mineral development policy", M.R. 64, 1963; *see also his* "Factors influencing the mineral economy of Canada—past, present and future", M.R. 106, 1970, Mineral Resources Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

5. To maintain and improve the nation's international competitive position in world mineral markets. If mineral exploitation is to make a positive contribution to the nation's economy, in terms of both mineral resource objectives and national objectives, then the nation's mineral policy must be directed to encouraging its mineral industry to remain economically viable. When a mineral enterprise gets into economic difficulty it is often too easy for national Governments to come to its aid with production or other subsidies. This lessens the desire of the enterprise to improve productivity and to eliminate operational and administrative "fat", and is usually self-defeating in the long run;

6. To ensure that infrastructure necessary for rational mineral exploitation is provided, either by Government or by industry. Infrastructure includes power, transportation and community facilities, communication, education, research and social and cultural amenities. This is one of the more obvious areas to which mineral economics can contribute. In the economic evaluation of a new mineral project, all related costs and benefits should be evaluated, including required infrastructure, to ensure that the project will bring, at least in the long run, a net benefit to the nation's economy. There will be little or no net gain to the economy if all the rewards from a particular project have to be invested in infrastructure to make the project operable. Moreover, if the infrastructure is solely or largely of value to one operation, then consideration should be given to providing that the cost of infrastructure becomes a direct charge to that operation, either immediately or over the life of the operation, rather than to the economy as a whole;

7. To ensure that requirements are met for technical and economic information systems, including the development and dissemination of data such as geological and mineral maps and reports, statistics and technical information. It is this element that provides for government services—another cornerstone of Canadian mineral policy. Canadian governments, federal and/or provincial, provide basic geodetic, topographic, hydrographic, geologic and geophysic maps, the aerial photographs required for mineral exploration, and ore dressing research required for the design of mineral concentration plants. In developing nations, it may be that similar services must be obtained through foreign aid assistance. Just as important as the dissemination of data is the procurement of data from operating companies. Such data should not only relate to technical information but also to financial, economic and ore reserve information. Provision should, therefore, be made in the formulation of mineral policy for the procurement, maintenance and dissemination of data. It is expensive information and should be carefully collected, properly maintained and effectively used;

8. To optimize any potential that mineral exploitation offers with respect to economic development in disadvantaged regions and thus to alleviate regional economic disparities. Most nations have, in some degree, the problem of regional disparities, a problem of increasing concern to Canada. In many instances, mineral exploitation can serve as a basis for regional development, a fact for which provision can be made in the formulation of mineral policy;

9. To forecast problems related to mineral depletion and declining regions in order that the unfavourable impact on employment and local economic activity is minimized. Mineral deposits, by the very nature of their occurrence, do become exhausted in either physical or economic terms and the facilities and communities, which have come into existence because of them, no longer have any purpose. All too often community pressures develop to keep a sub-marginal mine in operation—at great cost to the nation. As stated previously, this results in an inefficient use of labour and capital, and a decline in the over-all productiveness and efficiency of the industry. Instead, there is a need for policies to ease the severe dislocations resulting from mine closures and speed up the adjustment to change. In Canada, subsidies have been employed to support uneconomic coal and gold-mining operations and to ease the social disruption in dependent communities caused by the decline of these two industries. All in all, Canadian experience with mineral subsidies in these two industries has not been heartening. The subsidies have tended to be self-perpetuating, postponing, if not preventing, necessary change rather than facilitating adjustment to change through the adoption of more positive remedial measures;

10. To conserve mineral resources in the sense of achieving optimum recovery from given deposits and minimizing waste. Mineral policy should, in appropriate instances, provide for mineral conservation measures. One obvious example is the coincident production of petroleum and natural gas in a manner which will be least wasteful;

11. To establish standards of environmental quality and to minimize costs external to the mineral project itself. Many nations are becoming increasingly concerned for the quality of the environment. This concern will become increasingly a factor in the economics of mineral exploitation and, hence, in the corporate decision-making process. Indeed it has become a widely accepted ethic in Canada that the environmental costs associated with mineral exploitation must henceforth become just another operating cost. In the public sector, concern for environmental quality will become, increasingly, a factor in government legislation and regulations. Nations have a responsibility to identify the nature and extent of the "environmental problem" and to establish and implement environmental standards. To this end, there is a greater need for what might be termed "environmental planning", through which Government and industry jointly conceive realistic but effective environmental programmes which reflect the ecosystem, the social system, and the national and international economic system—all directed towards the achievement of national goals for environmental quality which are compatible with national economic and social goals;

12. To minimize external or foreign discriminatory actions affecting the nation's mineral trade such as tariffs, non-tariff barriers and administrative procedures. The Kennedy Round of GATT negotiations concluded in mid-1967 provided for increased liberalization of world trade. Although world tariffs are still high in a number of areas beyond the crude minerals stage and although there remain a number of non-tariff barriers to trade, the Kennedy Round brought expec-

tations of a new era in foreign trade which could provide many opportunities for trade expansion. With increased liberalization of trade, it is even more essential that a nation's mineral industry remain competitive and that it pursue new marketing opportunities aggressively, particularly in the field of more highly processed mineral products. Just as important, continued vigilance must be maintained to guard against the seemingly inherent instinct in some developed nations to protect their own industries from external competition;

13. To ensure that mineral exploitation contributes an equitable share of the tax revenue of the nation. If mineral exploitation is to be a net benefit to the economy, then it must not take place at the expense of other important sectors of the economy but must assume its share of the domestic tax burden, commensurate with the role it plays in the over-all economy of the nation;

14. To increase the development and use of domestic skills. One of the most valuable resources of any nation, at whatever stage of development it may be, is a cadre of persons possessing technical and managerial skills. Mineral exploitation, therefore, should be accompanied by adequate provision for the training of indigenous peoples in essential technical and managerial skills, skills which will be of continuing benefit to the nation, even after the exhaustion of a particular mineral deposit. If such a cadre already exists within a nation, provision should be made for its employment in the mineral enterprise, in such numbers as may be of net benefit to the nation;

15. To ensure that mineral resources and mineral industry activities contribute to and reflect general government social, economic, developmental, strategic and sovereignty policies and goals. There is need for continuing review of the manner in which mineral policy advances the attainment of both mineral resource and national objectives, in view of the changing internal and external conditions affecting mineral exploitation. Without being the subject of capriciousness, which can be costly in terms of mineral exploitation, mineral policy should evolve to reflect domestic and international circumstances as they relate to national objectives. It bears repeating that although a national mineral policy may be based on a number of fundamental concepts that evolve slowly, application of the policy to specific areas is a highly dynamic process.

Implementation of a National Mineral Policy

Having considered the elements that might comprise a nation's mineral policy in relation to both national objectives and mineral resource objectives, and to the special characteristics of mineral resources, the process is still not complete. It is finally necessary to articulate and implement the nation's mineral policy. Although this could be done in a number of ways, there are four principal avenues of implementation, the first two being implicit and the last two explicit.

First, there is considerable merit in the issuance of a statement, by the head of State or minister responsible for the minerals sector of the economy, of both the nation's general national objectives and its specific mineral resource objectives, along with a description of the principal elements which comprise the nation's mineral policy. This procedure has the advantage of setting, at the highest level, the general governmental environment in which mineral exploration will take place in the nation. It articulates, in the widest possible fashion, the philosophy of the nation as it relates to mineral exploitation.

Second, for some nations, particularly those at the very early stages of mineral exploitation, the mineral policy statement can be translated into action in respect to specific projects by means of a negotiated contract between the Government and the party interested in undertaking mineral exploitation. This technique has the advantage of enabling the establishment of contract conditions appropriate to the circumstances of particular projects. It has the drawback that it exposes the Government, at the time of negotiation or later, to the possibility of being criticized for having used its discretionary powers to negotiate special arrangements for special interests.

Third, for many nations, and probably for all nations as their mineral economies mature, the mineral policy statement will be articulated into specific laws and regulations covering all the elements of the nation's mineral policy. In Canada, for instance, both the federal and all the provincial Governments have sets of laws and regulations[4] which, in their totality, comprise all the elements of Canada's mineral policy.

Fourth, it would seem helpful to single out for special reference, one section of a nation's laws and regulations which can have the most impact on mineral exploitation, that is the section on taxation.[5] A nation's tax laws and tax regulations can be a powerful factor in the implementation of a nation's mineral policy, lending themselves to establishing priorities among, and providing incentives for, the various elements of the nation's mineral policy. During the past quarter of a century, tax incentives have been the single most important cornerstone of Canada's mineral policy, being in large part responsible for the present high position of the Canadian mineral industry in the nation's economy.

A final thought, which would seem to merit being expressed in words, relates to the concept of mineral resource management, as distinct from mineral resource administration. The latter term has connotations of a passive, static role on the part of Government. In contrast, the concept of mineral resource management implies an active, dynamic role on the part of Government in the evaluation, planning, policy and programme development and implementation, and direction of the nation's mineral resource activities, to ensure that they meet national objectives and, in so doing, bring optimum benefit to the nation. This is a role which calls for the application of mineral economics at a high professional level; it is the essence of mineral economics as it relates to a nation's mineral policy.

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[4] E. C. Hodgson *and* W. J. Beard, "Summary review of federal taxation and legislation affecting the Canadian mineral industry", M.R. 101, 1969, Mineral Resources Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

[5] E. C. Hodgson, "Digest of the mineral laws of Canada", M.R. 13, 1967, Mineral Resources Branch, Department of Energy, Mines and Resources, Ottawa, Canada.

An approach to mineral policy formulation: *W. Keith Buck and R. B. Elver*

This paper deals in a wide-ranging manner with the conception and implementation of a national mineral policy, starting from the requisite base of its relationship to national objectives. Consideration is then given to other factors which have major influence on the development of a nation's mineral policy: the political, economic, social and physiographic character of the nation and the stage of its development; the skills of its people; and its known or potential mineral resource base.

In formulating a policy, the unique characteristic of mineral resources as compared to other economic goods must be taken into account. These are, among other things, the complexity of the problems to be encountered in discovering and exploiting mineral resources; the depletability of the resource; domestic and international supply-demand conditions and factors that might bring about changes in these conditions; the economic use of natural resources; and the necessity of maintaining a proper balance between the use of resources and the welfare of society at large.

Brief reference is made to the potential benefits of a positive national mineral policy, using Canada as an example.

The main emphasis of the paper is upon a discussion of fifteen possible elements of a national mineral policy, including the maintenance of domestic supply and of regulation or standards for the exploitation and marketing of minerals; the encouragement of domestic industries while maintaining world competitiveness; further processing beyond the crude mineral stage; the provision of infrastructure; the collection, maintenance and dissemination of data; regional development, conservation, environmental planning, taxation, and the considerations to be devoted to the development of human skills and social improvement.

Four main avenues are outlined by which a national mineral policy may be implemented, covering the articulation of a basic national philosophy related to mineral exploitation and its translation into action and law; and finally, the establishment of tax incentives. The importance of the concept of active management is also touched upon.

Méthode à suivre pour l'établissement d'une politique minière: *W. Keith Buck et R. B. Elver*

Cette étude traite d'une manière très large de la mise en œuvre d'une politique minière nationale fondée nécessairement au départ sur ses rapports avec les objectifs nationaux. On considère ensuite les autres facteurs qui ont une influence dominante sur le développement d'une politique minière nationale : situation politique, économique, sociale et physiographique du pays, son niveau de développement, la qualité de sa main-d'œuvre et ses ressources en minéraux, potentielles ou réelles.

Pour l'établissement d'une politique, il faut tenir compte des caractères particuliers des ressources minières par rapport aux autres ressources, et notamment de la complexité des problèmes que posent la découverte et l'exploitation des ressources minières, de l'épuisement possible de ces ressources, des conditions de l'offre et de la demande nationale et internationale et des facteurs pouvant changer ces conditions, de l'usage économique des ressources naturelles et de la nécessité de maintenir un équilibre entre l'utilisation de ces ressources et le bien-être de la société en général.

Une brève allusion est faite aux avantages pouvant découler d'une politique minière nationale bien conçue, le Canada étant pris comme exemple.

L'essentiel de cette étude consiste en l'examen de 15 points importants pour l'établissement d'une politique minière nationale, à savoir le maintien de l'approvisionnement local et la mise au point de normes pour l'exploitation et la vente des minéraux; l'encouragement des industries locales, avec maintien au niveau de la concurrence mondiale; traitement des minéraux bruts; création de l'infrastructure; rassemblement, mise à jour et diffusion des données; développement régional; conservation, planification de l'environnement, taxes et attention à accorder au perfectionnement de la main-d'œuvre et au progrès social.

On met en évidence quatre manières principales d'instituer une politique minière nationale, comprenant l'énoncé d'une philosophie liée à l'exploitation des minéraux qui devra se traduire dans l'application pratique et la création d'une législation appropriée, et enfin par l'emploi de stimulants fiscaux. On considère également l'importance du concept de gestion active.

Un enfoque de la formulación de una política minera: *W. Keith Buck y R. B. Elver*

El presente artículo trata en forma amplia de la concepción y ejecución de una política minera nacional, partiendo de la base imprescindible de su relación con los objetivos nacionales. Luego se consideran otros factores que afectan notablemente el desarrollo de una política minera nacional: el carácter político, económico, social y fisiográfico de la nación y su grado de desarrollo, la capacidad técnica de sus habitantes y los recursos minerales conocidos o potenciales.

Al establecer dicha política se deben tener en cuenta las características particulares de los recursos mineros en comparación con otros bienes económicos. Estas son, entre otras, la complejidad de los problemas que se encaran en el descubrimiento y la explotación de los recursos mineros; el agotamiento de los recursos; las condiciones nacionales e internacionales de la oferta y la demanda y los factores que pueden alterarlas; el uso económico de los recursos naturales y la necesidad de mantener un equilibrio adecuado entre la utilización de dichos recursos y el bienestar de la sociedad en general.

Se hace una breve referencia a los beneficios potenciales de una política minera nacional positiva, utilizando al Canadá como ejemplo.

El artículo se concentra principalmente en la discusión de 15 elementos posibles de una política minera nacional, incluso el mantenimiento del abastecimiento nacional y reglas o normas para la explotación y la comercialización de minerales; el fomento de las industrias nacionales a la vez que se mantiene una competitividad mundial; la elaboración del mineral bruto; el establecimiento de un sistema de infraestructura; la compilación, el registro y la difusión de datos; el desarrollo regional, la conservación, la planificación del medio, los impuestos y la atención que se debe dedicar al desarrollo de la capacidad técnica y al progreso social.

Se señalan cuatro vías principales por las cuales se puede aplicar una política minera nacional, que abarcan la formulación de una filosofía nacional básica relacionada con la exploración minera y su transformación en medidas prácticas y leyes, y, finalmente, el establecimiento de estímulos tributarios. También se toca el tema de la importancia del concepto de administración activa.

LATEST ADVANCES IN OFF-SHORE PETROLEUM TECHNOLOGY

by Frank F. H. WANG

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Ten years ago only three or four countries had significant off-shore petroleum development. Today, prospecting is already under way off the coasts of more than seventy-five countries, encompassing all continents of the world except Antarctica. About 200 mobile drilling rigs and 125 self-contained fixed platforms are conducting drilling off the coasts of forty-five of these countries. Although the technology is still in an early stage of development, more than thirty countries are already producing subsea oil and gas with an annual value of about $6,100 million, representing between 17 and 19 per cent of the world's total oil production and over 6 per cent of the world's natural gas production. Projections indicate that by 1980, between 30 and 40 per cent of the world's oil production—four times the 1969 average off-shore output of 6.5 million barrels per day—will come from beneath the ocean (Weeks, 1969; Sherborne, 1970); the increase in gas production is expected to be even larger. The annual value of world subsea oil and gas production will soon exceed that of all other marine non-living and living resources combined, including fisheries and sea-water chemicals. It is apparent that off-shore petroleum development is rapidly increasing in its economic importance to the world petroleum industry, and in the worldwide surge to off-shore areas the industry is moving into deeper waters and further away from shore.

The rapid progress in off-shore petroleum exploitation under more severe ocean environment could only have resulted from the outstanding success in the development of off-shore petroleum technology. During the past few years, many technological advances have been achieved in the petroleum industry, and new trends are emerging which may, in the future, be regarded as milestones in the development of off-shore petroleum technology. Equipment and methods have changed greatly. They are losing their earlier land-based flavour, adopted when petroleum development first extended from land into near-shore waters. Accordingly, there has been an increasing involvement of a great variety of specialized engineering and scientific fields, such as weather and sea forecasting, naval architecture, submarine soil mechanics, submarine earthquakes, computer technology and many others. The petroleum industry has utilized many new undersea approaches, and numerous sub-systems or technological building blocks developed by the ocean engineering and aerospace industries. The many requirements of the future deep-water petroleum work, such as minimum attendance, safety, life support, rescue, communications and the like that are analogous to those of aerospace, will drive off-shore petroleum technology toward a degree of sophistication equivalent to or (because of the more rugged ocean environment) even more complex than aerospace systems. However, it is expected that through extensive engineering research in the future, the over-sophisticated, expensive off-shore petroleum techniques will eventually reach a proper degree of simplicity, and so increase reliability, minimize maintenance and lower costs.

In off-shore drilling, maximum water-depth for wildcat wells has increased to 455 metres (1,497 feet),[1] and drilling for deep-ocean geologic research from the drilling ship *Glomar Challenger* has been carried out in 6,140 metres (20,146 feet) of water, with penetration as far as 985 metres (3,231 feet) below the seafloor.

In the structural design of off-shore facilities, such as mobile drilling rigs, fixed platforms, mooring systems, pipelines, derrick barges and other floating construction equipment, elaborate computer programs[2] and scale-model testing techniques have been developed to reduce design time, increase accuracy and permit confident extrapolation of structures beyond today's experience. In the past few years, intensive engineering research, costing many millions of dollars, has developed the elaborate design procedures, design criteria and selection of fabrication and installation methods that are being practised off the coasts of many nations.

The continuing evolution of mobile drilling rigs has already assured that exploratory drilling is now technically and economically feasible in any foreseeably desired water-depth, far outpacing the present technological status of oil-well completion and production. With continuing technological progress, the ocean environment will, in the future, appear less hostile and may eventually be utilized in marine engineering operations as an aid instead of being an obstacle.

LATEST DEVELOPMENTS IN MOBILE DRILLING PLATFORMS

The most rapid advances in the past few years have been in the development of mobile drilling platforms. Today, floating drilling rigs are fully capable of con-

1 The current world water-depth record of wildcat drilling is 455 metres (1,497 feet) drilled in the Santa Barbara Channel off southern California in 1968. The world's deepest off-shore well was drilled in 1968 in the Gulf of Mexico, reaching a depth of 6,960 metres (22,840 feet) below the sea floor.

2 Computer programs require, as input, the anticipated size, shape and direction of waves; the currents; the wind; working (deck) loads; the suggested configuration of the structure and member sizes. Stresses in each member are then automatically calculated and compared to the allowable to arrive at the optimized design.

ducting drilling in water-depths beyond the shelf edge. This capability is clearly shown by the fact that in 1969 significant oil discoveries were made in 320 metres (1,050 feet) of water in the Santa Barbara Channel off southern California.

Increasing interest in deep-water exploratory drilling in widely varied ocean conditions, ranging from the hurricane-prone tropics to ice-covered Arctic waters, has led to the modification and conversion of older units and the construction of many diverse types of improved mobile rigs, including jack-up units, semi-submersibles, floating vessel types, unique hybrid types and several radically new designs. In most cases, attempts have been made to improve their stability and mobility and to cope with specific environmental, geographic and geologic conditions. There has been increased emphasis on self-propulsion or propulsion-assist devices which enable the new mobile rigs to be moved more quickly, with little or no assistance from other vessels, to distant ocean areas on a world-wide scale.

The size of the mobile rigs is still increasing. The prime reason is to operate in deeper waters, but other considerations include greater capacity for consumable supplies[3] (that is, fuel, water, drill-pipe, drilling mud) which make the new units more self-sufficient and capable of independent operations over longer periods of time and at greater distances off-shore. Today, the world's total number of mobile drilling units already exceeds 200[4] representing over $2 billion of capital investment. The newly built larger units have added considerably to the capital investment which is reflected by an increased drilling cost. This has led to the development of a pattern of operation—mobile rigs are generally used for exploratory drilling in new areas, and fixed platforms for development drilling in shallow and intermediate water-depths.

Bottom-supported mobile rigs

These installations, typically the self-elevating platform rigs (jack-up rigs) and submersible drilling barges, are designed to rest on the sea floor only during operations. Thereafter they can be floated and moved to other locations. Many new jack-up units have been built recently. Today one out of every two mobile rigs in service is a jack-up unit.

Innovations derived from practical experience with floating vessels and semi-submersible units have been incorporated in the newly built or designed jack-up rigs. Many have total propulsion systems or propulsion-assist units to speed the moving of rig[5] and to precisely position itself at the specified drill-site.

Another developing trend is the designing of jack-up rigs for specific work areas and environmental conditions.[6,7] The open construction of the self-elevating legs offers little resistance to waves, thus ensuring its stability and permitting operations in almost any weather. However, jack-up units on tow are particularly vulnerable when hit by storms. Since bottom scour and foundation failures are the most severe hazards, several new jack-up rigs built in 1969 and 1970 have a massive underwater base structure (mat-type seafloor foundation) to ensure stability while resting on relatively soft bottom sediments and to withstand the overturning forces resulting from winds and waves of hurricane intensity. The ship-shaped mat has been designed to provide less resistance and easy towing characteristics during transoceanic moves.

Because of the anticipated rig moving requirements, some jack-up units have been designed to pass through narrow passages, such as the Panama Canal, while others can be shipped in parts and assembled on location.[8] These requirements have led to the development of jack-up units with a "swinging bottle" design which allows the bottles to be retracted to stowed position during moving.

The newly built jack-up units are not only very efficient for exploratory drilling in moderate water-depths but are also highly versatile. They can serve as a fixed petroleum production platform[9] or as a barge for marine engineering construction[10] for example.

There have been little new developments of submersible units because of their rather limited water-depth capability and increasing competition from the more versatile jack-up platforms and semi-submersibles, as wildcat drilling moves steadily into deeper waters. In fact, a new trend is to convert present submersible units to other types of platforms, with improved designs for more versatile operations and for drilling in deeper water.[11]

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[3] Except for the very largest units, a mobile rig generally requires continual replenishment of equipment and supplies (fuel, water, drill-pipe, drilling mud), usually by supply vessels. The drilling of a 10,000-foot (3,048 metres) well may use some 1,500 tons of consumable items.

[4] As of April 1969, there were 213 off-shore mobile drilling units in service, 26 under construction, and 11 in the design stage (Crooke and Lacy, 1970).

[5] In 1969, Penrod Drilling Company's rig 58 became the first self-propelled jack-up unit to cross the Atlantic. The trans-oceanic trip from Sabine Pass, off Texas, to the North Sea took sixty-three days and twice encountered extremely severe seas with 112 km per hour (70 mph) winds and 12-14 metres (40-45 feet) waves.

[6] Transworld rig 60, built in Japan (the Mitsui shipyard) in 1970, is a self-elevating platform capable of operating in 60 metres (200 feet) of water. The rectangular upper hull (121 × 154 feet) is self-elevating on four 72-metre (272-foot) legs. The four legs are supported by a larger base structure (180 feet square and 100 feet high) with four stabilizing columns to ensure stability.

[7] A three-legged jack-up unit has been designed by Levingsten Shipping Co. in the United States of America, using a new rack-and-pinion jacking system that will eliminate the potentially dangerous lift pause cycle during raising and lowering. A unique jetting system will be installed for breaking free the legs from the sea-bed to facilitate the moving of rig.

[8] In 1968, the Soviet Union's new jack-up unit, the *Khazar*, was towed in three parts across the North Sea and Baltic, then 5,000 kilometres through rivers and canals to the Caspian Sea where it was assembled. In 1969, the *Khazar* started exploratory drilling north-east of Neftyanye Kamny in 50 metres (164 feet) of water.

[9] A large jack-up unit, the *Gulftide*, has been planned for use as a fixed production platform at the newly discovered Echofish field in the Norwegian part of the North Sea, until the required permanent production facilities can be constructed by 1972.

[10] Jack-up platform (*IHC-Holland*) was used in deep-water bridge construction in Japan. In 1969, the jack-up barge *Gem 126* was used in the construction of a deep-water tanker terminal off Immingham, England.

[11] In 1969, a submersible drilling barge, the *Louisiana* (built in 1957), was converted to a column-stabilized semi-submersible, capable of drilling either from a sitting-on-bottom position or a floating position in up to 183 metres (600 feet) of water.

Floating drilling rigs

Floating drilling platforms not supported from the ocean floor during drilling operations include two basic categories—ship-type floating rigs (drilling ships and barges) and semi-submersible rigs. These highly efficient types of designs have been further improved to operate in deeper waters and under more severe sea conditions.

During the past few years there have been many new drill ships built, several with new designs.[12,13,14,15] The dynamic positioning system, automated anti-roll devices for vessel stability, and the recently invented hole re-entry system have considerably extended the capability of drill ships to operate in essentially unlimited water-depth[16] and to drill deeply into hard strata below the sea floor.[17]

Automation[18] of the drilling operations on floating drilling units is progressing rapidly. A large platform can accommodate two automated rigs, both of which can be simultaneously operated from a single control station. A significant development is the $11 million 15,000-ton drill ship, the *Total Mar*, being built by the Société maritime de service (SOMASER) in France. This dynamically positioned drill ship will be equipped with an automated control centre aboard to continually monitor and control almost all rig and the vessel's operations.[19]

A recent trend in the development of semi-submersible units is the continuing increase in size and mobility and improvement in motion characteristics. Many new semi-submersibles[20] have total or partial self-propulsion systems to speed rig moving and are capable of conducting drilling in deeper waters and extremely severe seas, even of surviving in hurricanes.[21,22] Some of the new designs are not only very effective for drilling under rough sea conditions but also highly versatile in marine construction work.[23]

Many new semi-submersibles are equipped with a dynamic anchoring system, consisting of propulsion units or propellers installed on the pontoons, which, with the assistance of the static anchoring system (multi-point mooring), can precisely maintain position against extremely strong winds and high waves.

Hybrid-type mobile rigs

A new trend just developing is the construction of unique hybrid types of mobile rigs[24,25] that incorporate selected features of ship-hull rigs, semi-submersible units and jack-up units; thus, they are capable of operating in a wider range of oceanic conditions and geographic areas. These unusual rigs may resemble a ship while moving from one location to another, but once on location, they can take on the characteristics of a jack-up unit or a semi-submersible.

FUTURE MOBILE RIG DESIGNS

Perhaps most notable in the new mobile rig designs is a remotely controlled sea-floor operated rig that will

[12] The *Discoverer III*, built in a Japanese shipyard in 1970 at a cost of $8.5 million, has a revolving turret-mooring system that permits change of vessels heading, according to prevailing seas while drilling is in progress.

[13] A $13.5 million, 130 metre (431 feet) long drill ship with dynamic positioning and capable of drilling to 7,600 metres (25,000 feet) below the sea floor in practically unlimited water depth, is under construction in Italy for ENI.

[14] A former whaling factory ship, the *Cruz del Sur*, measuring 200 × 25 metres (665 × 80 feet) and displacing 26,650 tons was divided and converted into two drilling barges, the *Wodeco VII* and *Wodeco VIII*, each 133 metres (440 feet) long, 24 metres (80 feet) wide, and 9 metres (30 feet) deep.

[15] The new deep-water hole re-entry system was first successfully tested from the *Glomar Challenger* on 14 June, 1970 in the Atlantic. The sonar-guided drill string, equipped with hydrojet, was positioned into the guide funnel and conductor pipe assembly placed on the sea floor.

[16] The *Glomar Challenger* has held position and conducted drilling operations even in 50-knot winds and 5 metres (15-foot) seas. Perhaps the most exciting drilling operation was experienced on the edge of the Gulf Stream, north-west of Cuba, where the *Glomar Challenger* in the strong current had to steam 5 knots to hold position over the hole.

[17] At present the lack of blow-out preventer BOP (stack) and marine conductor (riser system) suitable for operations in abyssal water depths has restricted drilling to less than a thousand metres of penetration into petroliferous strata in deep ocean basins. However, with the newly developed technique for re-entering drill-holes in unlimited water-depth, it may soon be possible to develop and instal suitable pressure-control equipment and closed circulation systems at the drill-site in order to probe safely deep into petroliferous strata.

[18] Severe winds and violent motions of the vessel make drill-pipe handling extremely difficult, and many rigs now incorporate some forms of automatic or semi-automatic pipe racking systems.

[19] Automatic features include automatic pipe handling, automated bins for mixing and treatment of drilling mud, and detuning tanks to stabilize the vessel's rolls. It will be able to drill two 3,050 metres (10,000 feet) wells or one 4,570 metres (15,000 feet) well without replenishment of supplies.

[20] The *Ocean Prospector*, now under construction in Japan (in the Mitsubishi shipyard), will be the world's first totally self-propelled semi-submersible, powered by a 5,400 hp propulsion system.

[21] In October 1968, the *SEDCO 135F*, a large semi-submersible, was caught in a severe storm while anchored in the Hecate Strait off the west coast of Canada. It successfully weathered average 150 kph (92 mph) winds and 18 metres (58 feet) waves for 16 days, including brief periods under 30 metres (100 feet) waves, without any structural damage.

[22] The $12 million *Neptune Pentagone 81* was completed in 1969 as the first semi-submersible unit owned by the Société de forages en mer Neptune and the Institut francais du petrole. The unit can drill as much as 183 metres (600 feet) of water while floating and in less than 26 metres (86 feet) of water while resting on the bottom. Its five floating pontoons can be ballasted to submerge to 22 metres below sea surface to minimize wave disturbances and to increase the unit's displacement of 9,000 tons to 16,050 tons, thus improving its motion characteristics. It can conduct drilling even under 96 kph (60 mph) wind and 10-metre waves and can survive severe storms with 216 kph (135 mph) winds and 21 metre (69 feet) waves.

[23] A $9 million twin-hulled, semi-submersible barge, the *Choctaw*, built in the Netherlands in 1969, is the world's first semi-submersible capable of operating as a derrick barge and a pipe-laying barge.

[24] The off-shore *Mercury*, built at a cost of $9 million in the United Kingdom in 1969, is essentially a jack-up unit but has a self-propelled ship-shaped hull. It can operate in 83 metres (275 feet) of water and can sail 45 days or about 11,200 kms (7,000 miles) without refuelling.

[25] *Transworld rig 61*, built in a Japanese shipyard in 1970, is one of the most unusual hybrid rigs, combining many design criteria of the drill ship, the semi-submersible system, and the jack-up system. It has a 120-metre (400 foot) long streamlined ship-shaped main hull and a transverse framework of trusses and is self-propelled. Its four hydraulically operated columns can bear on the sea floor to raise the upper hull above water and to operate in a jack-up mood. But in moderately deep waters (up to 182 metres or 600 feet water-depth), the unit will operate afloat as a semi-submersible platform. Its present water depth limit of 182 metres can be extended to 6,095 metres (20,000 feet) by the addition of a dynamic positioning system.

be able to operate in 240 metres (800 feet) of water and drill to 9,140 metres (30,000 feet) beneath the sea floor.[26] Other novel types of floating platforms are also being investigated or designed with criteria to cope with a variety of adverse oceanic conditions.[27]

Technological problems

The continuing increase in size, weight, capital cost,[28] operating cost,[29] and mobilization cost[30] of mobile drilling rigs is a pressing problem. The trend must be reviewed if petroleum exploitation beyond the shelf is to prosper. There is an urgent need to reduce rig weight, possibly by new configurations of improved designs, use of light weight metals in fabrication and use of more compact gas turbines in driving the drill string (Ellis *and others,* 1969). Complete computer-controlled automated drilling, imaginative new approaches to material handling and use of two or more rigs per vessel would improve rig efficiency and reduce drilling cost.

Structural metal fatigue[31] is a critical problem common to most types of drilling units, particularly semi-submersibles. There is a need to understand better the dynamic performance of the metals in various structural members under extremes of sea conditions, and to improve the design of structural joints. More intensive engineering research should be focused on the towing characteristics of jack-up units, mooring conditions and improved anchoring systems of semi-submersibles, and more precise inspection and testing of the critical members and structural joints as well as the entire structure in order to reveal potential dangers.

Maritime safety

With the continuing increase in size and mobility of drilling rigs, many mobile units have been frequently moved from waters under the jurisdiction of one country to those of another country, and industrial personnel[32] of different nationalities have been employed. These new patterns of operations have made it necessary to modify the traditional approach to maritime safety to produce acceptable international safety standards,[33] including inspection and certification of the mobile units,[34] and to suggest structural and stability requirements of its construction.[35]

Latest developments in completion and production techniques

Oil and gas wells completion and production in the ocean environment is always more complicated and difficult than the drilling of exploratory wells, and the technical problems and costs increase substantially with water-depth. All the producing facilities, either installed above water or on the sea floor, must be designed to withstand stress and corrosion as well as the rigours and tremendous extremes of weather and sea conditions during the life of the producing field, which often extends from twenty to more than forty years. In addition, flexibility must be built in for convenient operation, maintenance and repair of the producing equipment. Despite recent technological advances, the record for off-shore production[36] on a commercial scale still lags more than 1,000 feet behind exploratory drilling.

Past experience and current engineering research indicate that above-water production systems, that is,

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[26] The project, initiated in 1970 by the Agency of Industrial Science (Technology of Ministry of International Trade and Industry) in Japan, will include a $14 million (5,000 million yen) five-year initial phase of systems design and engineering development and a $25 million (9,000 million yen) three-year phase of actual design and fabrication. The rig, scheduled for completion in 1978, will be competitive in drilling cost with conventional drilling units.

[27] A spherical hulled floating unit with exceptionally high strength and light weight, measuring 31 metres (105 feet) in diameter and displacing 4,000 tons, was designed by the Sanders Associates, Inc. in the United States of America. A water-filled tank at the top of the derrick will provide added mass to stabilize roll. It will withstand freezing in an ice-pack and can be towed at relatively high speed.

[28] The cost of constructing a typical jack-up unit is about $7 to $8 million, a semi-submersible ranges from $7 to $10 million, a drilling ship ranges from $5 to $11 million, and a drilling barge about $5 to $6 million (Kunzi, 1968).

[29] For operations in moderate water depths in the Gulf of Mexico, the daily "bare" rig cost averages $6,500-$9,000 for jack-up units, $8,000-$11,500 for semi-submersibles and $9,000-$13,000 for ship-type floating units, but the total operating cost is often two or three times the basic rate (Williams, 1969). In the North Sea, a typical one-string exploratory drilling from a semi-submersible costs $24,000 a day (West, 1969).

[30] The mass of iron built on the rig must be towed or propelled when moving to a new location, and this adds to the mobilization cost which may amount to as high as $3 million for a location at a distant part of the world (Ellis *and others,* 1969).

[31] There is virtually no knowledge on the range and frequency of loading cycles to which various structural members are subjected, and present understanding of the distribution of stresses within structural joints is particularly poor.

[32] Industrial personnel are neither passengers nor seamen in the traditional sense, thus requiring an intermediate degree of safety protection at sea.

[33] In 1967, the Inter-governmental Maritime Consultative Organization (IMCO) assigned to several of its subcommittees the task of devising an acceptable safety code for various types of drilling platforms and production platforms and establishing acceptable measures which would alleviate difficulties involved when units registered in one country operate in territorial waters within the jurisdiction of another.

[34] The United States Coast Guard, in co-operation with the National Offshore Operations Advisory Panel, has analysed the characteristics of various types of mobile drilling units, the nature of the operations and the type of personnel aboard, and accordingly established criteria for inspection and certification of drilling units which is essentially applicable to the floating mode.

In order to avoid drydocking and out-of-service time, the American Bureau of Shipping now approves inspection of mobile units by certified teams of divers who, during on-site inspection, can also clean the under-water hull and make the necessary repairs.

[35] In the United States, mobile drilling units have been constructed according to standards suggested by the American Bureau of Shipping, an organization of private industry.

In the United Kingdom, off-shore structures have been designed and fabricated according to the Mandatory Code of Safe Practice suggested by the Institute of Petroleum.

[36] In 1967, a $6 million above-water production platform was constructed in 104 metres (340 feet) of water 8 km (5 miles) off Louisiana, marking the record water-depth in which commercial production has been established. This platform was destroyed by hurricane "Camille" in 1969. At present a new giant platform, designed to accommodate twenty-four producing wells, is being built and scheduled for erection during the later part of 1970 in 92 metres (373 feet) of water in the Gulf of Mexico.

completion of wells and installation of all the production facilities on fixed platforms, are usually best in water depths up to perhaps 150 metres or slightly deeper. For depths from 150 to about 300 metres, either above-water or submerged systems, or a combined system, may be favoured depending on a number of factors, which include the technological capabilities and engineering services available nearby, the number of wells required to develop a given oil or gas field, water-depth, prevailing sea conditions, distance from shore, and off-shore facilities for petroleum storage and transportation. Fully submerged production systems, by which all the facilities are installed on the sea floor, appear most advantageous in much deeper water and for certain unusual circumstances in shallow water.

Above-water completion and production systems

Fixed production platforms have evolved in twenty years from 1,200-ton size, set in less than 6 metres (20 feet) of water, to structures weighing over 6,500 tons and operable in water depths of 92 metres (373 feet). Recently, there have been considerable improvements on fixed structure designs,[37] and fabrication and installation techniques,[38] including the use of the newly developed steel. As a result, above-water completion and production systems have been widely practised off many countries, with an increasing number of fixed structures having been installed, many of them in deeper waters. Today, large steel platforms can be economically erected in 120 metres (400 feet) of water and have been designed for 150 to 182 metres (500 to 600 feet). Within the next few years, fixed platforms may be developed for even greater water depths, possibly up to 305 metres (1,000 feet) or deeper (Barron, 1970; West, 1969).

Automation of off-shore production

The past few years have seen significant advances in the systems technology for continuous monitoring and automated remote control of off-shore oil and gas production. In the North Sea,[39] Persian Gulf,[40] and several other areas, unique new systems with sophisticated computers and telemetry networks, have been implemented to automatically control the off-shore well-heads, producing and treatment facilities on fixed platforms, submarine pipelines, and the on-shore production support facilities. The automated systems not only replace the very costly manned operations at remote off-shore sites but also improve the dependability of off-shore production operations regardless of the adverse weather conditions.

Unconventional types of fixed platforms

A revolution in the development of fixed above-water production platforms started in 1968 when an articulated buoyant cylinder platform (anchored spar buoy structure) was constructed for the French Oil Company, ELF-ERAP, in the Bay of Biscay off the western coast of France.[41] Similar to the bottom supported platforms, this type of fixed buoyant platform has the advantage of stability and virtual immunity to weather. With this new development, there will be future demands for various unconventional types of stable production structures[42] to extend water-depth capability, to cope with specific environmental conditions, and to reduce platform costs.

Technological problems

One of the most pressing problems in fixed structures is the almost exponential increase in cost with increasing water-depth.[43] There is still an urgent need for new types of structures that can be constructed at lower costs, for improved design of structural joints to lessen the problem of structural metal fatigue, for more efficient floating construction equipment, and

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37 Practically all the structures recently installed in the Gulf of Mexico are designed to survive expected maximum storm conditions in contrast to the older platforms designed to resist only a 25-year probability storm. Anticipated unusual difficult conditions, such as earthquake hazards off southern California, shifting sand waves and bottom scour in the North Sea, and drifting ice in the Cook Inlet off Alaska, are now included in the design criteria for the new structures. For instance, the construction of a heavy structure on extremely soft bottom in 90 metres of water was achieved by keeping air in the legs to make it more buoyant in order to reduce bottom support and avoid foundation failures.

38 A new generation of highly specialized floating construction equipment has recently been developed. The greatly increased lift capacity of the new derrick barges now permits very high quality prefabrication in shipyards of extremely large substructures and members. These can be towed afloat to a designated location and sunk by controlled flooding and simultaneous erection.

39 In the United Kingdom sector of the North Sea, an automated system, using a solid-state microwave telemetry network and a general-purpose computer system, is being set up to control operations at 10 off-shore platforms with an expected total of 100 producing gas wells in the "Leman Bank" and "indefatigable" fields located about 60 km off-shore (Keleher *and others*, 1969; Long, 1970). The computer operating console at the Bacton on-shore terminal will be able to control all operations, regulate gas production and transmission rates to meet gas sales, record well-test data for future uses, and measure the volumes and caloric values of the treated dry gas delivered to the Gas Council. Any equipment or operational malfunctions will automatically actuate recognizable alarm signals including a computer print-out to diagnose the malfunction.

40 At Khafji in the Neutral Zone (in the Persian Gulf) an automated system, using a network of telemetry cables, permits one operator at the central terminal on-shore to control and supervise all facilities from off-shore well-heads through flow stations and gathering stations to tanker loading docks.

41 The 7-metre (23 foot) diameter 123-metre (408 foot) long structure, the Elfocean, was designed by Equipements mécaniques et hydrauliques (EMH) and built and installed by Compagnie française d'entreprises metalliques (CFEM) at a test location in 98 metres (323 feet) of water in the Bay of Biscay. It has a long cylinder-shaped main structure extending above sea-level to provide drilling, production, and oil storage facilities, living quarters and a heliport. The submerged lower end of the cylindrical structure is connected through a universal-joint system to the ballasted stable base fixed on the sea floor. The base is designed to contain subsea well-heads. The more than 1,200 tons buoyancy force of the main structure ensures the over-all stability of the cylinder platform which is subjected only to rotational motion even under severe winds and heavy seas. Subsea completed wells, which can be drilled through a central conduit inside the cylinder, would allow produced oil to be treated on the above-water facilities and then stored in the submerged lower part of the cylinder.

42 Humble Oil and Refining Company has designed, for production in 305 to 395 metres (1,000 to 1,300 feet) water-depth, a submerged bottom-supported platform which would contain up to 40 subsea well-heads on the platform deck at moderate depth below sea level and be accessible to divers.

43 A large production platform constructed in 93 metres (340 feet) of water in the Gulf of Mexico costs $6 million. In 243 metres (800 feet) of water, a conventional piled template-type platform would cost $18 million.

much faster platform installation in order to avoid as much damaging weather as possible.

Despite the many problems arising from adverse weather, difficulties of access by surface craft, collision risks and human safety, there is a very great attraction in maintaining as many facilities as practicable at or above sea level. For the foreseeable future, above-water production systems using conventional platforms, articulated buoyant tower platforms, or other new types of structures, will continue to be most prevalent where sea conditions are less severe, where construction facilities are nearby, where water-depth is less than 305 metres (1,000 feet), where reservoir characteristics permit clustering many wells per platform, and where production problems and frequent work-over of wells are anticipated.

Ocean floor completion and production systems

There have been many improvements and new developments in underwater equipment and techniques for use in the subsea well completion systems whereby well-heads, manifolds, flowlines, pumps, compressors, separators, controls and other production equipment are installed on the sea floor. As of 1969, some 100 wells had already been completed on the sea floor but these wells either produce to nearby on-shore production facilities or, as "satellite" peripheral wells, yield production to the centralized facilities on a fixed above-water production platform. Today subsea completion is still technically difficult and rather expensive and most of the underwater equipment and techniques are still in the experimental stage.

Engineering research has been continuously pursued to improve the remotely actuated subsea well-head equipment and control mechanism. A system of acoustic signal control of subsea wells has been successfully applied to a group of wells in the Gulf of Mexico.[44]

Subsea well completions made during recent years have proven to be very successful for gas production but sometimes difficulties are encountered in oil production, particularly where the paraffin content of crude is high and tends to clog up the flowline. Clearing the lines and other servicing operations can usually be carried out by divers, by the recently improved "through the flowline" technique using "pump-down tools"[45] or by the newly developed wireline methods.[46]

A highly significant experiment of an entire subsea production system was being conducted in 1969 and 1970 in 21 metres (70 feet) of water, off the coast of Abu Dhabi in the Persian Gulf. This test, referred to as "Well Bravo" will determine the effectiveness, reliability, and cost of various equipment which could eventually be used in depths down to 200 metres (655 feet).[47]

Subsea well completion offers the potential advantages that it would avoid the hostile sea surface environment, eliminate expensive above-water platforms, reduce the requirements of surface support and eliminate the sea-surface navigational hazards. As the technology of subsea well completion and production improves, the first widespread subsea completion practice will come where a large number of development wells must be drilled and completed to produce in more than 120 metres (400 feet) of water in areas of greatly varying sea-floor topography, so that above-water platforms with centralized production facilities can be economically erected in suitable shallow water within a reasonable distance (Ellis, *and others*, 1969). Subsequent technological advances will make it possible to locate entire oilfield facilities on the sea-floor in ultra-deep water, with remote control from a centralized terminal, and with production going into underwater storage and shipped via tankers or submarine pipelines.

Manned and unmanned underwater work capabilities

One of the increasingly important new dimensions in off-shore petroleum technology is the necessary underwater manned and unmanned activities to support various operations and perform critical tasks in deeper and deeper waters. These include subsea well completion and maintenance, setting structures, installation of platform cathodic protection, inspection and repair of pipelines and underwater portions of structures and drilling equipment, and hazardous salvage work, such as bringing blown-out wells under control.

As a result of commercial demand for advanced diving services, diving technology has made significant

[44] Each well-head has two miniaturized long-duration radio-isotope generators which uninterruptedly power the electro-mechanically actuated valves. Production controls of these wells are actuated and precisely regulated by coded acoustic signals sent out from a central production console located on a fixed platform about 1.5 km from the wells. The two-way acoustic telemetry system transmits operational status reports, upon request from the production console, and automatically transmits any unscheduled operational changes or malfunctions. Most subsea equipment used is designed to be emplaced from the sea surface without diver's assistance.

[45] During the last few years, a number of subsea satellite wells in the Gulf of Mexico have been successfully serviced by the "through-flowline pump down" methods from the centralized console on the production platform. The methods have been undergoing rapid development, and now have developed into a practical economic procedure for well maintenance without the need of expensive work-over rigs.

[46] In 1969, the Institut français du petrole developed a flexible marine riser system which can be connected from a dynamically positioned surface vessel to a subsea well-head. Its oleopneumatic damping device automatically compensates for wave action and keeps the marine rise stationary even in heavy seas, thus permitting conventional wireline tools to be used in servicing subsea wells in deep water. Another system developed by IFP requires that the entire wireline winch be lowered onto the subsea well-head and remotely operated from a surface vessel, thus eliminating the need for a marine riser.

[47] The subsea well being tested by the British Petroleum Company and Compagnie française de petroles, referred to as "Well Bravo", was connected directly to a distant platform above water and also connected to two different sea-floor gas separators, which perform degassing, including gas dispersal and disposal underwater. One separator unit is equipped with a self-positioning system whereby it can lower itself to the sea-floor base. The whole unit, without the base, may be surfaced for major servicing, with minor operating adjustments to equipment being made under the bell by divers. The other separator has retrievable instrument capsules which may be brought to the surface for adjustment by attaching buoyant parachutes with diver's assistance. Other principal items undergoing subsea testing are well-heads; underwater communications; autonomous power sources for the provision of energy for operation and remote control of valves; telemetry; underwater tools and welding procedures; and submarines for diver support and transport, including navigational systems and sea-floor garages for the submarines.

advances during the last few years in terms of diving depth, diving duration and effective work time on the bottom, diving safety, special underwater tools and methods and technical skills in performing tasks.[48]

It is now quite practical to place men at depths of 180-213 metres (600-700 feet) and carry out efficient work under safe conditions. However, diving costs increase rapidly with water-depth and very deep diving is still limited to the exceptionally critical tasks.

Experimental dives and medical investigations have been carried out successfully, both in the dry and wet environments, to as deep as 457 metres (1,500 feet).[49] The results indicate that man has not yet reached the physical limits of deep diving.[50] It may be expected that commercial diving to these depths will eventually become practical in the future, and with the new developments in life support systems, pressure-chamber designs and special tools and methods, the entire continental shelf and the upper portions of continental slopes will be accessible to the diver. A world-wide rescue capability will be possible when the mating systems for fitting and lifting various types of diving capsules have been standardized throughout the world.

Experiments involving the use of fixed or mobile sea-floor habitats have been successfully conducted in many parts of the world,[51, 52, 53] and it is expected that habitat technology will soon find its full application in off-shore petroleum work. There is no doubt that the ability to work and live in permanent sea-floor bases for prolonged periods under considerable hydrostatic pressure will be an integral part of the new technology that will evolve as the petroleum industry moves into deeper waters.

The number of small, manned submersibles capable of performing limited but useful underwater oil-field work, continues to grow. More special designs have been used in recent subsea work boats to meet specific engineering tasks,[54] such as pipeline burying and inspection, salvage and maintenance work.

The mechanical arms and highly sophisticated manipulator systems attached to submersibles are designed to simulate a diver's dexterity and versatility. They need to be considerably improved in their speed and dexterity, but the models of future generations are expected to perform all intricate tasks below diver depth and to assist or replace the diver working in shallow water.

Some of the new submersibles have lock-out compartments, permitting divers to exit to the subsea work site and re-enter upon completion of their work.[55]

As petroleum exploitation progresses into deeper and deeper waters, the subsea work boats will, to a certain extent replace the physical efforts and hardships of conventional divers. It is expected that a new generation of submersibles with adequate work capabilities will be eventually developed and employed for servicing subsea wells in several thousand feet of water.

Special new designs of unmanned tethered submersibles, sea-bed vehicles, and other remote controlled devices have been developed for pipeline work and experimented with in other subsea oil-field operations.

However, a great deal of engineering research and development work is required to develop more sophisticated, versatile, unmanned units and devices that can reliably perform various complex tasks in deep water. But it is expected that divers, manned submersibles, and teleguided unmanned units will become integral parts of the future deep-water petroleum technology.

Future deep-water production systems

Intensive engineering research has been pursued during the past few years by the petroleum industry, in co-operation with the ocean engineering and aerospace industries, to develop entirely new deep-water petroleum production systems. The major objective is to develop all the desirable equipment and techniques that would be able to economically perform all the envisioned necessary work functions under varied deep-water conditions. Such work includes drilling of development wells; well completion; work-over and servicing of wells; production control and commingling; downhole fluid injection and secondary recovery; well stream processing; production equipment maintenance; and storage and transportation of oil and gas.

A number of new systems have been proposed, designed, or experimented with for production to 450 metres (1,500 feet) or greater water-depth. These

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[48] A new breed of diving engineers and diving technicians is emerging. They are highly trained men, embodying all the qualities of intelligence and physical and mental fitness of divers, who bring their technical expertise and engineering skills to the subsea oil facilities at increasingly greater water-depths.

[49] In 1970, volunteer members of the Royal Naval Scientific Service, United Kingdom, stayed 10 hours at a world record simulated diving depth of 457 metres (1,500 feet).

[50] It is still uncertain as to how deep man can go, but experiments with animals suggest an ultimate practical limit for work diving may exist somewhere between 305 metres (1,000 feet) and 760 metres (2,500 feet) (Smith, 1969). However, there are physiological hurdles to overcome in diving at the greater depths, and work efficiency may be significantly impaired, with considerable increase in cost, thus reaching a point of diminishing returns as a functon of diving depth.

[51] For example, Cousteau's *Conshelf* experiments, the Soviet Union's project *Benthos 300*, West Germany's project "Helgoland" in the North Sea, Canada's habitat *Sublimnos* in Lake Superior, habitat *Aegir* off the Hawaiian Island of Oahu, and habitat *Hydrolab* off the Florida coast.

[52] In 1970, scientists, engineers and medical doctors from 27 nations participated in the United States' *Tektite II* habitat programme in the warm waters off the Virgin Islands in the Caribbean.

[53] A unique subsea work system, now under development in the Netherlands, consists of work submarines (the recently completed *Nereid 330* and the next-generation submarine *Nereid 2000)*; a diver transport vehicle, the *Wet Sub*, now under construction; and a small habitat with wet and dry compartments to be used as a sea-floor base for oil-field divers.

[54] A "sea bed vehicle" constructed in 1970 in the United Kingdom can support two operators and three divers on the sea floor to depths of 182 metres (600 feet) and perform subsea work such as pile driving, pipeline inspection, trenching and pipeline burying, salvage and maintenance work. The vehicle travels on large wheels along the sea bed and the required power and life support are fed from a surface support vessel.

[55] The 25-metre long *Argyronete* is being built in France and will be in service in 1972 to become the largest lock-out submarine. It will be able to operate to 600 metres (1,970 feet) depth and accommodate six crew members in the dry compartment at atmospheric pressure and four divers in a wet section.

systems rely heavily on the past twenty years' experience of off-shore petroleum operations and the new technologies developed by the ocean engineering and aerospace industries, as well as analyses of the critical factors, such as safety; initial investment; operating costs; time required for installation; status of development of the important components to be utilized in the system; possible improvements of the system based on anticipated future technologic advances; water-depth limitations; and suitability to a variety of environmental,[56] geographical[57] and petroleum reservoir conditions.[58] Several of the new systems have been designed to place most of the equipment, when possible and practical, on the sea-bed or in the water medium below the level of waves,[59] thus eliminating the need for above-water fixed platforms. Operations of the subsea equipment will be continuously monitored and remotely controlled and actuated through subsea cables, hydraulic lines, underwater acoustic devices, or by radio or microwave telemetry to an antenna buoy moored above sea level. The automatic operations will be provided with appropriate alarms and safety devices for equipment failures.

In principle, there are three approaches in the development of new subsea production systems: exposed "wet systems"; "dry ambient pressure systems"; and "dry atmospheric pressure systems"; and technically there are no water depth limits for these concepts. In the exposed "wet systems,"[60] the major equipment items, such as well heads, manifolds, pumps, compressors, separators, controls, and production storage facilities, are installed on the sea-bed or on decks of submerged platforms at convenient diver depths, and are directly exposed to the sea environment.

While certain equipment units will be designed to be remotely controlled, other equipment will be operated by special-purpose manipulators. These manipulators will govern the design and lay-out of the wet systems. For the unexpected infrequent repairs and other tasks, either divers, manned subsea work boats, or unmanned tethered vehicles will be required.

In the "dry ambient-pressure systems",[61] major equipment items are encapsulated in thin-walled capsules which are dry inside but at full ambient subsea pressure. The principal advantages of these systems are that production equipment is protected from direct contact with the sea, that equal pressure inside and outside the capsule permits easy access for divers through the bottom opening, and that the divers, although subjected to pressure and decompression problems, can work more effectively in the dry environment. These systems will also provide means for dry personnel and equipment transfer, using a tethered bell or submersible as a transfer elevator to and from the sea surface.

As in the case of the wet systems, the dry ambient-pressure systems may also be designed to place the equipment capsules above the ocean floor at a convenient diver depth in order to reduce the pressure and to facilitate divers' work. Any equipment located below this depth will probably require the use of general purpose manipulators or manned subsea work boats in place of divers.

In the dry atmospheric pressure systems,[62] thick-walled capsules protect equipment and maintenance personnel from high pressures as well as from direct contact with the sea. The principal advantage of the dry atmospheric-pressure systems is the elimination of pressure-diving problems. But these systems require relatively heavy and expensive capsules; provisions for the more complicated personnel and equipment transfer;[63] means of maintaining the internal pressure; and means of conditioning and controlling the air mixture.[64]

As in the case of the dry ambient-pressure systems, all equipment inside the capsule with one atmospheric pressure would be designed to withstand accidental flooding, and, under unusual circumstances, well-heads may be located outside the capsules to reduce the hazards from high-pressure hydrocarbon leaks. This external "wet" equipment would be serviced by divers, manipulators or manned work submarines.

Transferring off-shore petroleum technology

Off-shore petroleum technology is expected to yield many benefits for other marine enterprises. For example, the current technology for constructing fixed off-shore platforms and mobile units will soon be widely applied to various new tasks of marine construction, such as floating airports, artificial islands-harbours, and floating cities.[65,66] Recently a jack-up platform designed

[56] Environmental conditions include prevailing weather, waves, currents, turbidity and temperature of water, and occurrence of major storms, earthquakes and ice.

[57] Some important geographical conditions are distance from shore; water-depth variations between the site and shore; availability of natural harbours, construction sites and other on-shore facilities and local markets for crude oil and gas.

[58] Petroleum reservoir conditions include reservoir size, depth, and characteristics; anticipated production rates of wells; reservoir pressure; gas-oil and water-oil ratios; and the extent of corrosion, sand and paraffin problems of the flowlines.

[59] All equipment placed under water will be designed for long life, reliable operation, and for ease of repair or replacement. Modular designs will facilitate replacement of equipment items in a single unit and permit deleting or adding modules according to changing production requirements. Redundancy will be provided so that failure of a component does not require immediate correction to prevent shutdown and to increase safety.

[60] For example, the system under development by the Deep Oil Technology Company is comprised of modular-type sea-floor templates designed to support well assemblies exposed to the sea environment.

[61] An example is the conceptual system designed by the National Tank Company and Production Systems International.

[62] A prototype system developed by the Lockheed Missiles and Space Company was recently successfully tested in 60 metres of water off British Columbia.

[63] Equipment mating techniques developed in the United States of America for submarine rescue have been adopted to the design of personnel transfer systems.

[64] The inside atmosphere might be breathable or inert; if inert, personnel would require individual breathing apparatus.

[65] A floating airport has been proposed in the Atlantic, located 35 miles from New York. In France, the Port Authority of Le Havre recently completed plans to build an artificial island-harbour to be located some 17 miles at sea. It is expected that before the end of the 1970s, a systems approach to land-air-sea transport interfaces will be realized in the construction of off-shore airfields in combination with off-shore port facilities, including tanker terminals, and provided with tubes and causeways leading to adjacent coasts (Goodwin, 1969).

[66] In the Sea City project proposed by the Pilkington Glass Age Development Committee in London, a 16-storey glass and

for drilling in the North Sea was used in deep-water bridge construction in Japan.

The off-shore petroleum industry recently saw how its technology could be advantageously utilized in another "ocean industry". In 1970, Deepsea Ventures Inc. successfully tested a pilot-scale dredging system for mining manganese nodules in 760 to 915 metres (2,500 to 3,000 feet) of water, 270 kilometres (170 miles) off the coast of Georgia and Florida. This prototype of a deep-ocean mining system applied the most advanced techniques for the control of long, unsupported drill pipe developed through years of petroleum drilling. An experienced oil rig crew was used for the operations.

CONCLUSION

It has been predicted that many new off-shore fields, totalling as much as 140,000 million barrels of recoverable oil, will be discovered during the next decade or so in the world's continental shelf[67] and upper continental shelf areas to depths of 705 metres (1,000 feet). This does not include the anticipated continuing new discoveries off the coasts of Canada, the United States and the Union of Soviet Socialist Republics.

At the present rate of progress, it is apparent that off-shore petroleum technology has already developed the capability of exploiting new reserves at these depths within this decade. The commercial development of petroleum in ultra-deep waters is likely to be largely restricted during the next one or two decades to a small number of the very largest, highly productive fields in the most favourable locations. But given the present capability and the confidence of profitable progress into increasingly deeper waters and the geological evidence to support the existence of large undiscovered off-shore reserves (often in areas where petroleum is not yet produced), offshore petroleum development will undoubtedly change the production and supply picture for many countries in the not too distant future and introduce new world petroleum trade patterns.[68]

concrete amphitheatre, measuring 1,430 × 1,005 metres (4,700 × 3,300 feet) and housing 30,000 people, with a heated inner lagoon, would be built on piles of floating pontoons 24 km (15 miles) off the Norfolk coast of the United Kingdom in 10 metres (35 feet) of water.

67 Taken as a whole, the shelf areas of the world are more favourable for petroleum occurrence than the exposed part of the continents, and many sedimentary basins are expected to have a great potential in terms of exploratory drilling success ratio and production per well and per unit area.

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68 The successful tests in 1969 and 1970 of the converted ice-breaking tanker *Manhattan* promise another change in world-wide trade patterns. The development of Arctic commercial shipping will not only make the vast resources in the Arctic accessible to world markets but will also create shorter direct trade routes between Europe and the Far East.

SUMMARY — RESUME — RESUMEN

Latest advances in off-shore petroleum technology: *Frank F. H. Wang*

In this article, the author reviews all the latest technological improvements and achievements which allow the petroleum industry to venture increasingly into deeper waters in its search for oil. He gives extensive treatment of the various existing types of drilling rigs insisting on their intrinsic originality. In particular, he deals with bottom-supported mobile rigs, floating drilling rigs, hybrid-type mobile rigs, and mentions the design envisaged for future mobile rigs. Some of the problems attached to the well-functioning of these devices are also touched upon.

In the second part of his article, the author elaborates on the various techniques used in completion and production systems for off-shore oil developments. In addition to the well-known above-water completion and production system, he studies the systems emplaced on the ocean floor. Some glimpses of future deep-water production systems are also given.

Développements récents des techniques pétrolières «off-shore»: *Frank F. H. Wang*

Dans cet article l'auteur passe en revue les récentes améliorations et réalisations techniques qui permettent à l'industrie pétrolière de s'avancer dans des eaux plus profondes dans sa quête d'hydrocarbures. Il insiste longuement sur les différents types de plates-formes de forage en rappelant les caractéristiques originales de chacune. En particulier, il examine les plates-formes de forage fixes, semi-fixes et flottantes et fait mention des plans envisagés pour la construction de plates-formes mobiles dans l'avenir. Il signale également certains des problèmes qui se rattachent au bon fonctionnement de ces installations.

Dans la seconde partie de son article, l'auteur expose les différentes techniques qui sont utilisées pour la finition et la mise en production des puits dans l'exploitation *off-shore*. Outre les systèmes bien connus de finition et de production au-dessus de l'eau, il étudie les systèmes installés sur le fond. Il donne quelques aperçus des systèmes de production envisagés pour des eaux profondes.

Ultimos progresos de la técnica de explotación del petróleo frente a las costas: *Frank F. H. Wang*

En este artículo el autor analiza las últimas realizaciones y mejoras tecnológicas que permiten que la industria petrolera se aventure en aguas cada vez más profundas buscando petróleo. Se examinan extensamente las distintas clases de máquinas de perforación de pozos, insistiendo en su originalidad intrínseca. Sobre todo se ocupa de las torres móviles apoyadas en el fondo marino, de las torres flotantes y de las torres móviles mixtas y se describe el diseño de las futuras torres o plataformas móviles. También se tratan algunos de los problemas relacionados que plantea el funcionamiento adecuado de estos dispositivos.

En la segunda parte de este artículo, el autor explica las distintas técnicas empleadas para organizar y aprovechar sistemas de explotación del petróleo frente a las costas. Además del conocido sistema de explotación y aprovechamiento sobre el agua, estudia los sistemas ubicados en el fondo marino. También se dan algunas ideas sobre los futuros sistemas de explotación en aguas profundas.

THE SEARCH FOR GROUNDWATER IN THE CRYSTALLINE REGIONS OF AFRICA

by Robert DIJON

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Across a major surface of the African continent, and especially in the humid tropical zones, igneous (or crystalline) rocks crop out or are present under a thin cover of sediments. Until recently these rocks, which are mainly of Pre-Cambrian age, were regarded as impervious. However, new methods of prospecting, developed mainly in the late 1950s, have made it possible to locate in these compact rocks exploitable groundwater reservoirs. Moreover, groundwater is nowadays exploited in tropical regions where surface-water is relatively abundant and scattered over a wide area. This situation is the result of various factors, such as:

(a) *Seasonal shortage.* Surface waters from surface streams and ponds dry out in certain areas during the dry season over a wide fringe of the desert zone;

(b) *Poor quality water.* The chemical composition and the pollution of surface-waters, which sometimes contain pathogenic elements, do not permit them to be considered safe for human use;

(c) *Local shortage.* At some distance from the main rivers, surface-water resources may become scarce, even in humid zones, and especially if they are to supply a large village or a town. The creation of modern populated centres has therefore led to the search for groundwater;

(d) *High cost of surface-water.* When, for such populated centres, surface-water is available only at a distance, the cost of a lengthy piping system and of installations for treatment has encouraged the search for locally available groundwater.

Prospection for groundwater in crystalline rocks and its exploitation are of vital interest to the greater part of ten African countries and to large areas of another ten countries. The population concerned numbers more than 50 million. Projects dealing with this type of operation were sponsored by the United Nations Development Programme and carried out in recent years by the United Nations in Dahomey, Somalia, Togo, Uganda and Upper Volta, while several others are projected in Cameroon, Mali and Mauritania.

The purpose of this article is to give a broad idea of the problems encountered and the methods used.

OCCURRENCE OF GROUNDWATER

It is known that the occurrence of groundwater, under natural conditions, is ruled by three sets of factors:

(a) *Morphological*: surface-water run-off and infiltration are in a close relation with morphology and especially the pattern of hydrographic net-work, and the slopes of the terrain;

(b) *Climatic*: the amount and the distribution in time of precipitation will largely decide what water resources will be available for infiltration and underground storage. However, a substantial amount of this hydraulic potential can be withdrawn to this infiltration by means of evapotranspiration;

(c) *Geologic*: the infiltration of water into the terrains, its conservation in quality and quantity, and its further extraction are closely related to the physical and chemical properties of the geological formations, for example, the existence of voids which may contain water; a proper structure of this "porosity" which would allow water to flow underground; and the absence, in the rocks, of soluble chemical components which might alter the quality of the water.

Of these, geological factors are of paramount importance, as they primarily govern the very concept of "groundwater reservoir". In most cases, geological units and groundwater units (groundwater "basins" or "provinces") have about the same boundaries. A short review of the geology of crystalline rocks in Africa is therefore given below.

CRYSTALLINE ROCKS IN AFRICA

The crystalline Pre-Cambrian shield, which constitutes the bulk of the continent outcrops, is present at shallow depths in vast regions of the continent, especially in West, East, and South Africa, in the Sahara and in Madagascar. The depressed portions of this shield, and most of its edges especially in coastal areas, have been covered with continental and marine sediments.

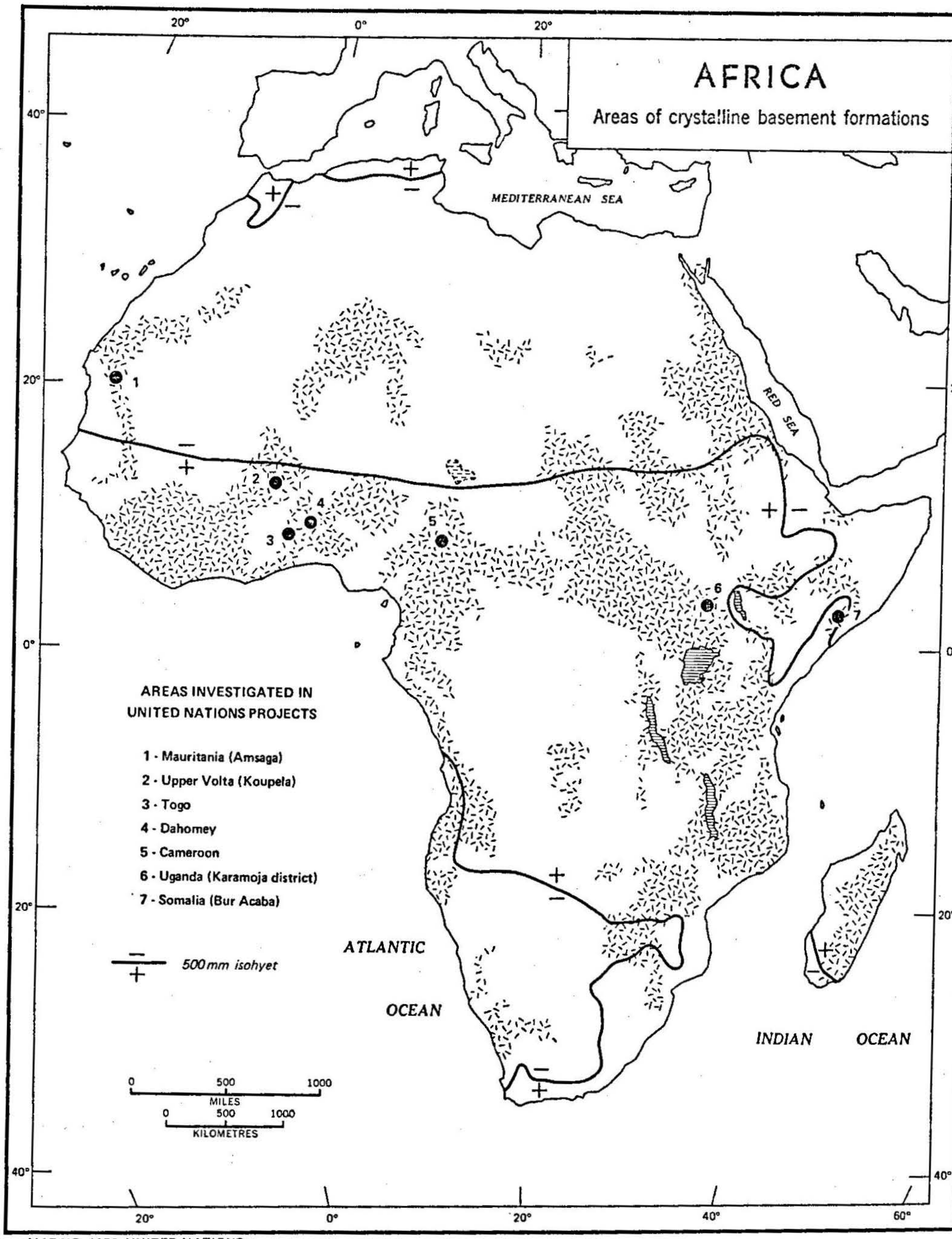
The chronology of the African Pre-Cambrian period is often a subject of dispute between geologists. For the hydrogeologist, the main interest lies with the vast lithological units, whatever their age might be. Three periods have been identified:

The lower Pre-Cambrian (more than 3 billion years):

This is characterized by granito-gneiss formations abundantly folded and penetrated by granitic batholites. It is known under such names as "Suggarien" in the Sahara; "Dahomeyen" in West Africa; "Premayombe" in Central Africa; "Basement Complex" in East Africa.

The middle Pre-Cambrian (from 2 to 3 billion years):

Folding and granitization are also the rule, but with a less advanced metamorphic process. It is mainly represented by schists and quartzites, under the names of "Atacorien" (quartzites) and "Birrimien" (schists) in West Africa; "Kerdous" in Morocco; "Mayombe" in Central Africa; "Upper Base-



MAP NO. 1979 UNITED NATIONS
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ment" in Zambia; "Limpopo" in Southern Africa; "serie de graphite" in Madagascar.

The upper Pre-Cambrian (from 1 to 2 billion years):

This includes various sedimentary formations affected diversely by metamorphism, and also volcanic formations (rhyolites, basalts). Such are the "Tarkwaian" in West Africa, the "Great Dyke" in Rhodesia, the "Witwatersrand" in Southern Africa.

This African shield is overlain by a sedimentary complex "Infra-Cambrian" or "Pre-Cambrian terminal" which includes granitic batholites such as the younger granites of Nigeria, and volcanic formations. The following local terms are used for this geological period: "Adoudounien" in Morocco, "Falemien" in West Africa, "Groupe de Katanga" in Central Africa, "Waterberg" in Southern Africa.

The hercynian orogenesis of the Carboniferous-Permian period has lifted large areas where Pre-Cambrian rocks crop out: Hoggar, Rguibat Highlands, Atacora Mountains and others.

During the Cenozoic period, especially in the Neogene, great geological phenomena gave the continent its general present appearance: orogenesis of the Atlas, fracturation of the shield accompanied by volcanic effusions, sinking of the Red Sea area, creation of the rift valleys in East Africa. After having been submitted to large movements of breaking tectonics, the continent is presently cut by large cracks into raised cupolas, and depressed or collapsed basins. The fractures follow two main, perpendicular orientations, SW-NE and NW-SE, and they are much more numerous and subdivided in the east along the two rift valleys. These are large subsident ditches, some 4,000 kilometres long, whose depth may reach 2,000 metres.

Important volcanic phases took place during the Miocene, Pliocene and even the Quaternary periods, in close relationship with the system of fractures, mainly in East Africa (Ethiopia lava flows, Mount Kilimanjaro in Kenya, and Ruwenzori). Other volcanic areas include, Tibesti, Hoggar, Aïr and Fezzan; Capo Verde, Fernando Po, and the Canary Islands; Madagascar and the Basutoland mountains.

The tectonic factors are of a great importance to the properties of crystalline rocks as aquifers because ancient orogenic movements brought certain crystalline areas to an upper position where, over a long period of time, they were submitted to intense erosion and weathering phenomena; also the faults and fractures which cut the continent into large blocks were active for numerous and lengthy periods.

This weathering and fracturing introduced into the bulk of the crystalline rocks secondary, important porosity, which endowed them with water-bearing properties, the primary porosity of the rocks, in their original state being almost nil. Most important is the weathering which occurred during Pliocene, Pleistocene and Quaternary periods characterized by diluvial rainfall over most of Africa.

Climatic and morphological factors

The quantity of water available for the replenishment of natural groundwater reservoirs relates to three main climatic factors: total rainfall per month and per year; the distribution of rainfall during short periods of time (intensity); the value of potential evapotranspiration ruled by the latitude, the altitude and the temperature.

Each one of these three factors prevails upon the others, depending on the areas considered, in the following ways:

(*a*) When total rainfall exceeds 1 to 1.20 metres/year neither the violence of rainfall, nor evapotranspiration is important, because there is always a substantial amount of rain-water available for infiltration;

(*b*) When the value of rainfall does not exceed 0.2 to 0.3 metres/year if the intensity of the rare rainfalls, that is, their concentration on a very short period of time is not sufficient, the meagre water crop is practically evaporated while it falls, and no water is available for infiltration;

(*c*) In the case of rainfall whose value lies in between the above measures, that, is between 0.3 and 1 metre, evapotranspiration is the dominant factor. During the most humid periods there is always in the water-balance a surplus available for infiltration. But during the dry periods most of the surface-water and shallow groundwater dries out. Such periods of prevailing arid conditions may last for three or six months.

Rainfall is closely related to latitude and to a lesser extent, to altitude. It is unevenly distributed, with important seasonal and interannual fluctuations. The equatorial humid regions (between latitude 10°N and 8°S and meridians 12°W and 40°E) have two rainy seasons with a maximum at the zenith of the sun (March-June and September-November) and practically continental rainfalls in the equatorial forest area between the Congo River and Lake Victoria, centering on the equator. The yearly rainfall exceeds 2 metres (up to 4-6 metres) on the West African coast from Conakry to Abidjan, from the Niger delta to Libreville, in the Congo loop, at the west of the Great Lakes, and on the eastern coast of Madagascar. Further, the tropical areas as far as latitude 15°N have only one rainy season, from May to October; to latitude 20°S and in Madagascar, it occurs from October till April. In the humid savannah belt, some 500 kilometres wide, the dry season may extend on four to five months. There is also a dry savannah belt, 300 kilometres wide, covering large areas, including most of East Africa and the central part of South Africa.

The desert subtropical zone in the vicinity of the tropics, and also most of Somalia, receive a very limited, irregular rainfall.

Mountainous areas in Africa are of quite limited extent. They are located mainly in the extreme north and south of the continent; the high altitudes found in the central part are related to volcanic insulated masses, not to mountain ranges. Most of the igneous and sedimentary formations in Africa have a tabular (mesa) structure. In West Africa the altitude is rather low (generally much less than 500 metres) and higher in east and southern Africa (1,000-1,200 and even 1,500 metres).

The drainage pattern varies widely. In crystalline rock areas of the arid zone, it is barely marked materializing into many closed basins; in the eastern highlands and in humid areas of the west, it is well ramified, sometimes following an arborescent design, but usually it is not deeply embanked.

Igneous rocks as aquifers

As mentioned before, groundwater is unevenly distributed in crystalline rocks and can be found mainly, if not exclusively, in weathered and fractured areas. Also some inclusions or intrusions of certain types of igneous rocks may have better properties than the bulk of the formation itself.

The purpose of any groundwater investigation in crystalline areas is:

(*a*) In weathered areas to evaluate the thickness, depth and hydraulic characteristics of the water-bearing layers;

(*b*) In fractured areas to locate in depth the fractured and fissured zones, to ascertain that the voids are not filled with clogging unconsolidated sediments or recrystallization products, and that they are saturated with good quality water;

(*c*) In areas where petrographic discontinuities are observed, to identify their extent, and their water-bearing and replenishment potential.

As the cost of well-digging and well-drilling in crystalline formations is high, it is important to site with accuracy the promising well locations and also to evaluate properly the optimum depth of the wells to be realized.

In this view, a hydrogeological survey in igneous rock areas requires a multi-operational approach, involving a strong component of photogeology, geophysics and reconnaissance drilling. However, it must be understood that groundwater resources occurring in igneous rocks are in most cases quite limited and expensive to develop. Therefore, they should be reserved for human (and eventually animal) consumption.

The following principles should always be kept in mind whenever a groundwater survey in igneous rocks is being considered (the term "igneous rocks" being meant to include both crystalline and metamorphic rocks especially with regard to Pre-Cambrian formations):[1]

(*a*) In weathered zones groundwater is contained in strata, generally thin and of a limited lateral extension, included in a clayey environment. The water-bearing material can be either an unconsolidated or a consolidated formation with an intergranular-type porosity;

(*b*) In fractured and fissured zones, water is contained in channels. Groundwater flow occurs in conditions recalling those related to carbonate rocks; however channels are often narrower than limestones and dolomites;

(*c*) Best groundwater reservoirs in Pre-Cambrian igneous rocks are found where these formations are both fractured and weathered. In fact the fracturation has often occurred where the rock has offered less resistance and the fracturation has created good conditions for weathering. It often happens also that such phenomena are associated with topographic depressions, which create favourable conditions for surface-water collection and infiltration.

The general pattern of a hydrogeological investigation in such areas would therefore be:

1st phase. General reconnaissance of existing wells and ponds; review of topographical and morphological features; lithological and structural studies (aerial photographs);

2nd phase. Geophysical prospection and eventual exploratory drilling. By the end of this phase, the well sites will be selected;

3rd phase. Test drilling and pumping;

4th phase. Control of the water-table, at least during one-year evaluation of the safe yield.

Methods of investigation

In these mostly flat and humid lands, where surface-water is almost always present, the population has always considered that the coming of the rains was enough to solve their water problems. Invocations to rainfall are often present in the cultures of the dry savannah belts: Mali statues raising their arms to the sky, worship of a "queen of rainfall" in the Lowveld (South Africa), enthronement of chiefs "bringing the rainfall" in Northern Sudan, are among the many examples.

Water, being considered as a gift from heaven—if not from the sky—was not often searched for in the ground, except when many temporary shallow holes were dug in the alluvium of the dried-up rivers. Water needs are usually modest, in an ancestral way of living. Besides, the digging of wells in crystalline formations requires an effort which is not often rewarded by a durable success; it also requires financial and technical means which cannot be found locally. This explains why the quest for groundwater in such regions has not been undertaken until recently. A major thrust was given after the end of the Second World War and especially since the accession to independence of the emerging nations of Africa.

In fact, the war developed a number of techniques and products which were later utilized by hydrogeologists, such as the study of aerial photographs and increased use of four-wheel-drive vehicles. Meanwhile, methods of geophysical prospection have developed, technically and in practice, and they have been systematically applied on a local or a regional basis to groundwater exploration for the last twenty years.

First phase: general reconnaissance

Hydrogeological reconnaissance is based primarily on the geological knowledge of the area. A geological map at a convenient scale is therefore useful, and quite often such maps are prepared by the hydrogeologists themselves. In basement rock areas the outcrops are sometimes scattered and small, emerging out of superficial formations originating from weathering phenomena. In such cases it is most helpful to prepare a physiographic sketch which includes data relating to topography, pedology, morphology, and structural geology (that is, the main orientation of fractures and folds). The identification of geological intrusions or inclusions (dikes of basic rocks) is of paramount importance. Some attention has to be given also to the type and distribution of the vegetation, which in some cases are related to the amount, quality and depth of groundwater.

In tropical areas morphological studies can be useful as they give information regarding depth, structure and lithology of the weathered zones, and therefore some indication of their water-bearing potential. This observation is to be applied especially to the lateritic formations, the slopes of the terrain, the types of relief, in relation to present and ancient (palaeo) climatic conditions. It is likely that the setting up of some basic principles, relating morphologic factors to the occurrence of groundwater in such areas, would save a considerable amount of work, time and funds. In general terms, however, it has been stated that in flat, tropical basement-rock land, the best groundwater reservoirs are related to topographic depressions, folded and fractured areas, and surface run-off (hydrographic network).

During the reconnaissance phase, the main water-holes, including ponds, wells and shallow holes in alluvium, are inventoried on maps and index cards; data such as water depth, water quality, lithological cross-sections of existing wells are collected and properly filed. The measurement of water resistivity provides a fast and inexpensive appraisal of the salinity of the waters. The index-cards and reports prepared dur-

[1] The Neogene and Pleistocene lavas will not be considered here, as in the areas of their major extension (eastern and southern Africa) they are often associated with sedimentary formation; also their groundwater potential has been little investigated, or not at all.

ing this phase contain indications regarding water needs (present and future), water consumption in the villages, and a preliminary evaluation of water availability. As an example, the United Nations Groundwater Project in Togo has surveyed such water needs, water consumption and water availability, in more than 800 villages and towns of the crystalline areas. All the data which have been collected are sometimes incorporated in a hydrogeological reconnaissance map. On such a map the geological formations are indicated by colours or patterns which are related to their water-bearing properties; the main wells, the boreholes, and the isopiezometric contours, water-quality characteristics and the depth of the hard rock substratum can be represented. This type of document makes it possible to identify and mark the areas upon which further investigation work has to be focused, taking into account the location of water needs, that is, the cities and villages and the most promising hydrogeological conditions in their vicinity.

Second phase: geophysical investigation and exploratory drilling

In the fractured and weathered zones of a crystalline area, the aquifer is heterogeneous and water availability is largely different from one point to another. The best well-sites have to be determined with a great accuracy, if significant yields are to be expected. Only geophysical methods can provide this accurate siting, and experience has shown that the chances of having producing wells are far greater (300-400 per cent) when such methods are employed.

Two main geophysical methods are utilized for ground-water investigation in crystalline areas.

1. *Electrical depth probes.* This method, the most widely applied, consists in measuring, by means of a "quadripole" (two electrodes sending the continuous electric current and two receiving), the resistivity values. Resistivity is a physical characteristic closely related to the geological facies of the terrains. In fact, this "apparent resistivity" often applies to a group of several layers each having different resistivities.

The spacing of the electrodes can be fixed as requested, depending on the depth of investigation to be reached: the arrangement of the electrodes can differ, along two main types: the "Schlumberger method" utilized in French-speaking Africa, and the "Wiener method" in English-speaking Africa.

The interpretation of the curves allows identification up to three superimposed levels each having a different resistivity. The contrasts are greater if the depth of investigation is shallow, and the results are much more reliable if the layers surveyed have been tested in preexisting, purposely drilled boreholes. It is also important to test the resistivity of the outcropping formations.

Such methods have been utilized with regard to the water-supply of cities and villages and also the watering of cattle in igneous rock areas in the following countries: Chad, Dahomey, Ghana, Ivory Coast, Kenya, Malawi, Mauritania, Niger, Nigeria, Togo, Uganda, Upper Volta, South Africa and Zambia.

The main aim was to evaluate the thickness and water-bearing properties of the weathered zone overlying the granito-gneissic basement, and of the intrusive formations, such as dikes.

2. *Seismic-refraction method.* The principle consists in measuring in a number of locations the characteristics of wave-propagation in geological formations after the ground has been purposely shaken by a hammering or an explosion. In an igneous rock area covered with a relatively thick weathered layer, this method gives better results than the electrical, as it allows much more accurate evaluation of the depth of the unweathered bed-rock. However, maximal thickness is not necessarily related to the best aquifers, and the trend has been in recent years to utilize both methods in "electroseismic" investigations, especially in the following countries: Cameroon, Chad (Ouaddai), Dahomey, Ivory Coast, Mauritania, Tanzania, Togo, Uganda, Upper Volta.

Electrical prospection involves a team of two, an engineer and an operator, and about seventy-five resistivity probes can be made each month. An additional operator is required in electroseismic investigations. The cost per month of such a team is between $6,000 and $8,000 for the electrical prospection, $8,000 and $10,000 for the electroseismic operation. The cost of siting one well is respectively $1,000 and $2,000. Such costs are currently applied by contracting companies; they can be reduced if properly trained local personnel is used. The cost of the equipment is in the range of $5,000 to $10,000.

The second phase of investigation may involve a certain amount of exploratory drilling in order to control and test the geophysical studies. Small diameter holes are drilled down, at least to the bottom of the alteration zones and often down to the fractured zones of the unweathered rock; a logging equipment is sometimes moved within the borehole in order to identify the porous and water-bearing horizons. Several drilling techniques can be used: the rotary is the fastest one, but there is a risk of clogging the thin water layer with the drilling mud if certain precautionary measures are not taken.

Third phase: test drilling and pumping

The construction of tube wells in crystalline areas is a difficult operation, as the layers to be bored are quite different in their mechanical properties. The nature and the structure of the weathered (soft) zone are closely related to those of the bed-rock. In some cases, the weathered zone is almost non-existent, or almost entirely clayey and therefore not aquifers. From a hydrogeological point of view the crystalline basement formation in tropical climates can be subdivided into two large categories:

1. *Orthogneiss, granite and paragneiss, poor in ferromagnesian elements.* From the top to the bottom the following horizons are found:

A: Soil and argillaceous concretions, more of less lateritic, one to several metres; briskly coloured (violet, red, yellow) and sterile

B: Clays, more or less sandy, variable thicknessess; contains seasonal groundwater in the dry savannah belt areas; the bottom of horizon B and top of horizon C are often quite fluid owing to the presence of the clayey "kaolinic porridge" resulting from the decomposition of the feldspathic elements of the bed-rock

C: Coarse sands and clays resulting from the decomposition of the bed-rock, less and less clayey in depth (up to 10 metres); in the lower layers, quartzy elements are abundant without much clayey element. This water-bearing horizon is most often not very thick (a few metres, maximum)

D: Fractured rock; may contain water in fractures or dikes which may act as natural drain of horizon C if pumpings are exerted through tube-wells which reach this fractured zone whose thickness does not generally exceed 50-80 metres and reaches 150-200 metres only exceptionally. Best yields are to be expected in the upper 20-30 metres

E: Unfractured rock

2. *Paragneiss rich in ferromagnesian elements (biotites and micaschists)*. The products of the weathering of these rocks are mainly clayey and therefore impervious, except when petrographic inclusions such as peridotites and quartzy dikes are encountered. The yield to be expected is much smaller than in the first category.

In general terms, 5 cubic metres per hour is a good yield for a well granite and granito-gneiss. In especially favourable conditions, artesian wells have been drilled in these formations (as in the United Nations project in Togo); while up to 30 (and even 100) cubic metres per hour could be extracted from non-artesian wells when the weathered zone is thick enough to be considered as an alluvial fill. A yield of one cubic metre per hour is quite appreciated in micaschists and metamorphic schists. An availability of 5 cubic metres per day is still interesting in areas short of water. Drilling in such formations requires the settling of a gravel-packed casing in the upper layer (ABC), with screens at the level of the C-aquifer layers. Considering the limited yields of such tube-wells a 6-inch casing (8-inch maximum) is sufficient for the setting of adequate pumps. Casing is not necessary through horizon D, and horizon E is not to be drilled.

The pumping tests should be conducted in order to test separately the aquifers of horizons C and D, eventually using a packer. It may happen that the waters of these two water-bearing horizons have a different composition indicating a possibly different age and/or origin, and also a different process of replenishment.

When the pumping tests have given positive results the tube-wells can be equipped by hand or motor-driven pumps. Also the water-bearing properties of a given geological environment having been established, a number of promising sites can be selected for future wells to be drilled or dug.

Fourth phase: control of the water-table

The construction of producing wells in such areas does not bring the hydrogeological studies to an end. It remains to make sure that the yields will be maintained through the seasons and through the years and also that the quality of the water will remain acceptable. It has also to be ascertained that additional wells can be constructed in the area without harmful interference with the existing exploitations.

For this purpose, it is essential to follow in some detail the fluctuation of the water-levels in some wells and to make the proper correlations between these fluctuations, the rate of the exploitation of groundwater, and the climatic conditions (rainfall, temperature, evaporation); this will lead to an accurate knowledge of the groundwater reservoirs and of the conditions of its replenishment and discharge.

CONCLUSION

These brief generalities give an idea of the complexities and sophistication of the groundwater research in crystalline areas. Such investigations have been in general costly and relatively slow, but most often successful. For instance nine out of ten wells drilled by the United Nations in Upper Volta have produced interesting yields in villages which are deprived of water resources during the dry season.

It is now time to re-evaluate as a whole the investigations already made, in order to assess cheaper and faster methods of identification of groundwater resources in such areas, using mainly aerial interpretations and geomorphology, complemented by a limited amount of reconnaissance geophysics.

It is time also to identify the reasons for success or failure encountered in the construction of wells in such areas. From past experience gained on several thousands of wells, the criteria of success for water-wells might be identified through computer studies. A first approach in this field has been made in recent years by the Bureau de recherches géologiques et minières (BRGM) through a study of some 2,000 wells, but a wider survey should be undertaken in the near future in which the United Nations might have an important role.

The United Nations is not involved only in the prospection of groundwater resources, but also in the strengthening of the relevant government services through the training of personnel, the supply of equipment and the organization of services. It has to be mentioned also that the United Nations groundwater projects have opened the way to further investments. Prospection work made by the United Nations in several countries of West Africa has been (or is due to be) followed by the construction of hundreds of wells with the assistance of the European Fund for Development (FED). The development of groundwater itself is undertaken on a pilot basis within the United Nations preinvestment projects. Drilling rigs, pumping installations, well-digging equipment (such as compressors and jackhammers) are supplied. African drillers and well-diggers are trained by international experts. This has been or is the case in particular in Cameroon, Mali, Mauritania, Togo and Upper Volta.

It can be estimated that at least 100,000 wells are necessary in order to provide some 50 million Africans, living in crystalline areas of the tropical zone, with the safe and permanent water-supply they need. Only a fraction of this total has been built. The United Nations has exerted special efforts, with a view to helping the African countries to help themselves, towards a solution of this important and specific problem which relates to the health and well-being of a large segment of the African population.

The search for groundwater in the crystalline regions of Africa: *Robert Dijon*

In crystalline rock regions of Africa, even under tropical humid climates, water resources are scarce, and during the dry season highly polluted. The development of safe surface-water supplies would require expensive treatment plants for small communities; therefore, in the last twenty years great efforts have been made to construct producing wells in areas which were considered practically sterile for groundwater. This problem is of a great interest to the major part of ten African countries and a considerable area of ten others. The population concerned numbers 40 to 50 million, needing some 100,000 wells, but only a fraction of this number has been built.

This paper provides an over-all view of the techniques used in exploration for groundwater resources after describing the main factors of groundwater occurrence in such a geological and climatic environment. The types of investigation and well construction involved are often of a rather sophisticated nature. The yields to be expected are variable, depending upon the climatic and geological conditions.

The United Nations has been and still is engaged in this type of operation in several countries of West, Central and East Africa, from Mauritania to Somalia. Investigations are carried out on a local or regional basis; wells are drilled or dug on a pilot basis, while the relevant government services are strengthened or organized within such United Nations sponsored projects through on-the-job training programmes, the use of appropriate methods and technologies and the supply of essential equipment both for exploration and water development (well-digging, well-drilling, pumping).

Recherche des eaux souterraines dans les régions de roche cristalline d'Afrique: *Robert Dijon*

Dans les régions de roche cristalline d'Afrique et même en climat tropical humide, les ressources en eau, peu abondantes, sont fortement polluées pendant la saison sèche. La production d'eau acceptable pour la consommation humaine dans les villages serait d'un coût élevé si l'on faisait appel aux eaux de surface, vu la nécessité de les épurer; c'est pourquoi on a déployé de grands efforts depuis 20 ans pour construire des puits productifs dans des zones considérées jusqu'alors comme pratiquement dépourvues d'eaux souterraines. Ce problème est d'un grand intérêt pour la majeure partie du territoire de 10 pays africains et pour une fraction notable de celui de 10 autres. Les populations intéressées sont au nombre de 40 à 50 millions d'habitants; il faudrait, pour satisfaire à ces besoins, prévoir environ 100 000 puits, dont seulement une faible fraction a été construite.

Cette communication présente une vue générale des techniques d'exploration des ressources en eaux souterraines et donne une description des principaux facteurs qui sont à l'origine de la présence d'eaux souterraines dans ce milieu géologique et climatologique. Les types d'enquête et de construction de puits sont souvent assez complexes. Les débits d'eaux souterraines obtenus varient largement avec les conditions du milieu (géologie et climat).

L'Organisation des Nations Unies a été et est encore engagée dans ce type d'opérations dans plusieurs pays d'Afrique de l'Ouest, du Centre et de l'Est, allant de la Mauritanie à la Somalie. Les recherches sont effectuées sur une base locale ou régionale; les puits sont creusés ou forés dans le cadre de travaux pilotes, les services techniques gouvernementaux étant renforcés ou organisés au titre de ces projets de l'Organisation des Nations Unies grâce à la formation du personnel en cours d'emploi, l'utilisation de méthodes et techniques appropriées et la fourniture de matériel d'exploration et d'exploitation des eaux souterraines (creusement et forage de puits, matériel de pompage).

Busca de aguas subterráneas en las regiones africanas de roca cristalina: *Robert Dijon*

En las regiones africanas de roca cristalina, incluso en climas húmedos tropicales, los recursos hídricos son escasos y, en la estación seca, se hallan altamente contaminados. El desarrollo de un sistema de abastecimiento de agua superficial potable requeriría plantas de tratamiento muy costosas para comunidades pequeñas. Por ello, en los últimos 20 años se han hecho grandes esfuerzos para construir pozos productivos en áreas consideradas prácticamente estériles en materia de aguas subterráneas. Este problema es de gran interés para la mayor parte del territorio de diez países africanos y para una fracción apreciable de otros diez. La población afectada, que suma entre 40 y 50 millones, necesitaría unos 100.000 pozos, de los cuales sólo se ha construido una pequeña cantidad.

Este artículo presenta un panorama general de las técnicas de exploración de los recursos de aguas subterráneas, prima descripción de los principales factores que originan la presencia de aguas subterráneas en un medio geológico y climático de esa índole. Los tipos de investigación y de construcción de pozos son a menudo bastante complejos. El rendimiento de agua que cabe esperar es variable, pues depende de las condiciones climáticas y geológicas.

Las Naciones Unidas se han dedicado y siguen dedicadas a este tipo de operación en varios países de Africa occidental, oriental y central, desde Mauritania hasta Somalia. Las investigaciones se efectúan en un nivel regional o local, los pozos se perforan o excavan a título experimental y los servicios técnicos gubernamentales se refuerzan u organizan dentro de estos proyectos de las Naciones Unidas mediante programas de formación en el empleo, el uso de métodos y técnicas adecuados y el suministro del equipo básico para la prospección y el aprovechamiento de las aguas subterráneas (excavación o perforación de pozos, bombeo).

FLOOD DAMAGE PREVENTION POLICIES

by Gilbert F. WHITE

Professor of Geography, University of Chicago

Recent trends in public policies for flood damage prevention reflect a broadening concern for integrated resource planning and a deepening interest in finding more harmonious human adjustments to the intricate and highly variable systems of the natural environment. Flood losses illustrate this trend better than most aspects of environmental management. They occur infrequently, but dramatically, and therefore command public attention. They present man with a clear statement of the cost of using a river valley. To cope with them effectively generally requires a co-ordination of physical measures within drainage areas and a judicious combination of social measures within administrative areas. Although man tends to deal with flood hazard initially through rather simple types of adjustments such as flood-plain land use or the construction of single-purpose control works, as economic organization becomes more complex he is inclined to turn to a larger array of measures and to place less complete reliance on a single, structural solution.

In this respect policies for dealing with flood damage illustrate a widening inclination among public managers of natural resources to take into account the full consequences of their actions. They are becoming more sensitive to the theoretically large range of alternatives—both physical and social—which are open to them, and they are more sophisticated in choosing among these alternatives and combining them (National Academy of Sciences, 1966 and 1968; Geographical Society of the Union of Soviet Socialist Republics, 1968). This leads to closer collaboration among engineers designing public works improvements and among the diverse administrators—political, fiscal, economic and planning—who are responsible for different phases of environmental use and economic organization.

It would be ironic if, as man gains in his mastery of building dams and levees, channelling streams, controlling watershed erosion and planning urban growth, the annual toll taken by flooding were to increase. Yet, this has been the experience until recently in Canada, the United States and some other countries. It promises to be the pattern in developing countries unless suitable steps are taken. A rising annual damage is not necessarily a sign of unwise or uneconomic management of resources. However, it usually indicates that the river control works are not having their intended results. Engineering works to curb flood are only one class of adjustments which man can make to flood hazard.

As background for an examination of current public policies, the theoretical range of adjustments to floods will be outlined, along with some observations as to how the choices are made among these alternatives. This review of policies, however, is based on incomplete information from many countries.

TYPES OF ADJUSTMENTS TO FLOODS

In using areas subject to overbank flooding, man has open to him three major classes of adjustment to the hazard of flood losses. He may ask (*a*) to change the flood; (*b*) distribute flood losses; or (*c*) arrange his use so as to change the losses. Each of these may be examined without offering any judgement as to how the choice is made or the merits of a particular choice. The spread of adjustment within these classes shows all of the possible solutions to a flood problem. There are many ways of classifying these adjustments, but one useful scheme is given in table 1 which also indicates the public policies which may guide each type (White, 1964; Senate Select Committee, 1960; Burton, 1962).

The simplest case would be a single farm located wholly on a flood plain. The farm manager has the theoretical choice of keeping the stream off the land, either bearing or sharing the losses, changing the land use or some combination of these. Where the present or prospective use is urban the problem is much more complex, but the possible types of choices are very similar. A city can curb the flood flows or let the residents and factories carry flood damages as a part of their normal operating expenses, or share the expense in some fashion, or alter the modes and patterns of land use. In practice, one of these often is chosen without conscious appraisal of the others.

The most common set of adjustments sponsored by Governments have to do with altering the stream regimen or channel. These are well known in the engineering literature and need not be described. They serve either to reduce stream discharge in a given reach or to so alter the channel as to reduce overbank flow. It must be remembered, however, that only rarely do they afford complete protection from all floods. Most levees will confine flows of only a specified magnitude (that is, with 25- or 50- or 500-year recurrence interval), few dams can store all the discharge of the unusual floods, and upstream land and forest improvement schemes may have little effect on downstream flows in certain circumstances of precipitation and temperature. This is important, because while engineers usually are careful to state the limits inherent in their design of new structures, other people are less discerning and may develop flood plains in blissful and misplaced confidence that the land never again will be inundated. From such situations come many of

TABLE 1. MAJOR TYPES OF ADJUSTMENTS TO FLOODS AND GUIDING SOCIAL POLICIES

Class	*Types*	*Guiding social policies*
Change flood	Levee and flood wall	Single-purpose construction
	Channel deepening, widening and straightening	Single-purpose construction; land-use regulation
	Detention reservoir	Single-purpose construction
	Storage reservoir	Multi-purpose construction
	Stream diversion (groundwater recharge)	Multi-purpose construction
	Upstream land treatment	Forest and cropland management
	Upstream sediment control	Forest and cropland management and single-purpose construction
Distribute losses	Bear the losses	None
	Relief and rehabilitation for flood sufferers	Public relief and rehabilitation
	Insurance	Licensing or public support; hazard information
Change use	Emergency evacuation and removal	Flood forecasting and disaster plans
	Design of vulnerable structures	Technical advice; building regulation
	Pattern of land use	Land-use and transportation planning; land-use regulation; hazard information
Mixed	Combinations of any of the above types	

the great disasters, such as Kansas City in 1952 (the largest single loss in United States history). Moreover, channel improvements are effective only so long as they are kept free of obstructions and deterioration, for thoughtless filling of a channel or building of an obstruction in a floodway can destroy the most skilful engineering design, as is illustrated by international experience on the lower Rio Grande.

The direct way for flood sufferers to adjust to damage is to bear it as a part of their regular operating expenses. In many societies these losses in fact are shared with others through systems of voluntary or governmental relief and through aid in rehabilitating destroyed property and operations. An alternate is insurance, in which premiums are equated with risk and thereby enable occupants to purchase reserves against a time of loss. To the extent that insurance does not make premiums equivalent to hazard, it becomes a device to share losses with other participants or, in the case of government-supported schemes, other contributors to national income (Krutilla, 1966).

The most ubiquitous individual adjustment is to arrange land use so as to achieve whatever the user regards as suitable balance of returns and costs. Changing use includes provision for emergency action when floods threaten, the design of new or altered structures so as to reduce flood losses without altering the flood, and a tremendous variety of patterns of land use. The latter may range from complete neglect of flood plain land to highly intensive development for commercial and industrial purposes.

Any of these may be combined with others. A mixed adjustment, for example, might comprise a detention dam and regulations to prevent more intensive land use in the partially protected reach downstream. "Flood proofing" is a term used to describe a combination of emergency and structural measures to reduce losses without altering either the flood or patterns of land use (Sheaffer, 1967).

THE DECISION PROCESS

The effect of a government policy in guiding any one of these possible adjustments is closely related to the way in which decisions are made in choosing among the range of possible adjustments. A dam constructed to detain flood flows is of no value for loss reduction unless the designated storage capacity is kept empty until peak discharge begins. A flood forecasting system may bring no decrease in damage unless it is linked with a warning system and a plan for emergency evacuation. A programme for reducing flood flows will gain little if it is followed by downward invasion of the flood plain so that reduced flows will inundate as much damageable property as did the higher flows formerly.

Every public measure assumes that managers of new control structures, or of flood plain property or of public services in the flood plain, will behave in an expected way. For example, it is assumed that storage capacity will be operated to detain peak flows, or that a flood hazard map will be used in locating new buildings in a valley. Sometimes they do, sometimes they do not. A failure to anticipate and deal realistically with the decision behaviour of such managers may negate the whole aim of the policy. The most dramatic and well documented example of this is in the United States, where investment of more than $7 billion in engineering works since 1936 appears to have been accompanied by enlarged national flood losses (White *and others,* 1958). While numerous hazard areas were being protected, people were moving into other, unprotected flood plains, often with the unwitting encouragement of government planning, finance or transport agencies. It is possible to cite similar cases in other countries where refined engineering programmes were offset by lack of understanding of the reactions of those adopting the various adjustments.

In table 1 the major types of adjustments to floods are set down beside the social policies which are intended to guide them. The crucial point to remember is that the policies in fact contribute to promoting or curbing a particular adjustment only to the extent that they are based on understanding of the likely reactions of those responsible for flood control or flood plain use. As a minimum, two questions can be asked of any public policy for flood loss management: first, what does it assume will be the reactions of managers of flood control structures and flood plain property?; and second, what is the evidence for this assumption?

There is a growing literature on the decision-making process in various social and cultural contexts, and it need not be reviewed here. However, a few observations that are especially relevant to flood loss reduction programmes may be noted briefly:

(*a*) Sophisticated methods permit comparison of the economic costs and benefits from flood-loss reduction measures (James, 1967; Lind, 1967). These now made possible a more nearly refined comparison of the likely outcomes of alternative adjustments;

(*b*) It is recognized that many public and individual managers do not select the optimal economic solution, and that their behaviour must be explained in terms of other aims and criteria (White, 1965);

(*c*) Among the significant factors affecting their decisions are their perception of the flood hazard and of the possible adjustments open to them (Kates, 1962). Only as these perceptions of the natural phenomena and the social opportunities are recognized for the reality they have with individual managers can practical policies be designed to affect or build on those views.

A preliminary global assessment

It would be illuminating to all involved in flood loss management to have an assessment of what is happening to the flood plains and the annual flood toll of the world. The basis for a careful assessment is lacking, but a preliminary venture may be made. I have shared in such an effort in the United States (Cook and White, 1962) and have observed flood plains in a number of other countries. From these scattered and largely unsystematic observations, and without any knowledge of China, I offer the following tentative conclusions:

(*a*) In western Europe and Japan the mean annual flood losses are mounting slowly, chiefly as a result of intensified use of areas, such as Florence and Grenoble, which are subject only to great and infrequent overflow;

(*b*) In eastern Europe the growth of losses is somewhat slower;

(*c*) In the United States and Canada the annual flood losses are growing rapidly but have begun to level off;

(*d*) In south and south-east Asia, intensified use of new valley land more than offsets the beneficial effects of major river control works;

(*e*) In South America there is widespread encroachment of urban growth on flood plains;

(*f*) In Africa the older cities suffer relatively little loss, but damage potential is beginning to enlarge as cities expand and as highway construction opens up new agricultural flood plains.

The general assessment, then, is one of increase in flood losses in most sections of the globe. We may ask but cannot yet answer whether or not this augmentation, so far as it occurs, is offset by increases in productivity from the use of these hazard areas.

Recent trends in policy

From a review of recent programmes and legislation in a number of countries, at least five trends seem to be evident in government policies for dealing with flood losses. The prevailing policy is still mainly one of supporting single-purpose construction, but these new stirrings indicate likely directions of change.

Flood forecasting

More precise and comprehensive systems for forecasting flood events are being installed. Making use of better understanding of the relations among run-off, precipitation, temperature, soil conditions, vegetation and valley storage, empirical formulae are developed to give warnings of arrival, magnitude and duration of flows. Combined with telemetering of precipitation and stream-flow, and with computer calculating, the coverage and accuracy of forecasts is enhanced. The World Meteorological Organization (WMO) has assisted in design of effective forecasting schemes. The United Nations Educational, Scientific and Cultural Organization (UNESCO) has aided in development of hydrologic models. Improved systems are widespread in Europe, North America, Australia and Japan. Where large storage reservoirs have been built, as in the Niger, Volta, Zambezi, and the streams of the Indian sub-continent, forecasts accompany the scheduling of power and irrigation releases. Forecasting is a key element in planning the utilization of the Lower Mekong under the auspices of the Lower Mekong Committee.

Such forecasts, however accurate from a hydrologic standpoint, will yield only modest returns unless they are linked with warning systems to get the information promptly to the people concerned. And the warnings may have little effect on losses unless local groups know how to use them, and have made the necessary preparations (Day, 1969).

Flood plain delimitation

Basic to most public action regarding flood losses is the delimitation of those parts of valleys which are subject to floods. Japan and the United States have ambitious programmes to map all stream reaches and coastal areas of special economic importance. Such mapping normally accompanies the investigation of river basin schemes in reaches downstream from prospective storage sites, as in the UNDP/FAO studies of the Rufiji and Ruvu basins in Tanzania, in the Senegal basin, and in the upper section of the Lower Mekong basin in Thailand. Ideally, all the flood plains of every country would be mapped for the benefit of potential users, but the cost often appears prohibitive, and the tendency is to concentrate on areas for which control works are being planned. Here, a dilemma arises. If accurate mapping is favoured for reaches where the damage problem is serious, it may always be applied to such areas as they emerge and may never be available to prevent acute losses from arising. It is like the housewife who, wishing to nurse a barrel of fresh apples over the winter by using only one each day, first chose a slightly rotten apple—and ended the season by eating a spoiled apple daily.

Two difficulties arise in setting up a policy of delimiting flood plains. One is in choosing between outlining the outside perimeter of some arbitrary hazard, such as the flood of record, and describing the approximate frequency of occurrence of floods in different zones of the flood plain. To simply describe an area as hazardous without assigning recurrence intervals is simpler, but it fails to discriminate degrees of risk and may not designate upper zones that would be inundated by rare floods. Yet, it is quicker, cheaper, and often easier to justify with legal and administrative officers. In the United States both have been tried: the simple flood of record method has been used by the United States Geological Survey, noting the floods recorded (the only large metropolitan area that has been completely mapped, Chicago, was done in this fashion); and the Corps of Engineers shows frequency zones in its more elaborate "flood plain information reports." The latter give basic data as well on channel conditions, flood plain uses and possible adjustments. The method of establishing whatever limits are chosen may range from rough interpretation of aerial photographs to detailed field surveys which set contour lines and measure channel cross-sections. It is possible, for example, to operate without topographic mapping, using only the aerial photos. The degree of detail obviously is much less, but cost and time are gained.

A second problem is in setting criteria for estimating the recurrence interval of a flood of given magnitude. There is no generally accepted standard, and even within the same country different government agencies may use different methods.

Flood control techniques

Although there has been a series of refinements in the conventional methods of controlling flood flows —levees, channel improvements, and dams—the basic strategy of construction is changing chiefly in the emphasis placed on integrating them with other measures for river basin development (United Nations, 1969). Increasingly, flood-control storage is combined with storage for power, irrigation and other purposes. And more attention is paid to flood problems on a basin-wide scale rather than to the solution of problems for individual reaches independent of areas downstream or upstream.

One consequence of this trend is that additional protection is being provided by reservoirs. The record shows that unless accompanied by land-use regulation and flood-proofing policies, no reduction in flood losses may accrue in the long run. Another result is the keener interest shown in techniques serving multiple-purposes. Thus, the linking of flood diversion with recharge of shallow aquifers is receiving emphasis in arid regions under national and United Nations studies, and the reservation of part of what were formerly single-purpose flood control reservoirs for recreation and conservation use is becoming common.

Economic analysis

As already indicated, the tools of economic appraisal are being sharpened by giving greater precision to benefit-cost analysis and to comparison of alternative measures on the basis of cost effectiveness. The Netherlands, the USSR and the United States have shown lively attention to such methods. When carried out in the framework of river-basin planning, such appraisal affords a more rigorous base for comparing alternative combinations of engineering work and, less adequately, engineering works with non-engineering activities. This is especially important in countries with very modest funds for capital expenditure: care needs to be exercised to prevent investment in projects yielding unduly low returns or paying out only over a very long period of time. The disaster conditions in which flood-control projects often are born may dull the public perception of the true public costs, and sometimes favour projects which offer security from floods but at a cost far exceeding the benefits.

Three brief cautions should be registered about the trend toward more intricate economic analysis of flood loss reduction measures. Even the most elegant methods can be no more sound than the data on land use and stream-flow on which calculations are based, and these often are extremely shaky or spotty. There is sufficient latitude for personal discretion in using these methods, that by making slight changes in methods or assumptions tremendous differences can be obtained in the numerical outcomes. Finally, the users of economic analysis frequently fail to specify all of the human behaviour which is tacitly assumed, so that the actual outcome for the region and nation may be radically less than shown in the estimates. There is nothing sacred about benefit-cost or cost-effectiveness analysis, and as often is the case with worshippers of false gods, undiscriminating devotion may lead the practitioner far from his goal.

Economic analysis does encourage a sharper statement of the goals sought in managing a water or land resource. Reducing flood losses is not an end in itself, although it sometimes is so taken for design purposes. Reduction in flood damages usually is undertaken by a Government to increase national economic efficiency, to promote the development of a particular region, or to prevent losses from falling too heavily on a sector of the population. What would be optimum for national economic efficiency would not necessarily be optimum for relieving the distress of a local flood plain, for the cost to the nation of protecting a town from floods might be greater than the benefits gained. This often is true of small stream reaches suffering from rare but catastrophic flows. From the standpoint of the region, feelings will run strong to obtain complete protection, while those concerned with efficient allocation of national investment will look for other, less costly means of providing partial reduction in losses, or may even conclude it would be better to abandon the site.

Multiple means

The moment the designer of a flood control project asks its ultimate social aims and then inquires what alternative measures are available to reach the same goal, he has opened up a method of thinking far more complex than that attaching to evaluating an ordinary engineering structure. This is what is happening in professional thinking about flood losses, and it probably is the most influential trend now affecting public policies. Essentially, the trend is away from reliance on manipulating flood flows, to consideration of possible flood control along with measures to distribute losses and to change flood plain use.

In its most restricted sense, the trend is toward providing whatever social guides are required to assure that levees, channel improvements and dams will serve their expected purposes. This stresses the prevention of channel obstructions, the proper operation of dams, and the regulation of land use to deter unexpected encroachments on partially protected flood plains.

In its broadest sense the move is in the direction of carefully weighing each possible adjustment and then selecting whatever combination seems best to contribute to regional or national goals. Under this view, if maximum net returns from capital investment is the goal, a modest expenditure to floodproof a few buildings having high loss potential would be preferred to a larger expenditure which would prevent all flooding, but would yield small marginal returns. To take an extreme case, an appraisal of an agricultural flood plain might well lead to the judgement that even though crop losses are substantial it would be wiser, in advancing agricultural productivity, to invest available capital and technical assistance in improved seeds and fertilizers than in curbing flood flows. Where the losses disrupt the local economy, crop insurance may be a more efficient alternative than loss prevention. A change in farm management and land use, with accompanying reductions in loss potential, may promise more lasting returns than a scheme to protect the existing patterns.

Wherever population growth is rapid, further encroachments on flood plains are likely. Restricting such encroachments to those that clearly are warranted in terms of the productivity which they will gain may be a more rewarding action than to try to protect each new settlement. Such an assessment is different from the engineering study which asks "Is the volume of loss prevented sufficiently large to justify protection expenditures?" Before settlement takes place the question properly is "Will the net returns from using this land warrant the public expenditures, including flood protection, to develop it?" And a supplement to this is the question, "Are there other ways in which losses might be reduced without controlling floods?"

Inquiries of this type in Australia, Canada, the United Kingdom and the United States, sometimes lead to decisions to invest heavily in a new flood-plain settlement, and sometimes to restrict the area to low-intensity uses such as livestock grazing (Burton, 1965a, 1965b). The multiple means employed may include engineering works, insurance, flood forecasting and flood proofing, architectural advisory service, and land-use regulations. No one government agency can be expected to administer such an array of activities. Nor is it easy to work out a detailed plan of action for a given river reach at any one time. Co-ordination can come either through regional land-use planning and administration or through articulation of national policies. In neither case is the management of flood losses the exclusive concern of one agency. Rather, it is in the thinking and action of several, perhaps many, agencies. In the United States the design of a national policy involved at least nineteen separate agencies (United States, 1966).

Policies for a developing country

One way of drawing together these observations on current policies for dealing with flood damages is to suggest those which would seem more appropriate for developing countries. These nations need not pay the cost of mistakes made by certain of the other countries with longer and patchier records of manipulating floods. To the extent they avoid such social cost they enhance their own development. And to the extent more developed countries follow similar policies, they increase their own efficiency in resource use.

As the International Hydrological Decade has demonstrated vividly, each country has its own distinctive set of agencies and laws to deal with rivers and related land resources. It therefore may be useful to focus on policies rather than on the agencies charged with carrying them out. I state the policies as minimum conditions which might be satisfied without requiring new organizations, elaborate procedures and heavy increases in professional personnel.

1. There should be readily available in one place a rough delimitation of the major flood hazard areas in the country. This can be in two forms: (*a*) maps of lists of stream reaches, lake margins and other areas believed to be especially hazardous; and (*b*) a section of an office where someone has sufficient knowledge of the country and sufficient skill in estimating flood frequency and magnitude to be able to give a crude judgement as to the hazard of a particular place. To begin with, a simple list of places known to have flood problems or a small-scale map compiled from previous hydrologic surveys might serve to alert interested people as to risky areas. While accuracy and complete coverage would be desired, neither would be required. The aim would be to quickly and broadly identify the chief reaches having risk, and to make available seasoned advice as to ways of estimating its approximate extent.

2. Plans for construction of new highways, land fills, or public buildings in river valleys should carry a note

as to the degree to which they may be subject to flood or may increase flood heights, and, if so, what measures are anticipated to deal with flood losses. This forces a conscious, recorded decision by some responsible official as to whether or not the flood risk is sufficient to warrant any change in plans or in auxiliary action.

3. Any project to control flood flows, including releases from multiple-purpose reservoirs, should include a statement of the assumptions it makes as to the actions which will be taken in remaining hazardous areas and as to the public measures, if any, considered desirable to cope with them. All too often, the assumptions are unstated, and no public measures are considered until it is too late.

4. Someone in Government should have the responsibility of being sufficiently trained to give technical advice on methods of flood-proofing buildings, regulating flood plain use, and administering flood warning and evacuation systems. There would be little point in identifying and requiring formal consideration of hazardous situations unless there is professional judgement as to what steps might be taken to deal with them.

None of these policies would require large or elegantly trained staff. The kind of proficiency suggested under points 1 and 4 could be obtained from short-term training. The sort of lists and maps suggested in point 1 could be compiled at small cost by comparison with detailed topographic and hydrographic surveys: initially, no field surveys would be made. Much more would be involved in carrying out a genuinely comprehensive policy. But I suspect it would be beyond the financial capacity of the countries for some time to come. The emphasis here is on avoiding new projects which fail to achieve their ends, and on preventing flood plain encroachment which will call for needlessly heavy public expenditures in later years.

From the outset the approach would be one of trying to assess the full range of adjustments open to man in dealing with a natural resource. Engineering construction would have its part, but in balance with other physical and social measures capable of advancing the long-term goals which flood loss management may serve.

When this type of approach to a natural resource problem is adopted, a larger number of administrative agencies is drawn in, greater emphasis is placed on the co-ordination of policies than on detailed plans, and more attention is given to ways in which research could provide new techniques — both physical and social — or new ways of assessing the wide variety of available techniques. Flood loss management is seen as one sector of activity contributing to national or regional aims, and not as an end in itself.

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SUMMARY — RESUME — RESUMEN

Flood damage prevention policies: *Gilbert F. White*

This article begins with a description of the theoretical range of adjustments that can be made to floods, by changing them, by distributing the flood losses, or by arranging land use so as to change the losses; and it discusses the major types of public policies intended to guide the adjustments, together with some underlying assumptions in the formulation of policies by decision-makers.

In making a global assessment of what is happening in the flood plains and the annual flood toll of the world, the author points to an increase of flood losses in most sections

of the globe and wonders whether or not this augmentation is offset by increases in productivity from the use of the hazard areas. He further states that the installation of more precise and comprehensive systems of forecasting flood events, the delineation of flood plains, the integration of flood control works with other measures for river basin development, the sharpening of economic analysis tools, and the decreasing reliance on the manipulation of floods in favour of some mixture of such measures with others designed to distribute losses and to change plain uses, constitute the major trends in government policies.

The article concludes with some recommendations for developing countries concerning the delimitation of flood hazards, the provision of information concerning the degree of risk to be associated with particular plans for the construction of highways, land-fills or public buildings, the inclusion of statements on the assumptions, associated with flood-control works, on the actions which are contemplated in the remaining hazardous areas, and on the training of government personnel capable of giving technical advice on methods for flood-proofing buildings, regulating flood plain use and administering flood warning and evacuation systems.

Politiques de prévention des dommages causés par les inondations: *Gilbert F. White*

L'article commence par la description d'une série théorique de mesures que l'on peut prendre pour lutter contre les inondations soit en dérivant les eaux de façon à répartir les pertes, soit en modifiant l'utilisation du sol pour changer la nature des pertes. Il traite aussi des principaux types de politiques destinées à diriger l'application de ces mesures ainsi que de certains principes de base que les législateurs doivent prendre en considération dans l'élaboration de ces politiques.

En faisant un bilan de ce qui arrive dans les plaines inondées et des victimes des inondations, chaque année, dans le monde, l'auteur met en évidence l'augmentation des pertes dues aux inondations dans la plupart des régions du globe et se demande si cette augmentation est ou non compensée par l'accroissement de la productivité des zones exposées aux inondations. Il précise en outre que l'installation de systèmes plus précis et plus complets pour la prévision des inondations, la délimitation des plaines inondables, l'intégration des travaux de lutte contre les inondations et de la mise en valeur des bassins fluviaux, ainsi qu'une plus grande précision des moyens d'analyse économique et une confiance décroissante dans la manipulation des crues en faveur d'une synthèse de ces mesures et de celles concernant la répartition des pertes et des changements dans l'utilisation des plaines fluviales, représentent les principales tendances de la politique des gouvernements.

L'article conclut sur quelques recommandations aux pays en voie de développement concernant la délimitation des dangers d'inondation, la fourniture de renseignements sur le degré de risque lié à tel ou tel projet de construction de routes, de remblayage ou d'édification de bâtiments publics, l'inclusion d'exposés sur les hypothèses de base pour la lutte contre les inondations concernant les mesures envisagées dans les zones restant menacées d'inondation et sur la formation de personnel de l'Etat capable de donner des conseils techniques pour la construction de bâtiments à l'abri des inondations, de réglementer l'utilisation des plaines inondables et d'administrer les systèmes d'alerte et d'évacuation.

Políticas para evitar los daños que producen las inundaciones: *Gilbert F. White*

Este artículo empieza con una descripción del alcance teórico de los ajustes que permiten afrontar las inundaciones, bien desviando las corrientes, distribuyendo las pérdidas, o haciendo un uso distinto de las tierras a fin de modificar la cuantía de dichas pérdidas. A continuación se discuten las distintas políticas de importancia para realizar tales ajustes, así como las hipótesis que deseen usar los que toman las decisiones.

Al hacer una estimación global de lo que sucede en las zonas inundables en el mundo, el autor señala el aumento de las pérdidas a causa de las inundaciones, y se pregunta si han sido compensadas mediante incrementos de la productividad en los mismos lugares. Luego añade que la instalación de sistemas de pronóstico más exactos y amplios, la delimitación de las llanuras inundables, la integración de las obras de defensa contra las inundaciones con otras para aprovechamiento de las cuencas fluviales, el perfeccionamiento del análisis económico y el menor énfasis en las obras preventivas en favor de una combinación con otras medidas para distribuir las pérdidas o modificar el uso de la tierra, constituyen las tendencias principales en la política oficial de los países.

El artículo concluye con algunas recomendaciones para los países en desarrollo sobre determinación de los peligros de inundaciones, obtención de información sobre el grado de riesgo que encierran ciertos planes de construcción de carreteras, rellenado de terrenos o los edificios públicos; inclusión de declaraciones sobre las hipótesis en que se basan las obras de defensa contra las inundaciones, relacionadas con la acción que se proyecta en las restantes zonas peligrosas, y capacitación de los funcionarios públicos capaces de prestar asesoramiento técnico sobre los métodos de protección de edificios contra inundaciones, regulación del uso de llanuras inundables y racionalización de los sistemas de alarma y de evacuación de personas y bienes.

THE ECONOMICS OF GEOTHERMAL POWER

by J. J. C. Bradbury

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This article, based on a rapporteur's report, is a synthesis of papers read before the United Nations Symposium on the Development and Utilization of Geothermal Resources, held at Pisa, Italy, in 1970. It covers a broad cross-section of experience in exploiting geothermal energy, especially in Hungary, Iceland, Italy, Japan, New Zealand, the Union of Soviet Socialist Republics and the United States of America

The main purpose in developing geothermal energy is to provide a source of cheap heat and power that can be applied to man's need. In order to be a viable source of energy, geothermal power must compete successfully with alternative energy sources such as natural gas, solid fuels, hydro-power and nuclear energy. The exploitation of these convential energy sources has now reached such a state of refinement and sophistication that they are able to produce energy at low unit costs; this, in turn, demands low production costs from geothermal energy if it is to be economically competitive.

It will be realized from the foregoing that no decision will be taken to develop a geothermal area unless there exists a good probability that its exploitation will be economically preferable to conventional alternatives. In these circumstances, it is necessary to have, from the beginning of a project, an indication of probable geothermal costs, in order that the decision to divert economic resources towards geothermal exploration may be based as firmly as possible upon a comparison with the costs of developing alternative energy sources. To this end, access must be available to the best possible estimates of not only probable exploration expenses, but also the costs of developing both well-field and power plant.

It has been pointed out by many authors that the development of geothermal power, being based upon an exploration process, is subject to uncertainties not present in the exploitation of more conventional alternatives. Nevertheless, despite difficulties in estimating these uncertainties, some attempt is necessary to assess the probable costs of projected geothermal developments in order to place them in a proper perspective against other energy sources. When international comparisons are attempted, further problems arise. There are substantial difficulties inherent in comparing international costs without having data compiled on an internationally consistent basis. National differences in the value of money, social conditions, productivity and standards of living are obviously important in this respect, and it would be prudent to expect wide variations in some cost elements when comparing performance in different countries. Despite the many qualifications which must necessarily attend these comparisons, it is desirable and advantageous to examine cost figures on an international basis.

At the present time considerable interest is being shown by developing countries in the possibility of geothermal resource development, and the United Nations alone is sponsoring five exploration projects. These countries, with no geothermal tradition or background of their own, must necessarily rely upon the costing experience available from those countries possessing geothermal experience. A full and free international exchange of information concerning projects in various parts of the world will do much to strengthen pre-operational cost estimating in the geothermal field.

Preliminary geothermal prospecting

The initial steps in a geothermal exploration project usually involve such specialized techniques as geochemical, geophysical and hydrologic surveys. Since the actual cost of this phase of exploration is dependent on such things as geological structure, hydrology, depth and temperature of the production zone, it is not easy to generalize on typical costs. However, the preliminary prospecting costs will form only a fraction of the total cost of a deep-drilling programme aimed at finding and testing production formations. A figure of $120,000 has been quoted to cover the preliminary exploration costs associated with the Kyushu development, in Japan.

In view of the uncertain and preliminary nature of these operations, questions have been raised as to whether the cost should be charged to the geothermal project eventually developed or absorbed as a general scientific overhead expense. In some countries, this preliminary investigatory work may be carried out by a governmental scientific agency which pays the cost out of its regular budget. These costs are often not charged to the geothermal development and thus remain a part of the country's general scientific overhead-costs. In developing countries working on much smaller budgets and with less comprehensive state-financed scientific facilities these preliminary expenses are much more significant.

In many cases, assistance is provided from another country with the necessary expertise or else through the medium of the United Nations technical assistance programme or through similar bilateral programmes. It has been argued that the cost of technical assistance provided by the United Nations need not be taken into account by the recipient country in the subsequent costing of a geothermal development. Such a policy would overlook the fact that the opportunity cost of the assistance received in the geothermal field can be expressed as the cost of assistance which has been forgone in an alternate field. In these circumstances, it seems advisable on grounds of financial prudence to take account of the costs involved in preliminary investigations when assessing the economic viability of geothermal developments.

Drilling programme

Following the completion of a preliminary exploration programme the next phase is usually concerned with the deep-drilling of production-size holes. At the beginning of this phase, much still remains to be learned about the well field characteristics and the main object of the initial holes is to obtain more detailed information about the geologic, thermal and hydraulic conditions of the field. In view of this initial paucity of information, the first hole has the highest probability of being a non-producer, although this probability can be expected to fall with succeeding wells as more and more detailed geological information becomes available. The high risk of failure associated with these early exploratory drillings has led to a desire to reduce the capital at risk by using "slim-holes" capable of obtaining the desired data at less cost than would have been involved with the use of standard diameter wells. A figure of $60/metre has been quoted for slim-hole test bores based upon a 6-inch and 4-inch casing programme to 1,000 metres, which compares with $98/metre quoted by the same author for an 8-inch production hole to the same depth. It is not, however, clear whether the small holes were bored by a large-size production rig or whether a smaller drilling machine was utilized.

Although, from the figures quoted, the "slim-hole" technique appears to give a cheaper well than the use of normal production-size holes, there may well be additional over-all project costs if it is necessary to mobilize and transport two different sizes of drilling rig. In addition, the need to purchase and handle a wider range of casings may also be a significant cost factor. However, the basic conception of trying to obtain drilling information as cheaply as possible is basically sound in view of the initial low probability of success. However, in the event of slim-hole wells striking usable fluid, their small diameters limit production in comparison with that which could have been obtained had the wells been of normal production size. It therefore seems that the economic feasibility of using slim-hole testing techniques as a supplement to, or substitute for, a normal production-size drilling programme must be evaluated carefully in terms of the probabilities of striking producing formations with initial drilling attempts.

A recent investigation carried out by the United Nations indicates that the use of a separate small-capacity drilling rig for exploratory slim-holes is not justified. In the event of finding a producing field, the additional cost of transporting a full-size drilling rig to the field would be substantial and would result in higher over-all costs than if the larger machine had been used for both slim-hole exploration and large-size production drilling. This investigation evaluated the total cost of drilling six exploration and six production wells as $760,000, using a single large dual purpose rig capable of drilling slim and production-size holes. The corresponding over-all cost, using two separate rigs, was evaluated as $796,000.

Using an average output of 1.3 MW and a success ratio of 1 in 6 for exploration wells, plus an average output of 5 MW with a success ratio of 5 in 6 for production wells, the above-mentioned alternatives might produce: 26.3 MW each. The corresponding costs would be $28,800/MW for the single rig and $30,300/MW for the two separate rigs. It should, however, be noted that in the event of failure to find a producing field, the former drilling régime would have $320,000 at risk compared with only $290,000 for the latter.

The cost of production-drilling depends upon a number of factors, including regional geological conditions and rock properties, drilling techniques, well-design and depth. In an attempt to eliminate cost variations arising from geological conditions, cost data relating to the drilling of geothermal, oil and gas wells have been studied in various regions of the Union of Soviet Socialist Republics. By averaging these data, it has been possible to derive basic relationships for predicting the possible cost of geothermal wells in any region.

The cost of drilling a geothermal well is made up of certain fixed costs associated with the preparation and setting up of the drilling equipment together with other incremental costs. The main cost of actual drilling operations is a function of both size and depth, with incremental unit costs increasing with depth because of the longer times taken to raise and lower the drilling-bit. On the other hand, the reduction of casing size with depth will result in reducing average costs for this item. Thus, the over-all average drilling cost will result from a combination of some operations having rising incremental costs and others tending to reduce average costs. This situation is clearly demonstrated by the following typical figures, showing the costs (in United States dollars) per metre drilled for various items with increasing depth:

	Depth (metres)		
	500	*1,000*	*1,500*
Preparation	28	17	13.3
Drilling	56	61	60
Casing	10	8	7.3
Finishing	6	6	4.7
Settlement	6	6	4.7
TOTAL	106	98	90

Although local conditions make it difficult to compare drilling costs in different countries, two papers submitted from Japan enable a certain measure of comparison to be made. A cost was given of $172/metre for a well of 1,200 metres depth. That this cost is high was explained by the fact that the project was the first of its kind and, consequently, experienced problems connected with drilling technology, management and machinery. This example emphasises that careful planning and programming are essential if drilling costs are to be maintained at minimum levels.

The employment of large "capital-intensive" drilling rigs, together with considerable numbers of rig operation personnel, means that drilling expenses are largely a function of elapsed time, and thus any delays or waiting time due to bad programming or rig management will result in severe cost penalties.

In a recent United Nations exploration project, five wells averaging 3,400 feet each were drilled at an average cost of $17/foot, excluding transportation, assembly and dismantling costs for the drilling rig. The average total cost for each well was $57,800, and $15,400 was spent during an average of twelve days, in assembling, dismantling and moving the drilling rig at each location. Of the over-all well cost, approximately 64 per cent consisted of day-rate charges, while the drilling footage costs amounted to 28 per cent of the total.

Although higher costs may be incurred by drilling deeper wells, in some circumstances, such a course of action may be economically justified if it results in an enhanced level of production. An example occurs at The Geysers field in California where a well was redrilled from 1,000 to 4,300 feet resulting in a tripling of its production to 180 kilopounds per hour. The average cost per well under conditions prevailing in California is approximately $150,000.

Fluid transmission

The cost of a fluid collection system in a geothermal field will depend upon several factors. The mass flow and steam/water ratio of fluid from individual wells will determine not only the number of collection points for a given output, but also the sizes of the associated pipe-work. In addition, the possibilities of interference between adjacent wells may vary for different fields, causing differences in collection system pipe-work costs. It will be seen from the foregoing that in the field of fluid collection, the eventual costs depend to a large extent upon local reservoir characteristics and are thus not susceptible to accurate estimation in advance.

With regard to the bulk transmission of geothermal fluids to the power-station, a decision may have to be taken as to whether the power station should be constructed close to the well heads or close to the cooling water. This problem was considered in some detail with regard to the Tauhara No. 1 borehole in New Zealand. This well is located one and a half miles from a source of cooling water in the Waikato River, and various economic factors determined the eventual site of the power plant. In this instance, well head generation would involve the additional capital cost of providing a cooling tower and would result in a lower plant thermal efficiency owing to the inferior vacuum obtainable with the tower. The lower thermal efficiency arising from this poor vacuum would have resulted in a 6 per cent increase in steam flow for the same power output. Nevertheless, despite these extra costs associated with the well head site, the large cost involved in constructing the necessary 24-inch-diameter pipe for the bulk transmission of fluid could not be economically justified. The utilization of geothermal fluid at the well head also eliminates excessive pipeline pressure drop and heat loss while the poorer vacuum allows savings in turbine size which arise from the lower specific volume of the exhaust steam.

Although some geothermal fields like Larderello, The Geysers and parts of Wairakei produce dry steam, present indications are that these may be the exception rather than the rule in geothermal development. Experience accumulated to date indicates that many of the new geothermal areas at present being explored will produce geothermal fluids consisting of steam and water mixtures. In Kyushu, steam is separated at the well head and the resulting steam and hot water are transported in two separate pipelines. Such a scheme presents difficulties of operation, since steam pipelines are prone to water-hammer troubles, and hot water pipelines may experience cavitation problems. Considerable work appears to have been carried out in New Zealand on the transmission of steam/water mixtures in various proportions over a wide range of flow-rates and at pressures up to 300 psig, and there are a number of horizontal pipelines in 12-inch and 16-inch diameter sizes successfully transmitting steam and water mixtures in New Zealand. This experience from Wairakei indicates that the joint transmission of steam/water mixtures does not present serious problems of chemical deposition.

The increase in size and cost of pipelines carrying a steam/water mixture, compared with those carrying a steam phase alone, has to be balanced against the extra power and revenue that could be obtained from the steam produced by low temperature flashing of the hot water. R. James, in his report on the economics of small geothermal power stations, presents graphs showing the variation in both capital and average generation costs arising from various condenser vacua and non-condensible gas concentrations. The main conclusions from this investigation are that both the capital and average generating costs at a given condenser pressure are less for steam/water transmission than for the transmission of the steam phase only; additionally, the required condenser pressure of 5 inches of mercury is close to that which gives the minimum generating costs for the range of gas contents studied. From these graphs it appears that changes in gas content have less effect on costs if steam/water transmission system is used than if only steam is transmitted, because the gas concentration in the steam entering the condenser is reduced by the addition of comparatively gas-free steam flashed from water in the secondary separator. These circumstances indicate that the advantage of steam/water transmission is even more marked where the non-condensible gas content of geothermal steam is high. Other graphs indicate that joint steam/water transmission is economically worthwhile with field enthalpies up to approximately 700 BTU/lb, especially at higher gas contents.

At The Geysers field the fluid transmission system is operating at 180 psig with well heads designed for 500 psig. Branch pipelines are of 8-inch and 16-inch sizes, while main transmission piping ranges from 10-inches to 30-inches diameter. All transmission piping is covered with a 2-inch thickness of fibreglass insulation wrapped with asbestos felt. The over-all cost of the pipeline system for The Geysers field is given as being in the range of $8 to $10 per kW of installed generating capacity. In this field no well is more than 1,200 feet from the power plant; as a result there is an average pressure drop of only 6 psi and a temperature drop of only 1-2°F in piping the steam to the power station

The steam transmission lines of the Namafjall development in Iceland have been designed as an overhead system with the centre-line about two metres above ground. This system has been adopted in view of the heavy ground accumulation of snow during the winter period. Stuffing-box type expansion joints are used to compensate for expansion of the pipe from cold to hot conditions, whilst minor temperature variations during operation are accommodated by bellows expansion pieces. Insulation consists of a 2-inch layer of fibreglass covered by waterproof aluminium sheeting.

Cost of steam at power station site

Steam costs are made up of the preliminary exploration expenses, the cost of the exploration and production drilling programme and the cost of installing the necessary transmission pipework. By far the greater part of steam cost is fixed in nature and arises from the amortization of and interest on the capital invested in the production of steam.

In view of this preponderance of capital charges, the length of the amortization periods used in financial calculations is of particular significance in its impact upon over-all power costs. It seems advisable to write off preliminary exploration expenses over the same period as that determined or estimated for the life of the production well. Considerable differences are seen in the assessment of amortization periods for production wells. While allowance must be made for variations in steam quality and geological conditions which affect the anticipated well life differently at different fields, it is difficult to reconcile the figures being used in various countries. In some instances, one is forced to conclude that the plant operators, probably in the absence of any previous operational experience, have adopted a very conservative approach to the estimation of well life. The selection of a very short well life will place a severe economic limitation on the economic feasibility of any geothermal development. It can be argued that if wells are still in production at the end of a very short amortization period, power production costs would then fall to very low levels as a result of the utilization of these written-off assets. However, if a too conservative approach is taken in the initial estimate of well life a prospective geothermal development might find itself at such an economic disadvantage compared with conventional sources of power that it might never be allowed to start. It is this ever-present need to compete with other energy sources which should require geothermal costing to be as realistic as possible rather than inflated in the interest of undue conservatism.

A further item in the cost of geothermal steam is the expense of either renting or buying the land needed for the well field and the transmission pipework system, and this will depend upon the minimum distance between wells which, in its turn, is a function of well interaction.

The variable costs associated with steam supply are very small and consist mainly of well and pipeline maintenance, which to a certain extent will be a function of the corrosive nature of the geothermal fluid. The mineral content of hot geothermal waters in some locations has been found to present problems by depositing calcium compounds in the well bores, and thus restricting the output. It is possible to remove these deposits by reaming, and the frequency of such remedial work will depend upon the characteristics of the water in question. In Otake an interesting experiment was carried out where the injection of 5000 kg of inhibited hydrochloric acid into a well choked with calcium carbonate improved the output by 100 per cent. Additional steam costs may also arise from the need to pursue a continual well-drilling programme aimed at the maintenance of steam quality and quantity.

Optimum operation steam conditions

Before any detailed plant design can be carried out, it is necessary to consider the optimum economic steam pressure under which a proposed geothermal power station will operate. Basically, in reducing design pressures, one is faced with the operation of two contradictory effects: first, the increased steam consumption rate of turbines working at lower pressures; secondly, the larger amount of steam taken from the field when it is drawn to a lower final pressure. Using various basic assumptions for possible reservoir conditions, it is possible to arrive at the conclusion that for dry steam the final well pressure should not exceed 75 psig. After allowing a 25 psi pressure drop, this fixes the optimum turbine stop valve pressure at 50 psig. The general conclusion is that for dry steam fields, the values of optimum production pressure are neither sensitive to the initial closed-in pressure of the reservoir nor to the amount of volcanic rock associated with the steam.

By considering a theoretical model of the existing Wairakei system, the conclusion may be reached that the optimum turbine pressure for maximum field life lies between 40 and 60 psig. Actual operating experience at Wairakei appears to confirm these theoretical conclusions as also does a 1964 cost estimate of a further possible 150 MW geothermal project in New Zealand.

Another important design parameter for a geothermal power plant is the condenser vacuum. Raising condenser pressures increases exhaust steam density and allows greater steam flows through the turbine, thus giving greater output, although at the expense of a higher specific steam consumption. Auxiliary power is reduced because of the increased density of the non-condensable gases to be exhausted, and also the higher steam condensation temperature which reduces coolant requirements. However, increased specific steam consumption places heavier demands upon the field output and incurs the extra cost of drilling additional wells and increasing transmission-pipe sizes. R. James, in "Power station strategy" evaluates a typical geothermal power project over a range of non-condensable gas concentrations with a view to establishing the condenser vacuum giving the lowest capital and generation costs, and presents graphs showing that minimum capital costs occur when the vacuum range is from 5 to 10 inches of mercury and minimum generating costs from 4.5 to 7.5 inches of mercury. Based upon this evaluation, a vacuum of 5 inches of mercury would seem to be appropriate for minimum over-all costs where non-condensable gas contents do not exceed 25 per cent.

Generating plant costs

The economics of geothermal power plant are dominated by comparatively high fixed charges and low variable costs: there are similarities in cost structure between geothermal and hydro power development, in that the incremental costs of both power systems are practically nil. However, not all hydro plants can operate at high load factors, whereas all geothermal stations can be relied upon to exploit their very low marginal operating costs by consistently running at high load factors.

Like exploration and drilling costs, the capital charges of geothermal generating plant are a function of both interest rate and period of amortization. Since a considerable proportion of the equipment bears a great similarity to conventional power-plant designs, the amortization periods adopted are of the same order: in the region of twenty-five years. The importance of amortization periods in over-all average costs is clearly illustrated in curves provided by Hayashida, which show the effect of various asset lives on the average cost of power using a 30 MW installation operating at 90 per cent load factor and 8 per cent auxiliary percentage.

The usual interest rate is within the 7-8 per cent range. It is not possible to adopt a common interest rate applicable to economic calculations for all geothermal locations. Although depreciation rates, being dependent upon asset lives, are susceptible to a measure of uniformity, interest rates are a function of so many economic, financial and social factors that international uniformity cannot be expected. In the economic analysis of any geothermal development, considerable care must be taken to use an interest rate corresponding to the local "opportunity-cost" of capital.

There is a substantial difference between geothermal and conventional thermal plant with regard to economies of scale. With the latter, it has been possible to obtain spectacular reductions in average unit costs because of substantial increases in generating plant output capacities. These increases have been made possible by the use of higher superheat temperatures, higher pressures and the use of several stages of reheat. These factors have kept machine sizes comparatively small, and this in turn has been facilitated by the employment of such techniques as liquid cooled generator windings.

With geothermal generation, the steam supply is usually of comparatively low pressure and temperature with low or no superheat. Under these circumstances, the specific steam consumption is relatively high, and increases in unit size, demand correspondingly larger machines to accommodate the associated steam flow. Although turbines of 55 MW capacity are at present being installed at The Geysers field, it is estimated that 80 MW will be the economic limit for geothermal machine size.

Despite the fact that geothermal machines cannot approach the scale effect achievable with conventional steam turbines, within the range of geothermal equipment sizes a definite scale effect can be discerned. Over-all capital costs are quoted, ranging from $147 per kW for 13.5 MW machines to $105 per kW for 55 MW condensing sizes. Non-condensing installations are less expensive in capital cost; in the size range of 5 to 10 MW per unit, capital costs are of the order of $90-130/kW. A comparison between condensing and atmospheric stations in Italy lists costs of $190 and $80/kW for 15 MW sizes. Capital costs of $300/kW are quoted in respect of the Otake field and $286/kW are given for Matsukawa, although these high costs are in part due to the cost of making necessary road improvements in mountainous areas and also the widely separated well locations. In general terms, unit capital costs for comparatively small geothermal power-plant sizes differ little from those applicable to conventional turbines in the 300 to 400 MW range.

In some geothermal stations, special consideration may need to be given to the question of condenser vacuum maintenance because of high concentration of non-condensable gases. At The Geysers installation if non-condensable gas quantities are not high, normal steam ejectors are used. However, the existence of higher concentrations of entrained gases necessitates the employment of power-driven rotary exhausters which add considerably to both the maintenance and investment costs. Water-jet ejectors are used at the Kamchatka power station, in addition to a single-stage start-up steam ejector and a piston vacuum pump. It is perhaps too early to make valid comparisons between these ejection methods, since performances are subject to improvement in the near future. A comparison of the vacuum pump against steam ejector at Kyushu indicates that the use of the former, under the prevailing conditions, results not only in lower annual operating costs, but in a higher net electrical output capacity.

Economics of operation

Since there is virtually no incremental component in the production costs of geothermal installations, average costs will vary inversely with the quantity of energy produced and, therefore, the load factor. Thus a reduction in load factor for a particular plant will result in a proportionate increase in average costs. It may be possible to utilize the different relative movements of economies of scale in plant cost, and load factor to obtain the most economic over-all operating régime. Under ideal conditions, increases in average costs arising from reduced load factors would be more than offset by economies of scale obtained from the utilization of larger machine sizes. This point of view raises interesting possibilities of operating geothermal plant economically at load factors lower than base load conditions. Theoretically, there should be a minimum economic load factor below which it would not be possible to operate conventional condensing plant economically. However, there is the further possibility of utilizing non-condensing turbines with low unit capital costs for low load factor operation. The degree to which non-condensing generation can be utilized is not only a question of plant cost, since the increased specific steam consumption of this method must be weighed against the desirability of conserving the geothermal heat source.

Current practice appears to be to operate geothermal installations on base load at the highest practical load factors in order to maximize the savings in fuel which would otherwise be used in conventional thermal power stations. In economic comparisons between geothermal and hydro-plants no fuel savings are involved and geothermal stations may therefore have some difficulty in competing with hydro-plants in certain instances.

From information given in several papers, it is apparent that plant availabilities have been good and that many geothermal installations have been able to run at very high load factors. A 90 per cent load factor is reported for Matsukawa, and for Otake factors in excess of 97 per cent over a two-year period are reported. The considerable experience at Larderello has shown that average load factors in excess of 98 per cent were achieved on the majority of installations. The simplicity with which geothermal power stations can be operated, particularly on base load, has focused some attention on the question of automatic control. Plans have been drawn up in Iceland to operate the 3.5 MW geothermal turbine-generator at Namafjall by remote control from a hydro-power station 12 km away. Many of the routine functions of the Kamchatka plant in the USSR are being modified for automatic control, and it is anticipated that this work will be completed in 1970. A 12.5 MW machine at The Geysers is being automatically operated for 16 hours each day.

With regard to normally attended stations, the personnel requirement of the Larderello power station is 1.2 men per installed MW. If all staff concerned with the geothermal production are considered, the figure becomes 1.8 person per MW.

Apart from capital charges, the most significant component of geothermal power production cost arises from plant maintenance. In addition to the usual maintenance associated with the operation of turbo-generators, special costs may arise from circumstances peculiar to geothermal conditions. In this respect, the experience reported from various fields is of considerable interest. Blading deposits occur on turbine blades at Larderello and these necessitate annual cleaning. At Kamchatka, on the other hand, neither corrosion nor blading deposits is reported after 5,000 hours of operation. Experience at Otake has been that siliceous deposits are the principal problem. During the course of the first annual turbine inspection, after 7,100 hours of operation, a slight siliceous deposit was observed on the first stage nozzle. By the time the second annual inspection was carried out, these deposits had begun to affect the turbine blades and, in addition, siliceous deposits had so affected the waste disposal pipeline that power generation had to be restricted. Despite the use of various chemical and mechanical methods it was not possible to remove this deposit from the open duct, and eventually a new one had to be installed to allow full disposal.

Corrosion may be caused by a high concentration of non-condensable gases in the geothermal fluid. At Otake it was found necessary to install a chemical pump for the control of the cooling system pH in order to neutralize the sulphuric acid being produced from sulphur in the entrained gases. In view of the absence of a boiler plant at a geothermal power station, the electrical auxiliary demand for station internal use will be less than that for an equivalent conventional thermal installation. Nevertheless, this percentage is subject to some variations from one field to another in view of differing basic fluid qualities. In these circumstances, the percentage auxiliary consumption is not necessarily the best indication of maximum net electrical output, since an increase in auxiliary consumption may produce a much greater increase in plant output.

Low temperature secondary fluid systems

Most geothermal power stations using water/steam fluids operate on the principle of passing the separated well steam through the high pressure stage of the turbine, then flashing the separated hot water for turbine use in a low pressure stage. The remaining hot water is usually discarded to waste unless a convenient consumer of low grade heat can be found. It is difficult to make any economic use of this large heat source, and unless there are obvious local low-temperature heating applications such as are found for district heating in the USSR and Iceland, a considerable waste takes place.

As a means of overcoming this waste, considerable interest is being shown in the possibilities of utilizing low temperature secondary fluid systems incorporating liquids with low boiling points. Under such an arrangement, the primary geothermal liquid is passed through a suitable heat exchanger where it vaporizes the secondary fluid which then passes as a vapour to an appropriate turbine for the production of power. Having completed its useful work in the turbine, the vapour is condensed to liquid and returned to the heat exchanger to repeat the process continuously. By a judicious choice of secondary fluid, with suitable physical properties, it is technically possible to utilize much heat that would otherwise be rejected as sensible heat in the plant effluent.

The main advantage arising from the use of a secondary system is that more power can be obtained from a given geothermal steam/water mixture. This, in turn, results in capital cost savings arising from the need for fewer wells to provide a given power output. The reduced requirement for primary fluid also reduces the problems associated with liquid effluent disposal. Apart from the technical advantages which it offers in the exploitation of two phase wells, the use of a secondary cycle allows power to be produced in fields where only hot water can be obtained at temperatures so low that a steam cycle is uneconomic. There is also an advantage in using a secondary cycle when the raw geothermal fluid is very corrosive.

Work on secondary systems has been carried out in the USSR, where the use of Freon 12 was compared with a conventional steam system for use at the Pauzhetka power station. From this comparison, it was found that both systems were approximately equal economically, although the employment of Freon would have involved a larger and more complicated installation with more difficult maintenance problems. It was eventually decided to design the power station using geothermal steam in view of the greater mechanical simplicity of this approach. Despite this, it is possible that secondary low temperature cycles may offer considerable promise for the future, although it may be necessary to find cheaper and more suitable fluids. In this connexion, it has been reported that a secondary cycle geothermal power station will be built in Nevada using iso-butane as the working fluid.

A small pilot secondary cycle plant, in operation in the Kamchatka area of the USSR, utilizes Freon 12 as a secondary fluid and is designed for a geothermal water temperature of 90°C. Although the plant has only been tested for 200 hours, indications are that the designed electrical output of 680 kW will be attained consistently. The greatest problem encountered with the project was the design of an industrial-size turbine to operate on a Freon cycle. Such experience as has become available during the initial period of operation indicates that turbine nozzle and blade erosion has been experienced due to small foreign bodies entrapped in the secondary fluid system and also the impingement of droplets of liquid Freon.

Pollution problems

The rising level of interest being focused on environmental pollution in various parts of the world is of significance in geothermal development. Air pollution arises if gases such as hydrogen sulphide are released into the air, and additional costs may be incurred in providing adequate means for their disposal. Since geothermal development is not at present carried out in close proximity to large centres of population, air pollution does not appear to be a major problem but unfortunately the same cannot be said about the disposal of geothermal water, which generally contains salt and may contain such chemicals as arsenic, fluorine and boron, as well as other mineral compounds leached out of underground deposits.

Where a geothermal power station is situated close to the sea, effluent disposal usually presents no problem, but where disposal takes place into a river important questions of both chemical and thermal pollution may arise. Unfortunately, although some minerals found in geothermal effluents, do not occur in high concentrations, their deleterious effect is significant even in small quantities. Boron, for example, can have harmful consequences to plant life in concentrations as low as 2 parts per million. This single factor alone can cause considerable extra expenditure on the design and installation of an adequate disposal system.

During the course of a recent geothermal development project in South America, plans were made to dispose of effluent into a nearby river. It was calculated that sufficient dilution would take place during the wet season to render the effluent contaminants harmless. However, it was found that during the dry season the boron concentration might have risen to unsafe levels exceeding plant tolerances. In this particular instance the river water was used for irrigation many miles down-stream of the geothermal site and this fact entailed the finding of an alternative method of effluent disposal. This example illustrates difficulties which may arise with effluent disposal despite the availability of a convenient river.

In some geothermal areas where no alternative method of disposal is available reinjection must be considered. This solution is costly, involving as it does the drilling of extra wells and possibly the use of additional power for pumping purposes. Furthermore, much still remains to be learned about the technique, particularly concerning the possibility of mineral deposition from the reinjected fluid occurring in the reception formations. The need to achieve temperature compatibility between the effluent and the reception formation will also pose difficult geological problems in the choice of well sites.

Effluent from the Otake development is led through an underground pipeline to the storage reservoir of a hydro-power station. This not only avoids both chemical and thermal pollution of an adjacent river, but also allows the potential energy of the liquid effluent to be utilized in the turbines.

Hot water systems

Developments in the exploitation of geothermal liquids which are not hot enough to be used economically for power production are reported from Japan where fruit, vegetables and flowers are produced in hot houses for the Tokyo market. In addition, geothermal heat is used in the breeding of eels, alligators and poultry.

In Hungary, geothermal water is used for district heating, industrial heating and animal husbandry. Hungary operates some eighty hot-water wells, each producing an average of 80-90 cubic metres per hour at approximately 85°C. The heating loads tend to be seasonal, although attempts have been made to try to improve load factors by the promotion of summer agricultural drying applications. The use of geothermal heating is expected to double in the next six to eight years and the present hothouse area of 400,000 square metres will be doubled by the end of 1970. With regard to district heating it was estimated that a geothermal scheme involves only 30 per cent of the cost of an equivalent coal-fired installation.

Hot water is found in over 20 per cent of USSR territory, although the present explored potential only amounts to 1 per cent. This paper covers district heating applications and also the possible utilization of absorption refrigeration machines, not only for summer air conditioning, but also for industrial use. The authors estimate that during 1970 the total fuel cost saving arising from the use of hot geothermal waters will be approximately $1,000,000 rising to $10,000,000 by 1980.

In the Makhachkala area, animal husbandry, horticultural and domestic uses are contemplated for geothermal hot water. In addition, the future large-scale use of soil warming and mine heating is foreseen to allow the exploitation of mineral resources all the year round in those regions subject to long and severe winters.

Using annual heating demand duration curves, Soviet specialists have investigated the possibilities of using geothermal water for district heating in conjunction with peaking boilers. They have stressed the importance of seasonal demands on the over-all geothermal load factor and also have indicated the limitations which apply to the direct use for heating of the cooler waters. To overcome the low temperature disadvantage of these less hot geothermal waters, it is suggested that heat pumps might be used for heating in winter and cooling in summer.

Multi-purpose installations

The large quantities of low-grade heat, rejected as hot water from the separators of geothermal power stations using steam/water fluids, have attracted much attention. This has resulted in the design of multi-purpose installations using as much heat as possible from both the steam and water phases with a view to achieving the greatest over-all economy. It is calculated that the hot water now wasted at Wairakei could provide central heating for a city of half a million people. Such multi-purpose uses are few, since in some geothermal fields there are no prospective heat consumers located within easy reach of the power station. However, in cooler climates, where opportunities have presented themselves for hothouse and domestic heating, some attention has been given to multi-purpose use. Such a system is in operation at Pauzhetka in the USSR; eventually Paujetsk power station will supply water at 110°C to 80,000 square metres of hot-houses as well as a domestic heating load. The Namafjall development in Iceland, in addition to generating electric power, supplies steam to a diatomite-drying plant and also supplies hot water to a local district heating scheme. In spite of this high degree of usage, it is estimated that only 16.5 per cent of the heat in the geothermal fluid is being utilized.

Up to the present time, little appears to have been achieved with regard to the extraction of minerals from waste geothermal brines. Any financial advantages arising from such a system could help to offset additional costs which might be occasioned by the increasing difficulties of effluent disposal. A small geothermal salt-production installation at Hokkaido in Japan has an annual output of 150 tons. Plans are in hand for constructing a new multi-purpose plant which would have a 7 MW electrical capacity, produce 100,000 tons of salt annually and also fresh water from an effluent evaporation installation.

Most geothermal waters contain many minerals, some of which cause severe effluent disposal problems. A multi-purpose approach to future geothermal planning and development may discover that some of these minerals are capable of economic use when viewed within the context of over-all resource exploitation. No generalizations can be made since each location must be judged on its own individual circumstances which embrace steam conditions, water mineral concentrations, local demands for both water and minerals, together with basic economic data such as interest rates and labour productivity. Nevertheless, the multi-purpose approach to the utilization of geothermal energy resources will probably be more prevalent in the future, bringing with it substantial over-all gains.

Papers submitted to the United Nations Symposium on the Development and Utilization of Geothermal Resources, held at Pisa, Italy, 1970

Armstead, H. C. H., "Geothermal power for non-base load purposes".

Boldizsar, T., "Geothermal energy production from porous sediments in Hungary".

Bondarenko, S., B. Mavritsky and L. Polubotko, "Methods for exploration of thermal waters and geological-commercial assessment of their deposits".

Hayashida, T., "Cost analysis on the geothermal power".

Hayashida, T. and Y. Ezima, "Development of Otake geothermal field".

James, R., (*a*) "The economics of the small geothermal power station".

James, R., (*b*) "Power station strategy".

Jones, P. H., "Geothermal resources of the northern Gulf of Mexico basin".

Kaufman, A., "The economics of geothermal power in the United States".

Komagata, S., H. Iga, H. Nakamura and Y. Minohara, "The status of geothermal utilization in Japan".

Kremnjov, O., V. Zhuravlenko and A. Shurtshkov, "Technical-economical estimation of geothermal sources".

Leardini, T., "Economie de l'énergie géothermique".

Makarenko, F., B. Mavritsky, B. Lokshin and V. Kononov, "Geothermal resources of the USSR and prospects of their practical use".

McMillan, D., "Economics of The Geysers geothermal field, California".

Mori, Y., "Exploitation of Matsukaya geothermal area".

Nakamura, S., "Economics of geothermal electric power generation at Matsukawa".

Naymanov, O., "A pilot-commercial power station in Pauzhetka, Kamchatka".

Ragnars, K., K. Saemundsson, S. Benediktsson and S. Einarsson, "Development of the Namafjall area, northern Iceland".

Tikhonov, A. and I. Dvorov, "Development of research and utilization of geothermal resources in the USSR".

SUMMARY — RESUME — RESUMEN

Economics of geothermal power development: *J. J. C. Bradbury*

The article discusses the basic factors involved in assessing the costs of the different phases associated with exploration for and development of geothermal energy resources. Following the discussion of general principles, figures are quoted for initial geothermal exploration, and the cost associated with drilling operations in many parts of the world is considered.

The question of fluid transmission is discussed with particular reference to experience gained in Iceland, Japan, New Zealand and the United States of America. The author then reviews the constituent elements which make up the total cost of steam delivered at the power-station site. Under this heading is considered the subject of the amortization period for various capital equipment.

Turning to a discussion of the optimum operating steam conditions, details are given of calculations based upon considerable experience obtained in the Waraikei field in New Zealand. In the section on over-all generating costs, attention is drawn to the different amortization periods adopted at various geothermal sites in respect of steam turbines and generating equipment. Experience is also quoted on the over-all capital cost per kilowatt installed for different

geothermal developments. The section on the economics of operation covers such factors as the influence of load factor on cost, the utilization of non-condensing plant, power-station availabilities and problems of plant maintenance arising from corrosion and silica deposition.

In referring to the importance of low-temperature hot-water fields, mention is made of low-temperature secondary fluid power systems as a means of exploiting this energy. With regard to the subject of pollution, attention is drawn to some difficulties that have arisen concerning undesirable minerals found in the geothermal fluids. After mentioning several applications of hot water geothermal fields for heating purposes, the article concludes with a summary of past experience concerning multipurpose geothermal installations and assessment of the way in which these developments may proceed in the future.

Economie de la mise en valeur de l'énergie géothermique: *J. J. C. Bradbury*

L'auteur expose les principaux facteurs à retenir pour évaluer le coût des différentes phases de l'exploration et de la mise en valeur des ressources en énergie géothermique. Après avoir passé en revue les principes généraux, il cite des chiffres au sujet de la prospection préliminaire des champs géothermiques et examine le coût des opérations de forage dans de nombreuses parties du monde.

Il étudie la question du transport des fluides compte tenu en particulier de l'expérience acquise aux Etats-Unis d'Amérique, en Islande, au Japon et en Nouvelle-Zélande. Il analyse ensuite les divers éléments du prix de revient total de la vapeur livrée aux centrales. Sous cette rubrique, il étudie la durée d'amortissement des différents équipements.

Examinant ensuite la question des caractéristiques optimales de la vapeur aux fins de l'exploitation, il présente des calculs détaillés, fondés sur l'expérience considérable qui a été accumulée à Waraikei, en Nouvelle-Zélande. Dans la partie consacrée au coût global de la production d'électricité, il fait observer que différentes durées d'amortissement ont été adoptées en différents lieux d'exploitation pour les turbines à vapeur et les alternateurs. Il mentionne aussi des données d'expérience concernant le coût total des centrales par kilowatt installé pour différentes installations géothermiques. Dans la partie qui traite des aspects économiques de l'exploitation, il passe en revue l'influence du facteur de charge sur le coût, l'utilisation d'installations ne comportant pas de condenseur, la question de l'existence de centrales électriques, les problèmes d'entretien dus à la corrosion et aux dépôts de silice, etc.

Evoquant l'importance des champs géothermiques d'eau à température relativement basse, l'auteur indique qu'il est possible d'exploiter ce type d'énergie au moyen de centrales à fluide secondaire à basse température. En ce qui concerne la pollution, il signale quelques difficultés imputables à la présence de certains minéraux dans les fluides géothermiques. Après avoir parlé de différents modes d'utilisation des champs géothermiques d'eau chaude aux fins du chauffage, il conclut en récapitulant l'expérience acquise dans le domaine des installations géothermiques à fins multiples et en envisageant l'évolution possible à cet égard.

Aspectos económicos del aprovechamiento de la energía geotérmica: *J. J. C. Bradbury*

En el presente artículo se examinan los factores básicos que se deben tener en cuenta al estimar los costos de las diversas fases de la exploración y aprovechamiento de la energía geotérmica. Después de analizar los principios generales se dan cifras para las actividades iniciales de exploración de recursos geotérmicos y se examinan los costos de las operaciones de perforación en muchas partes del mundo.

Se estudia el problema de la transmisión de fluidos con especial referencia a la experiencia adquirida en los Estados Unidos, Islandia, Japón y Nueva Zelandia. Después el autor pasa revista a los elementos constitutivos del costo total del vapor puesto en la central eléctrica. Bajo el mismo epígrafe se examina la cuestión del plazo de amortización del equipo de capital.

En el análisis de las condiciones óptimas de funcionamiento del suministro de vapor se dan detalles de los cálculos que se han hecho sobre la base de la considerable experiencia acumulada en las operaciones del campo de Waraikei en Nueva Zelandia. En la sección relativa a los gastos generales de generación se señalan a la atención los diversos períodos de amortización de las turbinas y del equipo de generación que se han adoptado en los varios campos geotérmicos, y se citan cifras sobre los gastos generales de capital por kW instalado. La sección correspondiente a los aspectos económicos de la operación de centrales geotérmicas trata de elementos tales como la influencia del factor de carga sobre el costo, la utilización de plantas de escape al aire libre, la existencia de centrales eléctricas y los problemas de conservación causados por la corrosión y los depósitos de sílice.

Al analizar la importancia de los campos de aguas geotérmicas a baja temperatura, se mencionan los sistemas de los fluidos secundarios de baja temperatura con el fin de explotar la energía en ellos contenida. Al examinar los problemas de contaminación, se señalan las dificultades que han surgido en cuanto a la eliminación de minerales indeseables que se encuentran mezclados con los fluidos geotérmicos. El artículo concluye con un examen del uso de campos geotérmicos para calefacción, un resumen de la experiencia acumulada en materia de instalaciones geotérmicas de fines múltiples y una evaluación del desarrollo probable de esos usos múltiples.

MULTIPURPOSE EXPLORATION AND DEVELOPMENT OF GEOTHERMAL RESOURCES

by Joseph BARNEA

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This article is based on an address delivered before the Symposium on the Development and Utilization of Geothermal Resources, held at Pisa, Italy, 22 September to 1 October 1970

It is now recognized that geothermal resources have vast economic significance, apart from their value in the protection of man's environment. Certain characteristics distinguish them from other natural resources and to some extent make them superior. For example, if we may categorize the most important groups of natural resources as water, energy, and mineral resources, we note that geothermal resources may contain elements of all of them.

Many natural resources serve more than one purpose. Petroleum and coal are used not only for their energy content but as raw materials for the chemical industry; in the future it is possible they might both be useful as a source of protein. However, their main use is as energy sources. Among conventional sources of energy, water, particularly the water of rivers, has the broadest multipurpose application. It was in river basins that the concept of multipurpose development was created, when it was realized that a river could have a variety of uses and that a dam controlling a river might have a variety of functions such as flood control, electric power generation, irrigation and improvement of navigation. In time, it became obvious that the single-purpose development of a river frequently was less attractive economically than multipurpose development. Once it was understood that a river could be developed for several purposes simultaneously, the customary planning of river basin development changed; it is now accepted that the first reconnaissance of a river basin cannot rest with the hydrologist alone, but that a broad approach, taking into consideration all the needs in the river basin, must be the basis even of the earliest survey.[1]

Out of the need to recognize at an early stage the many problems and opportunities in river-basin development arose new professional occupations: the river-basin planner, the water resources planner and the water economist. These people needed to know enough of the technology and economics of every aspect involved, to enable them to assist in the multipurpose programming of a river-basin development. The river-basin generalist, or river-basin planner, has to give leadership and direction to the team of specialists which he leads and he must make certain that multipurpose development is carried out in the best possible way.

In geothermal energy, we are at present at the same stage as was the case of river-basin development more than one hundred years ago: all major geothermal fields today are operated for one purpose only. However, we are coming to recognize that even more than in river-basin development, possibilities exist for multipurpose application. There were presented to the United Nations Symposium on the Development and Utilization of Geothermal Resources numerous papers showing that schemes for dual and triple purpose use are in the thinking and planning stage, and an even greater number of applications are envisioned. We can confidently predict that in the 1970s a change will be seen from single-purpose to multipurpose development.

When we glance quickly at the most important applications of geothermal energy that either exist or are being planned, we encounter this resource used for electricity production, desalination, medical purposes, house and hotel heating, the heating of greenhouses and mineral production. It can therefore be stated that in geothermal resources there is a broader potential for multipurpose application than is the case for other natural resources.

Another feature useful to note is that, with proper management, a geothermal resource lasts for a very long time and may, in fact, have the permanency of a river basin. This is an attractive feature because resources of fuels and minerals have a definite, limited life which comes to an end when the deposit is mined out, after which new resources must be sought. Geothermal energy, on the other hand, is a resource which may have a very long life, and this special economic feature therefore deserves special study.

In attempting to explain the broad and attractive multipurpose exploitation of geothermal energy, we are unfortunately faced with the fact that there are no geothermal generalists. The papers read before the Symposium implied that what we have today are specialists, and it is likely that very often no communication exists between the specialists. So far as I am aware, communication does not take place between the geothermal geochemist who analyses the water in the course of projects for electricity production and the chemist who analyses the water for possible medical or tourist use. The time has come to face the problem and to recognize the need for the geothermal generalist, or the geothermal resources economist, who, like the water resources planner, would possess wide knowledge of all the possible techniques and applications and who

[1] *Integrated River Basin Development* (United Nations publication, Sales No.: E.70.II.A.4).

would act as team leader at each stage of geothermal development, from exploration to operation.

In other new fields, where similar problems exist, they are handled by putting together interdisciplinary teams of specialists so that, on a given problem, a variety of technical competencies and economic experience can be brought to bear. It is possible that, in the immediate future, in the absence of geothermal specialists, we shall have interdisciplinary teams for geothermal reconnaissance exploration, planning and operation.

It is therefore the concern of all of us to consider how to produce the generalist who will be needed increasingly as geothermal development expands. Eventually a few specialists will become generalists through experience in the field; but this may not be soon enough, and Governments, companies or universities able to afford it may have to provide opportunities for selected people to work or to observe the work of the geothermal industry in order to obtain, in time, the geothermal generalist. What would be well to avoid is that universities should begin to train generalists long after they are needed, as was the case, for example, with water resources planning generalists a generation ago.

The multipurpose approach, then, is a necessity, applied at every stage of development from the first reconnaissance to the management of the reservoir. That this point of view is shared by others was clearly brought out in a paper submitted to the Symposium by the Union Research Institute of Hydrogeology and Engineering Geology, Moscow.[2] The authors state that the consideration described above necessitates a complex assessment of thermal water deposits, taking into account the technical and commercial facts relating to the extraction and utilization of thermal waters in specific conditions and regions:

> "Up till the present moment, the deposits of thermal waters from the viewpoint of their utilization have been mainly assessed taking into account their hydrogeological, thermodynamic and power generation aspects. Unfortunately, investigations conducted in this field did not deal sufficiently with the problems relating to the economics of reconnoitring, prospecting and utilization of thermal water deposits, though the geological-economic analysis should be regarded as one of the main elements of geological prospecting and primarily aimed at establishing their relative significance for the people's economy and priority of commercial development."

It is further stated:

> "The geological-economic assessment at the stage of preliminary prospecting of a thermal water deposit should concentrate on the solution of problems relating to the expediency of its development.
>
> "The geological-economic assessment based on the data of preliminary prospecting should characterize the future raw material base. It should elucidate the natural and economic factors, which are of great importance for selecting a variant of the deposit development, and contain an analysis of the effect of these factors on the selection of the main technological solutions. On the basis of all the results obtained from the preliminary prospecting, the technical-economic substantiations or reports (TES or TER) are compiled. These reflect the economic expediency and establish the priority of commercial development of the given deposit."

Finally, the authors are of the opinion that when the decision-making for detailed prospecting is done, an interdisciplinary team should be involved in decision-making:

> "The geological-economic assessment carried out at the stage of detailed prospecting is very significant as it determines the future of the deposit. That is why it should be accomplished by a number of specialists, viz. hydrogeologists, economists, experts in heat engineering and power generation, agronomists, balneologists etc."

It is an obvious comment that the usage in the USSR and other areas with colder climates of hot water for heating houses and hospitals, in district heating and in greenhouses, may have only a limited relevance, in warmer areas, whereas, in desert and semi-arid areas, the use of geothermal fluids as a source of water might be much more important. If climatic and other local conditions are taken into account in determining the composition of the interdisciplinary teams, their cost can be minimized.

The multipurpose approach is relevant not only in the final investment decision but (as was recognized in the paper quoted) in the first exploration stage. In this stage, three groups of problems have to be analysed and the exploration programme should supply information relating to (*a*) geology, water, gases; (*b*) needs and opportunities in the area; and (*c*) the possible effect of geothermal resource development on the water resources in the area and on the human environment.

In each of the three groups, there are many questions which will have to be worked out in detail, and it is to be hoped that the United Nations will one day develop a programme of geothermal exploration which will take into account all the items that have to be studied in a multipurpose geothermal exploration programme. For the present, one item may be singled out for more detailed discussion; that is water, included in category (*a*).

Chemical analyses of geothermal water samples should be examined in relation to several different factors, for example geothermal-geologic information; possible economic significance of the trace metals and other minerals contained in the water; use of the water for possible geothermal desalination; use of the water for balneological purposes; content of elements which might be detrimental to the environment (such as boron and arsenic); and the effect of possible geothermal development on the water régime of the region.

At present, most of the information provided by the geothermal geochemist is designed to answer only the first question, namely, whether we can estimate from the water sample the temperature and steam conditions of the geothermal resource for power production, However, complete water analysis should provide answers to the other questions also; the approach in exploration from the beginning should be the maximization of information, so that in the final planning no

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[2] S. S. Bondarenko, B. F. Mavritsky and L. F. Polubotko, "Methods for exploration of thermal waters and geological-commercial assessment of their deposits".

important problem connected with the geothermal potential has been overlooked.

With the rapid improvement in geothermal technology, it is important too that the latest technological advances be taken into account in the planning stage. Three of these advances were mentioned in the Symposium. The first is that active research and development are now in progress towards the use of hot water, not steam alone, for power production, by means of heat exchangers. This technology will come into general use very soon and should be taken into account in the exploration planning stage so that, where appropriate, power planning should not be restricted to the steam element only in a wet steam field.

The second advance is that minerals in geothermal waters have been found to have possible economic significance, and it is necessary, therefore, to analyse geothermal waters for trace metals and other minerals. The third case concerns the fact that hot water may be used for air-conditioning—a matter of significance in hot climates. Among the papers read before the Symposium, it was interesting to hear from the USSR and New Zealand that lithium bromide absorption machines have been developed to operate on geothermal water and that they are now being mass-produced in the USSR. However, the USSR paper provides no economic data on this subject.[3]

After the exploration has been carried out, decisions must be made for development of the resource, and, here again, a multipurpose approach designed to obtain the best economic results is vital. Often the sequence in which the geothermal resources is used is of great economic significance. A Japanese paper described how hot water was used first in a hospital, after which it was still sufficiently hot to be used for house heating. In the United Nations geothermal project in Chile, a certain procedure has been provisionally developed for the exploitation of the El Tatio field. First, the hot water-steam mixture from the wells is run through a separator, where the steam is separated for power use while the hot water is directed to a desalination plant to be transformed into fresh water, the salts and minerals being concentrated fourfold. This concentrated brine will then be pumped to a mineral processing plant where the valuable minerals will be extracted. As the hot water reaching the desalination plant will be hot enough for desalination, we shall have a desalination plant operating with no thermal energy input; as a result, this plant will produce desalinated water at a relatively low cost in a desert area where alternative supplies of water are more expensive. By concentrating the minerals fourfold through desalination at no cost, the mineral extraction becomes more economically attractive. This is an example of the significance of multipurpose planning, which is possible only after the full range of relevant information is collected.

We are now in a position to classify, to some extent, the possible multipurpose uses of geothermal energy and it can be stated that the following systems either exist or will come in existence during the 1970s:

(*a*) Single-purpose use of geothermal resources, for example for power generation alone, for medical use alone or in house-heating alone. Another kind of single-purpose use might be where one part of the resource is used for one purpose and the other part for another, similar, purpose: thus, if part of the hot water were used for public baths and another part for hotel heating, we would still have a single-purpose use, although the specific applications differ. We might, therefore, define this classification as the case of geothermal resources being used for several single-purpose applications;

(*b*) Dual-purpose application such as power production and desalination; or the sequential use of hot water, first for one purpose and then for another, when the same hot water is used for greenhouses and afterwards for swimming pools;

(*c*) Triple-purpose use, as in the case of the Chilean geothermal project mentioned above and other cases described in some papers, especially from Japan.

It is likely that the 1970s will also witness geothermal projects where the geothermal resource will be used for four or more purposes; certainly, we can depend on the ingenuity of our geothermal resources planners and on their ability to develop geothermal projects of many new varieties, basing their decisions on a full understanding of local needs and opportunities. As development tends more and more to become multipurpose in character, the economics of such projects will become more complex, both as to calculation and allocation of costs among the various end-products. We shall have a lot to learn from the economics of multipurpose river basin development, and we must apply the principle that the alternative cost of every single end-product should be cheaper in the multipurpose project than the product obtainable from a non-geothermal resource or from a single-purpose geothermal project.

This has been a very compressed discussion of the multipurpose approach of geothermal exploration within the concept of geothermal technology, but if one may dream a little and look further afield into the future, it can be supposed that geothermal resources will play an increasing role, and that considering the relationship that exists between geothermal resources and water resources, new and more complex relationships can be expected to develop. At the Symposium, it was learned (what was not brought out in the United Nations Conference on new sources of energy, held in Rome in 1961) that the future of a geothermal field may depend on the re-charge of water and on the hydrogeological conditions of the region. It might be possible one day to use brackish water as a re-charge for a geothermal field, thereby perhaps increasing the potential of the geothermal areas and making use of water which, in that area, has not found economic use. The United Nations, in the El Salvador project, is now trying for the first time to establish the technology of re-charge in a geothermal field, and it is hoped that once these techniques are established, low-quality water might be utilized for such purposes.

Today, in many countries, pump storage schemes are being developed whereby, using off-peak power of a thermal power system, water is pumped up a hill to be released and the power used during the hours of peak demand on the electricity system. Perhaps one day it will be found cheaper to let the boilers run in a

[3] A. M. Tikhonov and I. M. Dvorov, "Development of research and utilization of geothermal resources in the USSR".

thermal power station, using the hot water and steam to re-charge a geothermal field rather than using the steam to produce electricity for pumping water up a hill.

These are a few ideas for the distant future; there are many others and these have been brought forward only to demonstrate that the range of applications of geothermal resources will grow steadily in the future. The tempo and range of these multipurpose applications will depend on the ingenuity and broadmindedness of the small group of people who study and develop geothermal resources. It is on them—in fact it is on ourselves—that the multipurpose development of geothermal resources will depend.

SUMMARY — RESUME — RESUMEN

Multipurpose exploration and development of geothermal resources: *Joseph Barnea*

Given the economic importance of geothermal resources and their significance from the point of view of the human environment, as well as the fact that in their nature they contain elements of water, mineral and energy resources, it is important to consider all the possible economic uses of geothermal energy in order to obtain the maximum benefit from its utilization, as in the case of the integrated development of river basins.

A multipurpose approach should be made to the development of geothermal resources, from the very earliest stage of reconnaissance to that of reservoir management. Such an approach calls for generalists who are abreast of the latest technological developments and who are capable of maintaining an integrated approach to the decision-making process at all stages of exploration and development, keeping in mind the potential uses to which these resources can be put under specific conditions.

At the present time one can think of geothermal resources as having (*a*) a single-purpose use whether it be for power production alone or house-heating alone; (*b*) dual purpose use such as the association of power production with desalination; and (*c*) triple-purpose application, as in the UNDP project in Chile, where the United Nations, as the executing agency, is developing a procedure for the recovery of valuable minerals from geothermal brines as a result of a prior use of the geothermal waters for power production and desalination. In the 1970s, however, one may expect four and more uses of a single resource to come about, with a concomitant development of new and more complex relationships.

Recherche et mise en valeur des ressources géothermiques : *Joseph Barnea*

Etant donné l'importance économique des ressources géothermiques, leur intérêt du point de vue de l'environnement humain et le fait que ces ressources, par leur nature, contiennent des éléments de ressources hydrauliques, minérales et énergétiques, il importe d'en considérer toutes les utilisations économiques possibles afin d'en tirer des avantages maximums, comme c'est le cas dans la mise en valeur intégrée des bassins fluviaux.

Les ressources géothermiques doivent être envisagées d'un point de vue polyvalent, depuis le stade de la prospection jusqu'à celui de la gestion du réservoir. Un tel point de vue exige des généralistes au courant des derniers progrès de la technique et capables de conserver cette approche intégrée dans le cours des décisions à prendre à tous les stades de la recherche et de la mise en valeur des ressources géothermiques, en ayant présentes à l'esprit les différentes utilisations possibles de ces ressources dans des conditions déterminées. A l'heure actuelle, les ressources géothermiques sont utilisées tantôt à une fin unique, que ce soit la production d'énergie ou le chauffage domestique, tantôt à une double fin, comme dans le cas où la production d'énergie est associée au dessalement, tantôt à une triple fin, comme dans le cas du projet du PNUD au Chili, où l'Organisation des Nations Unies, en tant qu'organisation chargée de l'exécution, met au point une méthode de récupération des minerais utiles à partir de saumures géothermiques à la suite de l'utilisation des eaux géothermiques pour la production d'énergie et le dessalement. Mais on peut s'attendre que dans les années 70 une seule ressource fera l'objet de quatre utilisations et plus, tandis que s'établiront des relations nouvelles et plus complexes.

Prospección y aprovechamiento de recursos geotérmicos con fines múltiples: *Joseph Barnea*

Dada la importancia económica de los recursos geotérmicos, y su importancia desde el punto de vista del ambiente humano, así como el hecho de que los recursos geotérmicos, por su naturaleza, contengan elementos de agua, recursos minerales y energéticos, es importante considerar todos los posibles usos económicos de este recurso, para obtener máximos beneficios de su utilización, como en el caso del desarrollo integrado de las cuencas fluviales.

Se debe emplear un enfoque de fines múltiples para los recursos geotérmicos desde la misma etapa de reconocimiento hasta la administración del yacimiento. Tal enfoque exige especialistas que estén al corriente de los últimos cambios tecnológicos y que sean capaces de mantener un enfoque integral en los momentos decisivos de todas las etapas de la exploración y el desarrollo de los recursos geotérmicos, teniendo presentes los usos potenciales que pueden hacerse de estos recursos bajo condiciones específicas.

En estos momentos se puede pensar en utilizar los recursos geotérmicos con un solo fin, ya sea solamente para producción de energía o solamente para calefacción; con un doble fin, como la asociación de la producción energética con la desalación; y en aplicaciones con tres fines, como en el proyecto del PNUD en Chile, donde las Naciones Unidas, como organismo de ejecución, están ideando un procedimiento para recuperar minerales valiosos de las aguas salobres geotérmicas como resultado del uso anterior de aguas geotérmicas para la producción de energía y desalación. En el decenio de 1970 se pueden esperar, sin embargo, cuatro usos y más de un solo recurso, con el desarrollo concomitante de relaciones nuevas y más complejas.

L'INFORMATIQUE GEOLOGIQUE

par P. LAFFITTE

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L'utilisation massive des ordinateurs modifie les méthodes de travail de tous les secteurs de l'activité humaine. Pour les géologues et mineurs chargés d'inventorier et de mettre en valeur les ressources minérales de la planète, il importe, plus encore que pour d'autres catégories d'hommes, de bien connaître les possibilités nouvelles qui leur sont offertes, pour pouvoir en particulier :

a) Utiliser dans de bonnes conditions les ordinateurs; employer des méthodes de travail qui économisent le temps des spécialistes; savoir que certaines études, auparavant jugées impossibles parce que trop longues ou fastidieuses, deviennent très rapides et faciles;

b) Critiquer valablement les conclusions de travaux basées sur une utilisation incorrecte des techniques informatiques;

c) Prévoir l'évolution à court terme des possibilités nouvelles de l'informatique de façon à orienter leurs travaux vers des thèmes nouveaux;

d) Faire évoluer, si possible, les techniques de l'informatique pour qu'elles s'adaptent mieux aux besoins spécifiques de leur propre branche.

Avant d'analyser le champ d'action et quelques possibilités d'utilisation de l'informatique géologique, donnons quelques explications très brèves sur les processus de stockage d'information en ordinateur.

Comment enregistre-t-on une donnée dans un ordinateur?

Rappelons qu'en informatique on utilise la notion d'unité d'information élémentaire ou bit. Le bit correspond à une information simple: la réponse à une question qui se résout en une alternative (non ou oui) ou en langage binaire (0 ou 1). La combinaison de deux bits donne quatre possibilités de réponse : 1 et 1; 1 et 0; 0 et 1; 0 et 0. La combinaison de huit bits qui est parfois appelée un byte ou un octet ouvre 256 (2 à la puissance 8) possibilités. Un octet permet donc de représenter un caractère (lettre ou chiffre) alphanumérique avec facilité.

Une succession d'octets permet de représenter un mot ou une phrase.

Les ordinateurs sont des systèmes complexes comportant en particulier des mémoires. Certaines mémoires sont dites externes et peuvent se présenter sous forme de bandes ou disques magnétiques. Les mémoires internes sont des "unités de mémoire à ferrites". Chaque unité de mémoire est susceptible d'être aimantée dans un sens ou dans le sens contraire; il suffit de lier la notion 0 à un sens d'aimantation et la notion 1 au sens contraire pour lui faire supporter un bit d'information. Un groupe de huit ferrites (ou octet) supporte donc la représentation d'un caractère alphanumérique. Une succession d'octets permet de stocker en mémoire un mot ou une phrase.

La position des octets — ou des mots formés par des successions d'octets — est définie par leur adresse.

Une structure complexe de connexions permet d'effectuer des opérations diverses, de nature arithmétique ou logique, sur les unités d'information stockées. Les opérations, ou groupes d'opérations, sont réalisées à la suite d'instructions, qui sont souvent groupées en programmes. Une partie de ces programmes est introduite de façon comparable à l'introduction des données. Une partie peut être stockée dans des mémoires annexes de l'ordinateur. Une partie peut même être prévue par le constructeur de l'appareil (instructions câblées).

Par opposition au matériel — le *hardware* ou quincaillerie — l'ensemble des programmes constitue ce que l'on appelle souvent le *software*.

A. — CHAMP D'ACTION DE L'INFORMATIQUE GÉOLOGIQUE

Dans tout travail de recherche utilisant les ordinateurs, on peut distinguer les phases suivantes :

a) Enoncé des objectifs de la recherche et détermination des étapes de la recherche pour lesquelles l'informatique est nécessaire et le passage sur ordinateur utile,

b) Détermination des données à rassembler et du caractère des traitements machine à leur faire subir;

c) Recherche des possibilités d'utiliser les "connaissances" déjà formalisées et rassemblées dans les mémoires du système de traitement (stock de données, programmes, contrôles, etc.);

d) Etude des principes de formalisation des données à traiter; formalisation des traitements à faire subir à ces données;

e) Rassemblement des données à traiter (y compris les programmes d'utilisation du stock des connaissances antérieures);

f) Etablissement des documents d'entrée en mémoire des données en langage formalisé (fiches, bandes, etc.), rédaction du programme de stockage et des programmes de traitement;

g) Traitement machine. Contrôle. Corrections;

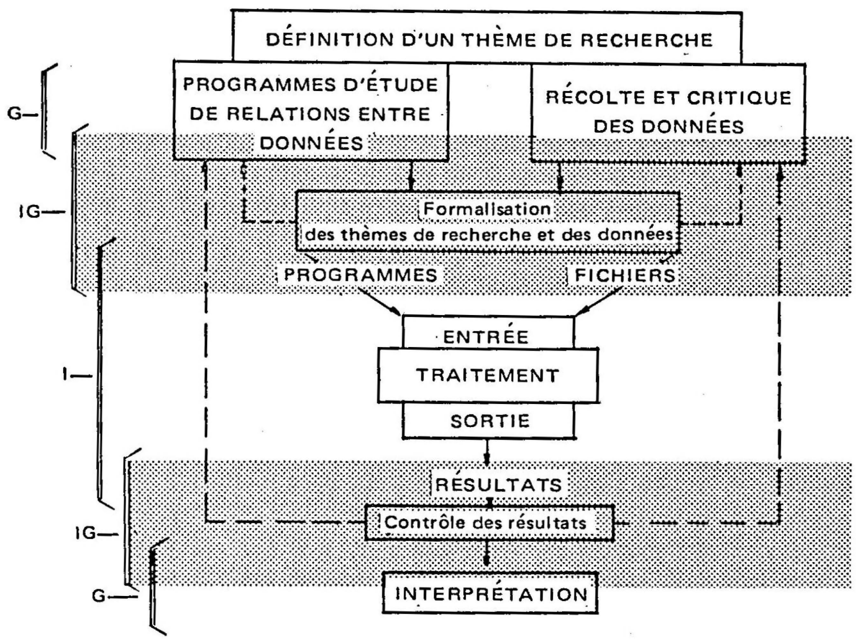
h) Etude des résultats. Conclusions provisoires. Modifications des traitements;

i) Nouveaux traitements. Contrôle. Corrections;

j) Conclusions finales (ou retour à *h*).

Il est à noter dans cette succession de phases un point évident qu'il n'est pas inutile de rappeler : aucun ordinateur, si perfectionné soit-il, ne peut remplacer les géologues dans l'énoncé des programmes d'études géologiques, le rassemblement des données sur lesquelles seront basées ces études, la critique et l'interprétation des résultats. Une autre observation mérite d'être soulignée : l'essentiel du travail des spécialistes d'informatique géologique réside dans les deux points suivants : *a*) l'étude critique de la possibilité et de l'intérêt de faire subir certains traitements à certaines données, et *b*) la formalisation des données et des programmes.

Dans le cas où l'on peut distinguer nettement des données et des programmes, ce qui est le cas des traitements de fichiers ou files, le schéma ci-dessous montre assez bien les domaines qui relèvent de la spécialité informatique géologique.



G = Domaine du géologue

IG = Domaine du spécialiste d'informatique géologique

I = Domaine du spécialiste de l'informatique

B. — Types de problèmes abordés par l'informatique géologique

En information géologique, on est assez vite conduit à différencier les données selon leurs caractéristiques et les programmes d'études selon leurs objectifs principaux. D'autre part, on a décelé l'intérêt de combiner l'utilisation de plusieurs programmes spécialisés, en vue de faciliter les prises de décision, et cette préoccupation incite à l'établissement de systèmes intégrés d'information géologique et minière.

Parmi les programmes spécialisés nous distinguerons les trois groupes suivants :

a) Banques de données;

b) Calcul;

c) Cartographie.

Bien que la collecte des données pose des problèmes non négligeables qui font l'objet d'une préoccupation constante et permanente, nous n'en parlerons pas et évoquerons sommairement les divers types de programmes.

Programmes "banque" de données

Les ordinateurs, par construction, s'adaptent aisément au traitement de programmes de ce type. Chaque programme est défini en tant que fichier comportant des articles; chaque article peut lui-même comporter un nombre plus ou moins grand de rubriques.

Les fichiers correspondant à des données numériques sont les plus aisés à réaliser. Il en existe de très nombreux dans les divers organismes géologiques, dans les sociétés pétrolières ou minières. Le nombre d'articles de certains d'entre eux est parfois très élevé.

La documentation automatique s'apparente aux programmes "banque" avec des données numériques et sémantiques. Il convient de signaler également des programmes qui permettent de sélectionner de façon automatique une liste des cartes minières ou géologiques qui contiennent, pour une région définie par ses coordonnées géographiques, telle ou telle indication.

Programmes "calcul"

De très nombreux programmes de calcul sont utilisés par les géologues ou les mineurs (voir bibliographie ci-après). D'autre part, des organismes tels que GOSSIP à l'Université de Reading en Angleterre et le Comité d'informatique géologique de Paris diffusent parfois des listes relatives à ces programmes.

La plupart d'entre eux concernent des données chiffrées et en particulier les données recueillies par des appareils de physique ou de géophysique. Il existe néanmoins des études sur des corrélations entre caractères touchant à des données sémantiques.

Mais ce point mérite une attention spéciale (voir sect. D ci-dessous). Il est loin d'être très étudié et c'est pourtant l'un de ceux qui, sur le plan de l'avancement de nos sciences, s'avèrent le plus prometteur.

Programmes "cartographie"

Les programmes de cartographie constituent surtout une technique de présentation des résultats de programmes du type calcul. Nous les avons néanmoins individualisés car il s'agit d'un ensemble spécialement important pour les géologues pour trois raisons.

En premier lieu, parce que les géologues habitués à lire des cartes apprécient tout particulièrement des sorties d'ordinateur de ce type. En deuxième lieu, parce que l'automatisation de la cartographie rend moins coûteuse et plus rapide la fabrication de cartes, quelle que soit leur légende. En troisième lieu, parce que la vision sous forme de carte ou graphique permet une synthèse d'observation par l'œil humain qui est une façon habituelle, mais aussi remarquablement efficace, de "traiter des informations" nombreuses à plusieurs paramètres.

De ce tour d'horizon il convient de retenir ceci : en matière de stockage de données, de calcul sur données numériques et de cartographie automatisée, on utilise déjà largement des ordinateurs pour résoudre les problèmes les plus variés touchant à la géologie.

Par contre, pour le traitement des données sémantiques, en particulier lorsqu'on veut faire subir à ces données un traitement un peu plus élaboré que la restitution en documentation automatique, notre science en est encore à l'heure actuelle à ses tout premiers essais.

C. — Systèmes d'information géologique et minière

De multiples informations d'ordre géologique, métallogénique, minier et économique interviennent dans l'élaboration de toute décision de prospection ou d'exploitation minière. On peut donc penser que la mise en œuvre de ces informations variées, leur traitement, est un élément fondamental dans la stratégie des entreprises minières. Les organismes et sociétés minières disposent de documents très variés : ouvrages, articles, cartes, description de gîtes et rapports divers, qui constituent déjà en eux-mêmes une synthèse, un regroupement partiel des données brutes d'observation.

Ces documents variés sont le fruit d'un traitement et regroupement partiel qui donne à chacun de ces documents l'aspect d'un sous-ensemble de données élaborées à partir des données brutes.

Dès qu'un problème se pose, décision de prospecter ou d'investir, par exemple, il importe d'avoir accès de façon économique à un ensemble de données particulières liées à cette décision. Cet ensemble, en général, ne correspond pas à l'un des sous-ensembles déjà regroupés dans un des documents évoqués ci-dessus.

Pour rassembler à l'intention des chefs de départements de recherche, des conseillers et des géologues les données liées à un objectif particulier, le Centre d'informatique géologique de l'Ecole des mines de Paris a effectué des travaux en vue de créer un système d'information géologique et minière (SIGMI).

L'objectif de SIGMI est de faciliter la création, l'élaboration et le traitement de l'ensemble des données nécessaires à une prise de décision particulière, à partir d'une série de sous-ensembles de données déjà stockées sous forme de cartes, rapports, fichiers, bibliographies, etc.

Un système d'information géologique et minière comme SIGMI comportera à la fois des références documentaires et des données géologiques et minières normalisées (numériques et non numériques). Un système sera opérationnel lorsqu'on aura des données et des moyens de traitements.

Les parties essentielles d'un tel système sont les suivantes :

a) Données: i) des banques de données, par exemple, des données rassemblées dans des fichiers de gisements ou des fichiers de sondages; ii) des systèmes de documentation automatisés; par exemple, en France, la bibliographie du Bureau de recherches géologiques et minières (BRGM); iii) des fichiers mixtes combinant à la fois des références bibliographiques et des données normalisées correspondant, par exemple, à une analyse de contenu;

b) Moyens de traitement. — Pour traiter l'ensemble de ces fichiers, les croiser, en extraire ce qu'il faut, les traiter pour rechercher des corrélations, etc., il faut des programmes adéquats, et éventuellement un langage informatique particulier. Une opération telle que SIGMI, en vue d'arriver à l'objectif défini ci-dessus, consiste donc en diverses phases :

i) Définir les normes méthodologiques permettant de normaliser les données géologiques et minières en vue de constituer des fichiers de diverses natures. Les fichiers choisis sont classés en six groupes : bibliographies, cartes et plans, rapports, fichiers de gîtes, fichiers d'objets géologiques et fichiers de descriptions régionales;

ii) Bâtir un langage adéquat c'est-à-dire permettant d'interroger de façon économique ces fichiers et de les traiter;

iii) Ecrire des programmes de traitement et mise à jour;

iv) Montrer, sur un ou plusieurs exemples, le caractère opérationnel des réalisations en cours.

A titre d'exemple à propos de la complexité de tels systèmes, voici l'état d'avancement fin 1970 des divers points de ce programme :

a) Bibliographie. — Le Bureau de recherches géologiques et minières (BRGM) avec lequel le Centre d'informatique géologique de l'Ecole des mines est en liaison a réalisé et mis en œuvre dans le cadre de son programme de documentation sur les sciences de la Terre le travail correspondant aux références bibliographiques;

i) Cartes et plans: un système d'analyse des cartes et plans est en place et son caractère opérationnel prouvé par divers essais portant sur plusieurs centaines de cartes (voir annexe I);

ii) Rapports : une étude préliminaire a été effectuée. Avant de passer au stade opérationnel, une concertation et la participation de diverses parties intéressées sont nécessaires (voir annexe II);

iii) Fichiers de gîtes : les méthodes d'élaboration et de stockage de données relatives aux gîtes ont été testées. Un certain nombre de fichiers sont en cours d'élaboration (voir annexe III);

iv) Fichiers d'objets géologiques : la méthode d'élaboration a été étudiée. Les fichiers correspondants sont en cours de réalisation;

v) Fichiers de descriptions régionales : la méthodologie est en cours d'élaboration;

b) Langage d'interrogation. — Un langage spécialisé pour le traitement et l'interrogation des fichiers (TIF) est en cours de constitution au Centre de calcul de l'Ecole des mines de Paris. La phase initiale de conception est terminée. Un compilateur est en cours de constitution. Ce langage pourra être mis en service fin 1971. Les questions posées en langage TIF doivent conduire, grâce au compilateur spécial, à une très notable économie dans le temps machine et la puissance des ordinateurs nécessaires pour effectuer les opérations courantes. Cette économie peut à l'heure actuelle être difficilement appréciée par rapport aux systèmes actuels tels que MARK, SAFRAS, SAGESSE et GIPSY. Lorsque TIF sera opérationnel il conviendra bien entendu de constituer une bibliothèque des programmes de traitement les plus courants. Actuellement TIF n'étant pas encore opérationnel, des programmes de chargement, de tri de sélection ou de corrélations écrits en cobol ou en assembleur 360 permettent des opérations les plus simples.

D. — Programmes concernant les données sémantiques

La formalisation des données constitue l'une des phases principales du travail d'informatique géologique.

La première idée qui vient à l'esprit est de constituer un glossaire auquel on associe un code. On peut ainsi associer à une notion géologique des chiffres, des lettres ou un mélange chiffres-lettres. Les géologues ont une pratique assez ancienne de tels codes; une partie de la légende des cartes géologiques est constituée par un code alphanumérique.

La carte géologique internationale de l'Europe à l'échelle du 1/1 500 000, par exemple, utilise pour le jurassique supérieur le code J 3 et pour le dévonien inférieur le code D 1. Autre exemple : le code des symboles chimiques; Cu pour le métal cuivre, Hg pour le mercure et Pb pour le plomb (ou encore les symboles alchimiques utilisés sur les cartes géologiques françaises pour les minéraux).

Les ordinateurs à faibles performances obligeaient les utilisateurs à se servir de codes courts établis dans le même esprit que le code des symboles chimiques. L'encombrement de mémoires annexes ne devenant plus une gêne, on passe à des codes mnémoniques, ou même on se contente de la codification que constitue la suite de lettres qui forme le nom (les sept lettres de "granite", les quatre lettres de "grès" constituent un code dont l'emploi est commode).

Codification sémantique

L'analyse des notions géologiques peut conduire à un type de codification particulier. Désignons les éléments, qui définissent par une analyse du contenu sémantique une notion A, par l'ensemble (A) $= a_1 \ldots a_k \ldots$ Affectons à chaque élément a_i une position fixe dans une chaîne de bits.

La chaîne (1 1 1 0 1 0 0 0) signifie $a_1 =$ oui; $a_2 =$ oui; $a_3 =$ oui; $a_4 =$ non; $a_5 =$ oui; $a_6 =$ non.

En affectant deux bits à chaque élément a_1, on peut en outre prévoir les cas ou l'élément a_i n'a pas été précisé (ni oui ni non = réponse inconnue).

La codification par ensemble d'éléments ordonnés qui vient d'être explicitée peut d'ailleurs être combinée avec une codification alphanumérique. A titre d'exemple dans une telle codification mixte, un grès grossier, pris, à ciment calcaire peut être codifié par un code de quatre lettres "grès", suivi d'une chaîne de bits qui précisent la structure, la couleur, la nature du ciment, la présence de fossiles, etc.

Outre les chaînes, on peut prévoir des structures du type des arborescences ou des treillis que les ordinateurs explorent aisément par une suite de réponses digitalisées (droite-gauche et continuer-stop).

Un tel système de codification présente de grands avantages : il assure à la mémoire une flexibilité beaucoup plus grande et des possibilités accrues en matière de recherche de corrélations, car il permet une recherche en mémoire-machine au niveau des bits élémentaires. Nous l'appellerons codification sémantique (*semantic coding*).

C'est à l'élaboration d'un système cohérent de codification sémantique que vise le projet GEOSEMANTICA 70, lancé par l'Ecole des mines de Paris et la Royal School of Mines de Londres.

E. — Perspectives d'avenir

La description rapide des problèmes abordés par l'informatique géologique a été faite ci-dessus en s'appuyant pour illustrer les exemples sur l'activité menée à l'Ecole des mines de Paris en liaison avec le Bureau de recherches géologiques et minières et la Royal School of Mines de Londres.

En fait, ces travaux se développent dans le cadre de liaisons beaucoup plus diverses aux échelons national et international. En plus des contacts directs entretenus avec d'autres équipes et développés en particulier grâce à des visites mutuelles et à des stages de longue durée, un comité international placé sous les auspices de l'Union internationale des sciences géologiques permet aux spécialistes du stockage, de la recherche documentaire et du traitement des données géologiques de se retrouver. En outre, pour la première fois dans la longue histoire du Congrès géologique international, une section spéciale traitera de l'informatique géologique lors de sa vingt-quatrième session qui se tiendra à Montréal, en 1972.

Il n'est pas douteux que l'accent mis sur l'utilisation des ordinateurs par les différents services de l'Organisation des Nations Unies et des institutions spécialisées et la prochaine installation à Genève du Centre international d'informatique des Nations Unies permettront, sur le plan international, de faciliter le développement des applications de l'informatique géologique au profit de la communauté mondiale.

Les systèmes et programmes décrits ci-dessus, et les systèmes et programmes nouveaux qui seront mis en œuvre par la suite, sont de nature à rendre de plus en plus service aux organismes nationaux et sociétés minières. Le souci d'efficacité nécessaire dans le travail considérable incite cependant à chercher à ne pas limiter son utilisation au niveau d'un seul organisme ou d'un seul pays. L'établissement en commun et la communication des données insérées dans ces programmes ou systèmes méritent au contraire d'être recommandés.

Il y a quelques années le chemin a déjà été tracé pour une coopération internationale utilisant le traitement sur ordinateur. En 1967, l'inventaire mondial des gisements de fer établi par la Division des ressources et des transports de l'Organisation des Nations Unies a fait l'objet, pour de nombreux gisements d'Afrique et d'Europe, d'une mise sur fichier et d'un traitement sur ordinateur. Le complètement et la mise à jour de ce fichier, l'extension à d'autres fichiers et la mise sur pied en commun de systèmes intégrés d'information géologique et minière peuvent constituer des éléments constructifs de la coopération future entre organismes géologiques et miniers du monde.

ANNEXE I

Système d'analyse de cartes et de plans élaboré à l'Ecole des mines de Paris

Ce système d'analyse de cartes et de plans a été testé sur 300 cartes de disciplines variées (géologiques, tectoniques, paléogéographiques, minières, hydrogéologiques, glaciologiques, océanographiques, etc.) s'appliquant à différents pays.

Il comporte l'établissement de bordereaux dont les rubriques concernent :

a) Les références bibliographiques;

b) Les données cartographiques : échelle, projection, réseau de coordonnées, surface représentée, documents annexés;

c) La localisation : coordonnées géographiques, nom;

d) Le contenu : données scientifiques, catégories d'objets naturels ou de phénomènes décrits.

Les essais ont été faits sur un ordinateur IBM 360/40, les programmes étant écrits en cobol avec quelques sous-programmes en assembleur. Une partition de 100 K est nécessaire (voir ci-dessous un exemple d'édition en clair des données relatives à une carte de Libye).

Exemple d'édition en clair de données relatives à une carte de Libye

```
NO DE L'ANALYSE=C280
ANALYSEUR=LESAGE
BIBLIOTHEQUE=CCGM
             EMP
             98242
DOCUMENT=C
EDITION=1935
TITRE=SCHIZZO GEOLOGICO DELLA CYRENAICA DEL DESERTO LIBICO, DELLA TRIPOLITANIAE DEL FEZZAN ORIENTALI
ECHELLE=3000000
RESEAU=GEOGRA
LIMITE NORD=N33D
LIMITE SUD=N21D40M
LIMITE OUEST=E16D
LIMITE EST=E25D
PAYS=LIBYE(P)
CONTENU PRINCIPAL DE LA CARTE=GEOL
FOND GEOGRAPHIQUE=CRS D'EAU
                  PEU NOMS
                  LIM ADM
CARTE GEOLOGIQUE=SYST
                 IGN GEN
                 VOLCA GEN
CARTE DES FORMATIONS SUPERFICIELLES=DET
SYSTEMES DU MESOZOIQUE=CRETACE
SYSTEMES DU CENOZOIQUE=EOCENE INF
                       EOCENE MOY
                       EOCENE SUP
                       OLIGOCENE
                       MIOCENE
LISTE DES FICHIERS CODES
```

Le système permet une sélection des cartes comme il est pratiquement impossible de le faire avec les moyens classiques manuels. Cette sélection se fait par combinaison de trois opérations logiques : *et, ou, non,* sur tous les termes, avec un nombre maximum de 10 par opérateur.

A titre d'exemple, on peut indiquer que le temps d'entrée d'une analyse avec création automatique des dictionnaires sur le disque magnétique et stockage codé de l'enregistrement sur la bande a été en moyenne de 8 secondes par carte. Le temps de sélection pour une recherche portant sur sept critères relatifs aux 300 cartes a été en moyenne de 8 secondes également.

ANNEXE II

Résultats de l'étude préliminaire faite sur l'analyse et la création d'un fichier de rapports

L'étude avait pour but de rechercher les possibilités de créer à partir des rapports géologiques et miniers inédits un système mixte de documentation et d'information, du modèle de celui qui a été décrit à l'annexe I ci-dessus pour les cartes et plans.

Un tel système peut se révéler extrêmement utile en raison des difficultés particulières rencontrées pour utiliser les rapports inédits : *a*) en nombre limité d'exemplaires souvent peu accessibles; *b*) portant des titres souvent peu précis; *c*) ne comportant pas de résumés.

L'analyse a conduit à répartir les données en sous-fichiers relatifs aux catégories suivantes de données : bibliographie, cartographie, géologie (géologie générale, levés géologiques), prospection, gitologie (fichiers d'indices ou de gisements), économie minérale, géochimie, hydrogéologie, géotechnique (voir ci-dessous la liste de données envisagée pour le sous-fichier "prospection").

Liste de données relatives à la prospection

```
SOUS FICHIER PROSPECTION=/
/NUMERO=
/NOM LOCAL=
/DIV ADMINISTRATIVE=
/SOCIETE=
/PAYS=
/LIM N=          /LIM S=          /LIM E=          /LIM W=
/TYPE DE PROSPECTION=
/MATERIAU=(prospecté)
/SURFACE PROSPECTEE=
/NAT ECHANTILLON= (sol, roche, ...)
/NB ECHANTILLON=
/NB STATION=
/NB PUITS=
/NB SONDAGE TARIERE=
/NB PROFIL
/NB BATEE=
/MAILLE=
/DISTANCE=(entre profils)
/PROFONDEUR=
/LONGUEUR TOTALE= (profils)
/ALTITUDE VOL=
/ORIENTATION=
/LONGUEUR= (profils)
/PROFONDEUR TOTALE=(puits, ...)
/GRAVIER LAVE=
/TRAVAUX COMPLEMENTAIRES=
(MINERAL=        /ABONDANCE=      /TENEUR=     /UNITE= )
{ELEMENT=        /TENEUR=         /FOND=       /UNITE= )
{  ou
{OXYDE=
/NB ANALYSE=
/METHODE=
/NB ANOMALIE=
/INTENSITE=
/NB INDICE=

/DIFFUSION=
```

Comme pour le fichier de cartes, les essais ont été faits sur un ordinateur IBM 360/40, les programmes étant écrits en cobol avec quelques sous-programmes en assembleur.

L'entrée des données a été faite en format libre, sous réserve que la longueur maximum des "noms" et "valeurs" soit inférieure à 255 caractères.

L'utilisation des fichiers susceptibles d'être créés nécessite la création de langages d'interrogation. Dans un premier temps, des questions simples pourront être posées à l'aide de tests arithmétiques pour les valeurs et de tests logiques (et, ou, non) pour les noms d'éléments. Dans un second temps, des opérations plus complexes, par exemple des calculs de type statistique, pourront être effectuées à partir d'un langage plus évolué tel que le langage du système TIF en cours d'élaboration à l'Ecole des mines de Paris.

ANNEXE III

Fichiers de gisements métalliques établis à l'Ecole des mines de Paris

FICHIERS RÉGIONAUX

Carte métallogénique de l'Europe

La carte métallogénique de l'Europe au 1/2 500 000 est préparée dans le cadre de la Commission de la carte géologique du monde, affiliée à l'Union internationale des sciences géologiques. Elle est publiée en commun par l'UNESCO et le BRGM. Elle concernera environ 6 000 gîtes.

Le fichier est établi au fur et à mesure de la mise au net des feuilles. Actuellement 2 500 gîtes sont reportés au fichier; ils concernent les feuilles n° 1 (ABERDEEN), n° 2 (STOCKHOLM, n° 3 (PERM), n° 4 (PARIS), n° 5 (MOSCOU).

Les fiches comportent les données suivantes : coordonnées géographiques, nom du pays, nom du gîte, type morphologique, indice de dimension, minéralisation (éléments principaux et éléments secondaires), type génétique et âge du gîte, nature et âge des roches encaissantes, bibliographie, remarques.

Des listes de gîtes classés par ordre alphabétique, par zone rédactionnelle et par éléments chimiques sont établies à partir du fichier et sont publiées avec les feuilles de la carte métallogénique.

Des méthodes de recherche ont été testées à partir du fichier partiel (voir ci-dessous un exemple d'édition en clair des données relatives à un gisement du Royaume-Uni).

Edition en clair de données relatives à un gisement du Royaume-Uni

```
(CME 03..011) TYNDRUM
ROYAUME UNI          TAILLE=1                 LONG.=355.17 EST        LAT.=56.25  NORD.
ORIENTATION= N.NE
MORPHOLOGIE=FILON
            REMPLISSAGE
CHIMISME=PB  (SULF)
        =ZN  (SULF)
TYPE GENETIQUE=TELETHERMAL OU EPITHERMAL
               AGE OROGEN=  VARIS.
               AGE ABSOLU= 550M.ANS PB/PB
              TELETHERMAL OU EPITHERMAL
            =  AGE ABSOLU= 230M.ANS U/PB
ROCHE ENCAISSANTE=SCHISTES
               AGE STRATI=     Y3
               =QUARTZITES
               AGE STRATI=     Y3
NOTES, BIBLIO.=SITUE DANS UNE FAILLE D'AGE ACADIEN (VI)
```

Fichiers mondiaux

Des fichiers plus complexes que le précédent, qui comprennent en particulier des indications sur les teneurs, la production, les réserves et l'exploitation, ont été constitués pour diverses substances :

a) Minerai de fer : fichier établi grâce à la collaboration de nombreux rédacteurs nationaux en vue de la révision par l'Organisation des Nations Unies de l'inventaire des ressources mondiales en minerai de fer. Il concerne actuellement environ 400 gîtes d'Europe et d'Afrique (voir ci-dessous un exemple d'édition en clair des données relatives à un gisement de Guinée);

b) Béryllium : fichier d'essai constitué en rubriques fixes pour tester la valeur d'études statistiques (en particulier de la méthode des grappes); il concerne 350 gîtes.

c) Molybdène : fichier constitué en rubriques fixes pour les mêmes fins que le précédent; il concerne 300 gîtes;

d) Etain : fichier en cours d'élaboration en format variable; il concerne actuellement 30 gîtes.

Edition en clair de données relatives à un gisement de Guinée

```
LONGITUDE =   13 DEG. 43     MIN. W
LATITUDE  =    9 DEG. 30     MIN. N
GITE POINTE
NUMERO DU GISEMENT =    1   PAYS = GUINEE
NOM=  CONAKRY
SUBDIVISION DE PAYS OU LOCALITE = CONAKRY
NIVEAU D'EXPLOITATION=  EN EXPLOITATION
UNITE DECRITE =   DISTRICT
DOCUMENTATION     NORMALE      DATANT DE 1967
MORPHOLOGIE =   STRATIFORME
DOMAINE GEOLOGIQUE = PRECAMBRIEN OU PRIMAIRE NON DIFFERENCIE PLISSE
ROCHE ENCAISSANTE=DUNITES
TYPE GENETIQUE=   ALTERATION SUPERFICIELLE
TYPE BLONDEL = LATERITES
COMPOSITION MINERALOGIQUE=GOETHITE          ABONDANT
HEMATITE        ABONDANT
COMPOSITION CHIMIQUE DU MINERAI
FE=51,50        S IO2= 2,50       S= 0,10          P=0,06          H2O+=12,1     PERTE AU FEU= .
AUTRES ELEMENTS
CA=0,05     AL= 9,80     CR=1, 20     NI= 0,02
RESERVES MINERAI EN PLACE (10**6 TONNES METRIQUES)
          MESUREES                  MESUREES,INDIQUEES          MESUREES,INDIQUEES,PRESUMEES
            =      9                     =      10                          =      10
   FER METAL=      4                     =      5                           =      5
MINERAI POTENTIEL= 1000  FER METAL= 450
TOTAL RESSOURCES= 1010  FER METAL= 455
```

```
PRODUCTION (10**3 TONNES METRIQUES)
ANNEE=    1966        MINERAI=     442          FER METAL=     200
METHODE DE TRAITEMENT CRIBLAGE
POURCENTAGE DE FINES
ANALYSE CHIMIQUE DU MINERAI MARCHAND
FE=52,20        S IO2= 1,60     S= 0,14         P=0,25          H2O+=10,8       PERTE AU FEU=
AL= 8,80                CR= 1,83                NI= 0,15                        = ,
QUALITE DE LA DOCUMENTATION= NORMALE
SURFACE INTERESSEE A L'EPOQUE METALLOGENE=) 100*100 KM
                                ZONE LIBRE= ALTERATION SUPERFIC
IELLE DE ROCHES BASIQUES ET LATERITISATION
```

D'autre part, des fichiers en rubriques fixes et contenant des données analogues à celles qui ont été reportées dans les fichiers mondiaux énumérés ci-dessus ont été établis et sont tenus à jour au laboratoire de géologie industrielle de l'Ecole des mines de Paris. Ils portent sur les substances suivantes :

a) Cuivre : fichier concernant 700 gîtes;

b) Plomb-zinc : fichier concernant 800 gîtes;

c) Manganèse : fichier concernant 260 gîtes;

d) Antimoine : fichier concernant 130 gîtes;

e) Spath-fluor : fichier en cours de constitution.

Enfin, en association avec des organismes miniers, des fichiers comportant de nombreuses données géologiques et économiques sont en cours d'établissement sur les substances suivantes :

a) Nickel-cobalt : 150 gîtes décrits;

b) Platine : 75 gîtes décrits;

c) Wolfram : 150 gîtes décrits.

Dans un premier temps, les rubriques considérées comme les plus essentielles seront introduites en ordinateur, en rubriques fixes.

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SUMMARY — RESUME — RESUMEN

Geological data processing: *P. Laffitte and A. Marelle*

After a brief review of data storage methods, the authors discuss the types of problem posed by geological data processing which may be resolved by combinations of simpler programmes, such as the following:

(*a*) Bank programmes (data file storage, automatic documentation);

(*b*) Computing programmes;

(*c*) Cartography programmes, in which the computer produces a map on the basis of the data;

(*d*) Correlation programmes.

As an example of combinations of specialized programmes and automatic documentation, the authors describe the geology and mining data system being developed by the Ecole des mines in Paris. This system is designed to facilitate the acquisition and processing of the data set required in order that a decision concerning prospection, research or mining operations may be taken on the basis of a series of sub-sets of data, such as maps, reports, files or bibliography. The authors describe the progress achieved at the end of 1970.

The latter part of the article is devoted to correlation programmes involving semantic data. Computer work requires a high degree of precision, and it is necessary to define without ambiguity the geological terms utilized in order to be able to codify them. The task of codification may consist of an actual analysis of semantic content. The authors propose a mixed codification system comprising an alphameric component followed by a bit string which may be considered as "yes" or "no" responses to questions on such subjects as structure, colour or the presence or absence of various characteristics. Correlation studies may be more fruitful under these conditions. The development of such a semantic codification system is the aim of the GEOSEMANTICA 70 project initiated by the Paris Ecole des mines and the Royal School of Mines in London.

L'informatique géologique : *P. Laffitte et A. Marelle*

Après un bref rappel des processus de stockage d'informations en ordinateur, les auteurs évoquent les types de problèmes abordés par "l'informatique géologique", et qui peuvent se ramener à des combinaisons de programmes plus simples, telles que les suivantes :

a) Programmes "banque" (stockage de fichiers de données, documentation automatique);

b) Programmes "calcul";

c) Programmes "cartographie" dans lesquels l'ordinateur établit une carte à partir des données;

d) Programmes "corrélations".

A titre d'exemple des combinaisons entre programmes spécialisés et documentation automatique, les auteurs décrivent le programme du système d'information géologique et minière (SIGMI) élaboré par l'Ecole des mines de Paris. Ce système est destiné à faciliter la création, l'élaboration et le traitement de l'ensemble de données nécessaires à une prise de

décision de prospection, de recherche ou d'exploitation minière à partir d'une série de sous-ensembles de données telles que cartes, rapports, fichiers, bibliographie. Les auteurs indiquent l'état d'avancement du programme à la fin de 1970.

La dernière partie de l'article est consacrée aux programmes de corrélations concernant les données sémantiques. Le travail sur ordinateur nécessite une grande précision et il s'agit de définir sans ambiguïté les termes géologiques employés pour pouvoir les codifier. Le travail de codification peut constituer une véritable opération d'analyse de contenu sémantique. Les auteurs proposent une codification mixte comprenant une partie alphanumérique, suivie d'une chaîne de bits qui peuvent être considérés comme des réponses "oui" ou "non" à des questions concernant par exemple la structure, la couleur, la présence ou l'absence de caractères variés. Les recherches de corrélation peuvent, dans ce cas, être plus fécondes. C'est à l'élaboration d'un tel système de codification sémantique que vise le projet GEOSEMANTICA 70 lancé par l'Ecole des mines de Paris et la Royal School of Mines de Londres.

La informática geológica: *P. Laffitte y A. Marelle*

Después de una breve introducción sobre los procedimientos para almacenar información en las computadoras, los autores recuerdan los diversos problemas de que se ocupa la "informática geológica", y que se pueden reducir a la combinación de los programas más sencillos, tales como:

a) Programas de "banco" (almacenamiento de fichas de datos y documentación automática);

b) Programas de "cálculo";

c) Programas de "cartografía", en los cuales la computadora establece un mapa partiendo de los datos;

d) Programas de "correlaciones".

Como ejemplo de las combinaciones entre programas especializados y documentación automática, los autores describen los programas del Sistema de información geológica y minera (SIGMI) preparado por la Escuela de Minas de París. Este sistema sirve para facilitar la creación, elaboración y trato del conjunto de datos requeridos para adoptar decisiones sobre prospección, investigación o explotación de minerales a base de una serie de subconjuntos de datos, tales como mapas, informes, fichas, bibliografías, etc. Los autores describen el progreso del programa hasta finales de 1970.

La última parte del artículo está dedicada al programa de correlaciones de los datos semánticos. El trabajo con computadora requiere una gran precisión y para la codificación es necesario definir sin ambigüedades los términos geológicos usados. La labor de codificación puede constituir una auténtica operación de análisis del contenido semántico. Los autores han propuesto una codificación mixta, que tiene una parte alfabético-numérica, seguida de una cadena de *bits* que podrían considerarse como respuestas afirmativas o negativas a cuestiones relativas a la estructura, color, presencia o ausencia de diversas características, por ejemplo. En este caso, las investigaciones de correlación pueden resultar muy útiles. El proyecto GEOSEMANTICA 70 iniciado por la Escuela de Minas de París y por la Real Escuela de Minas de Londres, está orientado a la preparación de tal sistema de codificación semántica.

Major developments in the Economic and Social Council in the field of natural resources

Creation of the Committee on Natural Resources

In a report to the Economic and Social Council at its forty-eighth session (E/4801) the Secretary-General of the United Nations, suggested that the Council might wish to provide guidance in the formulation and implementation of natural resources policies through such means as, for example, a substantive committee on natural resources. In a further report (E/4801/Add. 1), more specific information was given concerning the tentative terms of reference of the proposed committee.

In resolution 1482 (XLVII), of 3 April 1970, the Council recognized the importance of establishing an intergovernmental body in the field of natural resources, and decided to continue, at its forty-ninth session the discussion of that particular question on the basis of a draft resolution submitted to it at its forty-eighth session.

During the debate, at the forty-ninth session of the Council, there was general recognition of the paramount importance to developing countries of natural resources development. Mention was made of the increasing tendency of developing countries to request United Nations assistance, and attention was called to the many successes achieved at a cost which was low in comparison to the results obtained. The majority of representatives supported the proposal for the establishment of such a committee, and at the conclusion of the debate, on 27 July 1970, the Council adopted resolution 1535 (XLIX), by which it established a standing Committee on Natural Resources.

In this resolution, the Council recalled the important role played in the past by the United Nations in assisting Governments to investigate and develop their natural resources and expressed the conviction that similar co-operation should continue throughout the Second United Nations Development Decade on an enlarged and accelerated scale, with more adequate intergovernmental leadership and guidance. Thereafter, as stated in the resolution, the Council:

"1. *Decides* to dissolve the *Ad Hoc* Committee on the Survey Programme for the Development of Natural Resources;

"2. *Further decides* to establish a standing committee on natural resources composed of twenty-seven States Members of the United Nations, to be elected by the Council on the basis of equitable geographical distribution at its resumed forty-ninth session in the autumn of 1970, the representatives of States Members on the standing Committee being, as far as possible, experts in the field of natural resources;

"3. *Decides also* that the term of office for members of the Committee shall be four years, that for the initial period thirteen members shall serve for two years and the remaining fourteen for four years, the term of each member to be determined by lot, and that retiring members shall be eligible for re-election;

"4. *Decides further* that the terms of reference of the Committee on Natural Resources shall include, with due respect for the concept of the sovereignty of every nation, responsibilities for:

"(*a*) Assistance to the Council in providing guidance in the programming and implementation of activities in the United Nations system for the development of natural resources, particularly with regard to the development of water, energy and mineral resources, keeping in mind requirements for planning for the Second United Nations Development Decade and for the protection of the human environment, and new technological developments in the field of natural resources;

"(*b*) The establishment of guidelines for the provision and for the improvement and strengthening of advisory services to the Governments of Member States, to be made available at their request, for the planning, development and utilization of their natural resources within the framework of their over-all development plans;

"(*c*) The substantive review and reformulation of the survey programme as originally planned;

"(*d*) The analysis of existing resolutions in the field of natural resources, with a view to recommending the consolidation and streamlining of their legislative basis;

"(*e*) The selection and follow-up of priority questions concerning long-term problems and trends of world-wide significance in the field of natural resources;

"(*f*) The examination of reports concerning operational and research activities in connexion with natural resources, including reports from relevant panels and seminars already in the programme and from such as may develop;

"(*g*) Appropriate attention to the problems of research promotion and of the exchange and dissemination of experience and information in the fields of the development, utilization and conservation of natural resources;

"(*h*) Recommendations to the Economic and Social Council and, through the Council, to Governments and also to other bodies, such as the Governing Council of the United Nations Development Programme, on appropriate priorities, programme emphasis and other relevant matters concerning the exploration and exploitation of natural resources;

"(*i*) Assistance to the Council and the Committee for Programme and Co-ordination in maintaining the necessary liaison between the activities in the field of natural resources of the regional economic commissions, the specialized agencies, the International Atomic Energy Agency and other bodies doing relevant work, with a view to ensuring the utmost efficiency and co-operation;

"(*j*) Such other relevant functions as the Council may assign to the Committee from time to time;

"5. *Decides also* that the Committee on Natural Resources is to meet and report to the Council at least every other year;

"6. *Decides moreover* that the Committee on Natural Resources is to give high priority in its initial work programme to the formulation and submission of appropriate recommendations to the Council in regard to operative paragraph 4 (*d*) above."

At its resumed forty-ninth session on 13 November 1970, the Council decided to amend resolution 1535 (XLIX) in order to enlarge the membership of the Committee to thirty-eight members with a four-year term of office. For the initial period, nineteen members will serve for two years and the remaining nineteen for four years.

On 1 December, the Council elected the following countries for membership in the Committee: Algeria, Argentina, Australia, Austria, Bolivia, Brazil, Canada, Central African Republic, Chile, France, Gabon, Ghana, Guinea, India, Indonesia, Iran, Iraq, Italy, Jamaica, Japan, Kenya, Malawi, Mali, Netherlands, Norway, Pakistan, Peru, Philippines, Poland, Romania, Sierra Leone, Sweden, Turkey, Union of Soviet Socialist Republics, United Arab Republic, United Kingdom of Great Britain and Northern Ireland, Venezuela and Yugoslavia.

The following nineteen countries were elected for a two-year term: Algeria, Austria, Bolivia, Brazil, Canada, Chile, Ghana, India, Jamaica, Japan, Malawi, Mali, Peru, Philippines, Romania, Sierra Leone, Union of Soviet Socialist Republics, United Kingdom of Great Britain and Northern Ireland and Venezuela.

The Committee held its first session at United Nations Headquarters from 22 February to 10 March 1971.

Natural resources satellites

The Secretary-General had previously submitted to the Council at its forty-eighth session a report on natural resources satellites (E/4779 and Corr.1-3), concerning the potential contribution of earth-orbiting satellites to natural resources surveys (including mapping), and on the role that the United Nations might play in the organization and utilization of pertinent data obtained from such satellites. In the annex to the report, he made a number of tentative recommendations, and suggested that the Council might convene a small *ad hoc* panel of experts, competent in remote earth resources surveying and mapping; or should a standing committee be decided upon, it might be charged with the task of refining and elaborating the tentative recommendations.

At its forty-ninth session the Council requested the newly established committee on Natural Resources to examine the question.

The sea

In a statement to the Council at its forty-ninth session, the Under-Secretary-General for Economic and Social Affairs said that in the light of new discoveries of resources, decisive technical progress in ocean-drilling and political events affecting the régime of the oceans, the question of international co-operation relating to the seas and the oceans had assumed increased importance. He drew attention to a number of far-reaching economic problems that might arise in the context of the development of the resources of the sea and urged that they should be studied carefully, even though some of the parameters were not yet known.

In connexion with its consideration of this question, the Council had before it a report of the Secretary-General on international co-operation on questions relating to the oceans (E/4836) and a report on the exploitation and conservation of living marine resources (E/4842), prepared by the Secretary-General in co-operation with the Food and Agrictulture Organization (FAO) of the United Nations. The two reports, which had been prepared in accordance with General Assembly resolutions 2413 (XXIII) and 2414 (XXIV), were dealt with in the context of other achievements in the field of marine resources. In the course of the debate, mention was made of various other reports and studies in that field that had been completed or were being completed for submission to the General Assembly. Offering further comments on the report prepared with the co-operation of his agency, the representative of FAO said that the work relating to the conservation of fisheries was part of the Indicative World Plan for Agricultural Development that was being prepared by FAO.

At the conclusion of its debate, on 27 July, the Council adopted a resolution on marine co-operation (1537 (XLIX)), in which it requested the Secretary-General, in consultation with organizations of the United Nations system, to prepare a concise review of the current and foreseeable uses of the sea as well as the effects and possible conflicts that might be created by those uses. It also requested the Secretary-General to communicate the study to the Governments of Member States and to invite them to communicate to him their proposals for strengthening international co-operation in the marine environment. On the basis of those views and of the comments of other organizations in the United Nations system and taking into account the results of the United Nations Conference on the Human Environment, he was requested to submit a brief report to the Council on the subject.

Meetings

Second Meeting of the *Ad Hoc* Group of Experts on Geographical Names

The *Ad Hoc* Group of Experts on Geographical Names met at United Nations Headquarters for its second session from 10 to 20 March 1970 in pursuance of Economic and Social Council resolution 1314 (XLIV).

The *Ad Hoc* Group considered the desirability of holding a second United Nations Conference on the Standardization of Geographical Names and specific matters referred to it by the first such conference which was held at Geneva, Switzerland, for three weeks in September 1967.

The session was attended by twenty-five experts representing twelve of the fourteen major linguistic geographical divisions of the world as defined by the Geneva Conference. The Group discussed and prepared a list of its aims, functions and *modus operandi*, giving due consideration to future meetings of the Group, as well as to regional meetings concerned with the standardization of geographical names. Three working groups were organized during this session, one to study the procedures for the naming of undersea features, another on extraterrestrial topographic names, and a third to make a complete study of the various systems of transliteration and to analyse the advantages and disadvantages of each in the international standardization of geographical names. The Group also agreed to hold its third session in the early part of 1971.

On the basis of a decision of the Economic and Social Council at its forty-eighth session, the Secretary-General invited this Group of Experts to meet for its third session from 2 to 12 February 1971 to consider the provisional agenda, as well as other necessary guidance for the Secretariat responsible for the organization of the Second United Nations Conference on the Standardization of Geographical Names which will be held in London, England, during the first half of 1972.

Ad Hoc Group of Experts on Hydrographic Surveying and Bathymetric Charting

The *Ad Hoc* Group of Experts on Hydrographic Surveying and Bathymetric Charting met at United Nations Headquarters from 31 March to 10 April 1970 in accordance with Economic and Social Council resolution 1313 (XLIV). The Group considered such resolutions, adopted by United Nations regional cartographic conferences for Asia and the Far East, as were concerned with problems of hydrographic surveying and bathymetric charting. The Group also considered the status of hydrographic surveying and bathymetric charting and took into account present and future needs; ways and means of accelerating hydrographic surveys; the establishment of hydrographic services in developing countries, including the training of personnel; a review of modern techniques and instrumentation; and a review of the role of the International Hydrographic Bureau (IHB), as well as regional co-operation projects.

Six experts and an adviser of IHB were invited to take part in this meeting. The Group adopted eight recommendations as follows:

(*a*) That countries not already having hydrographic services, but having established mapping agencies, should take inventory of their real needs so that an objective programme may be devised;

(*b*) That countries requiring assistance should enter into bilateral agreements for the necessary help; further, that the United Nations pay increased attention to assistance needs in this field;

(*c*) That each country should implement the establishment of a reporting system for international consumption in accordance with the recommendations of IHB;

(*d*) That each country should consider the economic benefits that result from having adequately surveyed the continental shelves and that a coastal surveying capability be developed as a matter of high national priority;

(*e*) That basic capability in hydrographic surveying should be built up within the framework of an existing organization such as a national mapping agency or a port authority;

(*f*) That institutions holding hydrographic data should provide them to the hydrographic services or to IHB to help expedite the compilation of 1:1,000,000 plotting sheets which are the basic documents for recording deep-sea bathymetric data;

(*g*) That new hydrographic surveys should be considered in accordance with the standards, as laid down by the IHB;

(*h*) That countries interested in pooling various available resources should co-ordinate their plans within a region either by forming hydrographic survey projects or by organizing regional hydrographic commissions in consultation with IHB.

Panel of Experts on Water Resources Development Policies

At the invitation of the Government of Argentina, which provided host facilities, the United Nations Panel of Experts on Water Resources Development Policies was convened at Buenos Aires from 8-13 June 1970.

The Panel, which was composed of twelve experts, took an interdisciplinary approach to questions of water policy and hence included, in addition to high-level policy makers, water resources planners, political scientists, public administration experts, geographers, economists and lawyers. Some of the experts were of cabinet rank, including the Director of the Service de l'Hydraulique, Ministry of Public Works of Algeria; the Secretary of State for Water Resources of Argentina; the Minister for Irrigation and Power of India; and the Deputy Minister of Water and Power of Iran. The Secretariat was represented by three staff membres from the Resources and Transport Division. In addition, two regional economic commissions, and all major specialized agencies with responsibilities related to water were represented. A large number of high-ranking government officials from Argentina, Brazil and Uruguay attended the proceedings as observers.

Work proceeded in plenary sessions and in three working groups established to deal with detailed questions of water planning, technical and economic aspects, and with institutional aspects of water policy.

In the draft report elaborated in the course of the week-long meeting, the Panel underlined the importance of adequate planning procedures for the achievement of set objectives of over-all economic and social policies. In reviewing recent technological developments affecting the use of water, the Panel found a trend of expanding the basic entity for water resources planning beyond the river basin, through a growing number of cases of inter-basin transfers or the establishment of regional or even national water-grid systems. The Panel noted in this context the California and Israeli water-grid systems and discussed proposals for the water transfer systems in North America, Central Europe and India. As regards the institutional aspect of water resources development, the Panel pointed to the need for modern water legislation which would allow for the easier transfer of water rights from "lower" to "higher" uses, for a more resource-oriented administration, and for new imaginative institutional arrangements for the development and use of international water resources, the scope of which still requires a more adequate legal definition.

The Panel is expected to be reconvened during 1971 to discuss and approve a draft final report on water policies currently under preparation by the Secretariat.

Symposium on the Development and Utilization of Geothermal Resources

The United Nations Symposium on the Development and Utilization of Geothermal Resources, which was organized in collaboration with the Government of Italy, was held at Pisa from 22 September to 1 October 1970. Three hundred and eighteen participants from forty-six countries were present at the Symposium.

The technical sessions of the Symposium were concerned with the whole range of geothermal energy exploration and exploitation, including scientific engineering and economic aspects. The 182 papers submitted were grouped by subject, and for each a rapporteur presented a survey of development within his field which was followed by a general discussion. The papers presented, and the discussions which followed, demonstrated a rapidly growing interest in geothermal resources as a source of thermal energy for space heating and for the generation of electric power. The association of thermal waters with deep sedimentary basins discovered in eastern Europe and the USSR suggested that a much wider distribution of hydrothermal resources may exist than had been supposed in the past.

Prospecting techniques have been defined. In the field of geophysics, electrical surveying techniques were described that have been developed for the detection and mapping of the hot dilute brines that appear to be common in volcanic areas.

In the field of geochemistry, isotope studies were described which demonstrate that geothermal water is derived in very large part from the atmosphere, that the chemical constituents of hot springs can often be used to determine the temperature of the water as it was before it reached the surface and finally that, in many cases, the fluids withdrawn from geothermal reservoirs are being replaced by inflowing water.

Techniques for the utilization of geothermal water and steam were described, and these also indicate substantial progress. The use of geothermal water or steam for space heating and power generation using conventional steam turbines remains fully competitive with alternative sources of energy. At the same time experiments with the use of secondary fluids to drive turbo-exchangers after these fluids have been heated by thermal water in heat exchangers was described and is being actively investigated both in the USSR and the United States of America. The successful development of equipment of this kind could greatly enlarge the potential for geothermal electric power development by making economic the use of deposits of relatively low temperature water.

The use of the thermal energy in geothermal water for desalting by flash distillation was described, as was the extraction of the mineral component of geothermal brines.

The economic advantages arising from the use, in suitable circumstances, of geothermal brines for the simultaneous production of electric power, desalted water and useful minerals, were described in the final technical session of the symposium.

Interregional Seminar on Mineral Economics

From 12 to 23 October 1970, the United Nations, in co-operation with the Government of Turkey, convened an Interregional Seminar on Mineral Economics at Ankara, Turkey. The Seminar was the latest in a series of seminars designed to provide assistance to developing countries in the exploitation and utilization of their mineral resources, in implementation of resolution 1033 C (XXXVII), adopted by the Economic and Social Council 14 August 1964. Previous seminars have been held on the following subjects: Geochemical Methods for Mineral Exploration (Moscow, USSR, 1965); Ore Concentration in Water-short Areas (United Nations Headquarters, New York, 1966); and Geophysical Methods for Mineral Exploration (Moscow, 1967).

The programme of the Seminar embraced the various aspects of the economics of the mineral industry within the context of the world economy and the problems of economic development. The agenda was divided into three parts: the first group of lectures examined the position of the mineral industry as a whole, and its position within the framework of the economics of developing countries. The second group of lectures reviewed the mineral resources of the developing regions of the world, while the final group of lectures treated the specific elements involved in the economics of mineral resources development.

The programme of lectures included the following topics:

Group One. Economics of mineral exploration; Significance of mineral resources in the economies of developing countries; An approach to mineral policy formulation; Organization and management of mineral industries.

Group Two. The Mineral position of Africa, Asia, the Far East, Middle East and Latin America. In addition, an account was given of mining activity in Turkey during the decade 1960-1970.

Group Three. Mining legislation; Mine taxation; Minerals and metals in international trade; Changing patterns in mineral supply and demand; Modern ore transportation and its economic significance; Marketing of minerals and metals; Possibilities of more extensive processing of minerals in their country of origin; Conservation of mineral resources and protection of the environment; Development and improvement of national capabilities in mineral economics.

The series concluded with an account of the mineral exploration activities of the United Nations during the decade 1960-1970.

In addition to the programme of lectures and discussions, three concurrent technical field excursions were organized, which permitted the participants to visit some of the interesting mining and metallurgical installations in Turkey.

Sixth Regional Cartographic Conference for Asia and the Far East

The Sixth Regional Cartographic Conference for Asia and the Far East was held at Tehran, Iran, from 24 October to 7 November 1970 in accordance with resolution 1313 (XLIV) adopted by the Economic and Social Council on 31 August 1968.

The Conference was attended by 162 participants from 36 countries. In addition, the Food and Agriculture Organization sent two observers and two intergovernmental organizations, as well as five international scientific organizations, each designated one observer to the Conference.

The Conference considered several items, including geodesy and ground-control; medium-scale and large-scale surveying and mapping; earth-oriented satellites for geodesy, cartography and earth resources studies and inventory; photo-interpretation; topical maps and national atlases; small-scale mapping; hydrographic surveying and bathymetric charting; and geographical names.

Twenty-nine resolutions were adopted by the Conference. The first was in appreciation of the offer made by the Government of Japan to hold the seventh United Nations Regional Cartographic Conference for Asia and the Far East in Japan, during October-November 1973. Of three other general resolutions one concerned continued submission of information to be entered into the Bibliography of Cartographic Literature, a practice which has already been initiated by the Federal Republic of Germany; a two-part resolution concerned technical assistance to developing countries seeking assistance in the various disciplines of cartography; and a third resolution concerned documentation for future United Nations cartographic conferences, requesting national mapping agencies and their respective Governments to abide by procedures and dates set down by the United Nations for the submission of technical papers.

Other resolutions covered substantive items of the agenda as follows: an extension of geodetic and mapping control; satellite geodesy; geodetic contributions to crustal movements; orthophotomaps; cadastral and urban surveying and mapping; application of mapping techniques; map compilation techniques; training facilities; earth resources observation satellites; topical maps and national atlases; photo-interpretation; a regional economic atlas for Asia and the Far East; training in photo-interpretation; geographical names; aeronautical charting; small-scale mapping; time-zone charts; financing of hydrographic assistance; the Intergovernmental Oceanographic Commission (IOC) Programme for the South China Sea; report of the *Ad Hoc* Group of Experts on Hydrographic Surveying and Bathymetric Charting; marine geophysical surveys; the international tsunami warning system in the Pacific area; and the South China Sea Hydrographic Commission.

New natural resources projects

The United Nations will be the executing agency for twelve new or second-phase projects in the field of natural resources, which have been approved by the Special Fund component of the United Nations Development Programme (UNDP). These projects were among others authorized by the Governing Council of UNDP at its eleventh session, held at United Nations Headquarters in January 1971. The total cost of the eleven projects will be $19,159,900, with UNDP contributing $9,678,900. The projects pertain to the following countries: Argentina, Burundi, Cameroon, Chile, Greece, India, Lesotho, Morocco, Niger, Rwanda, Tanzania, Upper Volta and Yugoslavia.

Under a two-year project, the Governments of Burundi, Rwanda and the United Republic of Tanzania will be assisted in planning the development of the Kagera River basin (REG-147) at a total cost of $1,365,700 of which UNDP will contribute $974,700. A plan will be prepared for developing the water and land resources of the Kagera River basin, and in training personnel to carry on such development.

A three-year project for groundwater investigation and pilot development (CMR-16) in Cameroon has been approved by the United Nations at a total cost of $1,501,200. The UNDP will contribute $966,200 to this project which will assist the Government in improving the techniques and intensifying the pace of groundwater research and use in three departments of northern Cameroon, by strengthening the groundwater exploration and exploitation services working in the region.

Assistance will be provided to the Government of Lesotho in exploring for diamonds (LES-3) and assessing the diamond-bearing potential of kimberlite bodies which have already been located in various parts of the country; and in locating additional kimberlite bodies. Of the estimated cost of $663,100, UNDP will contribute $513,100.

In Morocco, the approved project is for a mineral survey in the Anti-Atlas (MOR-35). Assistance will be given to the Government in its task of mineral development by undertaking a search for economic mineral deposits and by investigating previously located occurrences in about 17,500 square kilometres of the central-eastern part of the Anti-Atlas. Training of local staff in modern methods of exploration, and the testing of these methods, will be an important part of the project. The cost will be $2,322,500, UNDP contributing $1,081,500.

The Government of the Niger will be assisted in a mineral exploration project in two areas (NER-22, phase II) at a cost of $1,457,000 of which UNDP will contribute $1,039,000. The purpose of this project will be to complete a mineral exploration programme in the western part of the Niger, including the detailed assessment of a molybdenum occurrence near Kourki, and to carry out in central Niger preliminary geological exploration to determine if a basis exists for the execution of detailed studies in the future.

In Upper Volta, the project (UPV-16) will assist the Government in executing a programme for mineral exploration in the northern part of the country. The cost will be $1,810,900 of which the UNDP contribution will be $1,169,900.

In India, three projects have been approved by the United Nations. The first project is for a duration of two-and-a-half years at a total cost of $1,338,700, of which UNDP will contribute $683,700 for mineral surveys in Uttar Pradesh (IND-94). The purpose of the project is to assist the Government in undertaking economic feasibility studies of industrial rocks and minerals in the northern and southern districts of Uttar Pradesh, and by carrying out detailed investigations along the copper-bearing Sonrai fault zone as well as broader scale surveys on other geologically similar structures in the Jhansi-Sonrai area.

A four-year project has been approved for assistance to the Government of India in establishing a coastal engineering research centre and in the development of hydraulic instrumentation (IND-101) at a total cost of $1,874,300, the UNDP contribution being $936,300. By providing more advanced equipment and training staff to apply it to programmes of coastal engineering and general hydraulics, the capability of the Central Water and Power Research Station at Poona should be strengthened.

Lastly, in India, the Government will be assisted in carrying out a three-year groundwater survey in Rajasthan and Gujarat (IND-114) at a total cost of $2,133,900, the UNDP contribution being $664,900. This project will assist the Government in determining the technical and economic potential of groundwater in the semi-arid Mehsana and Banaskantha districts of Gujarat, as well as in five areas in the arid region of western Rajasthan.

In Europe, under a project to last three years, the Governments of Greece and Yugoslavia will be assisted in the integrated development of the basin of the Vardar and Axios rivers. (REG-203). The total cost will be $3,638,100 of which UNDP will contribute $1,143,100. The purpose of the project is to assist in the formulation of an appropriate programme for the development of the Axios-Vardar river system.

In Latin America, two projects have been approved. The Government of Argentina will be assisted by UNDP, to the extent of $707,200 towards the total cost of $2,286,200, for launching and operating the newly-created National Institute of Water Economy, Law and Administration (INELA) and enabling it to provide technical services and guidance to Argentina and, progressively, to other Latin American countries (ARG-44).

The estimated cost of providing assistance to the Government of Chile for off-shore exploration for petroleum (CHI-41) is $2,406,400, of which the UNDP contribution is $942,400. The project will be for the purpose of locating geologic structures favourable for the entrapment of hydrocarbons.

Notes

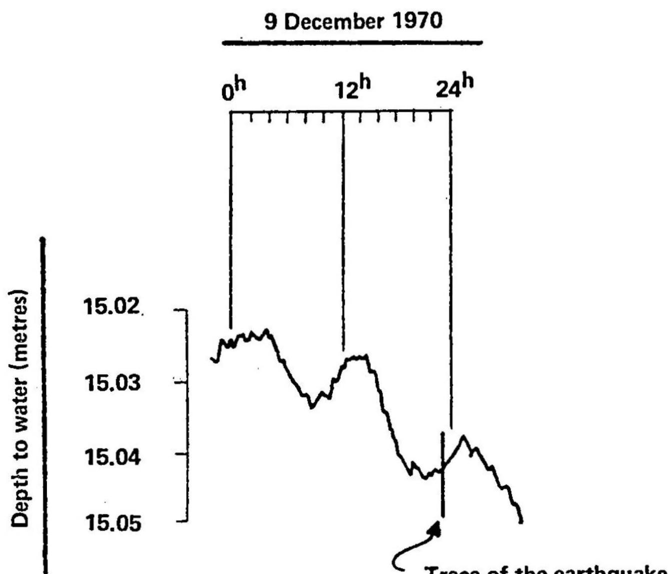
Effect of the Guayaquil (Ecuador) earthquake of 9 December 1970 on groundwater in Nicaragua

The pressure waves of powerful earthquakes can travel around the earth, and their effects may be recorded by sensitive seismographs thousands of kilometres away. As the shock travels from the epicentre, the earth is set in motion in a series of vibrations that weaken with distance. The water-table may also vibrate, and there are many cases known in which groundwater levels have been disturbed by distant earthquakes.

A powerful earthquake (Richter 7.6) occurred near Guayaquil, Ecuador, at 2235 hours on 9 December 1970. The shock wave arrived in north-western Nicaragua, 1,500 kilometres distant, about twenty-five minutes later and caused the water-table to vibrate.

The sketch shows the graph of 9 December as obtained by a Stevens Type-F water-level recorder installed in a shallow well at Posoltega, Nicaragua. The depth of water was 15.025 metres below ground at midnight 8/9 December. After rising and falling through the day in response to changes in barometric pressure, the depth was 15.040 metres at midnight 9/10 December. Owing to the compressed time scale, the effect of the Guayaquil earthquake appears as a vertical line at 2300 hours, at which time there was a fluctuation of water-level of 12 millimetres that may have lasted for only a few seconds.

The recorder is operated by the staff of the UNDP project "Groundwater Investigations in the Pacific Coastal Region (Chinandega area) of Nicaragua". The executing agency is the United Nations.



Vibrations recorded in Nicaragua of the Guayaquil earthquake

Obituaries

Emmanuel S. de Breuvery

"As we say goodbye to Emmanuel de Breuvery, we should only speak of hope. . . . It was hope which stimulated the work — and his work, in turn, produced hope. It traversed the frontiers of new knowledge, of new and better ways of doing ancient things. It covered the broadest range, preparing the peaceful uses of the atom; probing new sources of energy, sometimes in the face of wide scepticism; experimenting with new techniques of mapping and exploring mineral resources; searching for groundwater in desert areas; untangling the intricate problems of harnessing the resources of international rivers, and more recently—this was in fact his last undertaking—breaking the ground for a rational utilization of marine resources for the benefit of all mankind."

These were the opening remarks of a eulogy delivered on 17 January 1970 by Philippe de Seynes, Under-Secretary-General for Economic and Social Affairs, at the funeral mass of one of the world's foremost resources economists, Emmanuel de Breuvery. For eighteen years he had been a member of the United Nations staff, a span of years during which, as Mr. de Seynes said, "the vast drama of the developing world unfolded before our eyes . . .".

Emmanuel S. de Breuvery was born in Caen, Normandy, the son of an army officer, the grandson of a diplomat. He became an economist purely by chance; as a Jesuit novice, he was trained as an economist, there being a shortage of priests in that field. He studied at the Ecole de science politique in Paris and later worked in investment banking in France, Germany and the United Kingdom. In 1937, his career again took an unexpected direction when a Jesuit assigned to teach economics in China got an ulcer: he stayed in Paris, and Emmanuel de Breuvery took his place.

In Shanghai he organized the faculty of economics in the French Jesuit university there, but he found that his training as a banker was useless to him in this task. "I had to turn to the real need—resource economics. I travelled on foot, on horseback, planning the development of resources over three quarters of the whole of China, including Tibet."

After the war, Emmanuel de Breuvery left China and became an economic adviser to the French Government at Bangkok before joining the United Nations Secretariat in 1952.

Emmanuel de Breuvery resigned in 1964 at the mandatory retirement age of sixty, but he continued to serve as an adviser and consultant, especially in the field of marine resources.

James MacMillan Brown

On 12 August 1970, James MacMillan (Hamish) Brown suffered a heart attack and died at the age of forty-nine. He had just returned from an arduous trip to Somalia and Ethiopia, crowding a month's work into a couple of weeks. During his seven years with the United Nations, this had been his *modus vivendi*: pressure work at Headquarters interspersed with frequent trips in response to urgent calls from Governments and project personnel in almost every part of the world. His contribution was unique in that he was not only the chief geophysicist of an Organization which has played an outstanding role in applying geophysics to the global search for natural ressources, but also an economic geologist of note.

Before joining the Secretariat in April 1963, Hamish already had an established position as a practitioner of the geological arts. After six years of war service, he achieved the rare distinction of graduating from the University of Glasgow with a double first—in geology and geophysics. He then became the first geophysicist on the staff of the Overseas Geological Survey, assigned to a territory that included countries now known as the Democratic Republic of the Congo, Kenya, Uganda and the United Republic of Tanzania. As such, he was part of the famous scientific team that in the early 1950s worked in the Ruwensori Mountains in Uganda and the Congo, bedding down in snow-drifts at times, even though he was on the equator. In addition, his contributions towards an understanding of the terrestrial magnetism of East Africa were outstanding.

Recently Hamish received signal recognition: he was elected an honorary member of the Canadian Exploration Geophysical Society, the first and only person to be so honoured.

His death triggered an unprecedented movement within the United Nations. His friends have obtained sanction to set up a James MacMillan Brown Memorial Fellowship. Funding will be obtained entirely outside the United Nations from individuals and firms.

Thomas Glenn Murdock

With the death on 2 January 1971 of Thomas Glenn Murdock, aged 70 years, the Resources and Transport Division has lost one of its senior technical advisers. He had worked in the United Nations since 1965 after a distinguished career in the field of mineral resources.

Tom was born at Hidenite, North Carolina. He served as a military engineer in the First World War before graduating from the University of North Carolina and engaging in post-graduate work at the University of Alabama. His early professional career was spent mainly as a mining engineer with private companies in Latin America. The Second World War saw him engaged in strategic mineral work for the United States Government in Brazil and Ethiopia. From 1947 he was United States Minerals Attaché in Ankara, and later, in Elisabethville, formerly the Belgian Congo, American Consul and Minerals Attaché for Africa south of the Sahara. From 1961 to 1965, he was with the Bureau of Mines in Washington.

Tom Murdock's broad experience in all aspects of mineral resources development, particularly in the developing countries, made him a valuable member of the Division. His special expertise in mineral economics and mining legislation was sought after and made available to many developing countries. He was a believer in helping people to help themselves; the mineral projects with which he was associated, therefore, focused attention upon the training of national staff at all levels, providing them with a foundation for continuing independently. The Geological Survey Institute project in Iran and the Institute of Applied Geology in the Philippines are good examples of his approach.

During his service with the Secretariat he undertook more than a score of missions. His last major task was to organize and help direct a mineral economics seminar in Ankara.

His professional stature, tremendous capacity for work and readiness to share his knowledge with others, commanded the high esteem of all who knew and benefited from association with him.

United Nations publications in the field of natural resources, 1968-1970

MINERAL RESOURCES

Proceedings of the United Nations Interregional Seminar on Ore Concentration in Water-Short Areas, August 1968

Sales No.: E.68.II.B.4

The proceedings cover the principles, operation, application and economics of ore concentration in water-short areas. The importance of experimental testing to determine the variable and optimum conditions for processing specific ores and the best process to adopt are stressed.

Survey of World Iron Ore Resources: Occurrence and Appraisal, February 1970

Sales No.: E.69.II.C.4

The study is a substantial revision of the earlier Survey of World Iron Ore Resources: Occurrence, Appraisal and Use, published in 1955. The survey takes into account the great number of new developments in the supply and utilization of iron ore and is a major contribution to knowledge of the magnitude and distribution of world iron ore resources.

Mineral Resources Development with Particular Reference to the Developing Countries, May 1970

Sales No.: E.70.II.B.3

The study defines the various operational stages in mineral resources development and indicates the institutional framework within which these are usually executed. The study also covers mineral development policy and legislations and includes the United Nations operational and substantive activities in the field of mineral resources development.

WATER RESOURCES

Solar Distillation as a Means of Meeting Small-scale Water Demands, March 1969

Sales No: E.70.II.B.1

The study defines conditions under which solar distillation may provide an economic solution to the problems of fresh water shortage in small communities.

The First United Nations Desalination Plant Operation Survey, May 1969

Sales No.: E.69.II.B.17

The present survey is the first of a continuing series planned with the objective of compiling a progressive record and analysis of the economic and technological development of desalination plants throughout the world.

The survey includes all plants engaged in commercial production for which it was possible to obtain records of operation throughout 1965. Plants with a capacity of less than 10,000 gallons per day, specialized boiler feed-water plants and experimental plants were excluded.

Integrated River Basin Development, November 1969

Sales No.: E.70.II.A.4

The publication is a revised and updated edition of an expert panel report prepared in 1958 on the subject. It includes, in addition to a new preface which reviews technological and economic developments during the past ten years, new annexes of economic planning, health aspects, problems of reservoir development, water desalination and international water resources law.

ENERGY RESOURCES

A Study of Power Generation Based on the Utilization of Low-grade Fuels in Developing Countries, May 1969

Sales No.: E.69.II.B.11

The study examines the possibilities of using low-grade fuels such as peat, lignite and oil shales as well as domestic, industrial and agricultural wastes for electric power generation and heat production in developing countries.

MARINE RESOURCES

Mineral Resources of the Sea, May 1970

Sales No.: E.70.II.B.4

The report contains up-to-date information relating to known mineral resources of the sea, as well as the most recent technological developments regarding exploration and exploitation techniques and points out problems relating to mineral development in the marine environment which require special attention.

CARTOGRAPHY

Fifth United Nations Regional Cartographic Conference for Asia and the Far East, April 1969

Sales No.: E.68.I.14

Volume II of this Conference, which was held from 2 to 22 March 1967 in Canberra, Australia, was issued. This volume contains the proceedings of the Conference and the technical papers submitted.

International Map of the World on the Millionth Scale, 1970

Sales No.: E.F.70.I.3

United Nations Conference on the Standardization of Geographical Names, October 1969

Sales No.: E.69.I.8

Volume II of this Conference in three editions, English, French and Spanish, was issued. This volume contains the summary records of the Conference and the technical papers submitted.

World Cartography, Volume IX, October 1969

Sales No.: E.F.69.I.7

This publication covers four articles as follows: (*a*) The potential of geometric satellite triangulation for establishing continental geodetic control; (*b*) a unified plane co-ordinate reference system; (*c*) general organization, execution and cost of cartographic work; and (*d*) cartographic aspects of geomorphological surveys in relation to development programmes.

World Cartography, Volume X, November 1970

Sales No.: E.70.I.4

This publication covers: (*a*) The status of world topographic mapping; (*b*) A guide to standard technical specifications for aerial photography.

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