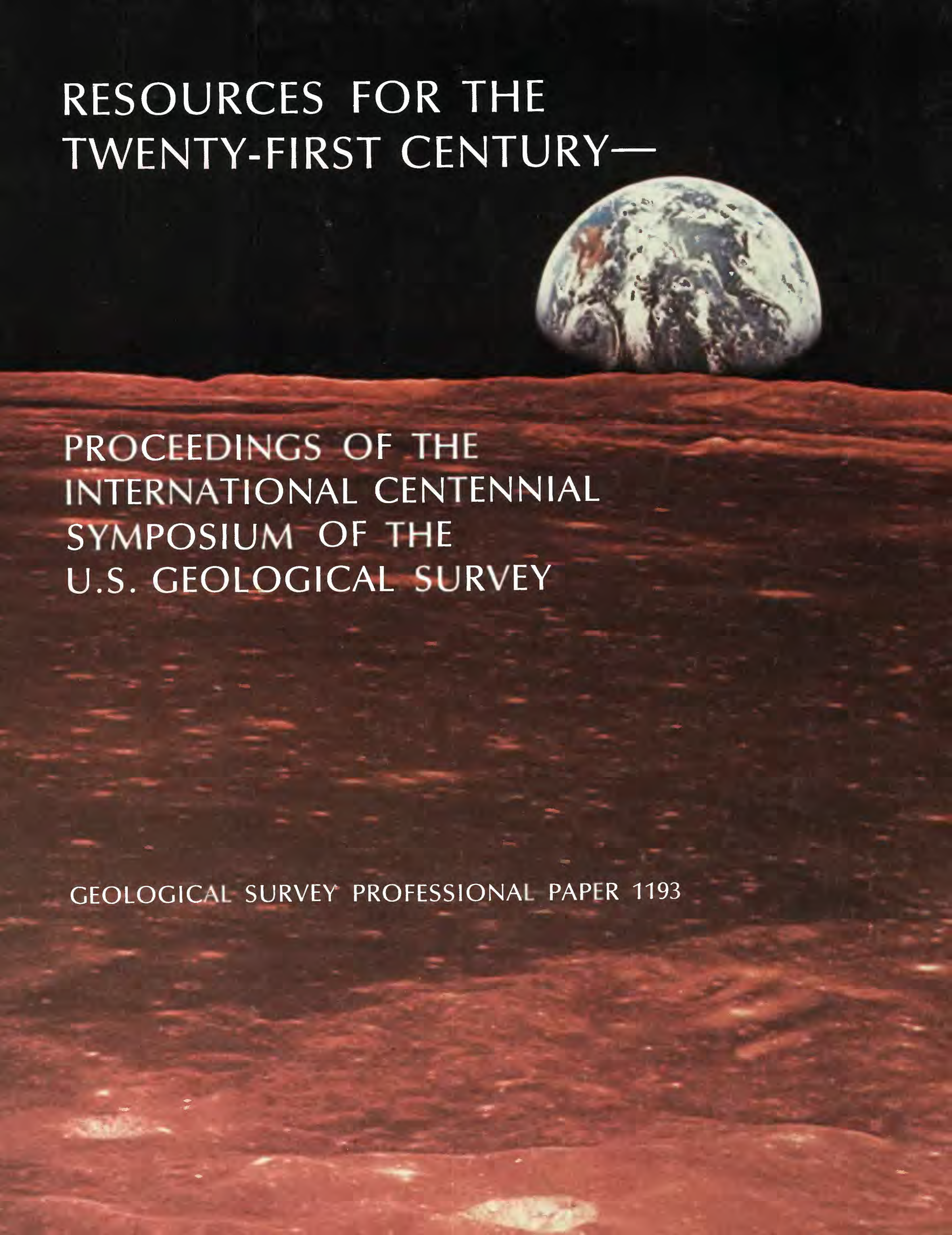
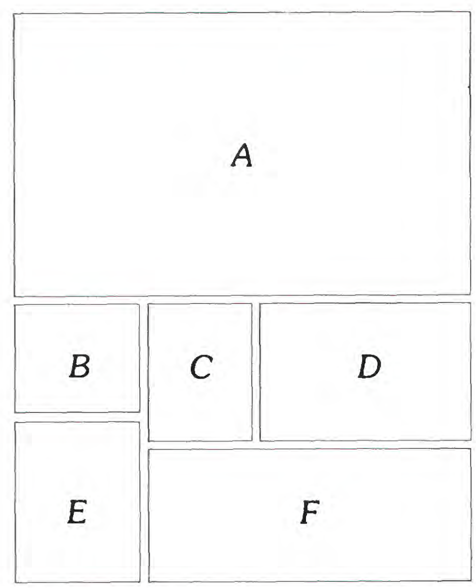
RESOURCES FOR THE TWENTY-FIRST CENTURY—

PROCEEDINGS OF THE INTERNATIONAL CENTENNIAL SYMPOSIUM OF THE U.S. GEOLOGICAL SURVEY



GEOLOGICAL SURVEY PROFESSIONAL PAPER 1193

Cover: Earthrise—An astronaut's view of Planet Earth, across the heavily cratered far side of the Moon. The geologically dynamic Earth contrasts sharply with the inertness of its nearest neighbor. Apollo 11. NASA photograph no. 69 HC 905.



Title Page: *A*, View looking southeast at an early stage of the eruption of Eldfell volcano on the island of Heimaey in the volcanic archipelago of Vestmannaeyjar, Iceland. In this oblique aerial photograph taken in late January 1973, tephra falls and lava flows have already begun to bury or to burn buildings in the eastern part of the fishing port of Vestmannaeyjar. Approximately one-third of the town was destroyed by the time the eruption ceased in early July 1973. Photograph credit: Landvernd, Reykjavík, Iceland. Photographer: Sigurjón Einarsson (no. 9 in the slide set "Myndun og Motun Landsins," Skyggnur Landverndar 2). *B*, Poverty intensifies geologic disasters. In this village, all the adobe structures were destroyed by the 1976 Guatemala earthquake, whereas more modern structures showed little damage. Photograph by Samuel Bonis, Instituto Geográfico Nacional, Guatemala. *C*, Drought in northeastern Brazil. Photograph by Gordon Gahan, National Geographic Society. *D*, Guajiro Indians harvesting sun-dried salt at Manaure, Colombia—the last unmechanized flats of the national salt industry. Photograph by Loren McIntyre, National Geographic Society. *E*, Laying an oil pipeline in Colombia. Photograph by Loren McIntyre, National Geographic Society. *F*, The first geothermal well on Federal land, at Geysers geothermal field, northern California.

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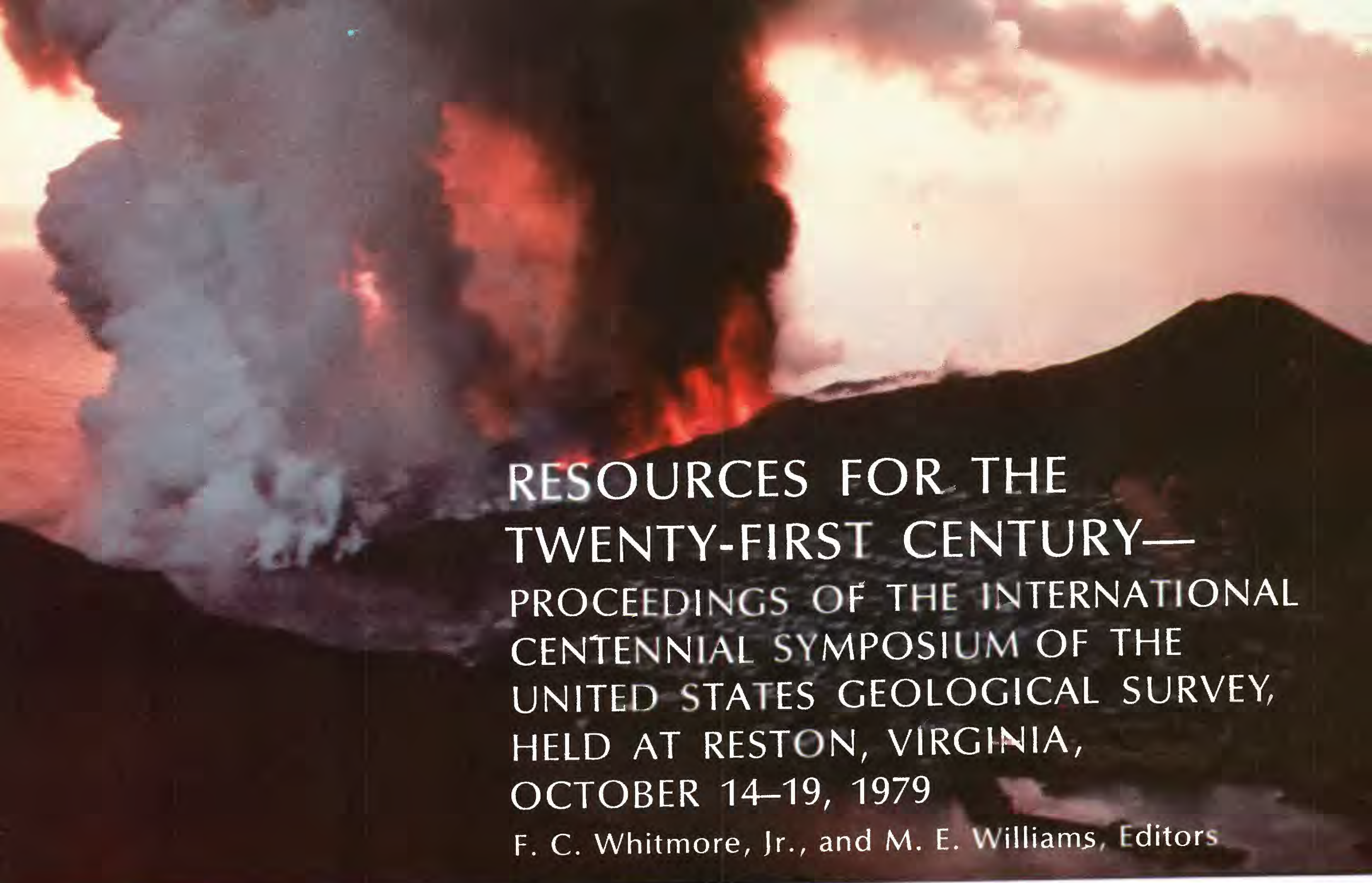

RESOURCES FOR THE TWENTY-FIRST CENTURY—

PROCEEDINGS OF THE INTERNATIONAL CENTENNIAL SYMPOSIUM OF THE UNITED STATES GEOLOGICAL SURVEY, HELD AT RESTON, VIRGINIA, OCTOBER 14–19, 1979

F. C. Whitmore, Jr., and M. E. Williams, Editors

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Foreword

In observance of its hundredth-year anniversary, the United States Geological Survey sponsored the International Centennial Symposium: Resources for the Twenty-first Century, held at its National Center in Reston, Virginia, between October 14 and 19, 1979. Papers were presented by fifty-six invited speakers from twenty-four countries and nine international agencies. In the course of the Symposium sessions, invited discussion leaders presented their comments, which were followed by discussion from the floor.

The concept of an international symposium was enthusiastically supported by Director H. William Menard. The Symposium program was designed, and the speakers were selected, by the International Activities Committee of the Geological Survey, under the chairmanship of John A. Reinemund with the guidance of Assistant Director James R. Balsley. Each speaker was assigned a subject, but was free to develop it as seemed appropriate. Thus the papers presented here reflect a wide variety of approaches and points of view and, not surprisingly, some differences of opinion.

The formal comments of the discussion leaders were prepared after reading advance copies of the papers. In addition to these, we present transcripts of panel discussions and discussions from the floor. The latter have been edited to give continuity and to emphasize the most pertinent points. These transcriptions have been read by their authors after editing.

In preparing the papers for publication it has been necessary, of course, to introduce some formality into their organization. We have, however, tried to retain the individuality of expression and the atmosphere of informal exchange of information that prevailed during the Symposium.

We are grateful to the speakers for their contributions, which add up to a broad and thoughtful look at the resource problems that face us. The task of many authors was made more difficult by our request that their papers be presented in English, and we thank them for their gracious acceptance of this.

We thank George Cohee, George Ericksen, Walter Hays, Della Laura, Charles Masters, and Morris Thompson for technical review of papers in their fields of specialization. We are indebted to Patrice LaLiberté, who has contributed her knowledge at all stages of the work, from copy editing to book design.

Frank C. Whitmore, Jr.
Mary Ellen Williams
Editors

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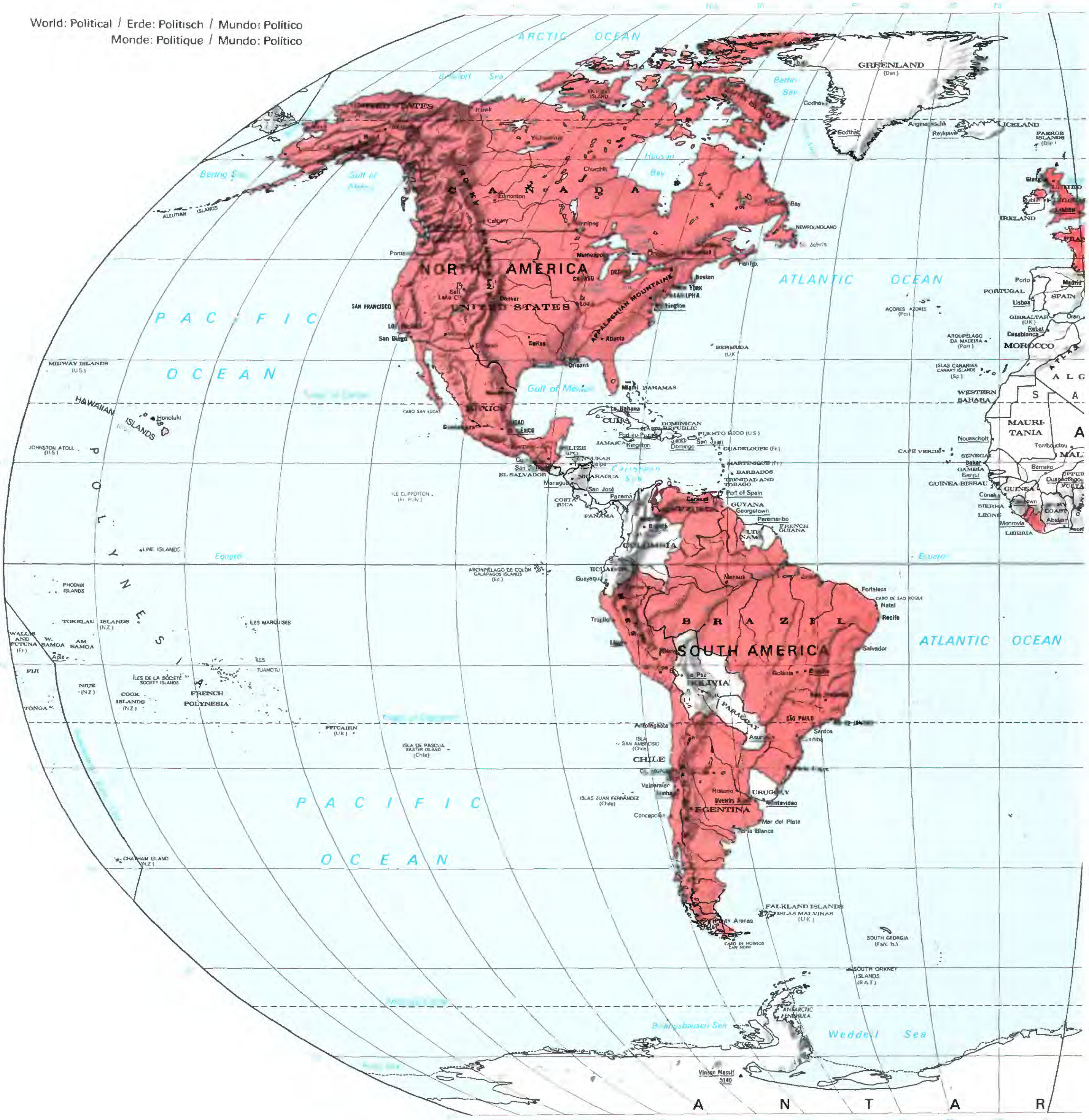
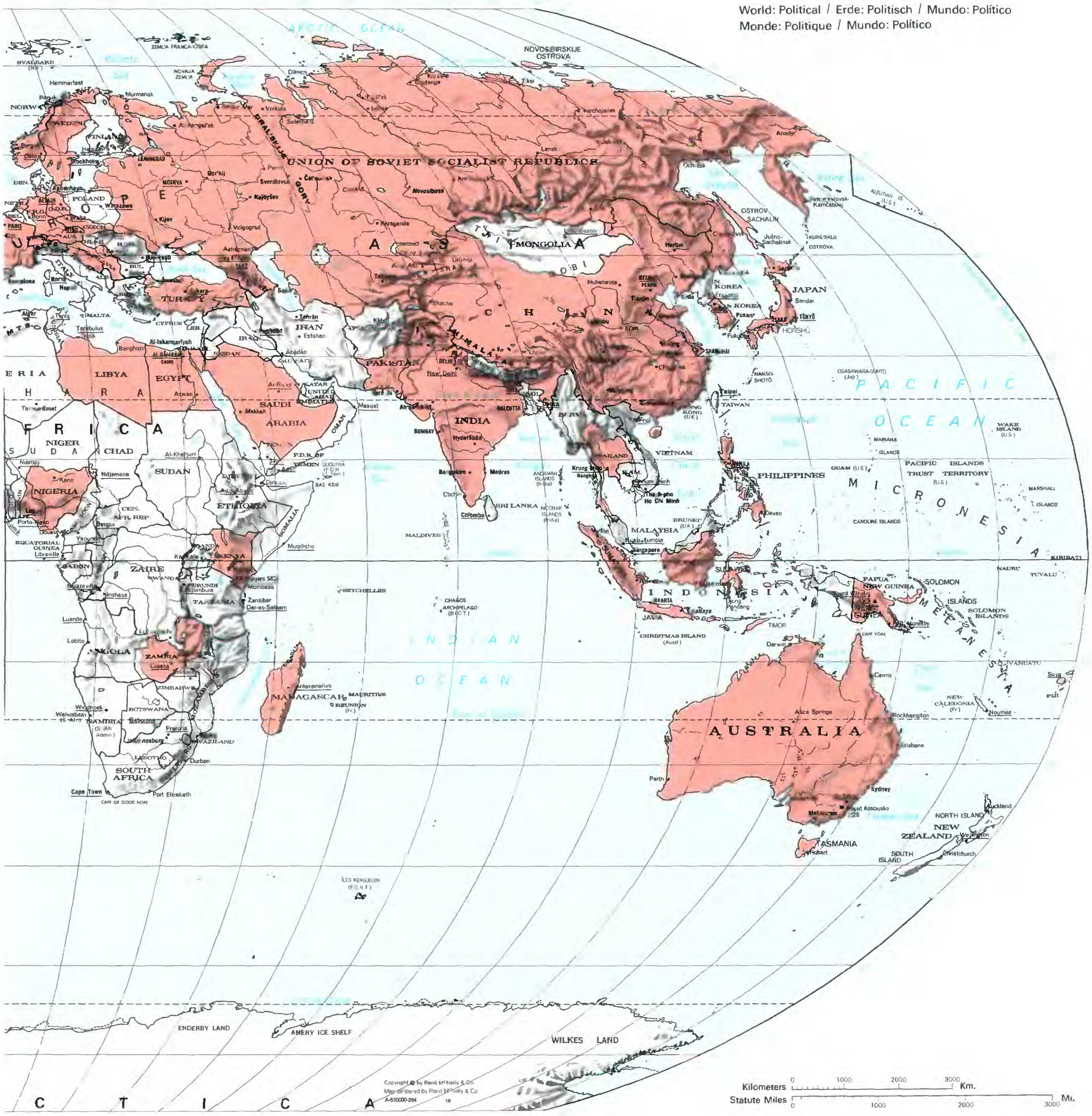
GEOLOGIC FACTORS AND THE ENVIRONMENT

The usual standards for the U.S. Geological Survey Professional Paper series have been modified to accommodate the variety of styles used by the participants in this symposium.

World: Political / Erde: Politisch / Mundo: Político
Monde: Politique / Mundo: Político





Map showing countries represented by speakers and delegations at International Centennial Symposium, United States Geological Survey. Adapted from Political World Map (Robinson projection), copyright by Rand McNally & Company, R. L. 80-Y-70.

Scope of Earth-Science Challenges for the Twenty-first Century

The International Centennial Symposium: Background and Objectives

Frank C. Whitmore, Jr.
U.S. Geological Survey

Welcome to the United States Geological Survey. We are happy that you have come to help us celebrate our hundredth year, for it is your presence that gives this occasion more than a mere symbolic meaning.

As Geological Surveys go, we are not ancient; many of you represent organizations that are older than ours. But the hundred years of our existence have been among the most challenging and unsettling in all of history, not least in the changing relations—or changing of awareness of relations—between Man and his Earth.

The United States Geological Survey was founded because of the desire of our people to know what the lands of our West were like. The motivation was pragmatic; we were an expanding Nation that foresaw the need for knowledge of agricultural land and mineral products as well as of the topography of country to be traversed by road and rail. The methods of survey were not new: the USGS was an extension of earlier Government surveys, which in turn drew on the experience of the older surveys of Europe, and upon our own State Surveys, many of which predate the USGS.

In the past century, the Survey's activities have, naturally, changed with the interests and needs of our country. We have gone from exploration to detailed mapping, from simple to complex analytical procedures; we study commodities unheard of a century ago. An important part of our work today deals with our environment: our effect upon it and its effect on us. We are proud that for us this is no new concern: our second Director, John Wesley Powell, was similarly aware of the environment, often to the point of enraging his opponents—and this still goes on, I'm sure. But Powell, though a prophet, was limited in scope to his own country. Earlier in our history, as in the Wilkes Expedition of 1838–1842, the United States had undertaken exploration outside our borders. But the opening of our West to settlement, and our ignorance of that vast area, dictated that the new Geological Survey concentrate its efforts within the United States. The little-known West had already produced gold and silver, and the impetus to further mineral exploration was great.

In the developing countries at that time, of which the United States was one, there was a tendency to regard resources as limitless; all we had to do was find them.

In the last hundred years, by contrast, we have become aware of the finite nature of our resources and of the degree to which the world environment affects us all without regard for national boundaries. Thus, interdependence became the theme for this symposium. Earth scientists must furnish the information on which planning for the future depends. Our interdependence is thus intellectual: we must share our ideas, which gain value because they have been developed under such widely different conditions and in so many parts of the world.

In this symposium we will look into the future together through the eyes of experienced and thoughtful speakers. It is our hope that the papers presented will form the basis for discussion both formal and informal, not only this week but in future, as we face the Twenty-first Century together.

We all owe thanks to John A. Reinemund, and the International Activities Committee of the U.S. Geological Survey, for originating and organizing this program.

Frank C. Whitmore, Jr.
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Welcoming Remarks: Interdependence of Nations and the Influence of Resources Estimates on Government Policy

H. William Menard
Director, United States Geological Survey

It is my pleasure as Director to welcome you to this International Centennial Symposium, and to express the hope that all of you will find your stay both pleasant and productive. My 14,000 associates and I are delighted—and highly honored—that you have come here from all parts of the world to attend this symposium convened in observance of the U.S. Geological Survey's one hundred years of probing the mysteries of this small planet that we all share. We are glad you can be with us!

By my count, we have 44 countries on six continents represented here this morning. You are delegates of more than 3,000 million people living on 37 million square miles (96 million square kilometers) of the Earth's crust. The dimensions of our discussions are thus truly global in scope; the topics we shall address transcend the boundaries and concerns of individual states. Shared knowledge and cooperative action will be required to solve the common problems that beset us as we contemplate the demands that will be made upon the earth sciences in the coming century.

The notion of interdependence in scientific matters is not new. No individual or nation has a monopoly of scientific truth on any subject, and for centuries the exchange of knowledge among scientists living in all parts of the world has been one of the great unifying forces of civilization. Thus the U.S. Geological Survey has from its very beginning entertained an active interest in earth science matters throughout the world, as evidenced by the innumerable exchanges between our scientists and their contemporaries in other countries through correspondence, visits, meetings, and the flow of literature.

In recent years we have institutionalized many of our relationships with scientists and scientific groups in other countries on a government-to-government basis, so that we now have agreements of one sort or another covering our services to more than a hundred countries. Some of these relationships have continued to flourish long after the occasion that brought them into being has faded into history. They have done so in part because of the demonstrated benefits that accrued to all parties to such arrangements, and lately, I submit, because of a gathering sense of apprehension over the continued availability of mineral resources that plainly will be needed by the world's growing human community.

That human community to which we all belong has grown from 2,500 million in 1950 to 4,200 million today—an increase of 70 percent. But of much more significance, the material demands of our community have grown even faster. World trade has increased by 570 percent; world energy production has increased more than five-fold on a tonnage basis; the value of manufactures, mostly of mineral origin, is today more than ten times what it was in 1950; and real prices of raw materials have been rising since the middle of the last decade.

These numbers have a sinister look about them. But the world has repeatedly been frightened before by the specter of scarcity, particularly in the case of exhaustible resources, only to discover its forebodings to be groundless as shortages regularly gave way to surpluses just when it appeared that only lean years lay ahead. Still, there remains the troubling reality that minerals *are* finite, coupled with the knowledge that in the 35 years since the close of World War II man has consumed more minerals than in all his previous history. The outlook is for continued increases in demand while we are having difficulties in supplying current requirements. Thus intense interest has focused on the future prospects of many mineral commodities. Specifically we are interested in knowing how much of each commodity we may plausibly expect beyond the supplies that are presently visible as proved or economically producible reserves. More to the point, we need to know how much is likely to be available under specified economic and technical conditions, both from known subeconomic sources and from sources yet to be discovered. We also need to have some indication of the confidence with which such estimates are made.

The answers to these questions are firmly embedded in a complicated matrix of economic, technological, political, legal, and logistical conditions that require the application of a broad range of professional skills to obtain a proper understanding and evaluation. Geology is only one of these contributing disciplines, but its role is critical. The entire process begins with the geological estimate of resources in place and the geological interpretation of the nature and circumstances of their occurrence. Until something is known about the magnitude and quality of a mineral resource, and where and how it might be found, no useful calculation can be made as to the amount that may eventually become available for use, the rate at which it can be produced, or what its cost and value may be.

As I have already mentioned, attempts to estimate the extent of undiscovered mineral resources have been made from time to time by a variety of methods, many of which ranked somewhere between tea leaves and Tarot cards in their effectiveness as forecasting tools. Until recently these predictive deficiencies have not mattered greatly because the prevailing market condition for most commodities most of the time has been one of surplus. Thus the conclusion expressed by the U.S. Geological Survey's Chief Geologist in 1920 that crude oil production in this country would probably never reach as much as 450 million barrels (60 million tonnes) annually was quickly mooted because with a yield of 472 million barrels (65 million tonnes) production handily exceeded that figure in the very next year (White, 1920).

But the signs of scarcity have now been with us long enough to warrant serious attempts to ascertain the remaining stocks of the world's mineral resources—the energy minerals in particular. We need to do this because governments tend to formulate policies based on perceptions about the relative abundance of vital resources. These policies aim at forcing or inducing specific events to happen in regard to exploration for particular resources, substitution of one material for another, conservation and re-use, and other actions that can have profound impacts on resource costs, life styles, and the physical environment—not to mention the relationships between the government and its citizens. The policies can be only as good as the perceptions on which they are based, and the perceptions in turn can be only as good as the estimates of resource availability and cost from which they are formed.

The history of oil development in the United States provides a number of examples of how varying perceptions about the state of the nation's oil reserves have guided—and misguided—national policy toward oil for the past seventy-five years (fig. 1).

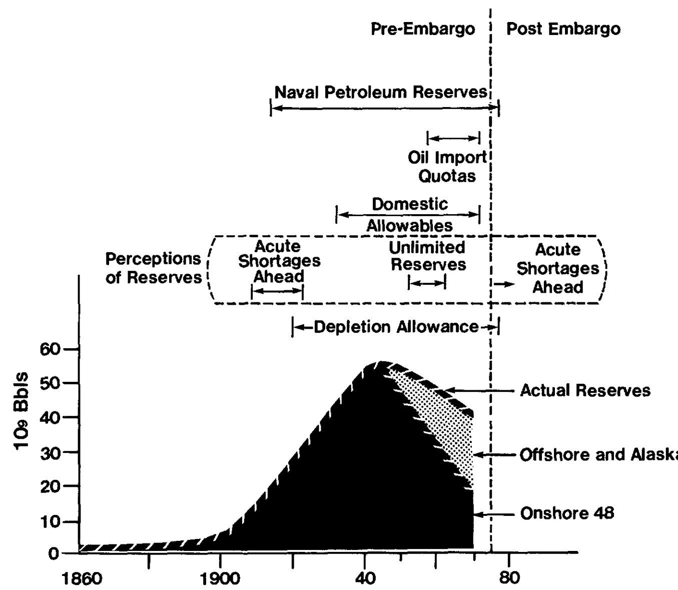

Figure 1 Petroleum reserves and national policy.

The first noticeable perception, formed in the early years of the present century, was the familiar one of looming shortages. It was induced by a combination of factors, including the boom-and-bust cycle of individual field production, the lack of credible data on how much oil remained and where it might be found, and the visibly rising demand for oil as a source of heat and power. This period of apprehension lasted for about 15 years—from 1908, when it was widely publicized at a White House conference of State Governors called by President Theodore Roosevelt (1908, p. 7–8) until after 1920, by which time the petroleum industry began to find so much oil that the prophets of doom were eventually drowned in the surplus that accumulated. But during this interval it appeared that no one outside the petroleum industry (which knew better) could bring himself to believe that the nation's oil supplies could possibly last for more than a few more years.

Meanwhile, unbeknown to anyone at the time because data were then unavailable, reserves—obtained as the difference between cumulative discoveries and cumulative production—continued to rise briskly; paradoxically, the higher they rose the gloomier became the forecasts of the estimators. And small wonder, for the true extent of the oil that would ultimately be found in the already-discovered fields would not, and could not, be known for many years. Contemporary estimates (1920 to 1940) were made before subsequent drilling extended field limits and found new pools within existing limits, and before new technology vastly increased the recoverable fraction of oil in the ground. Estimators naturally fell far short of crediting the fields then known with the full potential they would later develop. It was not until relatively recently—with the benefit of many years of history—that it became possible to know, for example, that ultimately recoverable oil from fields discovered by 1920 exceeded cumulative production to that point by 30,000 million barrels (4,100 million tonnes) and that accordingly a "reserve," partly actual but mostly potential, had thereby been created. This level was about 70 times the volume of oil actually produced in 1920.

But, with the valor of ignorance, government policy reflected the pessimism of the estimators. Even as the hidden reserves of oil continued to grow, the Federal government set aside four large areas of public lands to be maintained as petroleum reserves for the use of the Navy in the period of expected scarcity (fig. 1). In 1912 Naval Petroleum Reserves Numbers 1 and 2 were created in California; in 1915, Reserve Number 3 in Wyoming; in 1923, Reserve Number 4 in Alaska; on April 5, 1976 (Public Law 94-258, U.S. 94th Congress), Reserve Number 4 was designated the National Petroleum Reserve in Alaska (NPRA). On June 1, 1977 it was transferred by the Congress from the Department of the Navy to the Department of the Interior for exploration, appraisal, and development. During these same years, U.S. tax laws were amended to provide incentives to explore for new reserves, permitting, for example, the deduction of a percentage of gross income as an allowance for depletion and the expensing of intangible drilling costs. American oil companies were also encouraged to go abroad in their search for new supplies in other parts of the world. The result was that by 1930 oil was in surplus everywhere and the principal oil-producing states found it expedient to adopt a system of market sharing among oil producers. This system was based on allowable production rates for each well, along with other measures aimed at stabilizing prices and preventing physical and economic waste.

Despite these attempts to control production, the oil glut prevailed, subsidized ironically by the percentage depletion allowance and by the drilling and production regulations that encouraged the acquisition of excessive productive capacity even more than the addition of new reserves. This was the situation until well into World War II, when the greatly expanded demand for petroleum products finally ate away the surplus. It was quickly restored by renewed exploration and development following the war, and the difficulty was soon compounded by the appearance of large volumes of low-priced oil on the world market, much of it from the vast newly-opened fields of the Middle East.

Once again the country was awash in surplus oil, and the State allocations imposed on domestic production were supplemented in 1959 by Federal quotas levied on oil imports. In the name of national security, it was argued, the Nation could not afford to become excessively dependent on foreign oil. Better to protect the market for high cost oil produced at home and thus preserve a vigorous industry that could be depended upon to supply all future needs from the vast undiscovered resources yet to be tapped in our own country.

Even as this argument was being made, however, the premises on which it was based were steadily eroding. Production had begun to outpace discoveries by 1941, and reserves, defined earlier as the difference between the two, had begun a long decline that was not publicly recognized until 1970, when domestic production reached capacity and thereafter began to decline. The State-imposed allocations disappeared, as did oil import quotas, and three years later the shock of the Arab oil embargo, combined with the obvious and growing shortages of both domestic oil and gas, finally brought public perception back full circle to the apprehensions of shortage that had been widespread a half century before.

Thus, for better or worse, national policy toward mineral resources is shaped by estimates that must be made of quantities that can neither be seen nor measured, and much confusion has resulted from the fact that these estimates by highly respected professionals in the field frequently disagree by wide margins. Often these divergent conclusions can be reconciled by painstaking analysis, but generally not in terms that are especially useful in resolving the controversy or contributing much to public understanding of the differences.

One such imbroglio was the long-standing disagreement between the estimates of undiscovered petroleum potentials published by various U.S. Geological Survey scientists and those of Dr. M. King Hubbert, an acknowledged authority on petroleum matters. Ironically, Hubbert came to work for the Survey at the peak of the controversy between him and that agency, and continued in its employ until his retirement 13 years later. All the while he vigorously promoted his model and method against a succession of estimates made by his associates.

Hubbert's model hypothesized that the production and discovery history of an exhaustible resource such as petroleum roughly approximates a logistic curve, rising exponentially from zero to a peak, and thereafter declining exponentially back to zero. The path of this curve can be calculated once sufficient history has been acquired, and future production and discovery rates can be ascertained for every succeeding year to exhaustion. Ultimate production can be determined by measuring the area under the curve, and future discoveries can be ascertained by subtracting past production and current reserves from the total (Hubbert, 1962). The Hubbert model thus purports to include all factors—technological, economic, social, and political—that bear upon oil discovery and production through the complete cycle, from beginning to end.

The study done by Hubbert in 1962 for the National Academy of Sciences led him to conclude that approximately 175,000 million barrels (24,000 million tonnes) of crude oil would ultimately be produced from the United States and its continental shelves (excluding Alaska). Of this total, 99,000 million barrels (13,500 million tonnes) had already been discovered, leaving 76,000 million barrels (10,500 million tonnes) to be found in the future (Hubbert, 1962, p. 72). A second model, developed in 1967 as a corollary to the first, described the rise and fall of crude oil discoveries per unit of exploratory drilling over the history of the petroleum industry in the lower 48 States of the United States (Hubbert, 1967). Figure 2 depicts the widely varying success rates experienced between 1860 and 1971.

The models of all the other Geological Survey scientists (except for the most recent study by Miller and others, 1975) were patterned in one way or another after the hypothesis advanced by A.D. Zapp (1961). He related the volume of oil that would ultimately be discovered to the amount of drilling that would be necessary to test the entire area of the United States that is covered with sedimentary rock. This unpublished report to the National Research Council dealt only with the 1,860,000 square miles (4,560,000 square kilometers) of such rock in the United States and its continental shelves, exclusive of Alaska. Zapp estimated that some 5,000 million feet (1,525 million meters) of exploratory drilling would be required to test the area of sedimentary rock to an average density of 1 well for each 2 square miles (5.2 square kilometers). He further estimated that by 1960 some 130,000 million barrels (17,800 million tonnes) of crude oil had been discovered by a total of 1,100 million feet (335 million meters) of exploratory drilling completed as of that date, indicating that an average of 118 barrels per foot (53 tonnes per meter) had been discovered during the first hundred years of exploratory drilling in the United States. At this rate, drilling the full 5,000 million feet (1,525 million meters) could be expected to discover a total of 590,000 million barrels (81,000 million tonnes) of crude oil. According to Zapp's calculations, 300,000 million barrels (41,000 million tonnes) of those 590,000 million barrels would be economically recoverable and an additional 290,000 million barrels (40,000 million tonnes) were classified as submarginal under technological and economic conditions then existing (Hendricks, 1965).

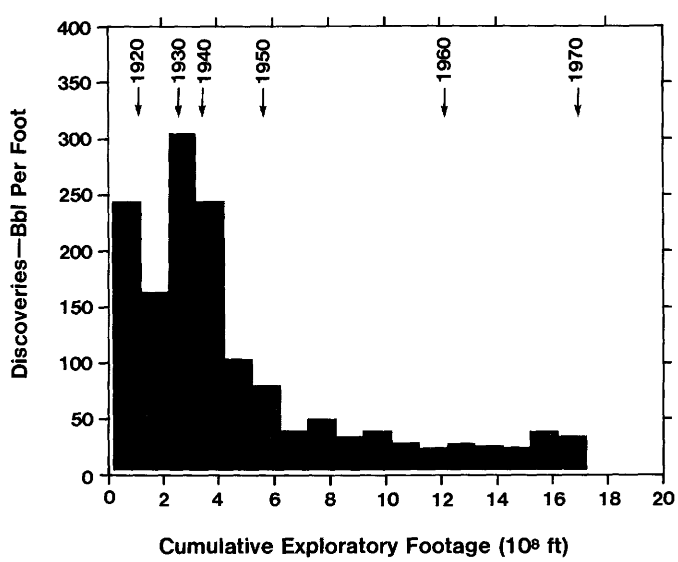

Figure 2 Crude oil discovered in the United States per foot of exploratory drilling, 1860–1971. (Success rates are given for only the lower 48 States.)

Subtracting the 130,000 million barrels (17,800 million tonnes) already discovered from Zapp's 300,000 million total for economically recoverable oil left 170,000 million barrels (23,200 million tonnes) remaining to be discovered and produced in the future. Calculated on the assumption that the undrilled portions of the United States would prove equally as productive as the drilled areas, this amount was a multiple of the 76,000 million barrels (10,500 million tonnes) that Hubbert subsequently considered as remaining in the same area when he based his 1962 study on calculations of exponentially declining discovery rates.

Figure 3 compares the two predicted discovery rates with each other and with the subsequent experience of the petroleum industry. Later modifications of Zapp's estimates and methodology made by Geological Survey scientists V.E. McKelvey and D.C. Duncan in 1963 and T.A. Hendricks in 1965 (which included Alaska) resulted in predictions of 200,000 and 300,000 million barrels (27,400 and 41,000 million tonnes) of undiscovered recoverable crude oil, respectively (Hendricks, 1965). A later estimate made by S.P. Schweinfurth yielded a total (as of 1970) of 350,000 million barrels (48,000 tonnes) of undiscovered recoverable petroleum resources. This revised estimate included figures on both the crude oil and natural gas liquids remaining to be found in the conterminous United States and their margins out to a water depth of 2,500 meters (Theobald and others, 1972). By March 26, 1974, the Survey had retreated substantially from Schweinfurth's high figure, giving a range of 145,000 to 290,000 million barrels (20,000 to 40,000 million tonnes) for undiscovered petroleum liquids yet to be found in the United States and its continental margins to a water depth of 200 meters (Department of the Interior, news release). The following year the Survey abandoned the Zapp approach and released the results of a systematic basin-by-basin assessment of recoverable oil content which further reduced the figures for undiscovered recoverable crude oil in the 48 conterminous States and their continental margins to a range of 36,000 to 81,000 million barrels (4,900 and 11,000 million tonnes), with a mean value of 55,000 million barrels (7,500 million tonnes) (Miller and others, 1975).

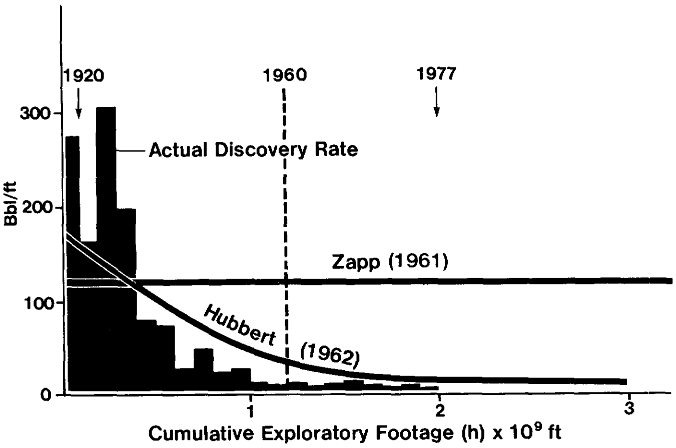

Figure 3 Hubbert vs. Zapp forecasts and consequences.

For all their differences, Hubbert's predictions and the divergent estimates of other Survey scientists have this much in common: both were concerned with gross amounts of recoverable oil believed to be contained in sedimentary rock in the area defined in the estimates. Neither dealt with the distribution of the oil by field size, or, except by implication, with the efficiency of the search effort directed to its discovery. Some worthwhile insights may be gained from analyses of these two factors.

Figure 4 presents a comparison of petroleum industry discovery experience with a random search under certain hypothetical conditions focusing on giant oil fields found in the onshore portion of the 48 conterminous United States. A giant field is determined in the United States to mean containing at least 100 million barrels (13.7 million tonnes) of ultimately recoverable oil. On figure 4, discovery success is plotted as an expression of the area of giant fields found per unit of exploration delineated in increments of 100,000,000 feet (30,500,000 meters) of exploratory drilling and named Hubbert Units after King Hubbert, who first devised these convenient units of measurement.

For the purpose of the exercise, the historical data on giant field discoveries were organized chronologically, so that the area of giant fields actually found could be ascertained for each successive Hubbert Unit. This was done throughout the full sequence of 14 units totalling 1,400 million feet (427 million meters) that were drilled between 1860 and the end of the series in 1963.

The heavy black line in figure 4 depicts actual discovery experience, while the shaded area represents the envelope formed by the results of ten computer simulations of random drilling over the same area as that actually prospected by the petroleum industry. Except for the first two Hubbert Units, the record of the industry and that of the random searches reveal similar patterns of discovery success. To this basic model are added varying assumptions about additional amounts of oil which might exist in the search area over and above the amount actually discovered. These values are represented by the four generally parallel lines near the top right-hand area in the figure. The values given are estimates for total undiscovered oil, projected from results obtained for giant fields and assuming that since giant-field discoveries have contained 58 percent of total oil found in the past, they will continue to do so in the future. Taking the bottom parallel line, for example, assume that 10,000 million barrels (1,370 million tonnes) of oil remained undiscovered at the end of the 14th Hubbert Unit. If 58 percent of this oil was contained in giant fields, a random drilling program would have discovered more area of giant fields than the industry actually did in each Hubbert Unit. The initial difference, say at the 4th Hubbert Unit, is relatively small: the random search would have discovered not quite twice as much area as industry. As the search proceeds, however, and as the number of remaining giant fields is reduced by discoveries, the difference widens rapidly so that the random search from Hubbert Units 9 to 12 would be at least twenty times as successful as the industry's record. If the remaining undiscovered oil were as much as 100,000 million barrels

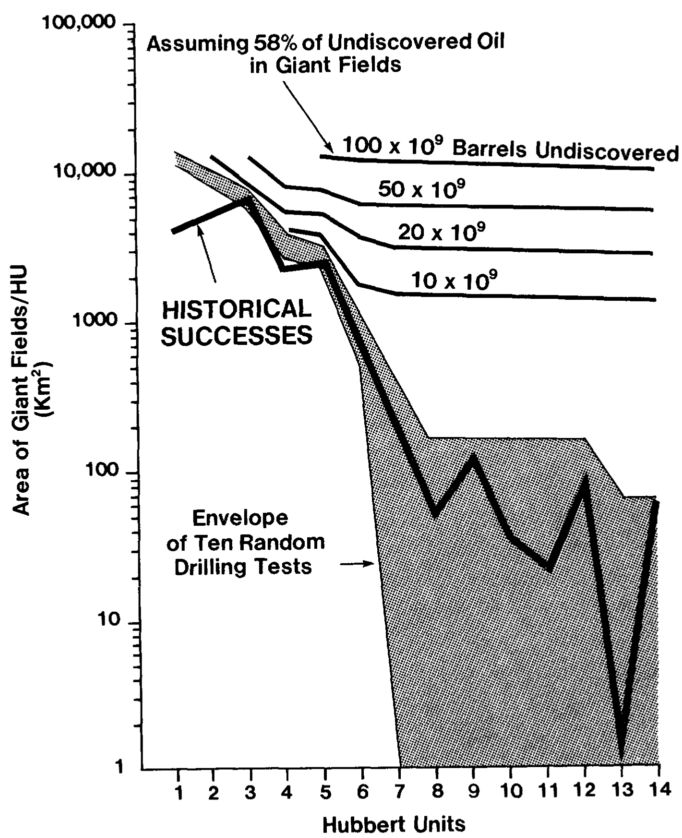

Figure 4 History, forecasts, and random drilling models. (In the United States, a giant field is defined as one containing at least 100 million barrels of ultimately recoverable oil.)

(13,700 million tonnes), the random search would be some 200 times as successful as the industry experience.

Since blind chance appears to do so much better than directed choice, one is tempted to conclude either that the giant fields implied by the postulated reserves do not exist, or that the industry is systemically looking for them in the wrong places. If the latter, then there must be social, political, and economic factors that counterbalance the industry's demonstrated technical capability for locating hydrocarbon traps. One conclusion that could be drawn from such a balance of influences is that the net effect of all professional effort comes to zero.

One reason (besides common sense) for believing that economic factors enter into exploration decisions is the differing discovery rates for different sized fields. Figure 5 shows the varying discovery success rates for different sized fields expressed as the number of oil and gas fields discovered per 10 million feet (3.05 million meters) on new field wildcat drilling; that is, drilling directed at finding discrete new fields rather than at discovering new reserves in existing ones. The size classifications are those adopted by the American Association of Petroleum Geologists, which has recorded annual discoveries of each class since 1945. (Discoveries are reported annually under "North American Developments," usually in the August issue of the AAPG Bulletin.) Class A fields are those expected to produce more than 50 million barrels (6.8 million tonnes) or 300,000 million cubic feet of gas (8,570 million cubic meters). Class B through Class E fields trend downward in capacity with Class E fields believed to contain less than 1 million barrels (135,000 tonnes) of oil or 6,000 million cubic feet (170 million cubic meters) of gas. In figure 5, the discovery rate charted for each field class reveals its own pattern of behavior. The rates for A and B, the two largest classes, have declined irregularly since 1945, and steeply since 1971. The Class C field rate has declined at a somewhat lesser rate, while the decline in discovery rates of the two smallest classes has actually been reversed since 1970.

The discovery rates for the three largest classes follow the conventional pattern for exhaustible resources: each discovery removes one target from the search area, thereby reducing the chances for additional discoveries by one. Where the universe is already small, as it is in the case of the larger deposits, a few years of successful exploration depletes the number of available targets fairly rapidly. This depletion is reflected in relatively steep declines in exploratory success. Even the small classes of fields show this characteristic decline over long periods, but the rate is much slower because of the much larger population to be depleted.

The turnaround in 1970 reflects an external factor, presumably economics. By this time, the domestic surplus of oil and gas had given way to shortage, and prices for both oil and gas had begun to rise—gradually at first, but

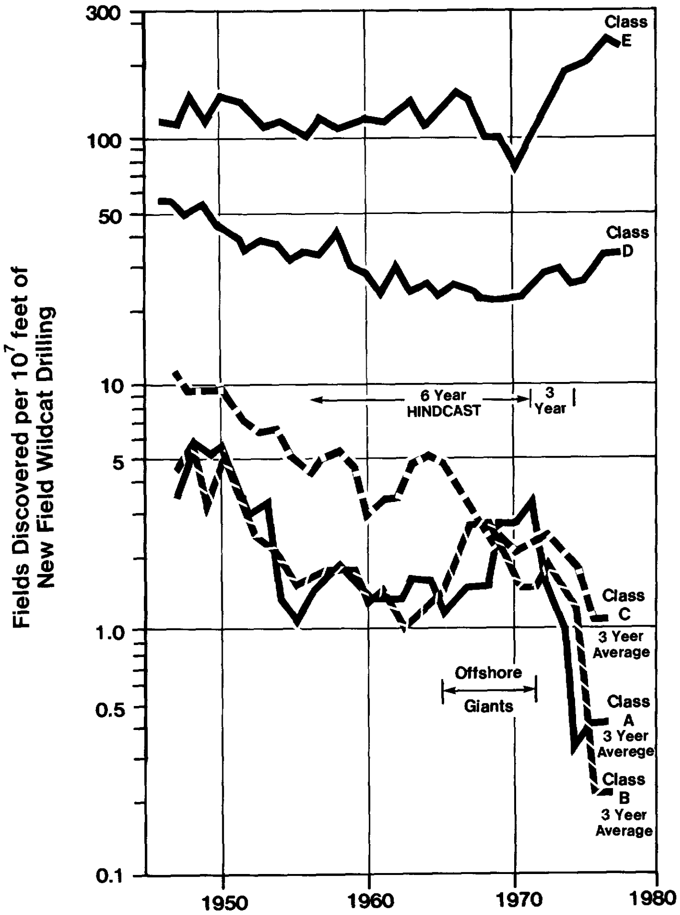

Figure 5 Success rate as a function of new field size. (Oil and gas discovery rates are shown for the entire United States.)

then in an increasing tempo until the rocketing rise in 1974. Newly discovered oil began to sell for three times its previous (1970) wellhead value, and gas could bring ten times the price it commanded a few years earlier. The result was that a lot of wildcat wells that would otherwise have been plugged and abandoned as failures became worth completing. Thus each "re-activated" completion added a new field discovery in one of the two smallest classes.

Figure 6*A* presents another aspect of the distribution of total reserves by field size. The five areas selected all show a characteristic normal distribution: the greatest number of fields tends to clump about the middle of the size range for each category. For example, in the United States, where the size of fields ranges from the insignificant to the single 10,000-million-barrel (1,370-million-tonne) Prudhoe Bay field, the largest grouping of fields is that between 100,000 and 1,000,000 barrels (13,700 and 137,000 tonnes) (area 2, fig. 6*A*). The limits at the high end are determined by geography and geology: these conspire to keep the number of very large fields to a few hundred

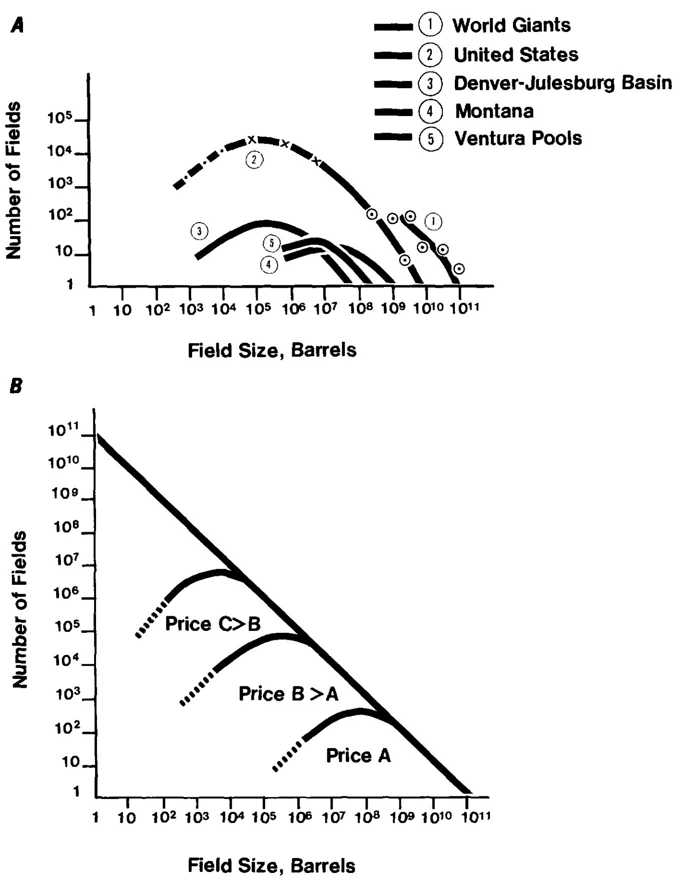

Figure 6 Size distribution of oil fields. *A*, Distribution of reserves by field size. *B*, Effect of price on number and size of producing fields.

(area 1, fig. 6*A*). The limits at the low end are set by economics. There are innumerable small pockets of oil and gas throughout the world, and how many become oil and gas fields is determined largely by price. The logarithmic scale (fig. 6*B*) shows this progression schematically.

It is almost an article of faith in the petroleum community that total reserves are a function of large fields. This has been true of the United States and it continues to be true of the world at large. But the future of oil discovery and production in the drilled-up interior of the contiguous 48 States will increasingly be a function of small field discoveries, made at steadily increasing cost—up to the point where other energy sources displace domestic oil and gas in the market. This suggests that most of the remaining recoverable oil and gas in this area will not be found in large fields, and that estimates of future discoveries based on the history of large field contributions have not taken this new fact into account.

It must be borne in mind that the history of petroleum discovery and production in the United States has been dominated by the occurrence and contributions of giant fields, which account for nearly 60 percent of all oil found and recovered in this country (Halbouty, 1970). The record, then, is the record of a mere handful (less than 300) out of more than 25,000 fields ranging in content from 10,000 million barrels (1,370 million tonnes) down to a few thousand. What the Hubbert model shows most clearly is the path traced by the petroleum industry as it proceeded to deplete, almost to exhaustion, this small population of highly lucrative targets. This was done under economic and technological conditions that were themselves shaped by the way in which these large concentrations of petroleum wealth were distributed.

To recapitulate: the Hubbert model is significant less for what it says about the *amount* of ultimate recovery than for what it says about the *rate* at which the petroleum resources of the United States will be found and produced, because when rate is recognized as the governing factor in discovery and production the value of the volume available for ultimate recovery ceases to be open-ended. Recovery becomes sensitive to economics and technology. For the Hubbert model the cycle ends at the point where the projection of historic economic and technological conditions against the diminishing numbers of the larger classes of fields reduces the return on new ventures to zero.

In contrast, Zapp and his successors deal only with the amount of resources postulated to be discoverable by specified amounts of exploration effort, arbitrarily supplying recovery factors as needed to obtain estimates of the recoverable portion. But these models speak not at all to the rate at which these resources will in fact be exploited, the time interval over which they become available, or the shape of the curve that describes the progress of future petroleum discovery and production. They are essentially open-ended—not only as to time, but with regard to the economic and technological conditions assumed for them as well.

Thus, in the context of sharply rising real prices for oil and gas to levels never remotely approached so far in the 20th Century, it now becomes possible to envision a greatly extended tail to the classic discovery-production curve under which the small contributions of many small fields over many years add to totals that are large in the aggregate. With an extraordinary commitment of time and effort, whose plausibility is suggested by the rapidly escalating costs, not just of oil, but of all forms of energy, the volume of oil ultimately found and produced in the United States now and in the 21st Century may eventually approach the predictions of Zapp and his colleagues. But it will take a long, long time!

Thus, national policy toward mineral resources has been and will continue to be dependent upon estimates of remaining recoverable supplies. National oil policy is only one facet of this many-sided problem of how nations, separately and in concert, can most effectively deal with their rising resource requirements. Policy toward breeder reactor development depends, among other considerations, upon our assessment of the future supply of uranium. Is there enough to last at projected rates of consumption, until safe and acceptable breeders can be put into operation? The answer will influence both the pace of breeder development and the relative balance between coal and nuclear energy as sources of electric power. Similarly, national policy toward the resources of the deep sea floor must first consider what they are, where they are, and how their value compares with similar resources onshore. Research and development policy aimed at bringing high cost energy substitutes to market must continually take account of the potential remaining in conventional resources.

Crude and uncertain as they may be, mineral resource estimates are essential ingredients of national policy. There are no substitutes available, and the only responsible action one can take toward them is to continue the pursuit of knowledge that will bring each successive estimate closer to the truth. It is to this goal that the efforts of the U.S. Geological Survey have been dedicated throughout the first century of its existence, and I can think of no more worthy cause to absorb its energies in the second.

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Greetings from the National Academy of Sciences

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I bring greetings to the United States Geological Survey from the National Academy of Sciences and congratulate both the Academy and the Survey on our mutual success over this past century.

I try never to be a poseur, although the nature of my current post is such that I frequently find myself affecting expertise in areas concerning which I know almost next to nothing. I will not do that to you this morning. You are the earth scientists, I am not. I am a biochemist.

Accordingly, I would like to say just a few words which may put our mutual efforts into a kind of perspective. Most of the history of science proceeded along a rather leisurely path. It was not very expensive; it involved relatively few people. It consumed very little in the way of resources. Slowly, it changed its character. World War I made the first big difference. Until that time, it had never been thought that the pursuit of science, in and of itself, is a responsibility of a nation-state. There were scientific enterprises already in being, such as the U.S. Geological Survey, for specific and relatively narrowly conceived purposes. But until World War I the idea had never been seriously considered that accumulation of scientific understanding of the natural world, of itself, is a formal responsibility of the state.

World War I somewhat changed that. It was the first technical war and nations began to think in some what different terms. But it was World War II that genuinely gave impetus to the scientific enterprise of the world as we now know it.

For the United States, our credo was expressed in a small volume called "Science, the Endless Frontier," by Vannevar Bush (1960). For the first time, it was clearly stated that the accumulation of scientific understanding is worthy of support with public funds and that the principal reason for so doing is a shared belief that inevitably, as a consequence of the accumulation of scientific understanding, there would inure to the benefit of the nation increased military security, improved agriculture, an expanded economy, and a generally enhanced daily life. This nation accepted that credo; the formal event was creation of the National Science Foundation but the philosophy was distributed over the entire governmental structure, including the U.S. Department of the Interior and the Geological Survey.

Modern science was the phoenix that rose out of the ashes of World War II. Since the United States emerged from that war essentially unscathed—in fact, richer and stronger than before, while the rest of the industrialized world was recovering from World War II—the United States obtained a giant step ahead into the era of modern science. By about 1959, American science comprised two-thirds to three-quarters of world science, measured in terms of numbers of people involved and resources brought to bear. But that was the peak.

From that time forward, the other nations of the world began to develop their own scientific enterprises, doing so in their own styles based on their cultural traditions, so that no two nations do it quite the same way. By now science in the United States constitutes something of the order of one-third of world science taken across the board, measured again in terms of numbers of people involved and the resources brought to bear. Western Europe plus Japan comprise a second third and, in a general way, the Soviet Union and the other socialist nations of Eastern Europe are most of the other third, with China, Brazil, Mexico, India and other developing nations just coming on the scene in a major way. The American role will subside still further as a fraction of the total, not because our endeavor will decrease over the long run, but because of the continuing growth of world science. These developments alone would not have been troublesome to United States science, but other more recent developments give us cause for concern.

The credo stated by Bush and his colleagues has certainly been demonstrated to be well justified. Research in the years since World War II has expanded our knowledge of what man is and of the universe in which we find ourselves in a way that remains mind-boggling to those of us whose memories span that period. Surely, in the field of your interest, developments with respect to continental drift and plate tectonics stamp the last two decades as an era apart in the history of earth science. Recently gained understanding of living cells, of genetic mechanisms, and early approaches to understanding the nature of the brain

[1] Deceased December 29, 1981.

again stamp this as a unique period. The chemists have changed the world in that they can manufacture practically any conceivable chemical compound at will, providing the earth scientists will give them the raw materials. The physicists have given us the basis, through solid state physics, of microelectronics and of the modern computer, which may yet prove to be the greatest transformation in human history since the appearance of language.

Unfortunately we still bear one other legacy of World War II. Nuclear weaponry remains on the front pages of our newspapers and remains the overriding single problem of the era in which we live. That too is a problem that is not remote from the earth sciences that must provide the mineral resources necessary for such a program.

All in all, the success of the scientific venture for two decades has indeed lived up to all of its promises except in one degree. It has indeed expanded the economy, it has improved material aspects of the quality of life in a way we never knew before. It has increased agricultural productivity in a way we could never previously have imagined. As a result of this scientific advance, perhaps the most dramatic statistic describing the change in the United States in living memory is the fact that when the population of the United States was 100 million, the agricultural labor force was 14 million, and that now, when the population of the United States has grown to be 200 million, the agricultural labor force has become 4 million. No other set of numbers so dramatically describes the social transformation of American society.

We went along rather happily with all this, until in recent times the tone began to change. The shared belief that the support of science and what it makes possible is inevitably in the national interest has begun to erode. It has begun to erode because of a series of episodes which, one after another, begin to gnaw away at public faith: the DC-10, Love Canal, Three Mile Island, allegations of the carcinogenicity of almost everything we use. These, one after another, have begun to bother the American public and, with a small time delay, the citizens of other nations as well. The public begins to wonder whether, at the other end of this road on which science has set society, there is benefit or catastrophe. Under those circumstances, it may well turn out that public willingness to support these shared endeavors will diminish. Perhaps we have already seen the beginning of this trend. It began in Fiscal 1967 in the United States when, for the first time, appropriations in the support of science generally leveled off. That support declined until 3 years ago when across the board the decline was about 20 percent in purchasing power from what it had been in 1967. Thanks to special efforts by Presidents Ford and Carter, we had started to turn that around but then, as in the rest of the economy, inflation took its toll and despite those efforts we have not really recovered.

Indeed, we have fallen back considerably in this general enterprise for a set of reasons that most of you will recognize. The simplest of these is the fact that since 1967, the size of the American scientific community has doubled. We were producing scientists at a rate that increased the scientific population by about 8 percent per year. Since 1967, therefore, we have more or less doubled our numbers. That generates a kind of pressure on the system: all these scientists want scientific jobs and all want to do science.

The intrinsic costs of doing science have risen at a rate that nobody can estimate. I always say "about 5 percent per year," as if I know; I haven't the faintest idea of the intrinsic rate at which the costs of doing science necessarily escalate. It has to do with our increasing sophistication and the increasing cost of instrumentation required for the kind of science we would like to do tomorrow as compared to what we did yesterday. The rate of cost rise is surely not insubstantial. As the enterprise has grown, whether science be done in a Federal agency, a university, or an industry, the associated overhead costs keep rising. They eat into the bottom line of the money that is appropriated in the name of research.

These three factors—the size of the scientific population, the intrinsic costs of doing science, and the overhead structure—together have very much eroded what is really feasible with the amount of money that is available to the American scientific community. That is very, very trying because, at the same time, the challenges have actually increased and the opportunities are even more inviting; the identifiable problems are, perhaps, more serious than ever.

Within the realms of earth sciences, I need not tell you what the challenges and the opportunities are; they are obviously enormous. Plate tectonics has revealed much, but not quite enough. It explains in a general way why one class of earthquakes should happen, but it does not really tell you yet exactly where it will happen or when it will happen. But the present level of understanding does make you feel good in that when an earthquake happens you will understand it to some degree. It has provided some basis for understanding of ore body formation but not quite enough; it has not yet given you the predictive power you would like to have. So it does not tell you exactly where to drill for what. When you are successful, even on a random drilling basis, Bill (Dr. Menard), you will feel better about having found it because you will pretend that you understood why it was there. But if we continue, if there is a sufficient interest and if sufficient effort is put into understanding ore body formation, then surely in due course predictive power will increase.

Our understanding of continental drift has improved enormously as a result of the improved drilling capability which has been provided in recent years, particularly by the travels of the *Glomar Challenger*. I know that you will continue to improve on drilling technology and give the earth sciences a whole raft of new scientific capabilities if the country will pay for them and if we put in place the institutional structure that is necessary but is now completely missing.

The most powerful tools will be seismographs, new seismic techniques which are just being born, new drilling capability, the *Glomar Explorer* being the first in that line, and of course a whole series of space-based platforms. These platforms will enable us to make all sorts of examinations of the Earth from its outer stratosphere all the way back into deep earth, using all sorts of new techniques which are just being born: laser ranging, acoustical ranging for the deep ocean, long-line microwave interferometry, base-line interferometry, diverse electro-optical devices, and silicon-charge devices which will provide, in effect, a new type of camera which will go directly into the computer with its information rather than going through photographic techniques on the way. All of these will marvelously enhance the ability of the earth sciences to understand that object which is the center of our interests, the Earth from its outermost regions down into its core.

If all of that is successful, we will be better able to find minerals that we require, better able to predict earthquakes one day; we will understand our role in the long-term climate process, something which we must do in the very near future if we are to develop sensible policies with respect to the use of energy within this and all other nations. The opportunities are there, the new tools will be available. Whether or not American society and other societies will provide those tools is a political question and not a scientific question.

I confess that until recently I have been rather disturbed by the erosion of public faith about which I have spoken because of my understanding of the political climate in which we now live, and the awareness that the enormous inflation hurts scientific enterprises as it hurts everything else. I would have been content if one way or another we could cajole the American people and their Congress into supporting science at a constant rate and constant dollars and wait for a better day, as it were. I thought that would be doing very well. We have not succeeded in doing that but I would have settled. At this point, I am unwilling to settle.

As we now see tomorrow or the day after tomorrow, the importance of dealing with the problems before us that require scientific understanding looms ever larger in many ways. This nation's monetary problems and its inflation problem have roots in the technical nature of our economy, the resource base and how it relates to the rest of the world, at least in some way.

Our military security has changed. We have produced one trillion dollars' worth of weaponry since World War II. We have gone from the moment when the worst that the Japanese could do to the U.S.A. was to destroy a fleet at Pearl Harbor, to a time when the nation is so vulnerable that it can be completely destroyed in about 15 minutes. Hardly a rational outcome for the expenditure of a trillion dollars.

The vulnerability of the United States is not merely related to weapons; it results also from the geopolitics of the Earth and the very complex world in which we live. The United States was a very special place in the history of human beings. Thanks to the Constitution, amazingly, this really has been a democracy; the ideal of liberty was more real in the United States than any place else in the history of human beings. After World War II, we grafted on to that structure the remarkable scientific venture which excited the imagination of human beings, taught us more about ourselves and our universe than one could have dreamed that we would learn within our own lifetimes, and fulfilled the prophecies—and more—of "Science, the Endless Frontier." Suddenly it is all terribly vulnerable.

The United States must deliberately set out to recapture its place in the world view. But we can no longer simply buy it. We cannot do it by military means because no nation will ever be allowed aggrandizing military ventures any more. We have to go back to recapturing the imagination of human beings the world over. We have learned how to do that in the past. We did it gloriously for twenty years after World War II. We can do it again. And science is the means.

We have the resource base. We have the largest trained scientific manpower base in the world. To be sure, we will have to compete with the sophisticated manpower of all the other nations. I do not expect us to be first in everything; what is important is the extent to which science and its applications can continue to take our society in the directions that Vannevar Bush promised. It is absolutely imperative that we continue to make an all-out try.

The resources that we must ask for are small in terms of the fraction of the GNP that is required. We can easily afford it if the people of the United States have the will. Nothing else will retain the position of the United States on the world scene and nothing will preserve our own self-image as to who we are and what we think we are. That's an enormous challenge. It is one which I know you will share and one which you will gladly take up. You will have a lot of company but you will have to join me in persuading the Congress and the people of the United States that it is worthwhile. They have begun to walk away. They think that we made promises we could not keep, that we exaggerated and that much that we have offered has turned to ashes in their mouths. But that is exaggerated hyperbole offered by disaffected persons and that then becomes grist for the mills of the news media.

We have had problems, we have had very real problems. In the total scheme of things they are small problems, not large problems. They must not be allowed to loom quite so large. The mote in the eye should not be mistaken for being disease; it is only a mote in the eye. We have problems which we can manage. We have resources we can yet find. We have resources we can share with the rest of the planet while other peoples share their resources with us. Science remains, as far as I can make out, the most powerful tool that our civilization has developed to mitigate the condition of man. It behooves us to use it. Thank you.

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Major Challenges and Opportunities for National Geoscience Programs— A Brazilian Viewpoint

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These are days of high significance to the world of geology. This Centennial meeting in honor of the United States Geological Survey brings us to one of the greater international geological science organizations, if not the greatest. Its achievements are grand and its technical staff is, doubtless, among the world's leaders in their specialties.

For us, as Brazilians, this date evokes gratitude for some important experiences. We should not forget that our country is highly indebted to the U.S. Geological Survey for knowledge of its own geology. In the early 1940's, Brazil was, practically speaking, in the earliest stages of development in the geological science. We did not even have one school of geology. The few earth science professionals we had were graduated from the only mining engineering school of our country. Our lack of exchange with more developed countries and the absence of budget resources almost condemned us to a state of stagnation in the field of the geological sciences.

During this time the influence of the U.S. Geological Survey began in Brazil, as a consequence of mutual efforts at resource development during World War II. At that time, the first discoveries of tantalite, columbite, beryl, and scheelite were made in northeastern Brazil; all these being minerals of strategic importance, essential to wartime industry. With many of the traditional European and Asian supply sites in the hands of the enemy, this region became the target of an intense prospecting effort for those minerals. The first U.S. Geological Survey missions to Brazil date from that time. Outstanding among those associated with USGS work was William Drumm Johnston, Jr. He was responsible for teaching and guiding several Brazilian mining engineers who today hold important positions on the Brazilian mineral scene.

USGS SERVICE TO SCIENCE IN BRAZIL

After the war, except for a short interruption, the U.S. Geological Survey intensified its activities with doubled enthusiasm. We want to emphasize the meaning of these Survey activities. It was neither a matter of commercial interest to guarantee the supply of cheap raw materials to American industry nor a case of political influence. It was, fundamentally, the pure scientific and technical interest of an organization engaged in the advancement of geology in a still underdeveloped country. The main effort was always directed toward the training of Brazilian professionals so that, in the future, they could themselves conduct the work related to mineral prospecting.

The list of jobs done by the USGS in Brazil is very long indeed. A recent survey shows that 153 USGS professionals have worked on many Brazilian projects since 1942. We should like to mention a few of them and the following projects: the survey of the "Quadrilatero Ferrifero," State of Minas Gerais, today the Brazilian iron ore producer, undertaken by the team of Joel B. Pomerene, Garn A. Rynearson, Joseph O'Rourke, Philip W. Guild, J. E. Gair, Norman Herz and others and led by John Dorr; execution of the "Bahia Project" whose objective was the geological mapping and evaluation of the mineral resources of the State of Bahia, staffed by Richard W. Lewis, Jr., and Ray H. Hagell; the pioneer uranium prospecting surveys carried out by Max G. White, Gene E. Tolbert, J. J. Matzko, Helmuth Wedow, Charles J. Pierson, Donald Haynes and others; execution of the "Tungsten Project," an integrated investigation of the scheelite producing area in northeastern Brazil; survey of the nickel deposit of Niquelandia, State of Goias, by William T. Pecora; the establishment of the Mineral Analysis laboratory (Laboratorio de Analises Minerais—LAMIN) of the Mineral Resources Prospecting Company (Companhia de Pesquisa de Recursos Minerais—CPRM). This complex job, involving the choice and installation of equipment and personnel training in the United States, was done by Albert P. Marranzino. Other projects include the investigations of the geology of the Maranhao Basin by Donald F. Campbell; the installation of regional laboratories at Goiania as a preliminary project of the Center for Mineral Technology, operated by CPRM; a broad program of assistance to the National Department for Water Resources and Electrical Energy (Departamento Nacional de Aguas e Energia Electrica—DNAEE) involving the organization and improvement of the services of these agencies, and several other projects carried out by Don C. Perkins, William F. Curtis, Woodrow W. Evett and Leonard E. Snell. There were also USGS training programs in both the United States and

Brazil for the DNPM and CPRM staff; the magnificent job performed by Francis X. Lopez, which gave our geologic cartography an extraordinary headstart by training several of our professionals to use this important geologic tool; and the invaluable support of the USGS to the first five Brazilian schools of geology. We should not forget Professor J. T. Stark, who taught in Sao Paulo and Recife; Max L. Troyer, Stuart L. Schoff, Harris G. Rodis, William B. Sinclair, and T. W. Offield who conducted support missions to the Government's Northeast Development Agency (Superintendencia do Desenvolvimento do Nordeste—SUDENE) that is responsible for the social and economic development of our country's poorest region; and Mackenzie Gordon, Jr., who made the first coal studies in Brazil. As supervisors of all these activities, besides Max G. White and Albert A. Marranzino, we should like to mention Alfred J. Bodenlos and S. Anthony Stanin, who also performed technical jobs of the highest standards, including Bodenlos' investigations of magnesite in Bahia. Finally, one cannot forget those in charge of the coordination of this work, especially John A. Reinemund, head of the Office of International Geology, and George Ericksen and Alfred Chidester, former heads of the Branch of Latin American and African Geology.

THE FUTURE OF GEOLOGY IN BRAZIL

It is worthwhile to emphasize the contributions of the U.S. Geological Survey to Brazilian geology, because they improved our geologists' knowledge and gave them the self-confidence needed to face the great challenges of the future that are the topic of this symposium and of this paper.

Now, mineral problems present several aspects. On the one hand, it can be seen that for many ores the best mines have been quickly exhausted due to increased consumption. Thus, there is a continuing need for ever more sophisticated and advanced techniques of prospecting, mining and ore dressing. So it is necessary to find new mines, which are often located in more remote and inaccessible areas, at greater depths, have lower grade ores, and involve increasingly complex mining techniques and ore dressing methods sometimes not yet fully developed.

On the other hand, we have financial problems, too. Today, budgets for great mining projects amount to hundreds of millions in dollars. Now, when most other enterprises in fields of human activity also require such large expenditures, the competition for the limited amount of funding available is very strong indeed. Therefore the indebtedness of major mining companies, even the great multinational firms, rises every year. State participation, sometimes requested by private businessmen themselves because of insufficient proper funds, grows continually even in the Western world. As a matter of fact, we know that in order to carry out very large projects in recent years, it has become necessary to have joint ventures by many multinational companies supported by a pool of international banking organizations.

Then we have to consider how to address the political risks. In countries with different ideological and political trends, private enterprises are often subject to expropriation, frequently without adequate refund. The shortage of funds and technology, especially in the Third World, has also caused many problems in countries where the multinationals were at work.

As a consequence of government intervention, the free market economy is not functioning as it did in the past. It is not unusual for some governments to enter specific ore markets in order to sell their new materials at privileged prices, resulting in the well-known practice of "dumping" that solves their need for capital. This action, naturally, disturbs the pricing of mineral commodities and requires private companies to adopt different ways of conducting their affairs since they cannot compete against such practices.

In our opinion, another great challenge for a mining community is how to change the very attitude of certain branches of government toward mineral prospecting and resources exploitation. Especially in relation to prospecting that is very difficult. The main difficulty for resource development in a country like Brazil is how to convince government organizations to appropriate sufficient funds for achieving successful mineral programs. Usually, economists, accountants, and similarly-oriented officials are not receptive to budget proposals for projects with exceptional risks and long capital-return periods. Moreover, public opinion is largely negative about mining operations. For example, it is often alleged that mining is one of the major causes of pollution and environmental problems. We must face a task of considerable magnitude if we are to change the public view of mining.

We also believe that the more developed countries should understand our legitimate concerns in the Third World for ways to process and export raw materials at a more sophisticated level of beneficiation and refinement that will increase their exchange value. In these times of growing social tensions, all should work to reduce the gap between rich and poor, industrial and nonindustrial, developed and underdeveloped countries. This would also benefit the already developed countries. One of the quickest ways to do this is to increase the per-capita income of a developing country by promoting its industries with its own natural resources.

BRAZIL OFFERS FINANCIAL INCENTIVES TO FOREIGN INVESTORS

In Brazil, our government, aware of the gigantic task ahead of it, feels that there is room enough for active participation in development by the state, by the multinationals, and by Brazil's own private companies. Therefore, as strong as state enterprises may appear, Brazilian laws do accept and encourage the presence of foreign companies in the mining industry.

Until recently, major restraints limited the participation of foreign private industries only in oil and nuclear minerals exploration, because prospecting and mining activities for these commodities were state monopolies. Recent legal modifications have changed matters as concerns oil. PETROBRAS is allowed to sign "sharing contracts" with developers who can make open bids for some of the promising areas revealed by previous work. These areas are then investigated by the successful bidder who is entitled to receive, in case of discovery, a share of the oil found and produced.

The law that created NUCLEBRAS also allows participation in joint ventures for prospecting and mining nuclear ores. Some of these types of association are already in operation.

BRAZIL'S GEOLOGICAL FRONTIERS

Brazil is known as one of the last geological frontiers on our planet. It is one of the few countries in the world where it is still possible to find outcrops of great dimensions that contain high grade ores. Our Amazon region has a vast not-yet-fully explored area where we hope to achieve sizeable results.

The energy crisis torments the world including Brazil, which especially needs mineral fuels, either liquid or solid. Today our daily oil production of 172,000 barrels amounts to less than 15 percent of our 1.1 million-barrel per day needs. However, due mainly to recent offshore discoveries, we hope to produce about 500,000 barrels per day by 1985—about 350,000 of that from the coastal waters of Campos, north of Rio de Janeiro.

Great advances have been made in the search for coal, and our present reserves amount to 14 billion tons. Present production is on the order of 5 million tons yearly and a great effort is under way to increase this to 27 million tons a year. On the one hand, this will certainly require much financing, but, on the other hand, the mining companies involved will have many profitable opportunities.

IMPROVED PRODUCTION AHEAD FOR ENERGY FUELS

Brazil intends to overcome, or at least to reduce significantly, its energy crisis. It is common knowledge that the Brazilian Government is engaged in a program to produce alcohol as a fuel and thus to provide a 170,000 barrel per day oil equivalent by 1985. With the production of an equal amount of oil equivalent from coal and with the projected increase of oil production to 500,000 barrels per day, Brazil will be able to produce about 50 percent of its needs in mineral fuels even though oil consumption will range from about 1.6 to 1.7 million barrels per day by 1985. This will considerably improve our trade balance, as oil is, by far, our main import.

The outlook for uranium is also promising. As a result of prodigious exploration efforts in recent years, our uranium reserves jumped to an estimated 198,000 tons of U_3O_8 concentrate, putting Brazil in 5th place in the world. And these reserves will tend to increase in the near future. It is very important to mention that these ores are associated with alkaline rocks, granites, migmatites, metaconglomerates, sandstones, and carbonatites.

Next year, the first Brazilian uranium mine will start operation with an initial production equivalent to 500 tons a year of yellow cake. This may soon be doubled. A complex of 3 nuclear plants with 3.2 million kW power was nearing completion in 1979. The first plant, producing about 626,000 kW, is scheduled for operation in 1981. In this program, Brazil is incorporating up-to-date technology related chiefly to the nuclear fuel cycle.

Our position is also very good in aluminum. Today, we still import some aluminum; however, that will change shortly. Our bauxite reserves amount to 3.9 billion tons, located mainly in the Amazon region, where the hydroelectric potential is approximately 100 million kilowatts. For the whole country, this potential is estimated to be about 209 billion kilowatts, but only 24 million kilowatts are produced today. Thus, Brazil may well become an important world aluminum exporter. Our government is now installing two integrated projects: the one, ALUNORTE, for alumina production with a capacity of 1.6 million tons per year; the other, ALBRAS, for aluminum itself with a capacity of 320,000 tons per year. Situated in the neighborhood of Belem, the hub of the Amazon region, both projects are joint ventures with Japanese companies. In addition, a third, the Trombetas project, will soon start to export bauxite. This project is a joint venture between Companhia Vale do Rio Doce, the state-owned company, and several foreign enterprises.

Until now, if we spoke about Brazilian mining we referred only to iron ore. In fact, Brazil was once called a "one-ore country," which indicates our great dependence upon this ore. Today, iron continues to be responsible for 92 percent of our mineral exports, and recently the Brazilian Government initiated the Carajas Project, the biggest mining project in the world. With an investment of about 2.3 billion dollars including an 887-kilometer railroad, it involves the establishment of a gigantic iron mine with an 18-billion-ton reserve. As a whole, Brazil is estimated to have a reserve of about 70 billion tons of iron ore.

It is important to mention that Brazil is currently responsible for 25 percent of the world's iron ore trade; some years ago we had only 4 percent. These figures indicate the importance of Brazil as a raw material supplier.

It can also be said that we have or approach self sufficiency in many other important minerals, such as cassiterite, with fairly large reserves in Rondonia, Amazon region, and in the State of Goias. These reserves may increase substantially. Brazil is also potentially a tin exporter. Manganese also represents an important export item since we have significant reserves in the Amapa Territory (estimated at 30 million tons) and at Urucum in Mato Grosso State. Brazil is the world's greatest producer of niobium with large reserves at Araxa, in the State of Minas Gerais. Tungsten also plays a valuable role in our economy; significant scheelite deposits are found in northeastern Brazil.

Base metals, however, represent one of our greatest challenges. The search for copper, one of our most expensive imports, has not yet revealed significant reserves. Another Brazilian problem is the scarcity of sulphur. The first known ore deposit was only discovered in 1978 and is still being evaluated.

Geological sciences present several fascinating challenges, especially where research depends on techniques that are not yet well developed. For example, exploration of the bottom of the sea will require tremendous efforts by geologists. Economic problems, no doubt, are also some of the reasons that ocean mining has not yet been completely explored. Investigations on the bottom of the sea have been and are more expensive than those on the land, and the mining of marine ores will certainly be much more expensive than of underground ores. However, the exhaustion of the best surface mines will reduce the differential in these investments and thus contribute to an increase in the exploration of the mineral resources of the seas.

Brazil has made a significant effort in this new field through such target projects as the first systematic survey of the continental shelf. Besides being the most promising area for oil, our continental shelf presents great geological possibilities for sulphur—a mineral resource now totally imported.

PROMISING TECHNOLOGICAL RESEARCH

Another field of interest with great possibilities is the technological research related to reducing both the cost of mineral processing and the energy consumption which it requires. Lower processing costs will also help offset the high costs resulting from the processing of lower grade ores.

This Centennial year for the U.S. Geological Survey also marks the inauguration, in Rio de Janeiro, of our Centro do Tecnologia Mineral or CETEM. Operated by the technical staff of CPRM, this mineral technology center performs a wide range of activities, including technological research on the treatment of Brazilian ores. Although Brazil has many similar institutions performing some of the same activities, CETEM brings together the human and material resources that will establish it as one of the best institutions of its kind in the world.

Brazilian mining, which is predominantly open pit, uses up-to-date equipment such as drag lines, large shovels and trucks. Efforts are made to satisfy ecological imbalances; however, no major problems have appeared on this subject thus far.

In this fortunate epoch for the mining world, we, the working scientists, are glad to express our message of faith and confidence in the geological sciences to which we dedicate our lives. With formidable problems and difficulties to be solved, the future holds much work for us. However, as long as organizations such as the United States Geological Survey and its technical staff exists, as long as there is such an organization with integrity in its purpose and methods of action, the world may be confident that all the challenges confronted in the geological field will be met and conquered.

There is no doubt that professional understanding among earth scientists from different nations, working together to discover new sources of the mineral resources vital for mankind's survival, will provide a better understanding among all people. That is what we all want.

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Mineral Resources for the Twenty-first Century: Challenges and Opportunities—An Indonesian Viewpoint

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INTRODUCTION

Today, as never before in history, mankind seems to be most concerned about resources for the future. This is particularly true with regard to mineral resources, which are unrenewable and which are playing an ever-increasing role in world affairs. Mineral development has become an essential factor in economic and industrial development, not only for the developed countries but for the developing countries as well.

In the past, especially after the end of the Second World War, great worry has been expressed by people in various circles at various times, about raw-material shortages in general and higher costs of minerals in particular. Until the early 1970s, people did not anticipate the expected shortages, but since the oil crisis in 1973, the possibility of the world facing an oil shortage in the near future has become all too real for many people in the industrialized countries. Today, most of us will agree that, except for oil, fears about shortages of supplies of minerals in the near intermediate future are groundless. We see nothing in the record to support the view that in 25 to 30 years' time the world will be threatened by real shortages of minerals.

The paradox of mineral resources is that, with well designed resources management and planning, mineral exploitation tends to increase ore reserves rather than diminish them. In some cases, ore reserves grew even faster than consumption. For example, according to available statistics, in the period between 1950 and 1970, world reserves of copper, nickel, iron ore, and bauxite have grown by more than two to five times.

Potentially available resources for most minerals are more than adequate. Continuing advances in exploration and mining techniques will undoubtedly open up ways to develop and to market many hitherto uneconomic mineral deposits. New technologies in ore dressing, metallurgy, and recycling have already dramatically improved the supply situation of many metals.

Indeed, from a global point of view, there is no reason to fear that the world will be running out of supplies of basic mineral commodities. But on an individual country basis, the picture certainly looks a lot different, especially if we take the case of the resource-poor countries that are advanced industrially, such as Japan. In these countries, "effective depletion" of a number of traditional domestic mineral resources has already taken place. To sustain their industries, these countries already have to rely heavily on the importation of mineral raw materials from other countries. In fact, a clear shift of major mineral production away from the developed to the developing countries started about two decades ago, and this trend, obviously, is not reversible.

Actually, the whole of the Earth's crust is a huge storehouse of minerals. It contains enormous amounts of minerals and mineral-bearing materials. Mineral deposits are not evenly distributed around the Earth, but their distribution is not random: it follows orderly patterns related to the geologic history of the Earth's crust. Thus unusual abundances of certain metallic mineral deposits occur in the so-called metallogenic provinces in some parts of the world.

Probably, from a global viewpoint, the Western industrialized countries, the developing countries, and the countries of the Eastern bloc share the world's mineral resources in rough proportion to their respective geographical areas. But within each group of countries, the regional distribution of minerals is very uneven. There are great regional differences between the "haves" and the "have nots." Some countries like Canada, the USA, the USSR, and Australia are indeed very rich in mineral resources; but no country in the world is actually self-sufficient in all minerals.

Since modern civilization cannot sustain itself without metals, fuels, and other materials that are extracted from a wide range of minerals, this uneven distribution of minerals in the Earth's crust leads to interdependence of countries and of various parts of the world, in meeting each other's needs.

This brings us to the problem of mineral resources development in the developing countries. Indeed, one cannot discuss mineral resources on a global scale without taking into account the resources potential of the developing countries, for at least two reasons. First, the fact that until now we knew very little about existing global resources pertains in particular to the situation in the developing countries. Second, as briefly mentioned before, in the last twenty years there has been a clear shift of major mineral production away from the developed to the developing countries of the world.

Many developing countries are richly endowed with a variety of mineral resources, and within these last thirty years, some of them have become very significant mineral raw-material producers. Unfortunately lacking other economic resources, most of them today are depending too heavily on the export of only one or two mineral commodities to sustain their economies.

The developing countries in general face more or less the same set of problems in developing their mineral resources. Obviously, the most difficult problems are how initially to obtain risk financing for mineral exploration and, once the economic feasibility of a project is proved, how to gain access to the international market and, finally, how to obtain stable and equitable prices for the product.

Today, most, if not all, mineral commodities produced in many developing countries are needed by the industries of the developed countries. At this stage in world affairs, one can say that the primary objective of the developed nations is a dependable source of mineral raw material, while the primary objective of the developing nations is the maximization of benefits from their mineral resources.

Competition for low cost sources of minerals will certainly intensify in the future among a growing number of industrialized nations. Unless the problems of mineral resources development in developing countries are resolved, and a mineral resources inventory can be made on a global scale, the world could prematurely face serious mineral demand-supply imbalances. These are now mankind's great challenges: first, to obtain the know-how and technology to develop the resources of the Earth to meet present and future demands for all; and second, to find a new pattern for development, which is rational and acceptable to both the consuming developed countries and to the producing developing countries.

FUTURE SUPPLY OF MINERAL RAW MATERIALS

Economic expansion and rapid development of natural resources in general, and of minerals in particular, are both likely to continue at an accelerated pace over the next few decades. Most probably, during the remainder of this century, man will use nearly as much of the Earth's mineral resources as he has during the whole previous course of human evolution.

For certain basic mineral commodities, effective depletion of presently known reserves in some major producing countries is already becoming visible. For future mineral resources development, advances in science and technology will certainly be important on a global scale. However, emerging economic and socio-political factors are not always conducive to mineral resources development in various parts of the world.

Thus, it is obvious that the problem of mineral supply adequacy for the world in the 21st Century does not merely involve technological and economic/financing aspects. New or future socio-political attitudes and actions, resulting in changing development patterns, might be even more decisive in determining the levels of future mineral development prospects.

Let us now try to elaborate a little bit on the various aspects of the problem.

Technological Aspects

Technological and scientific developments could alter the outlook for minerals from time to time. Advances in mining and mineral extraction technology are opening up the way to market many hitherto uneconomic mineral deposits. That is, technological development may bring what was formerly in a marginal or submarginal grade to a mineable grade. Marketing possibilities for ores mined from formerly submarginal deposits are presently improving because of steadily increasing demands created by general industrial development.

On the exploration side, we have no doubt that science and technology will aid in the discovery of new sources of minerals. The discoveries may be due to better inventory techniques, better instrumentation, better exploration concepts or better methodology, or from a combination of all these factors.

Among the various geoscientific methods used in combination in mineral exploration, probably the technological advancements in geochemical and geophysical methods are of primary importance. The main purpose of further developing these methods should be to accelerate regional prospecting campaigns over vast areas, especially in remote parts of the world, and to increase depth penetration. In addition to these, further improvement in remote sensing techniques will speed up mapping and exploration work in general, especially in far distant regions of the globe that are inaccessible for conventional terrestrial survey work.

Knowledge of the Earth's mineral resources has increased considerably during the past decade. There is no doubt that, with today's accelerated advances in science and technology, it will increase at an even faster rate in the future.

Last but not least, the operation of any modern mineral industry is energy intensive. Because of substantial price increases in these last six years, energy becomes a particular concern for mineral development undertakings. Both the availability and cost of energy can be decisive for the location of future processing facilities. As such, energy-saving technology in mining is of great significance for new mineral ventures.

Economic and Financing Aspects

It is to be anticipated that up to the end of this century, consumption growth rates for certain minerals will remain high and depletion of existing reserves will lead man to search for new resources. According to some estimates, every year about 5 percent of existing world production capacity is coming to an end because of exhausted reserves. Only increased new finds will make it possible to satisfy the world demand for mineral raw material in the decades to come. Since the easy mines have been found, mineral prospects for the future are either those with lower mineral content or those located in more difficult regions of the world.

The shift in mineral development toward lower grade minerals means that most future exploitation and extraction of minerals will have to be done on a large scale and will become even more energy intensive. All this means that larger investment capital will be needed to search for new mineral prospects and to establish new production facilities. Consequently, one can reasonably expect that the relative cost of mineral raw materials will show some increases in the future, in spite of technological improvements and increased efficiency in the production process.

Another problem faced by the mineral industry today is the problem of financing exploration and production ventures in the developing countries. Major mineral prospects for the future are most probably located in the still underdeveloped parts of the world. Historically, mineral development has been stimulated by the concept of profit, and in the past, practically all mineral development in several parts of the world outside the Eastern bloc was conducted by foreign, privately owned companies. These companies generally operated on the basis of traditional concession agreements. They provided all the capital and know-how and managed and directed the enterprise. Today, this practice is changing very fast in the developing countries all over the world as a result of rapidly growing strong feelings of "economic nationalism." On the one hand, increased host-government control or majority local ownership makes it no longer attractive for private companies to spend risk capital for mineral exploration and investment. Thus, the traditional flow of foreign private capital for the development of indigenous mineral resources in many developing countries cannot be expected to continue. On the other hand, it is unrealistic to expect developing countries to have large amounts of scarce capital to spend in risky undertakings like mineral exploration.

In many cases economic nationalism has resulted in direct or indirect involvement of host country government in the ownership of production facilities or in the operation of the enterprise. In the past two decades many developing countries have succeeded in formulating new policies and entering into partnerships with private foreign companies to undertake mineral development on the basis of special contractual arrangements. It has to be noted, however, that for many others, both host countries and private companies, it may still take some time before this new form of partnership in mineral ventures is acceptable.

As a result of this changing situation, movements of private funds in the mineral sector have become rather limited. For example, private capital will not, as in the past, respond readily to market demands for particular minerals. This may result in price fluctuations or acute shortages in the supply of certain critical minerals. Such unhealthy situations will affect the industrialized consuming developed countries as well as the producing developing countries.

Political Aspects

For many developing countries, mineral resources development plays a dominant role in the advancement of the national economy. Since mineral resources are finite, they should be regarded as a part of each nation's heritage. Thus it has become a principle that it is the responsibility of the state to safeguard and control mineral resources developments for the maximum benefit of the people.

Each country has the right to determine the use of its mineral resources. Against this background, many developing countries have in the 1970s applied policies that exercise their sovereignty over their mineral resources. Although in practice there can be great variations as to the application of these policies, in general these all lead to greater involvement of the host governments in mineral development undertakings. The result has been expanded government participation in the ownership of mineral resources development enterprises or an expanded government role in the overall management of those enterprises.

Mineral developments in the developing countries in the 1970s have clearly shown the irreversible trend of increasing host-government or local participation in new mining ventures. Such trends have placed relations between the foreign companies and the host governments or nationals of these developing countries on a new basis.

In some countries where governments do not pursue a policy of complete national ownership or majority control of mineral resources ventures, foreign private companies may still retain partial or full control over their operations. But in these cases, the governments concerned have taken the necessary steps to ensure that the private companies are operated in a manner consistent with the host country's development priorities.

Another political aspect of mineral resources development is related to the fact that minerals are not equally distributed among countries and continents. This may lead to minerals becoming a potential basis for national and international dispute. Changes in conditions of demand and supply may thus give rise to problems arising from political instability and dislocation. And last but not least, there is always a danger that critical minerals in short supply could be used by the producing country or countries as political weapons in international relations.

THE INDONESIAN EXPERIENCE

The way each country goes about its mineral resources development is not to be separated from its historic background and its political and economic interest. To enable the reader to appreciate our viewpoint on problems of future mineral supply adequacy, it might be worthwhile to elaborate a little bit on the Indonesian experience. The following is a brief review of Indonesia's mineral potential, its development policy, and the performance of Indonesia's mineral industry.

Geography of the Indonesian Archipelago

Indonesia, a former colony of the Netherlands, declared its independence in August 1945. It was not until 1950, however, that its sovereignty was actually established over the whole territory of the former Netherlands East Indies. Thereafter, for about 15 years the country went through various political upheavals, which hampered overall economic development. This situation continued until 1966, when at last national stability was attained after the great political upheaval in 1965.

Like many other developing countries in the world, Indonesia today faces the typical economic problems and challenges associated with its growth and it is not superfluous to say that Indonesia's problems are commensurate with its geography and the size of its population.

The territory of the Republic of Indonesia, which include parts of the continental Sunda and Sahul shelves and adjacent rise, covers a total area of about seven million square kilometers. It occupies approximately 4 percent of the Earth's surface, and consists of 1.9 million sq. km of land area, 1.9 million sq. km of continental shelf, 2.7 million sq. km of continental slope and rise, and 0.4 million sq. km of abyssal plains. Superimposed on the map of the United States of America, the western and eastern boundaries of Indonesia would respectively reach across the lower 48 States and a considerable distance into the Pacific and Atlantic Oceans (fig. 1). Laid over the map of Europe, the distance between the extreme western and eastern edges of the Indonesian archipelago would extend from London to Moscow.

The Indonesian archipelago consists of more than 13,500 islands, of which perhaps 6,000 are inhabited by people. The whole archipelago lies within the tropics and is characterized by high temperatures, high humidity, and abundant rains in the greater part of the territory. Located on the crossroad between two continents, Asia and Australia, and two oceans, the Pacific and the Indian, this archipelago occupies a strategic position on the map of the world. As such it is astride and commands sea routes that are among the most heavily travelled in the world.

Indonesia is the world's fifth most populous nation. Its total population was estimated at 135 million in 1977, of which about two-thirds live in Java. This makes the island of Java, an area the size of New York State, one of the most densely populated areas on Earth. Many of the other islands of Indonesia, including Sumatra, Kalimantan, Sulawesi, Irian Jaya, the smaller Sunda Islands and the Moluccas, are underpopulated.

Indonesia's population is young and is growing rapidly. Nearly one-third of the people are under ten years of age and two-thirds are under 30. In the 1974–79 period, the population growth was about 2.3 percent per year. For the next five years, 1980 to 1985, this growth rate is expected to decrease to 2.0 percent per year. Indonesia's large population is a valuable reservoir of low cost labour, and may become a big asset for future development. There are 120 ethnic groups living throughout the Indonesian archipelago, which give our country great cultural diversity but also great developmental differences ranging as they do from the Stone Age culture of central Irian Jaya to the modern society of metropolitan Jakarta.

In terms of gross national product, Indonesia at present is still one of the poorest nations in Southeast Asia, but being a resources-rich country, it certainly has the potential for self-sustaining economic development. The Indonesian archipelago is a large storehouse of a variety of natural resources. In addition to oil and gas, the country's mineral resources include tin, nickel, coal, bauxite, copper, and other minerals of lesser importance. Tropical timber is found in abundance, and the seas surrounding many of the islands also abound with fish. Indonesia's soil

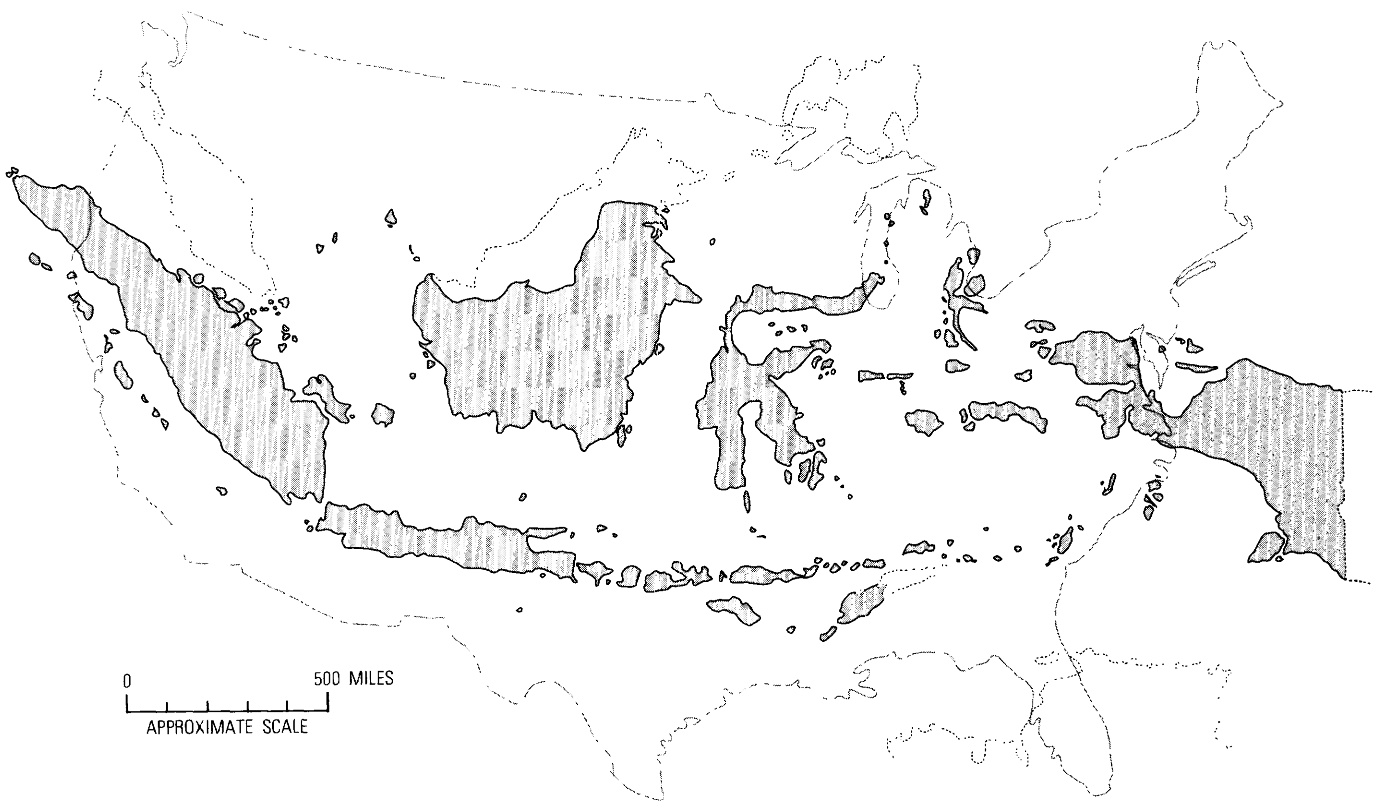

Figure 1 Map of the Republic of Indonesia superimposed on the map of the United States of America.

is well suited for growing rice, rubber, coffee, palm oil, sugar, tea, and spices. In fact, Indonesia is still basically an agricultural country, although in these last five years oil has become the single most important source of export earnings and government revenue.

Mineral Development Policy

From the outbreak of the Pacific war in 1941 until 1966–67 no systematic mineral exploration of significance had ever been carried out in Indonesia. Although there has always been great interest in Indonesia's mineral potential, economic and political conditions at that time were not conducive to private undertakings, and the exploration activities undertaken by the Government or State enterprises were limited to certain projects or targets.

In the late 1950s, Indonesia's mineral production, except for oil and gas, was fully in Government hands. Only the old mines, previously operated by the Dutch, were producing, and by the early 1960s, most of these were operating under very difficult conditions. There was hardly any additional investment for replacement or rehabilitation, and an all-time low in performance was recorded in 1966 for most existing mines.

After the great political changeover in 1966, it was immediately recognized that Indonesia needed to allow private foreign capital to participate in the development of the country's mineral resources. Thus the Foreign Capital Investment Law was promulgated in 1967, followed by the issuance of a new Mining Law in the same year. New economic policies were adopted by the government, which brought about relaxation of rules and regulations pertaining to taxation and foreign exchange control. Gradual improvements of the business environment and favourable market conditions resulted in a relatively quick recovery of the existing mineral industry. Meanwhile, foreign private companies responded favourably to Indonesia's invitation to undertake mineral exploration and development in various parts of the country.

Steady growth and expanding activity took place in the mineral sector, in particular during the period from 1967 to 1974. The oil crisis in 1973 and the succeeding worldwide economic recession have somewhat retarded this growth and expansion until now, but in general, long-term development prospects remain bright.

So far it can be said that the performance of the Indonesian mineral industry during the last ten years has been sufficiently encouraging. A great deal of the progress achieved and the new development begun since 1967 are due to foreign private-capital participation in the industry.

An important underlying factor, of course, is the fact that Indonesia is a politically stable country. Indeed the importance of political stability for mineral investment cannot be overstated. Because of its very nature, the mineral industry is very sensitive to socio-political changes, especially where private foreign capital is involved.

It is to be anticipated that Indonesia will continue to depend on the supply of foreign capital to assess and to develop its mineral potentials, maybe until well beyond the end of this century. This does not, however, mean that the development of the indigenous resources will be left completely in the hands of foreign private parties and that the government is only interested in collecting royalties and taxes from profitable ventures without taking any risk. In the early days of foreign investment in mining, the main emphasis was indeed given to production and foreign exchange earning. But shifting national priorities since then have entailed shifts in development strategies also.

Foremost among the contributions expected from foreign companies engaged in mineral development in Indonesia today are the opening of new development centres in regions outside Java, the creation of employment opportunities, the training and advancement of professional and managerial capabilities of Indonesian nationals, and the maximum utilization of domestically produced goods and services. For its part, the government will induce foreign companies to engage in domestic processing so that in the long run the development of mineral projects will strengthen the domestic industrial base. Indeed, the importance of transferring know-how and technology through foreign capital participation in the extractive industry cannot be overstated. Indonesia realizes that without properly trained people of its own, it will never be able to translate capital flow into meaningful development programmes.

In brief, foreign private investment should not be motivated by profit only; it must also fulfill a complementary role in the developmental processes of the country. The Indonesian government believes that foreign private investment in the mineral industry can continue to make a substantial contribution to national development.

Indonesia's Five-Year Development Plans

Started in 1969, Indonesia's series of five-year development plans emphasizes rehabilitation of the nation's economy as a major objective. The first Five-Year Development Plan gave high priority to agricultural production, improved irrigation facilities, and improved transportation systems.

The second Five-Year Development Plan (1974 to 1979) put special emphasis on improving living standards by stressing agricultural and food production. Specific objectives included the provision of adequate food and clothing, greater employment opportunities, expanded development of the country's infrastructure, and promotion of social welfare aims.

Indonesia's third Five-Year Development Plan (1979 to 1984) commenced on April 1, 1979. Its three fundamental policy objectives are (a) more equitable distribution of development gains, income and opportunities, (b) economic growth, and (c) national stability.

During the period from 1979/80 to 1983/84, Indonesia's export policy will be geared to diversification by both products and markets. Diversification of commodities will aim at reducing economic dependence on oil and natural gas, which now account for about two-thirds of our total export value. Growth of gross oil-export earnings during the third Five-Year Plan is expected to be considerably less than during the second. This will be partly due to increased domestic consumption and to an anticipated low rate of production increase. As a result of the implementation of this new export policy, oil export earnings by 1981/82 are expected to be overtaken by non-oil commodities. In the mineral sector, a substantial increase in non-oil exports in the future is to be expected from nickel products, and also from tin and aluminum metals. At the end of the third Five-Year Development, the mining sector (including oil and gas) is projected to account for 15.9 percent of the Gross Domestic Product (GDP).

The goal for real GDP growth is set at an average annual rate of 6.5 percent while the annual growth rates of the various sectors in the Indonesian economy during the period 1979/80 to 1983/84 are expected to be as follows: agriculture, 3.5 percent; mining (including oil and gas), 4.0 percent; industry, 11.0 percent; construction, 9.0 percent; transportation and communication, 10.0 percent; and the remaining sectors of the economy, 8.0 percent. With regard to population growth, this is expected to slow down from 2.3 percent per annum in the second Five-Year Development period to 2.0 percent in the third Five-Year Plan.

Mineral Resources Potential and Development

The mineral extraction industry in Indonesia is already a very substantial foreign exchange earner for the national economy in spite of the fact that systematic mineral exploration has so far only been undertaken in a relatively small part of the country.

Until now only about 25 percent of a total land area of more than 1.9 million sq. kilometers has been mapped geologically in some detail. The remaining area has only been roughly surveyed, and certain parts are, practically speaking, still "terra incognita." Surveys and explorations in the offshore regions started only in the late 1960s, but since then have continued at an accelerating pace, encouraged by substantial oil and gas finds in some offshore areas.

From a geological point of view the Indonesian archipelago is a very complex region of the Earth's crust. The Indonesian island arcs represent three interlacing orogenic belts, namely, the Alpine-Sunda (Tethys) Mountain System, the East-Asiatic System (representing part of the Circum-Pacific System), and the Circum-Australian System.

In the light of modern plate-tectonic theory, the Indonesian archipelago is seen as an area of interaction among three major crustal elements: the East Indian Ocean-Australian Plate, the Pacific Plate, and the Eurasian Plate.

The geological evolution of the archipelago occurred during long stable periods of sedimentation interrupted by more dynamic periods of mountain building and igneous activities, and was accompanied by metamorphism, contact metasomatism, replacement, supergene enrichment, and weathering processes. In the long geological history of the country these processes have created favourable environments and conditions for economic mineral formation and accumulation. From an exploration point of view, Indonesia undoubtedly is very interesting and attractive, and indeed there are reasons to believe that this country must possess more diverse mineral wealth than has actually been discovered. But so far, it has only been established that Indonesia's sizeable mineral potential of regional importance consists of oil and gas, tin, lateritic nickel, bauxite, copper, and coal.

Oil and Natural Gas: Exploration for oil in Indonesia dates from 1871 in West Java, and from 1883 in North Sumatra when the first successful production well was drilled there. Since then Indonesia's oil industry has developed steadily, interrupted only by the war in the Pacific. However, development activities did slow down in the early 1960s, but since 1966 there has been a great expansion of petroleum exploration efforts, especially in the offshore areas. Most oil in Indonesia is produced from sands and sandstones of Miocene and Pliocene age at relatively shallow depths, ranging in most fields from 500 to 1,600 meters. The offshore exploration efforts in the last ten years have resulted in discoveries of new oil and gas fields and have greatly increased the knowledge and understanding of the geology of those areas. The greater part of Indonesia's offshore region could be classified as continental shelf with an average water depth of less than 200 meters. Most oil prospects are found in Tertiary sediments, deposited in shallow marine or deltaic environments, generally in gently folded geological structures. Indonesia's crude oil is typically light, and low in sulphur content. The well-known Minas crude, from the Minas field in central Sumatra, which is representative of most Indonesian crude, has an API gravity of 34.5 degrees at 60° F with a sulphur content of between 0.06 percent and 0.10 percent in weight. With an average daily production of 1.6 million barrels in 1978 (1.7 million barrels in 1977), Indonesia today ranks twelfth among world oil producers. Offshore oil production, started only in 1971, accounted for 33.4 percent of Indonesia's total production in 1978.

Of great significance besides oil is the development of natural gas. In 1971 and 1972, large natural gas reserves were discovered in the northern part of Sumatra and in eastern Kalimantan. This led to the establishment of gas liquefaction plants and, since 1977, to the export of LNG from Indonesia to Japan. At present the domestic use of natural gas is relatively limited, but significant increases in the near future are to be anticipated as a result of our national energy resource diversification program.

Tin: In the hard mineral sector, tin has always been Indonesia's foremost mineral commodity. The stable condition of the existing tin industry and the country's tin reserves potential make it very likely that by 1982 or 1983 Indonesia may become the world's second largest tin producer, behind Malaysia.

The Indonesian tin belt, about 1,000 kilometers long and covering the tin islands of Bangka and Belitung, and those of the Riau-Lingga archipelago, forms only a southward continuation of the world's most potential tin belt, which extends from South China, through Burma, Thailand, and Malaysia, to Indonesia. At present, two-thirds of this rich tin belt in the Indonesian territory is below sea level. Offshore surveys have revealed that the shallow sea surrounding the tin islands conceals an aureole of submerged tin-bearing river valleys.

Present exploitation of tin in Indonesia is almost entirely limited to secondary deposits on land and shallow deposits in the near-shore areas. But substantial reserves have been proved, onshore as well as offshore, including primary deposits in some of the tin islands and deposits in the deeper parts of the offshore areas.

Nickel: Lateritic nickel ores and nickeliferous iron laterites are widespread in the southeastern part of the island of Sulawesi and in several small islands in the northern Moluccas in the eastern part of the archipelago. These deposits of nickel-bearing laterites are the result of the weathering process of extensive masses of peridotite and serpentinite.

Until 1976 Indonesia produced only high-grade ore for export to Japan for further processing. Since the completion of two new nickel processing plants, Indonesia exports, besides nickel ore, ferronickel (since 1976) and nickelmatte (since 1978). With the potential additional production of nickel metal from a third processing plant now (1979) in the final planning stage, Indonesian nickel production could reach 100,000 tons a year in the 1980s. That will put Indonesia in third place among the free world's nickel producers, behind Canada and New

Caledonia. These estimates represent about 11 percent of the free world nickel production projected for 1985.

Bauxite: Bauxite deposits of the lateritic type are widespread in various islands of the western part of the Indonesian archipelago. The ore occurs as concretions in clays formed through weathering of intermediate igneous and aluminum-rich metamorphic rocks. The concretionary bauxite is composed of the mineral gibbsite, with goethite and silica impurities, which determine its quality.

Reserves of high grade exportable bauxite are limited to the island of Bintan, but extensive deposits of lower grade bauxite are to be found in many parts of western Kalimantan and in some islands of the Riau-Lingga archipelago. At present Indonesia has no domestic processing plant and is exporting its bauxite to Japan. But plans are underway to establish a refining plant for processing indigenous lower grade bauxite into alumina for metal production at the Asahan Aluminum Smelter now under construction in North Sumatra.

Copper: Indications of copper mineralization are widespread in several islands of the Indonesian archipelago. Most of the occurrences, however, are small vein-type deposits of no economic importance. Of interest are the high grade copper deposits in central Irian Jaya, in which Indonesia's only copper mine is located. In northern Sulawesi indications have been found of extensive porphyry-type copper mineralization. From a geological point of view, similar mineralization can be expected in other regions in the eastern part of the archipelago.

Coal: Coal bearing sediments, ranging in age from Permo-Carboniferous to Pliocene, are quite widespread throughout the Indonesian archipelago. Coal deposits of economic significance, however, are confined to the Tertiary sediments in the western part of Indonesia, on the islands of Sumatra and Kalimantan. Eocene coals are found in nonmarine sediments deposited in intermontane basins, while Late Tertiary coals occur in the regressive sequence of the Neogene back-deep basins and, in the case of coal deposits in eastern Kalimantan, also in deltaic basins.

The Eocene coals are limited to extent, but they are generally more intensely coalified; these coals are hard, black, and lustrous, and resemble bituminous coals of pre-Tertiary age. The Late Tertiary coals are extensively distributed, but they are in general of lower rank; unless locally coalified by intrusive igneous activity, these coals are essentially lignites with moisture content of 40 percent and higher.

From existing documentation on the principal coal deposits in Sumatra and Kalimantan, one can infer reserves of hard black coal and lignitic black coal in Sumatra and Kalimantan respectively amounting to 200 million and 100 million metric tons. Estimates of possible and probable coal reserves, consisting mainly of lignitic hard coal and lignites, range from 10 to more than 15 billion tons for Sumatra, and in excess of 500 million tons for Kalimantan.

So far, coal plays only a negligible role in the national economy, but it has the potential to become Indonesia's major source of energy in the years to come. Although export prospects are rather limited, coal, if used domestically as an alternative to oil for primary energy generation, could maintain and enhance the role of oil as a foreign exchange earner for Indonesia.

Mineral Development, 1966 to 1978: Unfavorable political and economic conditions had caused a steady decline of the Indonesian mineral industry from the late 1950s until about 1966–67, but new life has been injected into the practically stagnant industry with the big changeover in the Government's economic development policy since 1967. As briefly mentioned before, the promulgation in 1967 of both the new Mining Law and the Foreign Capital Investment Law was of great significance to the mineral industry. On the basis of new partnerships known as "contract of work" and "production sharing" agreements between the Government or State enterprise and foreign private companies, a considerable number of new projects have been started.

At present the Indonesian mineral industry produces oil and gas, tin, nickel, copper, bauxite, coal, gold and silver, manganese, iron sand concentrate, natural asphalt, and a wide range of non-metallic minerals and rocks for the domestic market. The growth of Indonesia's mineral industry within the last ten years is very obvious, especially when compared with the situation in 1966 (see table 1).

Table 1 Production of main mineral commodities in Indonesia
[All commodities are given in tons except where noted]

COMMODITY	1966	1978
Petroleum (barrels)	176,481,097	596,698,420
Natural gas (MCF)	----	820,130,292
LNG (m^3)	----	8,094,026
Tin	12,782	27,409
Bauxite	701,223	1,007,746
Copper concentrate	----	180,933
Coal	319,829	264,180
Gold (kg)	128	254
Silver (kg)	6,867	2,506
Manganese	787	5,889
Nickel ore	117,402	1,256,450
Ferronickel	----	19,733
Nickelmatte	----	5,729
Iron sand	----	233,341
Natural asphalt	13,905	162,000

Source: Department of Mines and Energy, Jakarta, Indonesia.

Among the most significant achievements of the industry in the 1970s are the opening of new prospects and the establishment of new projects that are producing new commodities like copper concentrate (since 1972), ferronickel (since 1976), nickelmatte (since 1977) and LNG (since 1977). Oil production has increased considerably, and with the increase of crude prices since the end of 1973, oil export has become the country's main source of foreign exchange revenue. In 1978, export of Indonesia's mineral products, including oil and gas, had a total value of more than US $7,936 billion or 71.5 percent of the country's total export, which amounted to US $11,093 billion (see table 2).

Table 2 Revenues from Indonesian minerals export compared with Indonesian export totals, in U.S. dollars
[Compared percentages of the whole are given in parentheses below the dollar amounts]

COMMODITY	1966	1978
Oil and gas	$217,314,494 (31.2)	$ 7,474,923,121 (67.4)
Other minerals	40,892,111 (5.9)	461,157,627 (4.1)
Minerals totals	258,206,605 (37.1)	7,936,080,748 (71.5)
Export totals	$695,962,000	$11,093,000,000

Source: Department of Mines and Energy, Jakarta, Indonesia.

National Geoscience Programme: As mentioned before, a great deal of the progress and the new developments in the Indonesian mineral industry since 1967 have been brought about by foreign private capital. It is to be anticipated that foreign capital will continue to play a dominant role in the development of Indonesia's mineral potential, maybe until well beyond the end of this century—into the 21st Century.

Shortage of capital to develop indigenous mineral resources is a common problem among developing countries. But apart from the problem of financing, all resources-rich developing countries like Indonesia should endeavour within the shortest time possible to attain technical and scientific capability in order to assess their own resources potentials. To leave this matter forever in the hands of foreign private parties is certainly against the national interest.

The setting up of a clear, well defined and realistic national geoscience programme, including manpower training and institutional development, is a prerequisite for a country like Indonesia if it is to become self-sufficient and self-reliant in resources assessment. Since the late 1950s, Indonesia has gradually built up its capability to undertake its own geoscience programme which includes systematic geologic mapping and various aspects of applied geology such as mineral inventory, land use and engineering geology, water-resources development planning, inventory of geothermal potential, prevention of calamities caused by natural hazards like volcanic eruptions, landslides, earthquakes and the like.

In the past, it was not easy to secure the necessary understanding and subsequent budget appropriations for basic geoscience programmes like systematic geologic mapping, marine geology, regional gravity and magnetic surveys, and other fundamental investigations. Part of the reason that the Government had shown "little interest" in the implementation of national geoscience programmes was indeed budget constraints and different overriding national priorities. However, as an insider I have to admit that another part of the reason was that geoscience programmes usually tend to sound too "scientific," and that most geologists and geophysicists have difficulties in communicating the results of their work to the general public in a reasonably comprehensible way. This deficiency should be corrected if geoscience programmes in general are to succeed in developing countries.

It has been our happy experience in Indonesia that both the understanding and support of politicians and government authorities for geoscience programmes in general and for geology and mineral exploration in particular have grown rapidly within these last few years. Substantial assistance in geology and mining has also been extended to Indonesia by various agencies of friendly countries, in particular by the U.S. Geological Survey and the U.S. Bureau of Mines, and by various international organizations.

In accepting foreign assistance, Indonesia puts great emphasis on training and transfer of know-how, because, as I mentioned before, without properly trained people of our own, this country will never be able to translate capital flow into meaningful development programmes. Indonesia's present capability for carrying out its own national geoscience programmes is reflected in the current status of various mapping, surveys and resources inventory activities, carried out by the Indonesian Geological Survey and other national agencies.

CONCLUSIONS

Rapid and accelerated development of mineral resources is likely to continue worldwide until the end of the 20th Century. On a global scale, potentially available resources for most basic mineral commodities seem to be more than adequate to meet mankind's ever-increasing demand. Nevertheless, there are reasons for mankind to worry about regional problems of temporary but recurring mineral supply shortages due to political and socioeconomic factors.

As a result of rapid effective depletion of known mineral resources in many developed countries within this century, major mineral developments are shifting away from the developed to the less developed parts of the world. Considering the question of future mineral supply adequacy, two major problems come to the foreground. In the first place, more efficient technology is required to develop lower grade mineral deposits. In the second place, to open up resources in the underdeveloped parts of the world, a new pattern for mineral resources development is needed, which is acceptable to both the producing developing countries and to the consuming developed countries.

Unless the problem of initiating mineral development in developing countries is resolved and unless mineral resources inventory can be made on a global scale, the world could prematurely face serious mineral demand-supply imbalances before the end of this century. Resources development aid extended to the developing countries should be oriented toward manpower training and institutional development in order to make these countries self-sufficient and self-reliant in assessing their own resources as soon as possible. But we also have to realize that problems of mineral development involve not only technological and economic matters but also political factors, which in many cases can override other considerations.

The Indonesian experience has clearly shown that regardless of a country's mineral potential, more than anything else, it is the government's political philosophy and attitude which ultimately determine the levels and possibilities of mineral development. Hence, future mineral supply adequacy will likely be influenced less by the physical scarcity of resources than by human or political factors. It is in the interest of both the developed and the developing nations that they cooperate more closely and genuinely to undertake mineral resources development on a world-wide basis. The danger of imminent resources depletion should not lead mankind to scramble for scarce resources or to make war, but rather to search jointly for new resources in a genuine spirit of cooperation.

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Discussion

D. J. McLaren
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The papers we have just heard emphasize two principles that will become increasingly important as the world considers resource availability for the next 100 years:

1. The inequality of distribution of energy and mineral resources on a worldwide scale, and
2. The trend, already apparent, that as resource depletion advances in the more developed areas of Earth, mankind will turn increasingly to areas now occupied by developing nations and to the oceans.

The first principle forces interdependence for resources on all of us. The second requires an adjustment and an understanding between the old and the new resource rich areas of the world.

The great debate currently raging in the many public forums established by international agencies has been concerned with how to strike a balance between the old and the new, the developed and the developing, in regard to the transfer of money, goods, and expertise in return for resources. By loan, by gift, by political influence, by tough economic bargaining? The particular stage of economic development that a country has reached has a strong influence on the method preferred.

The papers we have heard illustrate two approaches to the problem. The minimal approach would be to allow foreign exploration, extraction, and export in return for rent and royalties, and this was perhaps the dominant system in the past—the so-called colonial era. With increasing recognition of the value of natural resources to national economies, this approach has become unacceptable. New systems of economic sharing have developed, followed by subsequent ownership of the means of production accompanied by education and training to the extent that the resource-rich country may ultimately assume full control of the development of its own resources. Such evolution may follow many routes, and we shall probably hear about some of them during this week. A point made here is that economic nationalism should be coupled with an accurate knowledge of the resource base of a nation if practical benefits are to flow from realistic national policies. This is in fact frequently ignored by the politician in both the developed and developing worlds, and by some major international agencies. Dr. Ramos tells of the difficulty of impressing Government with the necessity to appropriate sufficient funds to undertake prospecting and development. This point is made equally strongly by Dr. Sigit who rightly points out that it is a government's political philosophy and attitude that ultimately determines the levels and possibilities of mineral development. A knowledge of the physical resource base, however, in relation to the world market, can be a very important factor in influencing political decision.

A national geoscience program should have at least three main components:

1. Long-term activities including a core geological mapping program and research;
2. Short-term activities including airborne surveys and photogeological interpretation to obtain basic geological information on unknown areas in the shortest time possible; and,
3. A capability to do detailed geophysical, geological, and geochemical work on small areas with mineral potential.

This is a tall order in a country without its own exploration industry and, perhaps, with only a developing Geological Survey or its equivalent. There is, nevertheless, a rich source of information and interpretation that may be tapped by enlightened regulation. This source is to ensure full disclosure of all geoscience and technical data acquired during exploration and production, including substantiated reserve figures of the resource being extracted. Building on this, an administration can control and encourage development from a knowledge base, and establish a policy on supply rate for home consumption and export. Knowledge will be needed from the start, and may be considered of equal importance to royalty payments and taxation. Such knowledge might precede the development of an exploration industry within the country, and might well accelerate such a development.

In the time available it is scarcely possible for me to illustrate this in any detail with an example from my own country, but briefly, in the late 1940s the Province of Alberta, at that time surely a developing region, led the world in regulation of information flowing from a successful exploration program for oil by multinational companies. Judicious timed release of information derived from drilling, and public access to cores and samples, resulted in accelerated discovery and development. I would emphasize that this kind of stimulation can only be done with in-house competence in the earth sciences and not only competence in mineral economics and engineering.

Finally, I should like to refer to the fact that in addition to the necessary efforts that must be made in establishing an earth science base within a country, there are forces at work in the world beyond those of bilateral or multilateral aid or purely economic stimulus. There is a reservoir of scientific competence that can work disinterestedly. This is made up of those for whom research has a social as well as a scientific goal. I should particularly like to mention the remarkable achievement of AGID (Association of Geoscientists for International Development). In the short time they have existed, they have demonstrated the reality of this surge of enthusiasm in developing and developed countries by earth scientists who are concerned that their science should be utilized for the betterment of man. From my own experience, and as an example, I should like to mention two or three projects within the International Geological Correlation Programme that have an important bearing on resource development in the two regions we have heard about. Project 32 on "Stratigraphic Correlations between Sedimentary Basins in the ESCAP Region" counts Indonesia as an active participant and beneficiary. This project sets out to describe the sedimentary basins of a vast region, correlate them and examine the controls of mineral and chemical distributions, particularly hydrocarbons. Similarly, Project 42 on "Upper Paleozoic of South America and its Boundaries," under Brazilian leadership, attempts to establish adequate correlation for Upper Paleozoic sequences in the Andean area and the intracratonic basins of South America and West Africa. These are examples of geological coooperation on a large scale. In addition, two general projects of paramount value should be mentioned: 98 – "Standards for Computer Applications in Resource Studies" and 143 – "Remote Sensing and Mineral Exploration". These are only four projects out of over 60 in IGCP, that are carried out by scientists all over the world, in developed and developing countries, with the motivation that they are interested in the problems involved, and the belief in the need for collaboration and technology transfer within their chosen fields. Let us not forget that this third and powerful scientific force in the world is capable of playing an important role in the understanding of global resources waiting to be tapped.

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Discussion

Pierre Laffitte
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Mineral resources policy is different in France because there are fewer mineral resources now than before. Mineral resource policy should be structured on an international basis, but each country wants to develop its own. This policy is dependent upon the scale of the national mining industry, and the ratio of supply to demand. If there is a big demand for minerals and no resources, the policy will be different than in the case when most resources are exported.

In France, our mineral resource policy focuses on the following items:

1. Reduction of demand (example—oil and energy policy).
2. Development of some new technologies using less mineral resources.
3. Encouragement of surveying in order to find new resources.
4. Establishment of training programs and developing new scientific and technologic skills.

Number four is the most important of the mineral resource policies. People need to be trained, not only specialists but also people in administration and politics. This training should include all the sciences, not just earth science.

Private companies invest where they want to (Canada and Australia for example). They are not as likely to invest in developing countries. This is a problem that must be solved between the individual mining company and the government.

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Problems and Requirements for Identifying, Exploring, and Developing Resources

Selected Resources Problems of Underdeveloped Nations, and Suggested Solutions

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INTRODUCTION

The resource problems of small, underdeveloped nations are so great that it is difficult to talk of basic science when death is so omnipresent. Thus, a person who is interested in basic science finds himself at professional meetings repeatedly preaching about the practical human effects of what we are or are not doing with the resultant risk of being stigmatized as a politician, not a geologist. But when we talk about resources in a poverty-level society, we are dealing with daily problems of actual existence; it is a life and death matter. It is difficult indeed for a conscientious geologist to escape this pervasive reality. Even an all-encompassing geologic event like the 1976 Guatemala earthquake disaster can be reduced to these terms: most of the 23,000 deaths were caused by poverty, not by the earthquake. Prosperous people living in seismic-resistant structures survived; poor people living in adobe huts did not (figs. 1–3). The world geoscientific community, which responded magnificently to the crisis, was shocked by the death toll, and it was attracted by the dramatic geologic phenomena, but it was not conscious of the fact that geology is selective with its curses as well as its blessings.

◀ Seismic subsurface survey in Belize: vehicles carrying vibrators. Photograph by Michael E. Long, National Geographic Society.

Figure 1 Poverty accents geologic disasters. In this village struck by the 1976 Guatemala earthquake, 100 percent of the adobe structures were destroyed.

Figure 2 Not one window of this properly constructed village schoolhouse was damaged as a result of the 1976 Guatemala earthquake.

The resource problems of underdeveloped nations must be approached on a long range, systematic basis. If there were simple, rapid solutions they would most likely have been found already. Hit or miss solutions, such as a sudden major mineral discovery, are not probable, and even then do not necessarily lead to national prosperity. This leads us to the most important resource of all—people.

People—The Most Important Factor in Development

The single most important factor inhibiting resource development, in Guatemala as in most developing countries, is the lack of trained professionals working on the problems. The arduous field work required, without any compensating financial reward above that of the more "civilized" professions, has restricted field workers to a dedicated, or eccentric, few.

For priorities to have significance they must be developed, at least in part, by the participants: those who will carry out the plans and will be affected by their success or failure. If national governments, and their societies, decide that geology is sufficiently important, they will devise the appropriate incentives to produce and retain capable geologists. Although money is not the only means of reward, it is probably the easiest and quickest. A possible incentive would be to increase per diem field allowances to a level that would significantly augment the base salary, thus yielding an attractive total income. In this way it could not be claimed that salary increases were going only to a favored group. It would be obvious, rather, that just rewards are to be given to stimulate the greatest sacrifice, for in our developing countries all recognize that field work is indeed a sacrifice.

Once we have even a few capable, seasoned geoscientists we are in a position to discuss needs and priorities with our more experienced foreign colleagues. With a small nucleus of capable local professionals, sometimes with only one dedicated person, there is much that a country can do with the help of foreign geological assistance. Without such a local nucleus, benefits tend to be transitory and not necessarily directed at the country's needs.

Furthermore, without a capable local core of technicians, governments often feel themselves at the mercy of the foreign experts who come to develop their resources. Although this feeling has been more than justified historically, it can also produce a defensiveness that is completely counterproductive. Only with its own competent, trustworthy representatives can a country's national interests be truly protected on a flexible professional basis in the "give and take" necessary in resource undertakings. Otherwise, constant suspicion as to motives, engendered by ignorance, passes from the realm of caution to one dominated by an atmosphere of increased frustration, delay, expense, and wasted effort.

Figure 3 The 1976 Guatemala earthquake caused widespread destruction of adobe houses. Modern construction at upper right did not collapse. The village plaza was used for emergency housing and international rescue teams.

Of course, resource development projects must be carefully watched to safeguard national interests. Usually this has been done by retaining private foreign consultants, but they are often not completely trusted, and ofttimes they themselves are not appropriate for the special local situations. Their technical approaches have evolved from growth, schooling, and experience in research and applied sciences in more developed environments; consequently they tend to apply sophisticated criteria not suitable for completely raw situations. Experienced local technicians are more likely to be confided in and to make decisions based on the long term interests of their own country.

I have repeatedly used the terms "capable" and "experienced" in mentioning local professionals. This is essential. No matter how backward a nation, its government eventually shrewdly takes the measure of its professionals.

Government officials may come to us for grave public pronouncements on everyday natural phenomena or minor isolated events such as landslides, volcanic eruptions, and small earthquakes, but when really important things are involved, such as money (not necessarily lives), they do not confide in us. They have not been impressed by our professional abilities. And frankly, they are inherently dubious of the abilities of any scientist willing to work for government pay scales and conditions.

Only by proving our productivity and earning the recognition of our foreign colleagues will we be able to ask our own governments to respect us.

I think that external influence can also be critical in developing a country's own geoscientists. Making the training of nationals as professionals an essential part of international projects, not just giving lip service to counterpart participation, will awaken the governments of the underdeveloped world to the need for their own geoscientists. If promised counterpart scientists are not effectively forthcoming, the entire project ought to be reconsidered and perhaps retailored so as to be within the scope of participating local professionals. Foreign teams are also often able to augment local per diem scales and thus make field work more attractive.

Another direct potential source of geoscientists has been the contractual obligation of foreign companies to give scholarships in selected fields. Unfortunately, even with the added attraction of higher future salaries with foreign companies, very few students have chosen geology. Again, that darn field work!

A great impetus has been given to the geosciences in Guatemala by the insistence of world funding institutions on including geologic studies as part of large civil projects. Prior to and other than this, geology has been ignored. Because of this foreign initiative, the Guatemalan governmental electrification institution now has geotechnical departments and pays considerably higher wages than the regular government scale in order to attract geologists.

A part-way step to relieving our professional manpower crisis would be the more frequent use of those consultants who are available in our country and other developing nations, instead of automatically turning to the industrialized countries for them. In the developing world there is a small reservoir of capable geoscientists that is neglected because of prejudice. Use of these people would stimulate the geosciences in our countries by providing opportunity commensurate with ability and would give firm proof that we are indeed capable of producing first-rate geoscientists.

SYSTEMATIC GEOLOGIC MAPPING—A PRIORITY FOR UNDERDEVELOPED COUNTRIES

As an initial and continuing resource project for our countries, systematic geologic quadrangle mapping at scales suitable to outcrop and accessibility, perhaps at 1:50,000, is a practical and essential step. Almost all geoscientific endeavor proceeds from this basis. It is an excellent training ground in science, logistics, and administration for all of us. It gives us a familiarity with the country, its resources possibilities, and its resources needs. With a geologic map in hand we do not feel so overwhelmed, the problems are not so unknown, not so forbidding. We have a starting place and we can make definite plans, no matter what the project. Geologic maps are of immense psychological as well as practical value and give immediate returns in terms of time and money as well. Because of constantly changing industrial requirements and economics we never know entirely what is or will be important in the earth sciences. Thus, the most complete geologic map possible under the circumstances seems to offer the best means of evaluating what we have and how we can prepare for the future.

Geologic mapping is a flexible thing especially suited to our countries. It can be done by one qualified person or by an entire well-staffed geologic survey. Furthermore, by providing minimal but dependable support, we can attract foreign graduate students and professors to help us do systematic mapping. On this basis, Guatemala already has an extraordinarily successful mapping program. We feel that we have proved the possibility of doing something, even with the most limited means, as long as the desire exists.

We must remind you all that operationally we exist on the most elementary plane. Our daily battle is for a jeep, for gasoline, for subsistence-level per diem in the field. The increased cost of motor fuel has made the situation even more critical. Governments often do not translate their much publicized desire for resource development into liberal provision for the most meager requirements of field work. But government and higher level officials do respond to budget requests for satellite and airborne imagery because, despite all caveats, they look upon these techniques as a short-cut to rapid resources development and a most welcome substitute for distasteful field work. That is why, when we are approached with large proposals for expensive, advanced technology we usually mutter something to the effect that we would be happy to settle for a jeep.

BASIC DATA COLLECTION

An enormous amount of resource work has been done in all our countries, of which no record is readily available and much of which is irretrievably lost. This includes publications, reports, maps and physical data such as samples, cores, and well cuttings. Before it is all lost, this information must be compiled, catalogued, and made easily available in the form of published bibliographies and reference collections.

Other types of essential data can be relatively cheaply gathered and presented on maps, or computerized and stored for appropriate retrieval. This includes locations and inventories of mines and prospects, oil wells, water wells, fumaroles, springs, potential hydroelectric, irrigation, and water supply schemes, construction and road-building materials, seismic records, earthquake and volcanic eruption histories, and anything else of potential economic interest.

Most grievous to mention is the failure to publicize or make locally available the results of investigations by international missions. The irresponsible handling and storage of these reports by local institutions is equally regrettable.

Some types of data must be routinely gathered over long time spans or must depend on instrumentation that is routinely kept operational for unforeseen moments. These require greater effort and expenditure, but the potential benefits are so great that they are easily justified. In Guatemala's case, I immediately think of fumarole temperatures and compositions for geothermal energy, and strong-motion instruments such as accelerographs for seismic engineering. The latter information, or the lack of it, has assumed enormous significance these days. With the disastrous Guatemala earthquake fresh in our minds, much attention is now being given to seismic resistance in dam building projects valued in the hundreds of millions of dollars. But there is very little solid information to work with; no accelerograph records were obtained during the earthquake. Thus, many extra millions are being poured into seismic resistant design, without any firm basis for the assumed accelerations. Accelerograph records would have been of incalculable value.

Figure 4 The 1974 eruption of Volcán Fuego, Guatemala. Studies of volcanic effects on agriculture would be of great importance to developing countries in volcanic areas.

BASIC RESOURCE NEEDS IN ALL SOCIETIES

There are certain resource needs that are so basic and yet appear so easily satisfied to most of us that we tend to ignore them. Perhaps the most important of these is water. Incalculable human energy, health, wealth, and even life are lost directly because of inadequate water supplies. Certainly we must devote greater efforts in this direction. The relief of elemental human misery is priceless.

Petroleum costs have risen so dramatically that energy resources have become an urgent priority. Previously uneconomical or high risk sources of energy have suddenly become attractive. Because of their high costs and high risks these undertakings more than ever also demand more extensive and intensive geoscientific investigation. Petroleum exploration merits almost any reasonable effort and usually gets adequate attention. Other fuels require more concentrated effort. Hydroelectricity especially requires the most risky of geological decisions, as we are forced into more complicated dam and tunnel sites. Cement and fertilizer are two other basic needs that we tend to ignore until we have shortages, at which time they become crippling needs.

Geologic hazards directly affect our resources situation. The seismic threat is all pervasive, but we tend to ignore it except for seismic-resistant design in high cost construction, and, of course, for internationally financed projects. There is a desperate need for appropriate seismic zoning and seismic-resistant building materials. Most such seismic design depends upon continual geoscientific investigations.

The volcanic eruption threat is generally exaggerated in our underdeveloped countries if one considers it in relation to the normal attrition rates due to poverty. The real threats are the mud flows and floods that follow eruptions, destroying crops, roads and bridges, thus creating food shortages and driving up the price of produce. For people already living a marginal existence, any minor increase in food costs can be catastrophic. Thus, what is greatly required in volcanic studies is a better understanding of the behavior and control of mud flows and river floods. The quantitative effects of ash eruptions on crops, and agricultural ways of benefiting from the ash, is another area of investigation promising enormous benefits that would counterbalance many times over our property losses from volcanic eruptions (fig. 4).

REGIONAL AND COOPERATIVE RESEARCH

So many of the resources problems of developing nations are similar that they merit direct cooperative attack as a unit and in the region of their source, so that the special social, economic, and climatic conditions of developing countries can be appropriately related to this geology. Earthquake, volcanic, and geothermal problems of the Circum-Pacific and Caribbean belts come to mind immediately as other logical regional-geological groupings for cooperative effort.

The Association of Geoscientists for International Development (AGID) has been stimulating this concept recently by, among other things, sponsoring a tin workshop in Malaysia and a minerals symposium in Venezuela. The workshop included geologists from Thailand, Nigeria, and Bolivia, and the symposium on Mineral Exploration Techniques in Tropical Rain Forest Regions was held in Caracas. The success of both these group-oriented efforts has led AGID to propose the formation of an International Geoscience Research Institute for the development of mineral exploration techniques in tropical rain forest regions. It is pointed out that the tropical areas contain large Precambrian shield areas with high mineral potential but that they lag far behind the northern shield areas in commercial development. This difference can be attributed partly to extreme climatic influences that require novel exploration techniques and partly to other non-geologic factors, but the basic geologic potential is present. Such regional problems should be attacked on their own terms, for the benefit of each region's own people, something that we in tropical countries cannot currently expect from research that is oriented to the needs of the developed nations and the northern regions (fig. 5).

The AGID initiative should be vigorously supported not only for its intrinsic worthiness, but as an example of novel attempts to resolve the special and life-deciding resource problems of developing nations.

MAJOR CONCLUSIONS FOR THE TWENTY-FIRST CENTURY

1. For now and for the Twenty-first Century, the highest priority in the resources situation of underdeveloped nations is to find ways to increase the number of competent local geoscientists. Much increased field allowances and foreign pressure will help.
2. Systematic quadrangle geologic mapping provides the basis for all other work and is feasible for all developing countries.
3. Basic data collection and compilation is essential and feasible for all developing countries.
4. Water investigation must receive greater attention in the underdeveloped countries.
5. Research tailored to the special needs of developing nations is imperative. The International Geoscience Research Institute, proposed by AGID, for the development of mineral exploration techniques in tropical rain forest regions, is an effort in that direction, and should be supported.

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Figure 5 Karst in northern Guatemala. Special exploration approaches must be developed for tropical rain forest regions.

The Outlook from Korea on Resources for the 21st Century

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I am very much honored to be present at this centenary celebration of the U.S. Geological Survey, and I am pleased to speak about the expected resource problems for the 21st Century as seen from the Korean point of view.

MINERAL RESOURCES AND ECONOMIC GROWTH

Like some other countries, Korea now faces a serious shortage of fuel and of some mineral resources—a shortage that has been intensified by the high economic growth achieved in the last two decades.

Basically, resource problems are largely a matter of supply and demand. For example, when there is a small demand, generally the problem does not arise. That was our situation in the 1950s when the economic policy of Korea was directed toward stabilization rather than growth, with stress on reestablishing the industrial facilities that had been destroyed and damaged during the Korean War.

The prewar industrial structure of Korea was very backward and, through the 1960s, consisted mostly of small-scale light industry that produced only everyday necessities, mainly for domestic use. Accordingly, the demand for raw materials was generally small. Industry relied solely upon coal and hydroelectric power for energy, and the country was self-sufficient in firewood, charcoal, hay, coal and the like for household use.

In fact Korea's demand for minerals, metallic and nonmetallic, was so small at that time that almost all her production of mineral resources, except anthracite coal, was exported. This export of mineral resources continued to the end of the 1960s. These included tungsten, iron, copper, lead, and zinc ores in the metallic groups, together with kaolin and small quantities of silica in the nonmetallic group. In the present situation it is indeed ironical to recall that Korea, with her meagre natural resources, once relied heavily upon the export of these minerals as a way to earn foreign exchange.

After a notable economic setback between 1957 and 1960, a major change in economic policy was called for, and in the 1960s there was a big shift from stabilization to high economic growth through industrialization. The immediate effect of this new policy was to transform the existing light industry through expansion and technological innovation. Manufacturing particularly began to show marked growth far beyond that of other industrial sectors.

Subsequently, in the latter half of the 1960s the cement industry showed a great upsurge, and in the early 1970s the boom in the construction and electronics industries began. The changeover from coal to oil for railroad fuel in the early 1960s, coupled with later increases in road transport, and the general expansion of industrial facilities, were major factors contributing to a sudden increased demand for petroleum.

Korea's resource problems first became evident when her oil imports increased dramatically in the early 1970s; the situation became worse after the 1973 oil crisis. Also, a swift upturn in production in both the heavy and chemical industries naturally caused a greatly increased demand for industrial raw materials.

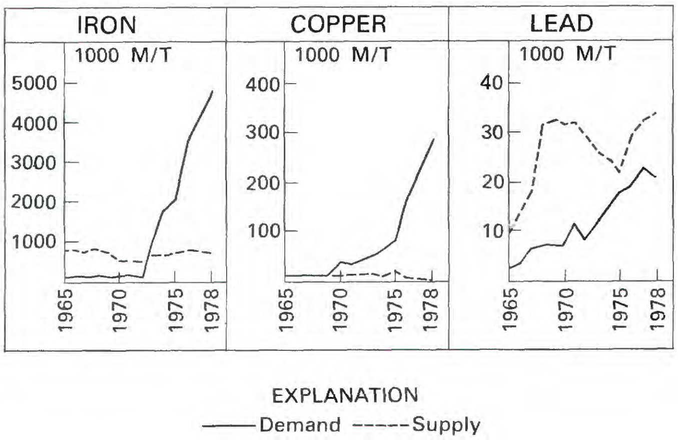

Figure 1 Supply and demand of metallic minerals in Korea, 1965–1978.

Figure 1 illustrates both supply and demand for iron, copper and lead ores from 1965 through 1978. Almost all iron ore production was exported until 1973, when a tremendous increase in demand occurred. As of 1978 Korea's domestic production met only 14.2 percent of that demand. Copper ore figures indicate a self-reliant trend up to 1969; but in 1970 and especially after 1975 there was such a sharp rise in demand, that, since 1978, 99.34 percent of the demand has had to be met with imports. Lead ore also shows a great increase in demand after 1972. Although in this case domestic production is still a little ahead of demand, the gap between supply and demand is narrowing.

The trends of energy supply and demand can be seen in figure 2. The energy import rate was 9.4 percent in 1962, 51.2 percent in 1971, and 66.8 percent in 1978—in which year petroleum accounted for 61.2 percent of that total. Nuclear generated power was introduced in Korea in 1978, and it now supplies 1.6 percent of our total energy demand.

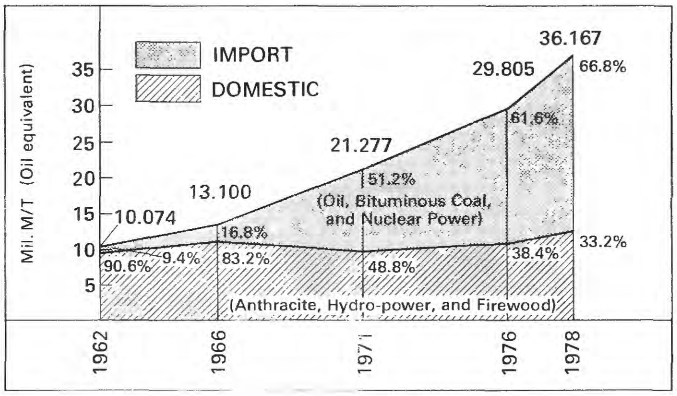

Figure 2 Trends of energy supply and demand in Korea, 1962–1978. [Increasing rate of total energy demand: 7.9 percent; GNP growth rate: 9.3 percent]

The growth of Korea's gross national product and of its industrial development during the 1960s and 1970s are compared instructively in figure 3 with those of the 1950s. Primary industry, including agriculture, fisheries, and forestry, showed an average increase of 4.4 percent while other industry showed an average increase of 13.5 percent. All told, our GNP has increased 12 percent on the average. This reveals the close interrelationship between economic development and the resource problems.

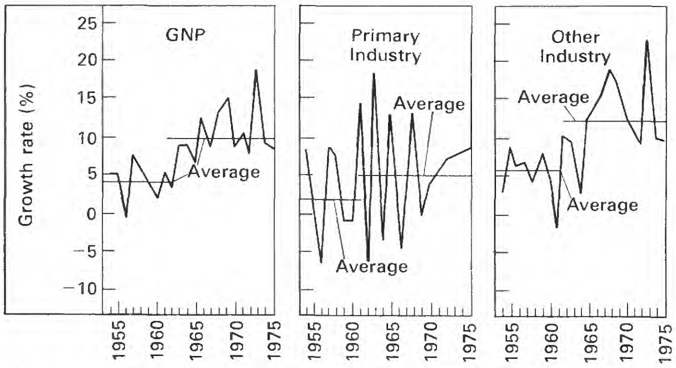

Figure 3 Growth rate of Korea's GNP and industrial development, 1955–1975.

It should be noted here that during the build-up stage, Korea's heavy industry changed from a labor-intensive to a resources-consuming type.

As we stated earlier, resources problems arise when demand exceeds supply. This in turn involves consideration of another important factor, that domestic supply capability is directly related to the availability of resources.

Available Mineral Resources in Korea

Reserves of various major minerals in Korea (as of December 1978) are shown in figure 4. First among the fuel minerals is anthracite coal with proved deposits of approximately 1.5 million metric tons. Although short of the projected total domestic demand, this supply of coal may last for about another 30 years at current production levels. The uranium ore available in Korea is of a low grade (0.04 percent U_3O_8), and the known deposits are estimated to be approximately 20 million metric tons. If, in the future, the technological and economic problems associated with its development can be solved, the domestic demand for uranium could be met to some extent.

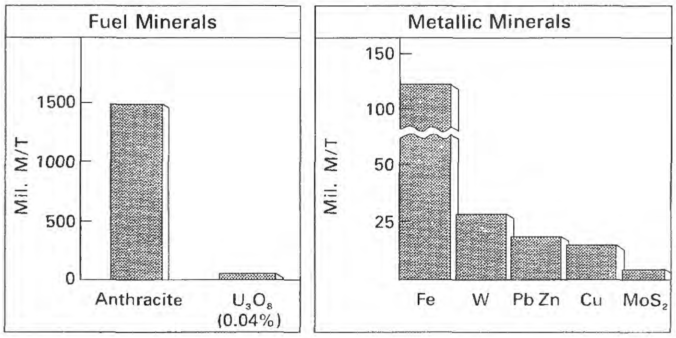

Figure 4 Estimated major mineral resources in Korea, as of December 1978.

Current estimates of available metallic mineral resources are: 126 million metric tons of iron ore (35.6 percent Fe); 14.2 million metric tons of copper ore (15 percent Cu); 17.4 million metric tons of lead and zinc ore (6.5 percent Pb + Zn); 26 million metric tons of tungsten ore (0.5 percent WO_3); and 1.5 million metric tons of molybdenum ores (0.5 percent MoS_2). Of these, however, only lead and zinc can now be produced in sufficient quantities.

Turning to the group of nonmetallic minerals (fig. 5), the available resources are estimated to be: 6.6 million metric tons of graphite (3 percent fixed carbon); 38.8 million metric tons of kaolin; 49.5 million metric tons of

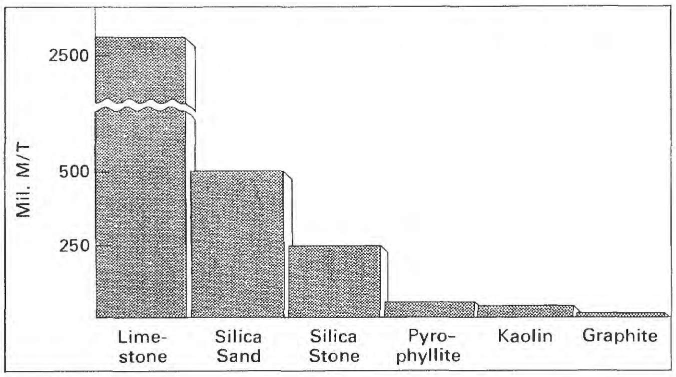

Figure 5 Estimated nonmetallic mineral resources in Korea, as of December 1978.

pyrophyllite (28 SK [Seger Cone Test]); 2.5 billion metric tons of limestone (51 percent CaO), 250 million metric tons of silica stone (98 percent SiO_2); and 499.6 million metric tons of silica sand (85 percent SiO_2). At present these resources are ample for our requirements and may be adequate for domestic demands for tens of years to come.

Except for nonmetallic minerals, Korea's natural resources are quite meagre, and it is fairly evident that, unless significant progress is made in locating large-scale deep-lying mineral deposits, Korea will have no choice but to remain a resources-importing country. Many of the advanced industrialized countries face the same prospect.

IMPACT OF THE OIL CRISIS ON KOREA

The 1973 oil crisis has had a great impact on the modern world's industrial systems. In fact, possibly no other single event has caused such world-wide economic turmoil. The aftermath has kept us particularly aware of the limits and the preciousness of resources in general, and serves as a warning to us to be very careful in planning future development.

In spite of the adverse effects of the 1973 oil crisis, Korea has maintained her economic growth above 10 percent by sharing out the oil price hikes amongst all sectors of industry, and by ensuring overall public cooperation. Fortunately Korean industry was still largely labor-intensive in 1973, and thus minimally dependent upon oil supplies. Korea was lucky enough to go through the subsequent economic turmoil without great difficulty. However, the rapid development of heavy industry, with its requirements for energy and minerals, and our people's changing life styles resulted in greatly increased demands for raw materials. The resulting difficulties in acquiring necessary oil and minerals made responsible Koreans realize that an adequate supply of resources was the key to further economic development. So in January 1978 the Korean Government created its Ministry of Energy and Resources.

Korea is now developing alternative energy sources to oil, encouraging the use of available domestic resources, making long-term plans for the importation of raw materials. By the year 2000, plans call for Korea's nuclear energy plants to furnish approximately 23 percent of the nation's total energy demand. Development of solar energy systems for home use, and planning of tidal power systems, are also being actively boosted. However, their contribution to the total energy requirement may be relatively insignificant.

MEASURES TO REDUCE THE RESOURCES PROBLEMS

Expansion of Exploration and Development Activities

The geological distribution and structure of Korea are complicated and, coupled with the rugged terrain, create difficulties for mineral exploration. Furthermore, the small scale and irregular nature of discovered ore bodies greatly restrict mechanized mining. And, like other densely populated countries, we also face the additional problem that agricultural and urban land shortages generally confine mining to the mountainous areas (fig. 6).

With all this, Korea is trying hard to improve both its exploration methods and the development of its mineral resources. In the first place, efforts are being made to enhance the level of scientific studies on the genesis of the mineral deposits and to master modern geophysical and geochemical exploration techniques. Efforts should also be made to expand basic studies in geoscience in general, but our present staff and budget constraints permit neither. As conditions permit, these studies will be pushed forward. Also, as a means for rapid surveying of the national territory, airborne geophysical exploration is going to be conducted systematically, together with the utilization of remote sensing data.

All these techniques are being applied not only on land, but also in exploration in the near offshore areas. Such efforts will next be extended to the continental shelves. As soon as these are all well in hand and employing the latest technology, we will turn to the exploration of overseas resources. As a step further, we hope to have opportunities to participate in international cooperative surveys of the deep sea and the polar zones.

However, development of our deep-lying resources demands increasing attention because most of the mines in Korea are not open pits, but lie deep underground. Thus mining requires a high degree of technology and safety precautions for operation. The latter is difficult and lowers productivity. Recently too, with living standards rising and job opportunities increasing in both manufacturing and construction, it is becoming difficult to persuade men to work in mines with bad working conditions. Therefore highly mechanized mining is urgently called for. This employment situation is particularly true in coal mines at present, but it will soon spread to the deep metallic mines as well.

Industrial hazards due to resources development are not yet serious in Korea. Sometimes, of course, examples of these are a landslide or an inrush of underground water in some of the coal mining areas. This kind of trouble is brought to the attention of mining engineers so that solutions can be devised. Wastes from metallic ores are being put to good use by civil engineers in construction projects. Nevertheless, because of continuing resources development, we are going to face industrial hazards or nuisances that run counter to people's awareness of the need for nature preservation. These two conflicting matters raise problems that have to be worked out.

Figure 6 Topographic map of Korea. ▶


South Korea
Internal administrative boundary
National capital
Internal administrative capital
Railroad
Road
0 25 50 75 Miles
0 25 50 75 Kilometers
North Korea
Demarcation Line
Sea of Japan
Yellow Sea
Korea Strait
Tsushima
Japan
Kyushu
Hamhŭng
Chŏngju
Wŏnsan
P'yŏngyang
Sariwŏn
Haeju
Ongjin
Kaesŏng
Munsan
P'yŏnggang
Ch'ŏrwŏn
Kansŏng
Ch'unch'ŏn
Kangnŭng
Parhan-ni
Samch'ŏk
Ullŭng-do
Seoul
Inch'ŏn
Suwŏn
Yŏju
Wŏnju
Ansŏng
Ch'ungju
Ch'ŏnan
Ch'ŏngju
Yŏngju
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Yŏngdŏk
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Kimch'ŏn
P'ohang
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Ulsan
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Chinhae
Pusan
Kwangju
Mokp'o
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Sunch'ŏn
Yŏsu
Samch'ŏnp'o
Kŏje-do
Chin-do
HŬKSAN-CHEDO
Cheju
Cheju-do
Kyŏnggi-do
Kangwŏn-do
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NAMES AND BOUNDARY REPRESENTATION ARE NOT NECESSARILY AUTHORITATIVE

Effective Utilization of Resources

I want to touch now on three ways of effective conservation of resources that are conducive to providing short- or long-term solutions to the scarcity of resources.

First, savings by cutting back on the use of resources can be increased. Like many other countries, Korea is already practicing such economies as a short-term measure. Examples include turning out one light in each home, controls on heating and cooling systems, no fuel deliveries over the weekend, and suspension of nighttime sports games. These are now general practices in Korea. For the long term, ideas and plans are being envisaged and developed in order to reorganize the high-energy-consuming industrial structure into a low-energy consumption or oil substitute type.

Second, recovery or recycling of used resources can be increased. Korea was experienced in the post-war period in the collection and reuse of waste products. Improved reutilization of industrial wastes could be of much help in our efforts toward resources conservation if it is more systematized on a larger scale. This would also help reduce industrial hazards.

Third, I can cite the development of not-yet-used resources. The chemical elements in use by the end of the 19th Century numbered only 22, but scientific technology and industry increased that number to 71 by 1970, for a 223 percent increase. Many of the elements used in recent years are rare elements, and low-grade ores of rare elements are expected to be used much more in the years to come. In addition, major resources that, until recently, have been derived from high-grade ores can now be utilized with low-grade ones because of advances in related technology. Therefore, further developments in large-scale ore dressing and refining technology for low-grade minerals will open the possibility for efficient uses of large amounts of hitherto uneconomical resources. Therefore, in the face of an unknown world to come, we geoscientists should use present trends to predict our mineral potential for the future. We should also assist in improving development and refining methods for the most efficient processing of available minerals.

Increase in International Cooperation in Relation to Resources

I should like to speak of international cooperation in solving resources problems. International cooperation has two aspects—the economical and the technical. Regarding technical cooperation, it can be briefly noted here that technical levels in the geosciences vary from country to country. Besides, the so-called resource nationalism which emerged before and after the oil crisis leads countries to explore and develop their own resources independently and with their own national capabilities.

Technical cooperation would be good for furthering mutual understanding between the nations. Korea has technical cooperation programs with such countries as the United States, England, West Germany, France, Australia, and Japan. As for cooperation with neighbouring countries in the field of geoscience, Korea is a member of the Economic and Social Commission for Asia and the Pacific (ESCAP), under United Nations' sponsorship. Two standing geoscientific organizations under ESCAP are the Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Area (CCOP) and the Regional Mineral Resources Development Center (RMRDC). Through these organizations we are exchanging geoscientific information on the land and continental shelves as well as on technology. Joint surveys are also conducted from time to time.

Korea and Japan have recently initiated a joint continental shelf oil development project; this is a good example of an undertaking of mutual interest to the two countries. It is a project that is productive not only because of the opportunity for technical and economic cooperation, but also because it offers a way to work out possible resource disputes between the two adjacent countries. Such cooperation should narrow technical gaps between the countries in a short time and also accelerate the solution of their common problems. International cooperation in the economic sector should aim at overcoming supply-demand difficulties. Resource markets have so far been based upon the resources-exporting countries; some major world enterprises should in the future be structured so as to give resources-importing countries the opportunity to actively participate in them. Solutions should, first of all, be sought rationally within the framework of current economic cooperation and always with mutual interests foremost. Accordingly, regional cooperation systems like the European Economic Community should first be developed and then, within such structures, efforts should be made to solve the resource problems.

I would like to make a few remarks about the Korea Institute of Geoscience and Mineral Resources (KIGAM), which is a corporate body inaugurated in 1976. KIGAM is a government-financed institute engaged in surveys, exploration, development, and processing of mineral resources. It also performs basic studies in the geosciences. As a geoscience research organization unique in Korea, KIGAM most closely resembles the Bureau de Recherches géologiques et minières (BRGM) of France.

Geoscience had long been comparatively ignored as a field of science in Korea, but recently, with the emergence of resource problems, it has fortunately begun to be important. But at present, we are lacking in competent geoscientists in Korea and trying hard to get highly qualified earth scientists to carry out our various missions. We are also making efforts to modernize all our research equipment and facilities. With all this scheduled for achievement in the near future, I hope and am sure that we Korean geoscientists will be able to contribute to the advancement of not only Korea but also the whole world.

Insofar as all these efforts can only bear fruit in common endeavors and mutual understanding and cooperation among the nations, our future days will either be bright or dark. On this critical matter of prosperity or poverty the wisdom of mankind will be tested.

Finally, in this grave and critical problem of resources we geoscientists have tremendous responsibilities and obligations and I, as one of them, am happy and proud to shoulder a part of those common burdens.

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Discussion

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U.S. Geological Survey, Retired

In expressing appreciation to Dr. Bonis and Director Hyun for their presentations of Guatemalan and Korean perspectives of problems and requirements for identifying, exploring, and developing mineral resources for the future, and before commencing discussion, it is appropriate to comment briefly on these views.

One speaker opened with the solemn observation that resources in an underdeveloped country represent the slim margin between life and death, which is not an abstraction easily to be ignored by geoscientists. Indeed, acquaintance with this problem in its various forms imbues this symposium. The other speaker closed by observing that the quality of the future depends on the results of common endeavors, mutual understanding, and cooperation among nations, and that upon this critical matter mankind will be tested in its wisdom. Those closing remarks identify the various national and international political processes as controlling factors in man's utilization of the great technical advances already achieved in identifying, exploring, and developing resources. Future trends in political awareness may not be as predictable as the nearly exponential rise in the technology of mineral exploration and exploitation; hence, the geologic profession needs to continue to alert appropriate administrative bodies to the human needs and technical significance of advances in science that improve our ability to identify, explore, and develop geologic resources.

Common points made by both speakers recognize the need to improve the training of geologic staff, thus upgrading their influence in their own countries, and to conduct research in basic geology, including general geologic mapping. In one paper, a forceful plea is made for the support of simple procedures and equipment, but both speakers see the need for improvements in methods of mineral exploration, particularly for those deposits that are concealed and have thus escaped detection. Such concealed deposits will become the major source for future discoveries of mineral raw materials throughout the world. The search for concealed deposits can be expected to involve particularly the integrated use of advances in conceptualization and modeling of ore deposits and improvements in geophysical and geochemical exploration as well as the remote sensing of mineral deposits. Happily, the problem of source is perceived, and the methods of searching for and development of mineral resources are constantly improving. In particular, the exploration geochemists are investigating methods of anomaly enhancement to develop procedures for use in the Arctic and in the arid or humid tropics where, as one speaker showed, the problems of mineral exploration are particularly intractable.

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Figure 1 This small Guatemalan village, located on the fault break of the 1976 earthquake, is almost completely devastated. Ground fractures can be seen in the lower center of the photograph. (Photograph by S. Bonis).

An Overview of Problems and Requirements for Identifying, Exploring, and Developing Resources—The Outlook from Venezuela

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INTRODUCTION

Venezuela is well known for its oil resources and its active membership in OPEC. Unfortunately, little information concerning the efforts and results of the exploration of the other mineral resources of Venezuela is available outside Venezuela.

In this report, I will attempt to summarize the information that we now have about energy and other mineral resources, giving special emphasis to the latter. This will permit an overall review of the problems that have been encountered in the exploration, evaluation, and development of the mineral resources of Venezuela.

In the field of energy resources, I will briefly consider oil and gas, and hydroelectric power, which are relatively well known, and will describe more fully coal, geothermal energy, and radioactive minerals, which are less well known outside Venezuela. Non-energy minerals of Venezuela will be described and attention will be given to the identification of the principal problems and requirements that have to be faced in the complex task of inventorying the potential of such minerals in Venezuela.

ENERGY RESOURCES

Oil and Gas

Venezuela has nationalized its oil industry, establishing four main operating companies under a holding company, plus an exploration unit. Technological assistance contracts have been arranged with former concessionaires. Exploration, development, and marketing programs are prepared periodically by the operating companies for presentation to the holding company. These programs are subject to approval by the Ministry of Energy and Mines, the policy-making organization of the Venezuelan government. The Minister of Energy and Mines is also the government representative in the holding company and acts as chairman of the directive council. Policies concerning exploration, evaluation, and development of oil and gas are established by the Ministry of Energy and Mines in light of the best interest of the country and subject to its international agreements.

The petroleum potential of Venezuela, as estimated by the Ministry of Energy and Mines in December 1978, is as follows:

Proven reserves	18,279,382,000 barrels
Semi-proven reserves	8,440,135,000 barrels
Non-proven reserves	7,706,107,000 barrels
Total	34,425,624,000 barrels

This estimate does not include petroleum in the Orinoco Oil Belt, possible offshore petroleum, and petroleum in non-traditional areas or sources such as tar sands and asphaltites. The Ministry of Energy and Mines has estimated natural gas reserves of Venezuela as follows:

Associated gas	40.3×10^{12} ft^3
Non-associated gas	1.6×10^{12} ft^3
Total	41.9×10^{12} ft^3

Non-official estimates of total gas resources, issued by the Ministry of Energy and Mines, are on the order of 175×10^{12} cubic feet.

It is not necessary to discuss exploration problems faced by the oil industry of Venezuela, since they are the same as in the rest of the world. Offshore exploration, based on the latest and most advanced technology, has begun recently. Heavy-crude processing technology, secondary recovery, and changes in refining standards are some of the most important recent goals set for the petroleum industry of Venezuela.

Coal

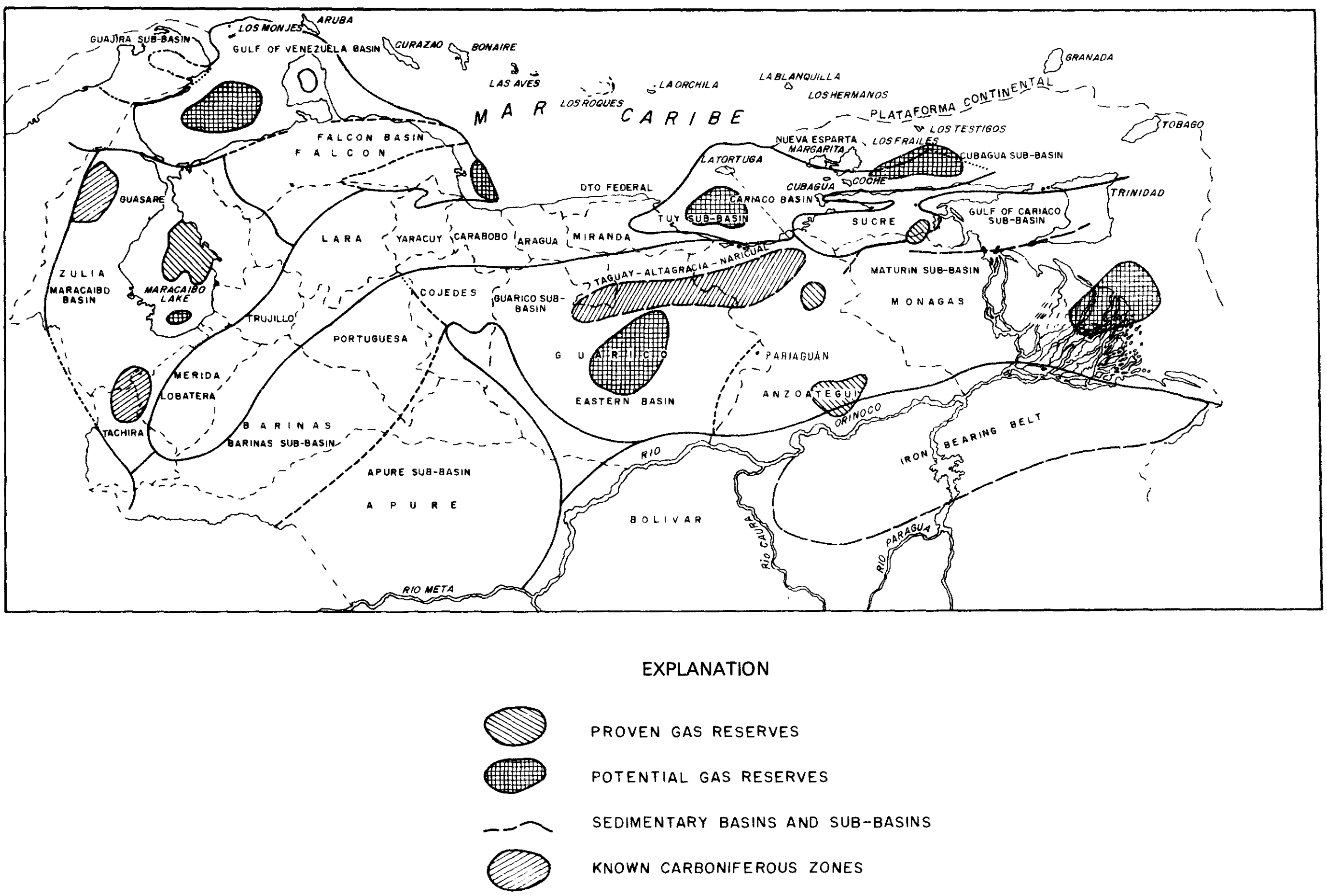
Because of the large oil and natural gas reserves, the development of coal resources in Venezuela is of low priority. However, the efficiency of an energy policy of a nation requires the development and coordination of all its energy resources, and Venezuela has large coal resources that should be developed as a means of diversifying its energy base.

Three coal basins are known in Venezuela: Los Andes, Naricual, and Zulia (fig. 1). The only coal production in Venezuela is from deposits in the Los Andes basin, the most important of which are near Lobatera, State of Tachira, which yield more than 95 percent of present domestic production. The cement factory of Tachira purchases most of this coal. Yearly production is 60,000 metric tons with proven reserves of 3 million metric tons, and the potential is estimated to exceed 20 million metric tons. The coal is suitable for mixing with imported coals for a variety of uses and for coke for some metallurgical processes. The Santo Domingo mine, which produces steam coal, is also in the State of Tachira. It has estimated reserves of 200 million metric tons. Coal near Rubio, State of Tachira, is of better quality and appears to be sufficient in quantity for mine development. This deposit is presently being evaluated.

Studies now underway in the Naricual basin indicate reserves of 14 million metric tons of coal and a total potential resource of 60 million tons. A regional governmental corporation, CORPORIENTE, has taken out a concession of 4,500 hectares in this basin with the expectation of opening a mine having the capacity to produce 250,000–300,000 metric tons of coal per year. The coal may be used as fuel for local consumption and for production of electrometallurgical coke. According to existing evidence, coal in the Naricual basin extends for about 200 km, and total resources of the basin are estimated to be many times that of the Naricual area.

The Zulia coal basin, in western Venezuela, has large resources of high-grade coal. CORPOZULIA, a regional governmental corporation, was recently granted an 8,250-hectare concession in this basin between the Guasare, Socuy, and Cachiri Rivers. Drilling on 600 hectares of this concession shows reserves of 161 million metric tons of coal and indicated reserves of 3,670 million tons. The planned yearly production from deposits here will be sufficient to supply a 2,000-megawatt steam power plant and to yield blast furnace coke for production of 5 million metric tons of steel.

Figure 1 Sedimentary basins of the natural gas and coal reserves in Venezuela (Source: Carta Semanal, Volume XX N° 25, 1977).



Coal also is known to occur in other regions of Venezuela as follows:

Eastern Venezuela:

1. An area of 50,000 hectares south of Pariaguánhas several coal beds having an accumulated thickness of 30 meters.
2. An area of 120,000 hectares north of the Orinoco River has several coal beds with an accumulated thickness of 50 meters.
3. An area of 20,000 hectares along the junction of the States of Anzoategui and Monagas has coal beds with accumulated thickness varying from 2 to 50 meters. Another 20,000 hectare area between these two states has coal beds with an accumulated thickness of about 45 meters.
4. Other coal-bearing areas about which little is known include the Naricual sub-basin, Quebradón, Parapara, Ortiz, Cara River, Taguay, Altagracia de Orituco, and Fila Maestra.

Western Venezuela:

The following geological formations in western Venezuela are known to contain coal beds:

1. Los Ranchos and Palmarito formations, State of Zulia
2. Isnotu and Palmarito formations, State of Tachira
3. Urumaco, Cerro Pelado and Agua Clara formations, States of Mérida, Trujillo, Barinas, Portuguesa, and Falcón.

Solar Energy and Wind Power

Solar energy is a feasible energy source in Venezuela, particularly for heating in the colder regions of the country, for heating of water throughout the country, and finally for obtaining pure drinking water.

Solar energy and wind power are potentially of great importance to rural regions of Venezuela, where installation of electric, irrigation, and potable water systems are economically unfavorable. The solar energy and wind power potential of several rural regions have been studied, with results as follows:

	Radiation (cal/cm²day)	Wind (km/hr)
Falcón	532	20
Tablazo	---	20.3
Orchila Island	488	21.5
Mérida	506	---
Barcelona	481	---
Barquisimeto	540	12.9
Ciudad Bolivar	460	---

These data are based on measurements during the last twenty years and represent reliable information for the implementation of solar or wind power systems. Furthermore, it is estimated that the meteorological conditions of other islands in the federal territories are similar to those of Orchila Island, and that the use of solar and wind power are economically favorable at present.

Production of drinking water on the Caribbean Islands of Venezuela by solar energy could be of particular importance. For example, on Orchila Island, a desalinization plant of approximately 4,000 meters^2, powered by solar energy, would produce 8,000 liters of distilled water per day. Wind power might also be used on these islands for generation of electricity and for pumping of water. Solar energy could also supply photovoltaic electricity to installations such as navigation lights, radio systems, relay stations and residences.

Geothermal Energy

Venezuela offers geologically favorable areas for the installation of geothermal facilities for industrial use. Until the present, however, there has been no evaluation of the magnitude of the potential for geothermal energy.

For convenience of discussion, Venezuela is divided into three main geothermal regions; eastern, central, and western. The western region is an extension of the orogenic belt whereas the eastern and central regions are associated with the south border of the Caribbean Plate. The eastern region includes areas in the State of Sucre and the northern part of the State of Monagas. Geothermal systems in these areas are associated with large faults, related to the convergent margin of the Caribbean Tectonic Plate and the South American Tectonic Plate. Among these are the El Pilar and the San Francisco Faults. The western region is characterized by Cenozoic tectonism and active structural systems such as the Bocono Fault. The central region is dominated by block-fault structures of Cenozoic age, such as the Lake of Valencia graben and the Villa de Cura allochthonous block.

In addition to the above-mentioned regions, thermal anomalies occur in the margins of the petroliferous basins of Barinas, Apure, and Maturin. High thermal gradients have been found in oil wells drilled in these basins. They require further study as possible sources of energy for recovery of heavy crudes.

Of the forty-seven geothermal fields proven by drilling up to 1977, approximately 56 percent are associated with Quaternary volcanic rocks, 21 percent with block-fault structures in highly seismic regions without Quaternary volcanic rocks, and 13 percent are away from seismic and volcanic zones.

In 1974–75, the first steps were taken to evaluate the country's geothermal resources by a group of experts from the Ministry of Mines and Hydrocarbons (now the Ministry of Energy and Mines) and the Compañía Anómina de Administración y Fomento Eléctrico

(Venezuela) (CADAFE), with the cooperation of national and international advisors. The evaluation included geological, geophysical, and geochemical field studies and interpretation of the results of these studies and of previous geological and geophysical studies that had been carried out for a variety of reasons.

As of 1979, there was sufficient information available to initiate a feasibility study for geothermal exploration as conceived by the Latin American Organization of Energy (OLADE). The main objective of this program was to establish at the national level the availability of geothermal fluids for industrial use. Ongoing studies of geothermal resources are expected to supply the data needed to evaluate the geothermal energy potential by 1982. These studies will lead to evaluating some 12,500 square kilometers, which include the El Pilar-Casanay zone where some surveying has already been done. The continuation of the survey in the western and central regions will depend on the results obtained in the eastern region.

According to present understanding of the geology of the eastern region, the following steps could be accomplished in one year:

1. Compilation, analysis, and interpretation of the region's geological, geophysical, geochemical, hydrometeorological, and hydrological information
2. Inventory of thermal manifestations
3. Reinterpretation and reevaluation of all existing geological and geophysical studies

Once these preliminary investigations are completed, the following studies will be carried out in the eastern region:

1. Preparation of thermal gradient maps
2. Installation of microseismic monitors
3. Preparation of detailed technical-structural maps
4. Carry out gravimetric-magnetic surveys
5. Carry out geoelectric surveys
6. Interpret the hydrologic balances of basins
7. Carry out hydrogeochemistry studies
8. Evaluate feasibility phase with the participation of national and international experts
9. Drill at least three deep exploration wells
10. Make a preliminary evaluation of geothermal fields
11. Identify areas having the best potential for exploitation

Radioactive Minerals

The search for radioactive minerals in Venezuela dates back to 1950, when the Dirección de Geología first carried out exploration with the cooperation of the U.S. Atomic Energy Commission. Later in the sixties, additional exploration was carried out and some locations of interest were defined. The situation of the uranium world market and national priorities halted the exploration programs at that time. In the seventies, an integrated areal survey, which included radiometric surveys, was made for most of Venezuela. The energy crisis in 1973 and the renewed interest in nuclear resources brought about new plans for organizing a systematic survey of radioactive minerals of Venezuela. An office was established to be responsible for nuclear energy and the Dirección de Geología and the Raw Materials Division of CONAN were designated as the agencies responsible for exploration for radioactive minerals.

The Dirección de Geología and CONAN have identified several sites as environments for accumulations of radioactive minerals, as follows: (1) Triassic-Jurassic rocks in the Andean Cordillera and Perija Sierra; (2) phosphate rocks of the Upper Cretaceous; (3) conglomerates and sandstones of the Precambrian Roraima Group; and (4) certain Precambrian granites.

Thorium has been found in Amazon Territory, in the area of Cerro Impacto where a carbonatite is covered by a lateritic capping rich in iron, thorium, niobium, base metals, and rare earths.

In conclusion, trace amounts of radioactive minerals have been found in a variety of geologic environments in Venezuela, but not enough work has been done to define the economic potential of these minerals. The lack of trained personnel and technology for evaluating anomalous areas has inhibited the evaluation of radioactive minerals.

Requirements for Most Effective Development of Energy Resources in Venezuela

The following factors should be considered in the development of Venezuela's energy resources:

1. The production rates of oil and gas should be determined by requirements for internal use and the need of export dollars for industrial development.
2. Conservation practices should be aimed at prolongation of oil and natural gas production to give the maximum time to develop alternative energy sources.
3. The development of energy resources such as coal, nuclear and other non-conventional energy resources of Venezuela will require acquisition of knowledge and technologies not yet utilized in the country and training of engineers and workers in the application of new technology.
4. The development of basic industries such as iron and steel production and electric power generation should be accelerated as a base for industrial development of Venezuela.
5. Coal should be utilized in the industrialization of Venezuela as fuel, for steam power electric generation, and for manufacture of siderurgical coke.

Metallic and Nonmetallic Mineral Resources

Systematic geological exploration and prospecting for metallic and nonmetallic minerals has produced a large number of geological maps that are basic to current and future exploration programs. Large-scale aerial surveys and remote sensing techniques have been utilized to explore areas of difficult access in the remote jungle and mountainous parts of the country. Crews of the Dirección de Geología, operating from base camps in remote areas and base offices in the larger cities, have been able to complete a preliminary evaluation of the mineral resources and to locate many potential mineral deposits in areas where such deposits had previously not been known. Only the most important mineral deposits can be mentioned here. Some of these deposits are being exploited, others are in the feasibility study stage, and others are at the stage of preliminary exploration.

Venezuela's most important metallic mineral resource is iron ore, and current reserves stand at 2,059 million tons of ore having 60 percent Fe_2O_3. All known deposits are in ferruginous quartzites in the Precambrian shields of Estado Bolivar. The industry, which originally was under control of the U.S. Steel Company and the Bethlehem Steel Company, is now operated by a national company called Ferrominera.

Venezuela produced 410,535,534 metric tons of iron ore between 1950 and 1977. Of this production, 387,749,776 tons were exported, with the United States leading the market with 71 percent of the total and the rest going mainly to European markets. The growing iron industry of Venezuela has consumed only 3 percent of total production.

Bauxite recently has been discovered in Venezuela as the result of a major systematic exploration program of the Dirección de Geología. Since Venezuela has tremendous hydroelectric potential, it has been a goal to locate bauxite in sufficient quantity to support a strong aluminum industry. The systematic survey of the Guayana Shield and the exhaustive studies of the lateritization processes of the tropics finally paid off with the discovery of several areas with potentially commercial bauxite deposits. Studies now underway will evaluate size and grade of these deposits.

The most favorable bauxite areas are in the lateritized peneplain on the Precambrian Parguaza Granite in the eastern part of the State of Bolivar. Preliminary studies indicated the existence of at least one large deposit of commercial bauxite. Preliminary evaluation by the Corporación Venezolana de Guayana indicates reserves of 500 million tons of bauxite suitable for the Bayer process. Feasibility studies for production of aluminum from this bauxite are now underway. Other localities in the Guayana Shield have high-alumina laterites, which are another possible source of aluminum.

Gold and diamonds are known to occur in the Precambrian Guayana Shield. For example, many gold-bearing quartz veins occur in the lava flows of the Pastora Formation near El Callao, Tumeremo, and the El Dorado area in the southeastern part of the State of Bolivar. Also, the lower basal conglomerate of the Roraima Formation contains gold that is liberated during erosion and is concentrated in placer deposits of streams draining areas where this conglomerate is exposed. Between 1955 and 1977, an average of 1 million grams of gold were produced yearly from such placer deposits.

A project has been completed by the Ministry of Energy and Mines to start production of gold in 1980 by the state-owned Minerven Company from an estimated 2½ million tons of ore with an average of 12 grams Au per ton. Individual operators plan to start operating small mines in the same area. The potential of the gold in this area is now being tested by the Dirección de Geología to provide basic information for large-scale development.

Alluvial deposits in the State of Bolivar have yielded excellent quality diamonds. Diamond mining now being carried out is primitive, and monitoring and control of production by the government is difficult. In 1977, recorded diamond production was valued at 107 million bolivars in fiscal revenues, equivalent to 10.4 percent of the recorded value of diamonds produced. The government, conscious of the potential of diamonds, has started a large-scale program with two goals: (1) to control indiscriminate exploitation of alluvial deposits; and (2) to locate the primary sources (kimberlite pipes) of the diamonds.

In general, the aforementioned minerals (iron, diamonds, gold, and coal) made up the total value of Venezuela's mine production in 1977, which amounted to 1,036 million bolivars, of which 88 percent was iron ore.

Several other types of metallic and nonmetallic mineral deposits exist in Venezuela. Reserves of lateritic nickel at Loma de Hierro are on the order of 57 million tons of an average of 1.5 percent nickel. A polymetallic base metal deposit at Bailadores in the Andean region of western Venezuela contains significant resources of copper, lead, and zinc. Alkaline intrusive complexes in the southern part of the Amazon Territory contain tin and other heavy minerals. Titanium has been identified in the metamorphic complex near San Quintin in the north-central part of Venezuela. Phosphates, gypsum, magnesite, kaolin, barite, and industrial minerals such as limestone, sand, and others are in many parts of the country. One of the most promising discoveries is the carbonatite complex of Cerro Impacto in the Amazon Territory. This carbonatite complex is a possible source of radioactive minerals.

PROBLEMS OF EXPLORATION AND DEVELOPMENT

Private capital is not prone to invest money in mining ventures in Venezuela for the following reasons:

1. Obsolete mining laws
2. Lack of definitions in certain mining policies
3. More favorable environments for investments in other areas of the economy of the country
4. Lack of mining tradition on a small scale
5. An oil-influenced economic environment that prevents or minimizes other activities

Tropical rain forest covers approximately 23 million km^2 of the Earth's surface between the Tropic of Cancer to the north of the Equator and the Tropic of Capricorn to the south. The main regions of tropical jungle cover are the Amazon Basin, Central America, West Central Africa, and the Indonesia/Southeast Asian region. The countries in this region are, for the most part, poor and underdeveloped, each with a generally low per capita income. The economy of these countries is supported chiefly by primitive agricultural activities and, in a few cases, the exploitation of raw materials.

Geologically speaking these areas are distinguished by vast extensions of Precambrian shields and post-Paleozoic folded sedimentary rocks and associated plutonic and volcanic rocks. Precambrian shield areas, both within and outside the area of tropical rain forests, currently are the sources of most of the nickel, titanium, and cobalt consumed by the industrialized nations and contribute more than 60 percent of the iron ore, most of the uranium and platinum, 75 percent of the gold, more than 30 percent of the manganese, 25 percent of the copper, and substantial proportions of the molybdenum, tin, tungsten, bismuth, and arsenic. On the other hand, the post-Paleozoic folded rocks with their igneous association (both volcanic and plutonic) have shown significant mineral potential in the Andes and in southeast Asia.

Considering that most mineral production from Precambrian shields and post-Paleozoic rocks is from outside the tropical rain forest areas, one may conclude that: (1) tropical rain forest areas are still essentially unexplored, and (2) the mineral potential of these regions may be similar to equivalent geological areas in other climatic environments. The main reason for less mineral exploration in tropical rain forest areas is that such exploration is difficult and expensive. Some of the factors inhibiting exploration in tropical rain forests are as follows:

1. Paucity of geological information.
2. Inaccessibility due to dense forest cover.
3. Deep lateritic soils obscure the geology and mineral deposits.
4. Exploration equipment has to withstand severe conditions of humidity and temperature, thus requiring special protection.
5. Shortage of professionals experienced in exploration in tropical rain forest environments.
6. Exploration requires establishment of complex operation centers to support field crews at costs that may be excessive for countries with weak economies.
7. The lack of economic development in most of these countries makes it almost impossible to carry out the long-term mineral exploration program that is needed for a proper evaluation of the mineral potential.
8. Raw materials prices established by multinational companies do not stimulate less-developed countries, whose mineral production responds to international requirements, to invest in mining ventures that may not be profitable or stable enough to justify the high costs of operations and the transfer of technology.

Problems associated with mineral exploration in tropical rain forest areas have been identified and openly discussed in the United Nations preparatory meetings in 1963 and 1970 (Bangkok and Ceylon University), by the Organization for Economic Cooperation and Development (OECD), and by the Association of Geoscientists for International Development (AGID) in 1977 (Caracas). At the last meeting the countries with tropical rain forest areas reiterated the multiple problems and frustrations in mineral exploration. It became clear that little progress has been made in research and exploration during these last years, despite the fact that the problem areas had been clearly identified.

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Problems and Requirements for Identifying, Exploring, and Developing Resources—The Outlook from Egypt

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LOCATION AND GEOGRAPHICAL BACKGROUND

Egypt is located on the northeast corner of Africa, overlooking the Mediterranean Sea and with a coast that stretches approximately 1,000 kilometers in an east-west direction (fig. 1). To the east, the Red Sea bounds the country, trending nearly northwest-southeast. Again, here the coast is almost 1,000 kilometers in length; thus giving Egypt a total area of approximately one million square kilometers, or 3 percent of the total area of Africa. Lying on the boundary line between the cooler temperate and the hotter tropical belts of the Earth's surface, Egypt forms an integral part of the great African Sahara.

Through the wilderness of the Sahara flows the great river Nile, giving fertility to the desert and attracting people to live on its banks. The shape of the Nile Valley is usually compared with the lotus, the linear slot-like Upper Egypt being the stem, the Faiyûm Oasis to the west the bud, the broad fan-like delta of Lower Egypt the flower. Its great river, the Nile, debouches its water northwards into the Mediterranean Sea.

To historians, Egypt is largely restricted to the Nile Valley that has been the scene of human activity through so many centuries.

To geologists, the Egypt of most importance is that vast desert area of one million square kilometers lying on both sides of the valley. This desert stretches from the Mediterranean on the north to the desolate regions of northern Sudan in the south, from the Great Sand Sea near the Libyan borders to the Levant on the northeast and the Red Sea on the east.

To archaeologists, Egypt means both the valley and the desert. The desert shows clear evidence of having been occupied in prehistoric times by nomadic hunters and temporary settlers, and the valley has great monuments of rural civilizations that flourished from 5,000 years ago.

Exploitation of minerals started very early in Egyptian history; the Pharaohs' men roved the deserts searching for valuable minerals, especially gold and gemstones. Nearly every gold-bearing quartz vein was investigated by the old Egyptians, not only in the Eastern Desert but also in the Sudanese desert to the south. Those ancients were talented enough to look for these minerals in their suitable metallogenic provinces. They even searched the minor outcrops of igneous-metamorphic complex of the Western Desert of Egypt and they were able to locate the precious stones in the quartz veins (south of Dungul Oasis) deep inside this desert.

Of this whole Egypt, the Nile Valley is a mere incident, covering 3.5 percent of the country's total area and measuring 35,000 square kilometers. It is really a thin wedge driven into the heart of the desolate Sahara.

The Nile divides Egypt into two distinct geomorphic provinces, the Eastern Desert and the Western Desert.

The Eastern Desert, with its igneous and metamorphic complex of rocks (fig. 2), is made famous by its rugged mountains along the Red Sea Coast and by the spectacular external drainage system whose wadis empty either into the Nile or into the Red Sea.

A bird's eye view of the Eastern Desert of Egypt best takes in all that is worth seeing in this desert and in the Sinai. From the highest pinnacles of wooded Elba (1,437 m) on the extreme southeastern or Sudanese corner of Egypt, the eye travels over the desert north of the bold peaks of Gebel Farayid (1,363 m) on the Tropic of Cancer. On their northern horizons lies the rose-red whaleback of Gebel Hamata (1,978 m) and beyond it the small jagged peak of Abu Tiyur (1,099 m) near Quseir. Little Abu Tiyur looks humbly north towards the vast Shayeb (2,187 m), the highest hill in this desert, where the view ranges over 320 kilometers from the loop in the Nile at Qena to chapel-crowned Gebel Katherina (2,641 m) in Sinai. In turn, Katherina overlooks flat-topped Gebel Egma (1,920 m), and Egma looks north to Gebel Halal (890 m) which looms over the green hills of Hebron.

The Western Desert, unlike the Eastern Desert, is a dead flat country. Save that it has a few green oases, it is one of the most desolate parts of the Earth. This desert of mostly low plateaus (300 to 400 meters) attains its greatest altitude in the extreme southwestern corner of the country at Gebel Uweinate (1,895 m) and on the Gilf Kebir plateau (1,100 m) to its northeast. Passing the Gilf, the country flattens down, until it abuts against a vertical cliff of limestone, clays, and sandstone. Here, the two major oases of southern Egypt are located; Dakhla to the west and

Kharga to the east. Between them the biggest phosphate reserves of Egypt are found at Abu Tartûr.

North of the bounding scarp, which rises 500 meters, the nearly endless country extends as far as one can see. Farafra Oasis lies more than 200 meters north of Dakhla while the nearly oval-shaped depression of Bahariya Oasis is another 150 kilometers northwest. Again, the bounding scarps of these two oases form the northern plateau of the Western Desert that stretches about 300 kilometers to the Mediterranean Sea. The Qattara, the largest depression of all that desert, is located in this plateau. Its area is 18,000 square kilometers and its lowest point is 134 meters below sea level and, surprisingly, it apparently came to the attention of the civilized world only in 1926. Southwest of this depression, several smaller ones are found, with Siwa Oasis the largest of them.

Faiyûm, with an area of 1,700 square kilometers, is a usurped oasis of the desert. Although it mostly lies several tens of meters below sea level, it is generally considered a part of the Nile Valley because it depends mostly on Nile waters to irrigate its fields. Its canal, Bahr Youssef, connects the Faiyûm depression with the Nile on the river's left bank.

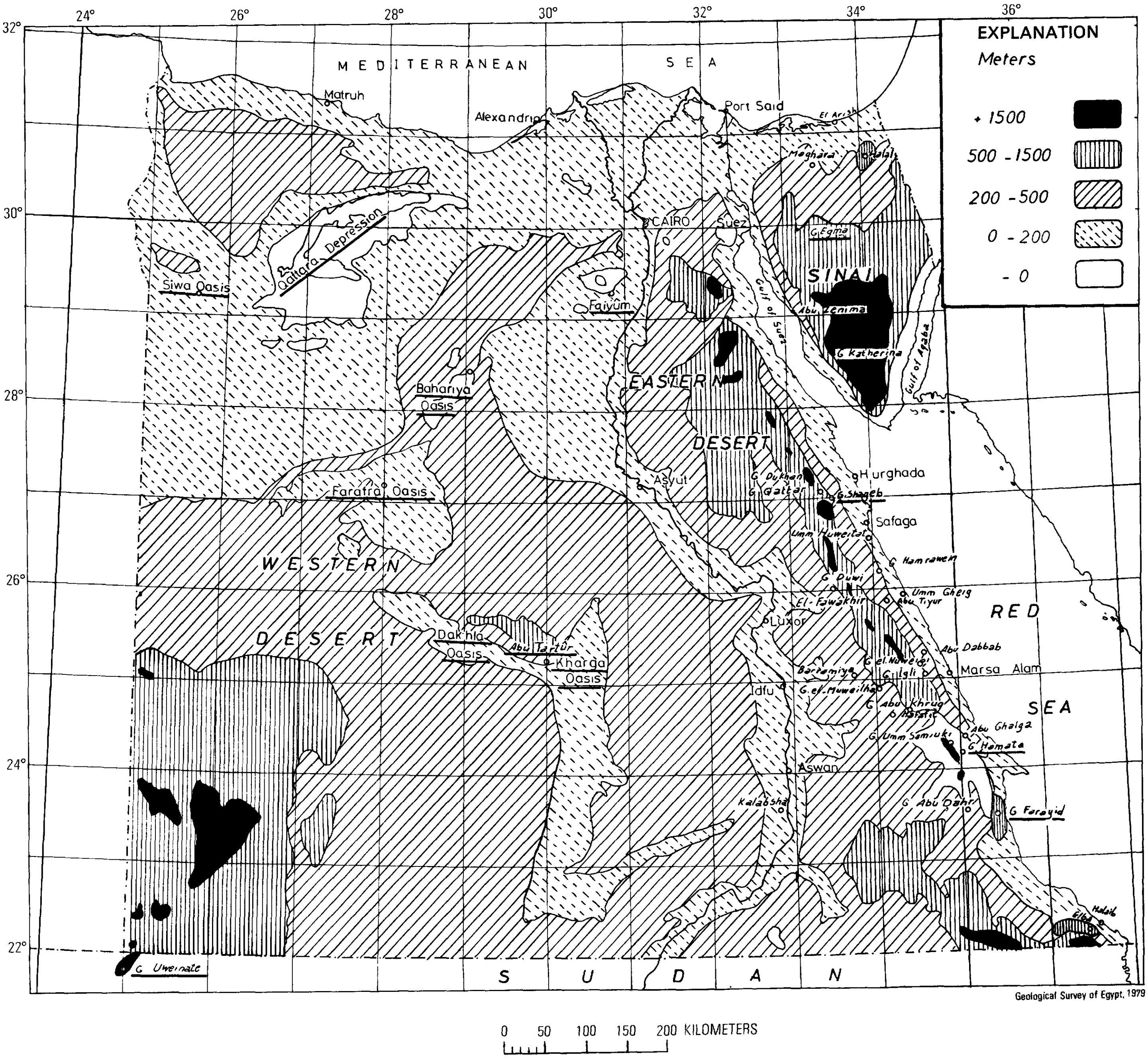


Figure 1 Relief map of Egypt.

STATUS OF THE GEOLOGICAL SURVEY OF EGYPT

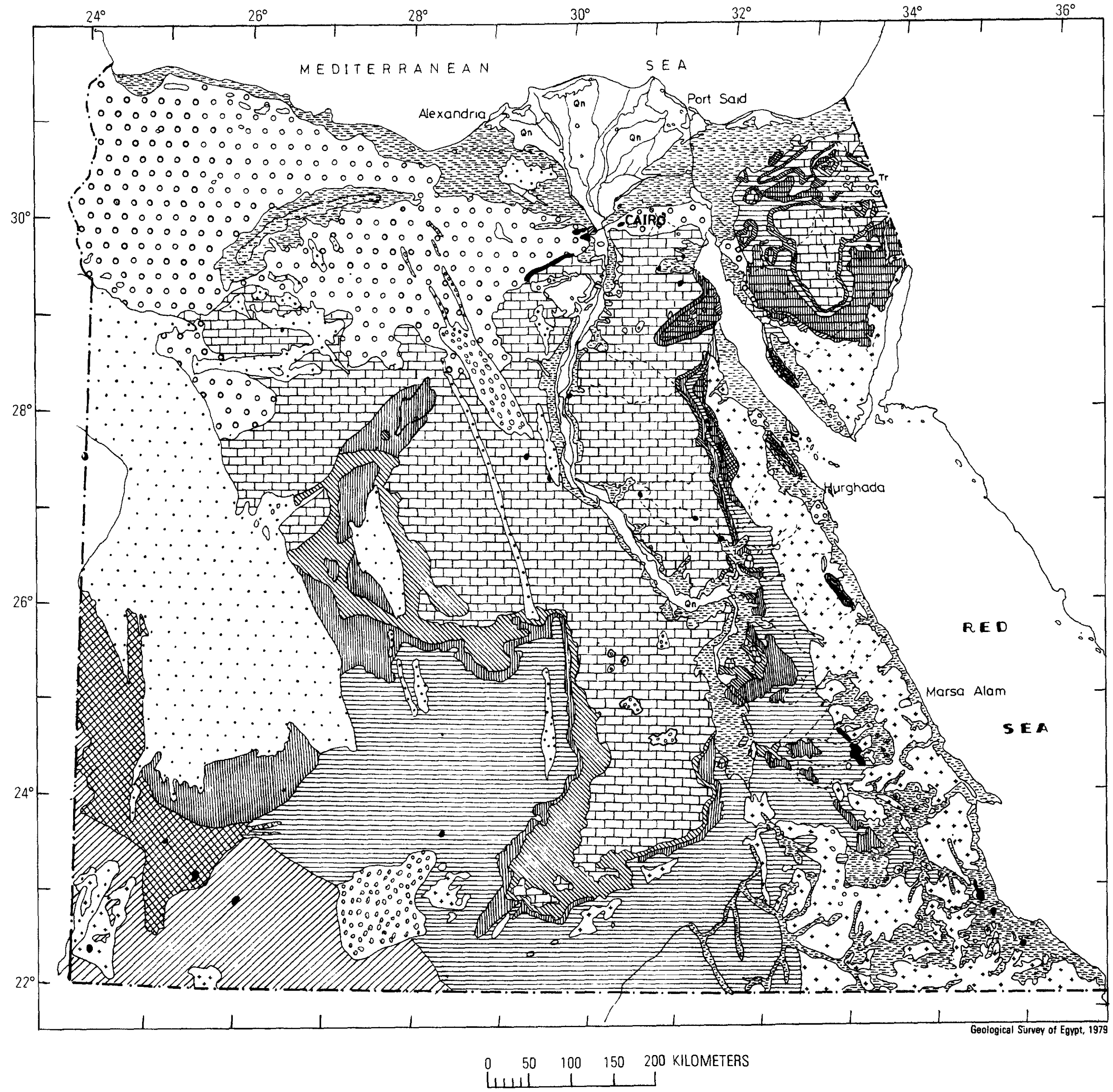
Established in 1896, the Geological Survey of Egypt has had an active role, particularly in the deserts of Egypt.

Almost 65 percent of the area of the country has been mapped at 1:50,000 scale while the rest has been regionally surveyed with smaller scales.

The Geological Survey of Egypt now has several operating divisions, including geological mapping by aerial photography and other conventional methods; exploration for minerals by geochemical and geophysical methods; drilling and mining investigations of ore deposits; chemical, mineralogical and ore dressing laboratories; and a special mining design office that sets up complete working projects for the exploitation of mines. Quarters for the newly established documentation centre are now being built in order to expand the services of the library. We also have a maintenance garage for more than 600 vehicles and workshops for repairing cars, drilling machines, compressors, and other equipment.

The Geological Museum also belongs to G.S.E. This is not only an exhibit place but includes the macro-, micro-, and vertebrate palaeontological laboratories. The earth scientists working for the Geological Survey of Egypt total 400, of whom 250 are active in the desert.

Figure 2 Geologic map of Egypt.



EXPLANATION

Qs :	Sabkha	
Qd :	Sand Dunes	
Qn .	Nile Alluvium	
Q :	Undifferentiated Quaternary Includes Older Nile Deposits, playa deposits, raised beaches and corals of Red Sea Coast.	
Tom :	Oligo - Miocene Includes gravel spreads west of Nile between Minia - Faiyum and Bahariya Oasis.	
Tpl -Tm -To :	Includes gravels and clastics above the Eocene rocks, the evaporites and clastics along the Red Sea and Mediterranean Coasts, and Pliocene limestone above the proper Miocene beds.	
Tv :	Extrusive rocks Mostly of Tertiary age, some of the Occurrences in Gulf of Suez are of Mesozoic age whereas some in Nubian Desert are of Quaternary age.	
Te :	Eocene Includes thick marine limestone with chert and clay beds covering many parts in south Egypt and extending northward up to latitude 30°N approximately.	
Tp :	Paleocene Represented by reefal carbonate with clays in the south, more marine carbonate in the north.	
Ku :	Upper Cretaceous Includes the Duwi Phosphate, the Dakhla shale in south, marine carbonates in the north.	
Kn :	Nubia Sandstone A clastic unit defined by a suite of Lithobio-stratigraphic units, exposed mainly in south Egypt.	
K :	Undifferentiated Cretaceous Includes clastics with rare carbonates below the Upper Cretaceous in south Egypt and Bahariya Oasis, carbonate beds at El Galalas, Sinai and Wadi Oepa	
Jr :	Jurassic Includes marine beds in north Egypt and clastics in the south west.	
Tr :	Triassic A carbonate/clastic section exposed at Arif El Naga.	
Pz :	Undifferentiated Paleozoic Includes mainly clastic section exposed in Sinai, Gulf of Suez and Uweinat area.	
Pr :	Undifferentiated Precambrian	

CHIEF MINERAL RESOURCES OF EGYPT [October 1979]

The chief mineral resources currently in production in Egypt include:

- Iron ore deposits of Bahariya Oasis amount to about 300 million tons. The ore is mainly goethite and hematite; its average thickness is 9 meters while its iron content averages 52 percent. At present, production is 1.2 million tons annually.
- Kaolin deposits, in the Kalabsha area, in the southern part of the Western Desert, are estimated to have reserves amounting to 16.5 million tons. Al_2O_3 content is 32 percent, and the thickness of the bed is about 5.0 meters. Annual production is 20,000 tons.
- Phosphate deposits along the Red Sea Coast between Safaga and Quseir are estimated to be reserves of about 50 million tons. The thickness of the minable beds is about one meter, with a tricalcium phosphate content of 65 percent. Annual production is about 130,000 tons.
- Phosphate deposits in the Nile Valley, between Idfu and Esna, have reserves estimated at over 100 million tons. The tricalcium phosphate (TCP) content is 64 percent, and the thickness of the minable beds averages one meter. Annual production is about 150,000 tons.

Development of other phosphate rock deposits is underway, including those in the Hamrawein area on the Red Sea Coast, where the reserves are estimated at almost 50 million tons, and at Abu Tartûr, where one of Egypt's biggest phosphate fields has been recently discovered. The G.S.E. is doing extensive geological exploration work there since it is charged with evaluating the reserves, estimated at more than one thousand million tons, and the quality of the ore at about 65 percent TCP.

The coal and carbonaceous shales in Sinai are other major deposits whose development and exploitation will soon be dealt with by the government. Our first coal mine was ready just before the 1967 war, and we hope greatly to extend it. The estimated reserves amount to 40 million tons in the Safa Mine alone. The tantalum-niobium deposits found in the granite of the Eastern Desert have been the subject of extensive studies during the last decade. In the Abu Dabbab area 48 million tons are estimated, with the percentage of tantalum at 2,740 ppm (parts per million) and the niobium at 1,140 ppm. In the Nuweibi District 82 million tons were estimated, with 9,100 ppm niobium content.

The nepheline syenite of Gebel Abu Khruq in the southern part of the Eastern Desert is a potential raw material source for alumina and cement. The alumina content averages 20 percent, and the estimated reserves are about 28 million tons.

The ilmenite minerals occurring at Abu Ghalga are estimated at about 40 million tons, with 36 percent TiO_2. Gypsum is present extensively along the Red Sea coast while potassium is known to be present in the subsurface of the Gulf of Suez. These and other mineral deposits show promise of economic value, and merit further prospection and investigation.

Other than the above mentioned mineral deposits, we also have some minable deposits of talc, asbestos, vermiculite, barite, chromite, and manganese.

Limestone, clays, dolomite, and gypsum are quarried extensively for use in the cement industry and also for building material.

Small mineral deposits are also valuable domestically and vital to the developing economy of the country. These lesser deposits include the cassiterite at Igla and Abu Dabbab; the copper at Umm Samiuki; the gold in several occurrences at Muweilha, Fawakhir, and Barramiya; the lead and zinc of Umm Gheig; the chromite of Abu Ḍahr, and many other occurrences. Perhaps their crucial importance lies in their location in the Eastern Desert of Egypt where the industrial infrastructure for exploitation of minerals is already present: roads, harbours, mining centers, desalination plants, and miners. So, even though these deposits are of limited occurrence, their presence contiguous to each other renders their development a profitable target.

It might be worth mentioning here that in 1978 the total production of the quarries, mines, and evaporite operations (mainly sodium chloride) amounted to 30,417,214 Egyptian pounds (fig. 3). At the top of the list with a revenue value of almost 15 million Egyptian pounds were the phosphates and iron ores from the mines. Next in importance were the sands, limestones, and gravels from the quarries. They contributed approximately 11.5 million Egyptian pounds to the national budget. Evaporites accounted for only 4 million pounds of the mining industry in earnings in Egypt.

GEOLOGICAL MAPPING

Another ongoing activity of the G.S.E. is the geological mapping of the country. Almost 65 percent of the total area of the country has been mapped to 1:50,000 scale using aerial photographs.

One sheet of another series, NG 36 at a 1:1,000,000 scale, was published in 1979. This International Map of the World (IMW) series map represents one-sixth of the total land area of Egypt, and by 1985 the other five sheets are scheduled for publication at the same scale.

Under the auspices of the U.S. Agency for International Development a joint project of our Survey and the U.S. Geological Survey has already resulted in the publication of two central Egypt quadrangles (the Qena and Aswan sheet) in another series. Produced at a 1:500,000 scale, each base map is a computer-enhanced Landsat image and is printed as a black and white halftone. The geologic tints are surprinted by 3-color process.

QUATERNARY RESEARCH PROGRAMS

One important result stemming from our recent mapping activity is that we have found old branches of the Nile, which are now completely silted up and covered by recent wash and drifted sands.

During its early geologic history, the Nile wandered over the country in the south of Egypt. The river detoured around many obstacles in its path, such as granites and other igneous rocks. For example, the wadi east of Aswan includes Nile silts, an indication that the river once occupied a channel east of its present path. Again, to the northwest of Aswan, west of Kom Ombo, the area is extensively covered by Nile silt. It seems that the river looped east of Aswan to avoid granitic obstacles there, heading westwards and fanning out, in the area west of Kom Ombo, before continuing its northerly path once again.

The importance of such areas is paramount now that the government is searching for areas along and near the Nile that are suitable for reclamation. The water in Lake Nasser rises 60 meters higher than before the Aswan High Dam was built. This also increases the area of land that can be reclaimed, and geologists are now busy looking for such land and similar "old channel" conditions along the river's course.

Thus Quaternary studies have lately gained much importance and more joint research programs are underway between Egyptian and American scientists.

The work in southern Egypt (especially in the Western Desert), by Fred Wendorf and his colleagues from Southern Methodist University of Dallas, Texas, has laid down the foundation of a chrono-stratigraphic succession for the Quaternary. Professor Vance Haynes, from the University of Arizona at Tucson, has been active in the study of geomorphic patterns of the features in our Western Desert.

The achievements of these two scientists and many others have resulted in the delineation of areas with extensive mud pans and other deposits of Quaternary age in the south of Egypt. Also a major part of these studies has been directed to the analysis and age determination of underground water in the south. It has become clear that this water is a fossil type, 35,000 years old. Water from some wells gave younger ages, such as 4,000 B.C., that indicate there were recent torrents over the present arid areas.

All this research has broadened our knowledge of the raw materials available for construction purposes. These include sand, gravel, and clay that are much needed, especially near the populous Nile Valley.

JOINT RESEARCH PROGRAMS WITH FOREIGN INSTITUTES AND COUNTRIES

Another type of cooperation between American and Egyptian scientists is found in the work of Elwyn Simons, of Duke University, on the vertebrate fossils of the Faiyûm area, some 80 kilometers southwest of Cairo. The fossils collected from the area are of Upper Eocene to Oligocene age, and prove that the Faiyûm is the largest graveyard for vertebrates of this time-span in Africa.

Cooperation with neighbouring countries is two-fold. Besides lending many of our geologists, engineers, and

Figure 3 Resources map of Egypt. ▶

technicians to most of the surrounding and many of the African countries, the G.S.E. is also active in executing geological works in some of these countries. In Libya, for instance, and for a period of four years, Egyptian geologists mapped four sheets at a scale of 1:250,000, an area of approximately 60,000 square kilometers.

With the Sudan Geological Survey there is a good cooperative program for surveying and exploring the mineral wealth in an area covered by four degrees of latitude along the borders, two in each country. Also there is a joint committee of all the countries overlooking the Red Sea, including the Saudis, the Sudanese, and the Egyptians, which convenes for discussion of matters of common interest.

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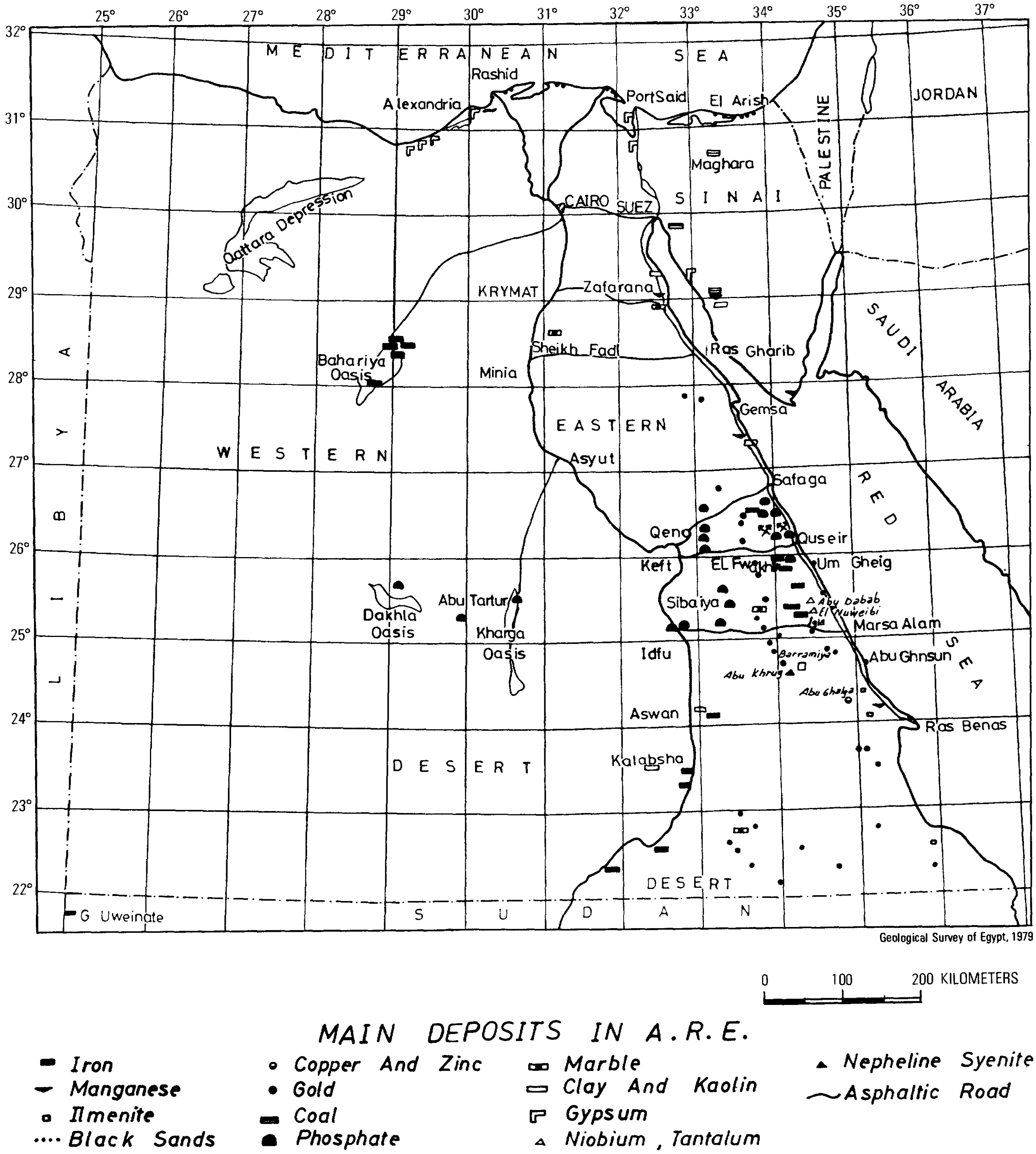

Discussion and Comments from the Floor

C. Guillemin (France): There are two kinds of developing countries: those that are rich, and those that can become rich.

Before identifying resources and before exploring and being able to exploit this kind of resource, there are two statements that should be made:

1. Geology, until further distribution of raw materials, does not possess equality. A preliminary effort of world organizations should be to establish a Geological Survey for the developing countries, who are actually with no knowledge of their possibilities. Perhaps we could do something like what the petroleum men did in finding oil for the world.
2. Another effort should be to have people who are able to do the survey work, from mapping to the discovery of the deposit. We must have mining geologists who are aware of what is needed in developing countries.

All of our systems of technological thinking and training are based on our ideas of exponential goals and exponential waste. Do we have to bring this to the whole world, while a new type of civilization, not yet defined, is yet to come?

An example is the small mining system: in developing countries they are using the same system that was used in Europe during the middle of the last century. Continuing rising cost of energy, especially important for mining operations, must cause us to think to the future of the large mine with its extra expense of energy. We must look toward a new kind of small mining system. In France we have many deposits with 5,000–20,000 tons of lead, copper, and so on of high grade. We can imagine a system of mining where waste is avoided, and more men than machines are employed. It is better to have miners than unemployed.

S. Bonis (Guatemala): There is a contrast between Egypt and Venezuela (countries of the two speakers). Egypt is a desert environment with no water. Venezuela has an excess of water with its tropical rain forests. There are also similarities. Both countries are meeting the need for research and development. In Egypt this especially applies to water resources.

I would like to ask Dr. Lavie for a brief history of development in Venezuela, and to relate it to the steps toward nationalization. Would Venezuela have been so bold as to take steps toward nationalization if they didn't have this group of excellent technicians?

H. Lavie (Venezuela): We would not have been able to do this unless we had been properly prepared, at least to understand what we were getting into. Our Geological Survey is 30 years old, people were prepared at American universities and slowly the groups grew. They kept in constant contact with international cooperative projects.

Speaker unidentified: You can have what are called "mining centers" to allocate minerals promptly. This would be of benefit to the developing country because this will teach the people at a very rapid rate. You will not have to wait 10 years for a return. However, if you have a huge deposit you cannot have small scale mining.

D. Rao (India): India has a peculiar problem with 630 million people. A population explosion will cause India to have 880 million people by the next century. Despite this overpopulation, India uses less metals than other countries.

The world has to depend on geoscientists. The basic metals must be available. If there is no technology, metals cannot be exploited. Technological considerations rather than economics will have to be taken into account in the future. There is a need to mine the mineral resources as they occur in nature, but we should not mine them in such a way as to leave nothing for the future.

Oil imports last year in India outstripped the value of all the minerals (iron, etc.). Therefore, when we go to the 21st Century we must know how our engineers and scientists will answer the energy crisis—what are the priorities, etc. We will have iron ore, manganese, chromite. We had no phosphate deposits in 1960 but today have located deposits in the Precambrian.

P.W. Guild (USGS): Until now the supplies of mineral raw materials available to the world would not have been significantly less if the profession of geology did not exist. By and large, geologists have studied ore deposits found by somebody else. This will not be the case in the future; without good science we are not going to find the hidden ores that will be needed when the bodies being mined now are exhausted. In a sense we have had a free ride for 150–200 years, but the time is coming when we must pay our dues.

The unequal distribution of mineral resources is well known. Some underdeveloped countries are mineral rich; others, apparently mineral poor. Still other countries have already essentially exhausted their deposits discoverable by conventional methods. However, I submit that in terms of human history *all* the easily found deposits will be exhausted and that in the 21st Century we are all going to be more or less on equal footing. Technological ability to utilize those resources we will have, and human institutions that will permit us to divide them in some kind of an equitable manner, will be absolutely necessary. Technical training such as that offered by the Association of Geoscientists for International Development (AGID) in methods for exploring areas of rain forest, among others, will help.

Y. Shimazaki (Japan): Problems: Guatemala has an extreme shortage of competent personnel and needs an improved infrastructure for scientific work. Korea has a shortage of mineral resources to support industrial growth.

The following conclusions were reached in Bonis' talk:

1. Developing countries need capable local personnel.
2. They need systematic mapping, data collection, and compilation.
3. More attention should be paid to water resources.
4. Research should be tailored to the needs of the country.

These are applicable to all countries in varying degrees—whether the country is developing or developed.

I fully agree with both Bonis and Hyun that the basic strategy for attacking the problems cited by both of them should be to train competent geoscientists. Also research concerning exploration methods under an unfavourable environment, such as extremely arid conditions, tropical rain forests, deeply buried blind deposits is a matter of urgency.

The most efficient means of tackling these problems is through cooperation of interested parties of various countries and international organizations. In Asia, aside from international cooperation under bilateral arrangements, multilateral cooperation is conducted very actively. Particularly, the activities of the bodies affiliated with the United Nations Economic and Social Commission for Asia and Pacific (ESCAP), namely, the Committee for Coordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP), the Committee for Coordination of Joint Prospecting for Mineral Resources in the South Pacific (CCOP/SOPAC), the Regional Mineral Resources Developing Centre (RMRDC), and the Southeast Asia Tin Research and Development Centre (SEATRAD), are noteworthy.

All of the above are dependent on funds. International monetary organizations such as the United Nations Revolving Fund for Natural Resources Exploration are becoming more actively involved in financing mineral exploration projects.

T. Thimmaiah (India): It is difficult to get funds from the government to do survey work and at the same time to develop mineral resources.

We are trying to cooperate with other countries in training geoscientists.

I am surprised that in South America and other places they cannot earmark certain amounts for development of natural resources. If you don't, it is difficult to build a nation. India has been independent for 10 years and has been developing during that time. We get funds from government and recognize the need to plan to develop natural resources.

Besides the Geological Survey of India there are corporations in India that have great responsibility in locating the mineral deposits in the country. There is cooperation between the central (Federal) and state governments. State government looks to the Federal Government for assistance (technical as well as other). Minerals cannot be exported directly from states to other countries; they must go through the central (Federal) government.

There is always a conflict between developing and underdeveloped countries. The underdeveloped countries often feel that they are exploited. Developed countries have to look out for the mineral resources of underdeveloped ones. Cooperation means coming to the aid of the underdeveloped. As an example, Africa is capable of producing many metals. We say we want to help, but do not come forward. India is in a position to help others now.

RADAM map. Detail of an experimental map printed during Projeto RADAMBRASIL. The sidelooking airborne radar images were computer-enhanced by USGS staff, who also gave cartographic and special technical training to the Federal and commercial map makers who have developed the screenless process for regular use in Brazil.

Opportunities and Perspectives in Surveying, Mapping, and Cartography

Surveying: Status and Further Development

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National Road Administration, Sweden

INTRODUCTION

Surveying or applied geodesy is the part of geodesy required for measuring and mapping limited areas of the surface of the Earth, and for the calculations required for such operations. There exists an interaction for geodetic measurements between accuracy, geometry and method of surveying, where

Accuracy	=	the standard error for the location of a point in space;
Geometry	=	the relative position between the point to be located and the known geodetic points (reference points) which are used for location; and
Method of surveying	=	the choice of surveying equipment as well as its total application (method).

The relation between accuracy, geometry and method of surveying is called the triangular relation of surveying.

The following discussion deals with methods of surveying and with instrumentation and registration of field data.

The development of surveying has been rapid and advanced during the last 10 to 15 years. The introduction of electronic instruments for the measurement of angles and distances has rationalized and facilitated fieldwork, and the development of different tools for calculation and plotting has also had an important impact on the whole profession. The development of the technique and methods of surveying has now come to such a level that we can regard surveying and photogrammetry as two methods complementing each other. In many cases there are requests for filling the photogrammetric gaps and in many cases, i.e., for engineering measurements, field surveying is more practical and rational than the photogrammetric technique.

During the development of the tools and technique for field surveying, the recording of the measured data has been the weakest link in the chain. Using modulated light beams for measuring distances, and microcircuits for measuring angles, has meant a tremendous step forward, but, in the data-recording operation, human error in the form of wrong reading, wrong notation and wrong punching has become a limiting factor. We have made a lot of investigations for controlling this factor and all the investigations have clearly shown that, with conventional recording technique, it is very difficult to improve the quality by diminishing the influence of the human factor. The development during recent years of tools and technique for recording the surveying data is therefore very interesting and important.

Another weak point of the field surveying technique is the procedure of checking and correcting the measured data when surveying is going on out in the field. It is always an expensive procedure to go back a second time for checking and amending as the costs of manpower and travel are generally high. It is therefore important to check the quality and the completeness of the data before the surveying team leaves the area.

Recent developments in surveying have also had an impact on the education and training of personnel for fieldwork, as the available equipment is much more complex than the theodolite and the tape, and as it also gives opportunities for more advanced methods of measuring and calculation than before. It is important for an optimal result that the operators have a good knowledge of the advantages and disadvantages of the different available techniques and instruments.

The development of improved surveying techniques has also had an important impact on industry, where surveying is essential to the siting and layout of structures. The limits on tolerances in surveying have become stronger as industrial technology has developed. This fact concerns not only traditional civil engineering operations but also, for example, highly technical, closely designed structures such as nuclear power plants. The siting and layout of the reactors, turbines and other parts of a nuclear plant impose requirements that are very advanced and important. When discussing the future of surveying it is therefore important also to consider siting and layout techniques.

RECORDING OF MEASURED DATA

The knowledge or supposition that the input data are not always altogether reliable has, as a rule, meant that computation programs have been provided with a number of numerical and graphical tolerances and reasonability checks, in the hope of discovering and reducing the number of errors, which can have a damaging and expensive influence on the results. We must assume that even if technical development goes very fast, not all surveying instruments will be provided with completely automatic recording in the immediate future. There are many reasons behind this statement, generally operational, personnel and economic ones. The entire procedure of recording and documentation must therefore be taken into account.

I stated earlier that recording of the measured data has been the weakest link in the surveying procedure. Let us therefore take a little look at what is going on now in the effort to strengthen this link. The following recording methods are listed in order of increased reliability:

1. Keeping records
2. Sound-recording of field data
3. Radiò transmission of data
4. Data storage on cassette tape
5. Data storage in a datastack
6. Semi-automatic systems
7. Total stations

The choice of the actual method of documentation must be adapted to the special tasks, personnel, available data routines, and other factors applicable to each particular case. The method of collecting data has a direct influence on the computer programs, forms, data communication, punching routines, and archive storage.

Keeping Records

The Observer as a Record Keeper (fig. 1): This method involves a reduction in capacity and in concentration. If the measurements are noted on white paper in sunlight, there is also a risk of dazzling. As a result, the possibility of carrying out correct alignments and readings is reduced considerably.

Figure 1 The observer as record keeper. Even if the control screw is located on the left-hand side of the instrument, the observer adjusts it with the right hand since his left hand is holding the record. Obviously the concentration needed to carry out a high-precision measurement suffers from this uncomfortable work posture and the data collected may have a poorer quality than would be the case if another recording method were used.

The Observer in Direct Sound Contact with the Record Keeper: The observer makes readings which he passes on orally to the record keeper, who is within hearing distance of the station. At best, the numerical values are repeated while the observer checks the scales simultaneously and can verify the correctness of the values. Unfortunately, this method of recording can seldom be maintained for long, since it is extremely time-consuming and tiring. The result is either that it is dropped or else that those concerned no longer react to what is said, whether it be correct or incorrect. The record keeper is much influenced by what is going on around him. If the environment is distracting, with traffic noise or radio communication, and if other audible and visible changes take place within the vicinity, there is a considerable risk that incorrect entries will be made.

During a close study of field records and sound tapes, the causes of erroneous entries were roughly sorted. The causes of the errors are grouped below in order of frequency:

1. Noise interference from traffic
2. Disturbing conversations exchanged at the station
3. Visible disturbances or tiredness
4. Interruption by radio communication

The Record Keeper Keys in the Data in a Desk Top Computer (figs. 2*A* and 2*B*): With this method the input data are controlled both numerically and graphically in the field. Survey values and results can be stored either on the printed list or on cassette tape.

The Observer in Radio Contact with the Record Keeper: In some cases, field circumstances make it impossible for the record keeper to be located within direct hearing distance of the observer. It may also be practical to carry out the recording in an undisturbed environment or indoors in poor weather and to receive the data from the observer via a two-way radio. The observer can pass on the survey data in a calm conversational tone without shouting and becoming stressed even if there is considerable traffic noise in the vicinity of the station. This technique can be supplemented by having the record keeper carry out certain calculations and can, consequently, be used both for surveying and for laying out construction work. In other words, a base station is established from which the values can be transmitted to and from the field personnel.

Sound-Recording Field Data

Recording on Sound Tape: Free-standing Tape Recorder: Instead of writing records and thus losing the original (i.e., the voice of the observer), recordings can suitably be made on a free-standing cassette tape recorder.

Figure 2*A* Instead of writing the survey data in a record, they are keyed in directly and are processed in a desk top calculator. The input data and the numerical results are printed out on a list and the points that have been calculated are reproduced graphically on the plotter table.

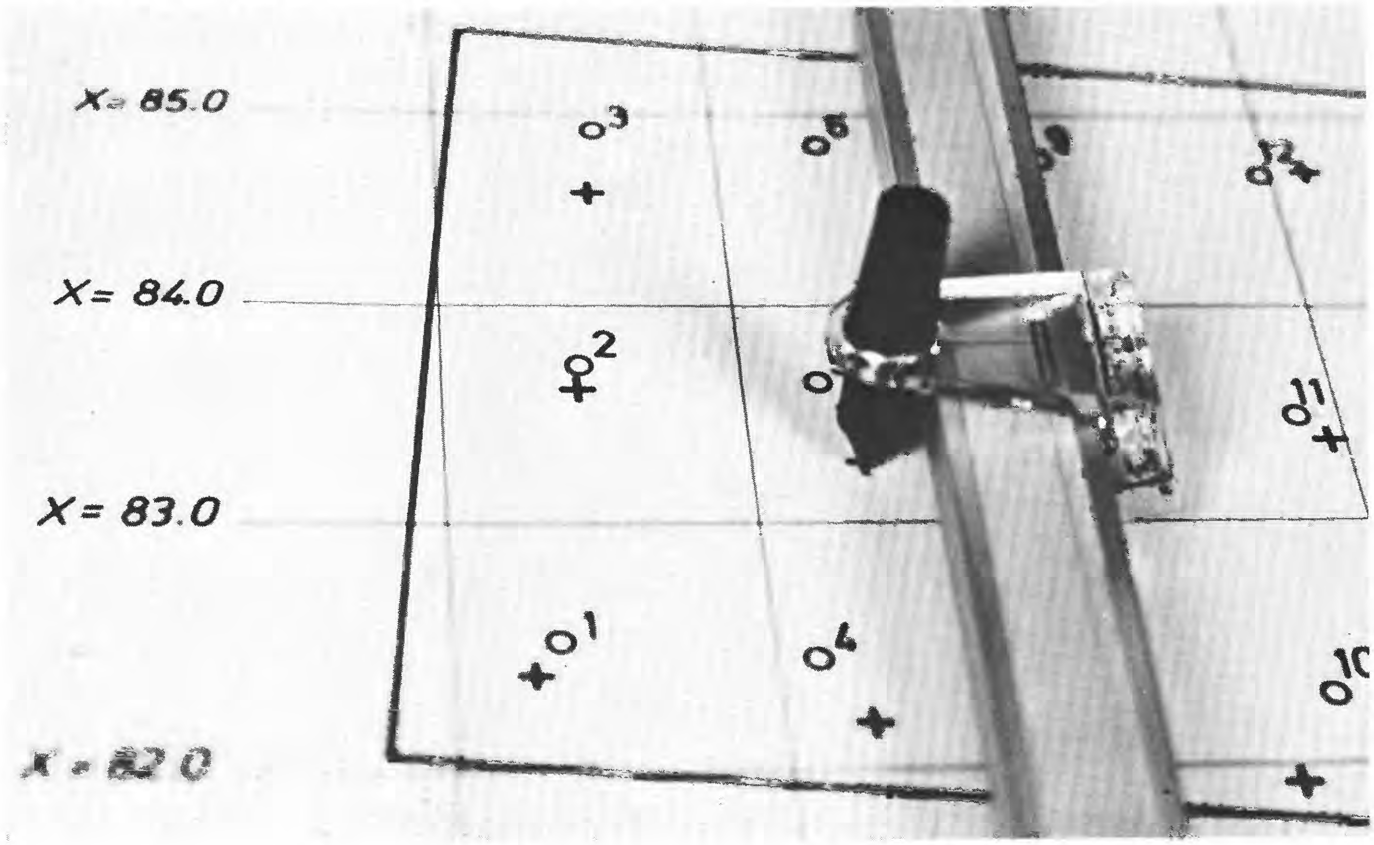


Figure 2*B* The position of the plotted point (+) can immediately be compared graphically with the theoretical position (o).

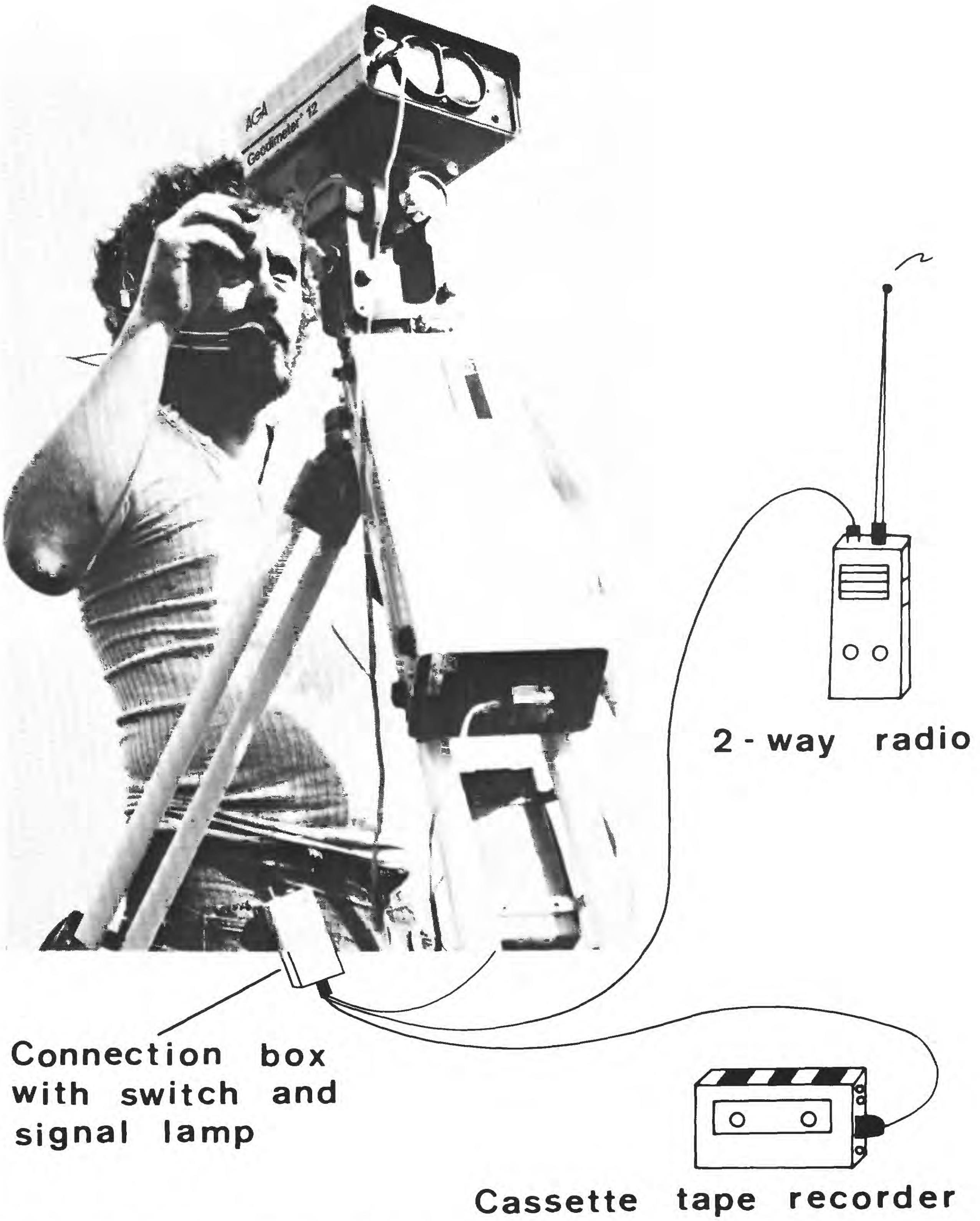


Figure 3 A specially manufactured connection box makes it possible to interrupt the radio communication and have the sound transmitted directly for recording on a cassette tape. In both cases the same microphone is used. The operator can monitor the sound during the tape recording to assure that contact has been established with the cassette tape recorder.

The most important advantages offered by recording on sound tape are that a repeatable original becomes available, and that the costs required for a record keeper are saved. Storage space is also reduced. In most cases, the cassette tapes are reused after the data calculations have been approved and finally presented.

According to advertising information, values can be read in eight times faster on sound tape than they can be documented in writing following dictation. The smaller types of tape recorder, which can easily be protected against cold and rain, are the most suitable for use in the field. The microphone must be screened in windy weather if the recording is not to be marred by disturbances.

Recording on Sound Tape: Cassette Tape Recorder Connected to Headset (fig. 3): The most rational method of using an electronic-distance-measuring (EDM) instrument is when a large number of objects is to be measured or located from the same station. The long measurement ranges of these instruments often mean that measurements are carried out at distances which oblige the observer and the prisma carrier to work out of hearing range of each other. The conversations involved must, in this case, be transmitted via a two-way radio.

In many cases, it is also necessary to carry out calculations with the aid of a calculator during ongoing surveying work. This gives rise to a difficult situation since a surveying instrument, a radio, a calculator and a record must be handled at the same time. One way of solving the problem is to equip the observer with a two-way radio which can be located anywhere or can be carried in a harness on the observer's back. The radio is connected to a headset with speech control, which in turn, is provided with an extra connection for a tape recorder. This will mean that the tape recorder can also be located in a suitable position.

The observer can now work freely with both hands while communicating via the microphone with the prisma carrier in the field and can switch over to recording survey data on cassette tapes when entering values in the record. This arrangement means that the radio can be located so that the best transmission and reception conditions are obtained, using special aerial equipment if necessary. The tape recorder can be protected by means of a suitable cover on rainy and cold days. Since the tape recorder has small dimensions, though using a standard cassette, it can often be placed in a pocket in the observer's outer clothing. A red signal lamp indicates that the contact is closed to the tape recorder and the monitoring facility provides further confirmation that the system is functioning satisfactorily. If the monitoring function is broken off, this means that the end of the tape has been reached.

Recording on Sound Tape via the Telecommunication Network (fig. 4): This procedure can also be used in conjunction with written records, but in this case the survey values must be read in orally.

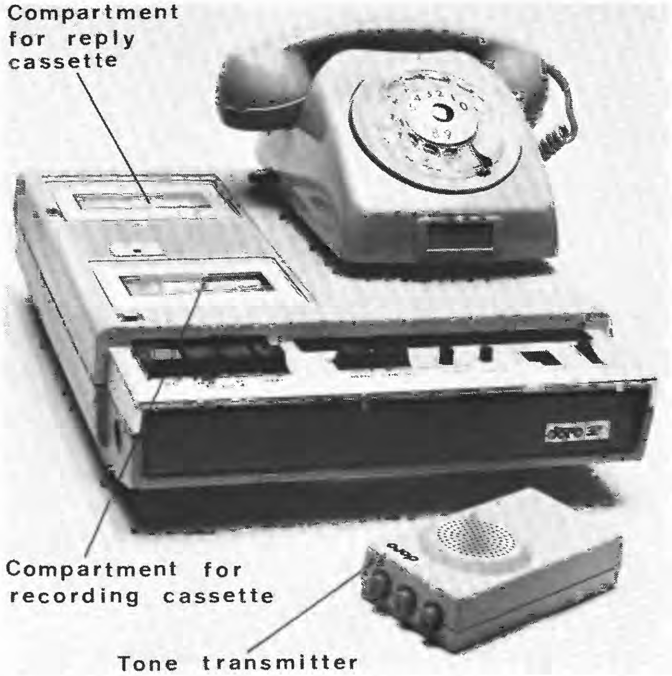
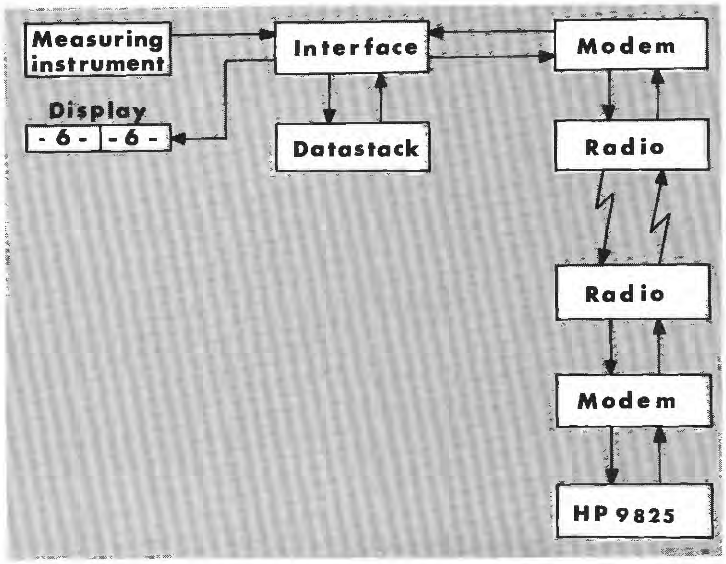


Figure 4 The reports can be made directly from the survey station in the field via relay stations to an office where the survey data are recorded on the speech recording tape. The data are stored there for later punching and processing. If recordings have been made on cassette tapes in the field, the contents can be transmitted to a subscriber with a speech recording unit by using the ordinary loudspeaker of the tape recorder to transmit the sound by telephone to the recording unit.

When the tapes that have been recorded in this manner are punched out, a playback machine of the SONY type should be used. Since this machine uses cassette tapes, the speech recording must either be made directly on a tape of this type or must be transferred to a cassette tape by connecting a conventional tape recorder to the speech recording device.

The increased spread and use of mobile telephones and of radio stations for mobile, stationary and portable use means that constantly improving facilities are available for rapidly reaching localities with punching and computer resources. The reports can be made directly from the survey station in the field via relay stations to an office where the survey data are recorded on speech-recording tape and are stored there for later punching and processing.

If recordings have been made on cassette tapes in the field, the contents can be transmitted to a subscriber with a speech recording unit by using the ordinary loudspeaker of the tape recorder to transmit the sound by telephone to the recording unit. It should be noted in conjunction with this that the best sound reproduction will be obtained if the telephone receiver is upright and the tape recorder is located approximately 100 mm from the receiver.



Radio Transmission of Data

By radio transmission of data is meant that encoded, electronic signals sent out from a measuring instrument or a calculator are broadcast for interpretation and processing at the receiving end. The technology behind this type of data transmission has been thoroughly researched in connection with major projects such as space research. Until now, the efforts made to apply the method for geodetic purposes have been mainly concerned with recording

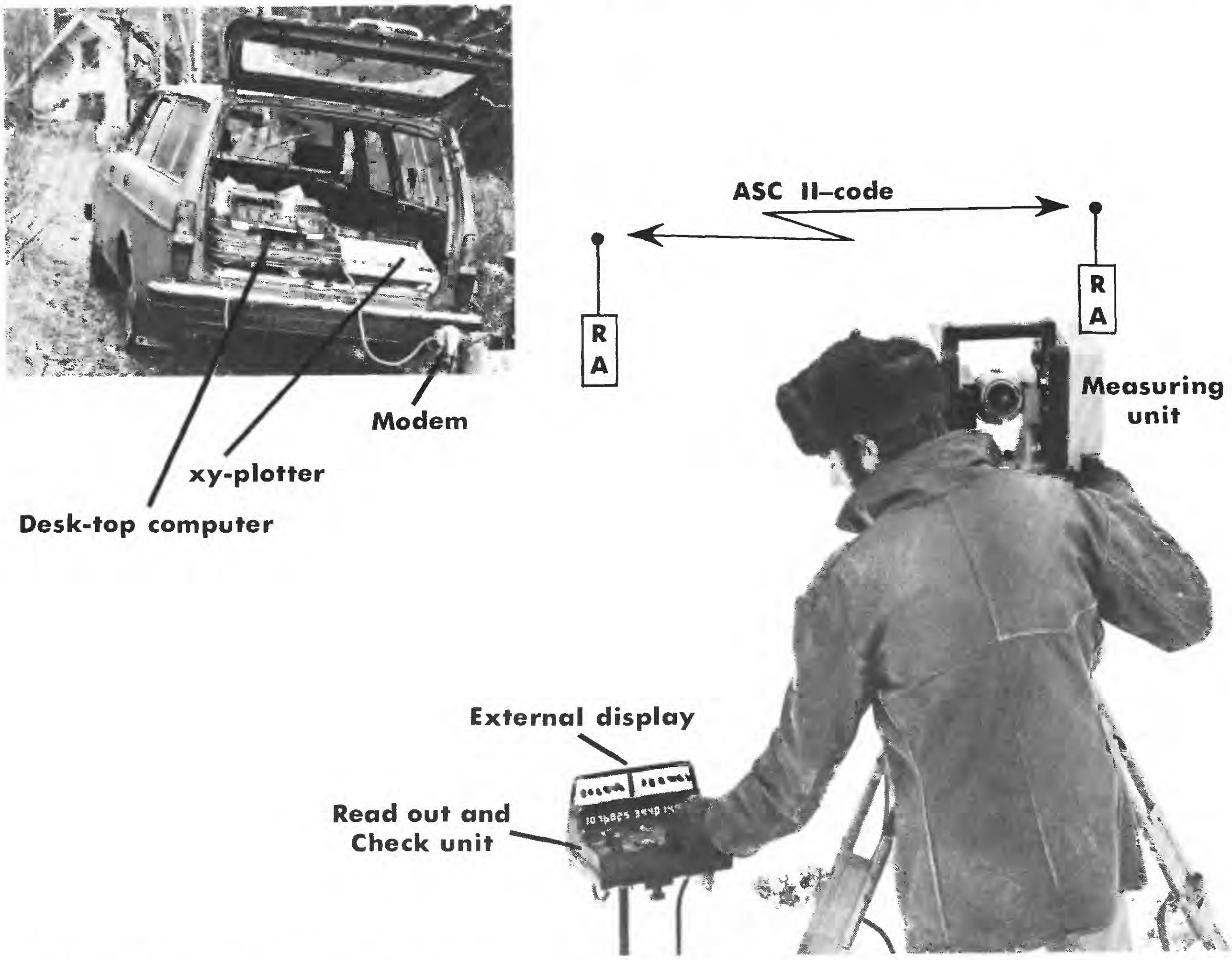


Figure 5 Principle sketch showing the dataflow between the measuring unit, datastack, and the desk top computer. In practice, an electronic measuring instrument radiates coded survey data to a computer located in an office building or in a car. Calculations, data storage, and mapping can then take place at the rate at which the information flows in via the receiver. Setting out data can be sent back to the datastack and be presented on the external display on the read-out unit.

signals from surveying satellites for determining the positions of points on the surface of the Earth.

In the case of the Geodimeter 700/710, this system means that the BCD encoded measurement signals from the instrument are broadcast ASCII-encoded in serial form, and that the signals are converted to a code which the computer in question can read on the receiving end (fig. 5).

In practice, the main instrument standing on a station in the field can broadcast survey data to a computer located in an office building or some other sheltered place with access to a main connection. Calculations, data storage and entries can then take place at the rate at which the information flows in via the receiver. Just as encoded signals can be broadcast from the surveying instrument to the computer station, it is also possible to transmit signals from the computer back to the instrument in the field.

Data Storage on Cassette Tape

Cassette tapes have, to an increased extent, taken over the part played by punched tapes in modern data-processing routines. Cassette tapes are used as program and data carriers in most types of desk-top computers and mini-computers.

One of the features involved in both writing records and keying in data via a key-set is that the original is lost, i.e., the observer's voice is not recorded and cannot, consequently, be later used for checking the values noted against the source. We may, however, assume that reliability will be better when data are keyed in than is the case when data are written since the unreliable punching operation and the interpretation of the handwriting concerned will be avoided in future. Another point is that a cold, shivering hand finds it easier to depress a key than to form a legible digit.

The basic philosophy behind the use of cassettes as data carriers should be that data can be taken from central computers for recording on cassette tapes which can be used in desk and field computers. The opposite must also be fully possible, i.e., it must be possible to transfer data recorded on cassette tapes in the field to a larger ADP system for processing. A procedure of this type means that there is little chance of distorting the data en route from the design stage to the practical use of the values in the construction stage (fig. 6). The surveying values can also be keyed in and stored directly in a desk top computer equipped with a cassette tape station.

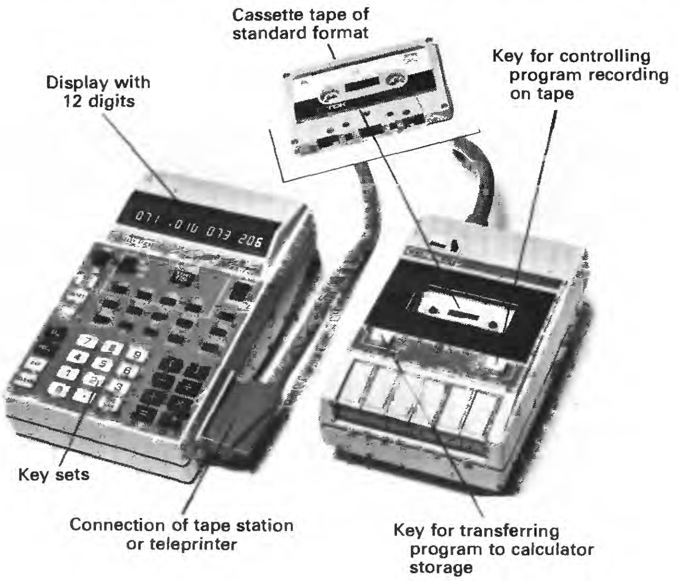


Figure 6 Data storage on cassette tape with the aid of a calculator of type Compucorp 326 with a Compucorp 393 cassette tape station. This equipment, which is battery-powered, can be used in the field if it is protected against cold and rain. It is used there as a calculator, data bank, and data collector.

Data Storage in a Datastack

A datastack consists of a storage unit (RAM) in which data can be stored in sequence. The surveying values are entered in numbered registers via a key-set which contains

Figure 7 The datastack has a wide field of applications for transmitting data among various types of desk top computers and terminals.

Figure 8.4 The datastack is used as an electronic field memory book where the actual distance and vertical angle are automatically stored. Other information is keyed in manually.

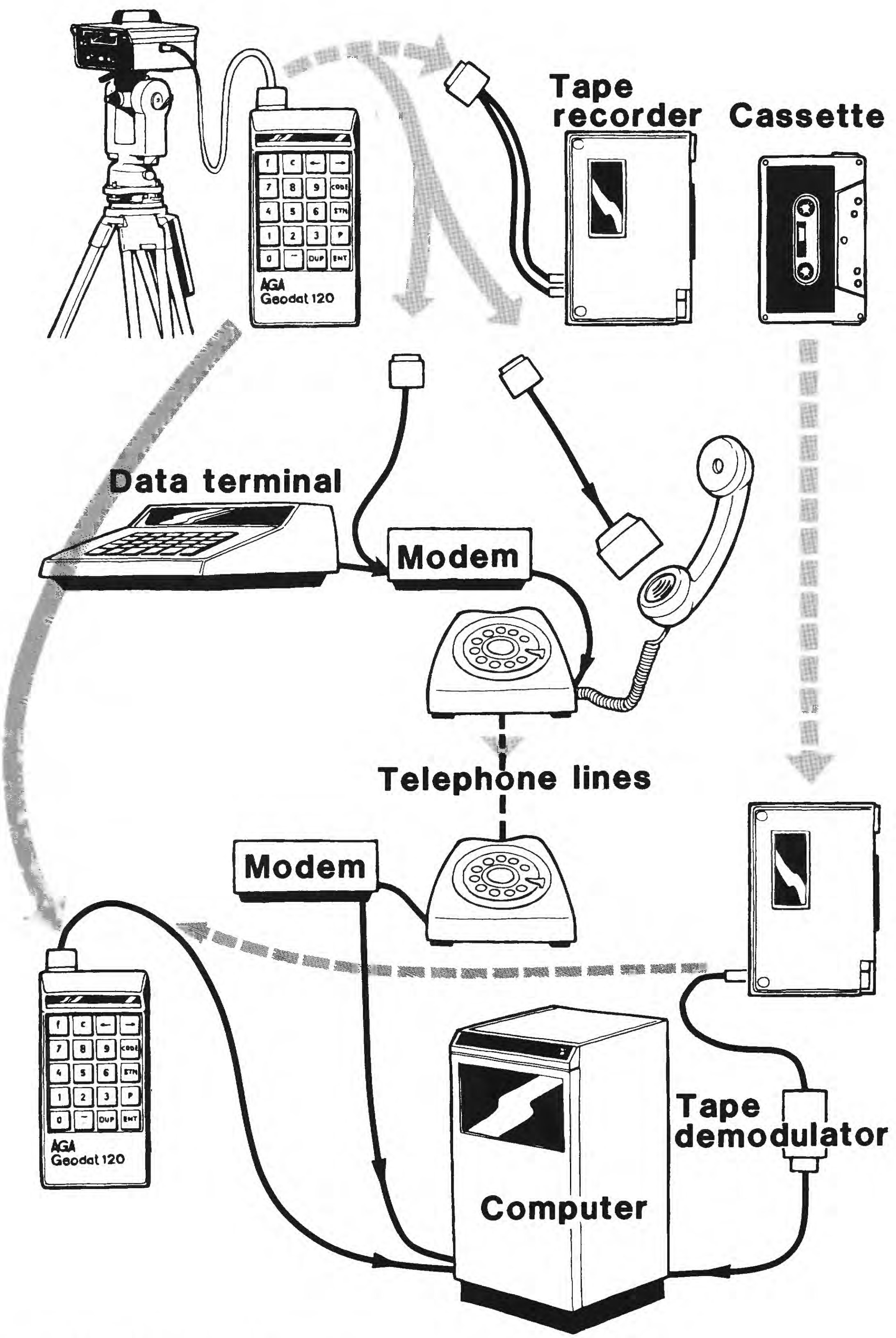


Figure 8*B* AGA Geodat 120 connections.

digits and code keys. A microprocessor and an internal programme memory (PROM) make the datastack programmable to the customer's requirements.

The display can be used to read off what is documented in the stack. Direct addressing can be used for searching in the registers. There are also facilities for stepping forwards or backwards from a position at a slow or rapid pace. When data are keyed in, a journal can be kept indicating the registers in which certain main data have been inserted so as to facilitate searching through the material in conjunction with subsequent checks and corrections. The main data can be broken down by survey station, section number, time and other categories. The key set and special instrument functions can be designed and programmed so that the datastack can be adapted for any specific purpose.

The content of the datastack can be transferred when convenient to a cassette tape or into the memory of a desk top computer. The data can also be sent by ordinary telephone lines via modem to a central computer.

The development trend seems to be that datastacks will be used as free-standing electronic field books (fig. 7) or as built-in components, or can be temporarily adapted to electronic surveying units.

The datastack will probably have replaced the written record to a considerable extent during the coming years, and the interest in this technique among instrument manufacturers is obvious.

Semi-Automatic Systems

Most systems for collecting and storing surveying data have some elements of manual processing involved. Semi-automatic systems mean, in the geodetic sector, that the surveying instrument is equipped with electronics for automatic scanning of horizontal and vertical angles and for recording of the slope distance. There can also be a combination of these three values where two or one of the sets of surveying data must be noted or keyed in manually on some data collector. The actual information is transmitted to some check unit where the values are also presented on a display before they are stored on a tape or in a datastack.

The manufacturers of surveying instruments have, in recent years, developed semi-automatic equipment. Some of the products are presented in the following text and in the figures.

Geodimeter 120 and Geodat 120: When the Geodat 120 is connected to the Geodimeter 120 we can make automatic recordings of vertical angle and slope distance while the horizontal angle has to be keyed in via the keyboard of the Geodat 120 (fig. 8*A*). The Geodat 120 can also be connected to the Geodimeter 700/710; then all three measured values are automatically stored (fig. 8*B*).

Wild Tachymat TC1: In the Wild electronic reduction tachymeter TC1 the registration of the measured values is automatically made on a cassette tape station attached to the top of the surveying unit. Additional data are keyed in via the built-in keyboard (fig. 9). A microprocessor controls the automatic angle and distance measurements and computes horizontal distance, height difference and coordinates.

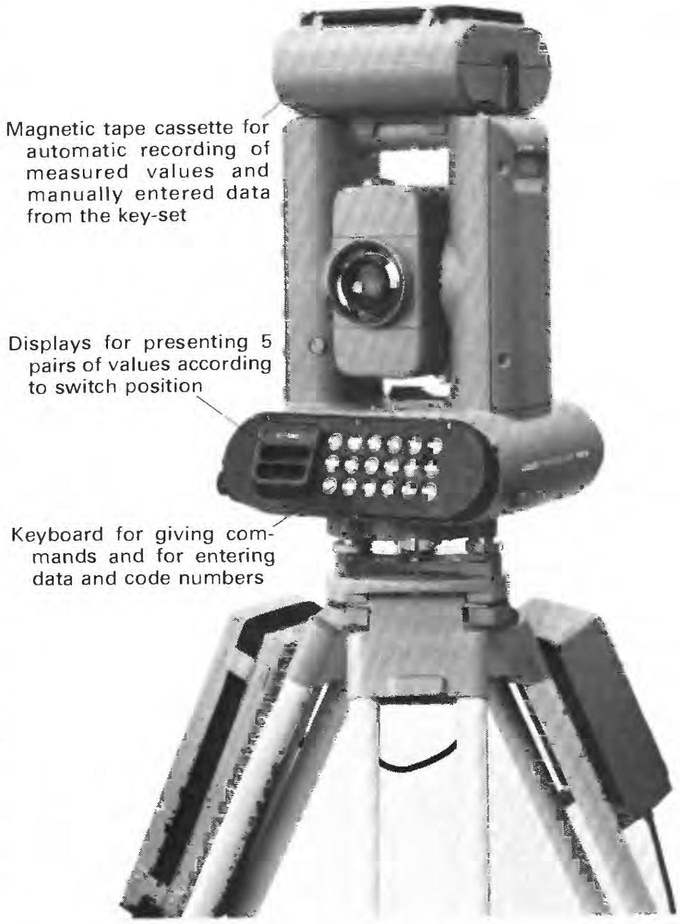


Figure 9 Semi-automatic system, Wild TC1.

Kern Electronic Tachymeter, E1 and E2: The Kern electronic tachymeter is a combination of an electronic theodolite and a distance meter (Kern DM501) (fig. 10*A*). By adding a recording device (Kern R32 or R48) to the electronic tachymeter it is possible to register and store the automatically measured data: horizontal direction, vertical angle, and slope distance. These data, together with general keyed-in information, can be directly fed into the built-in computer for evaluation.

A microprocessor in the theodolite controls the measuring process and sends the measured values to the recording unit. It also automatically computes horizontal

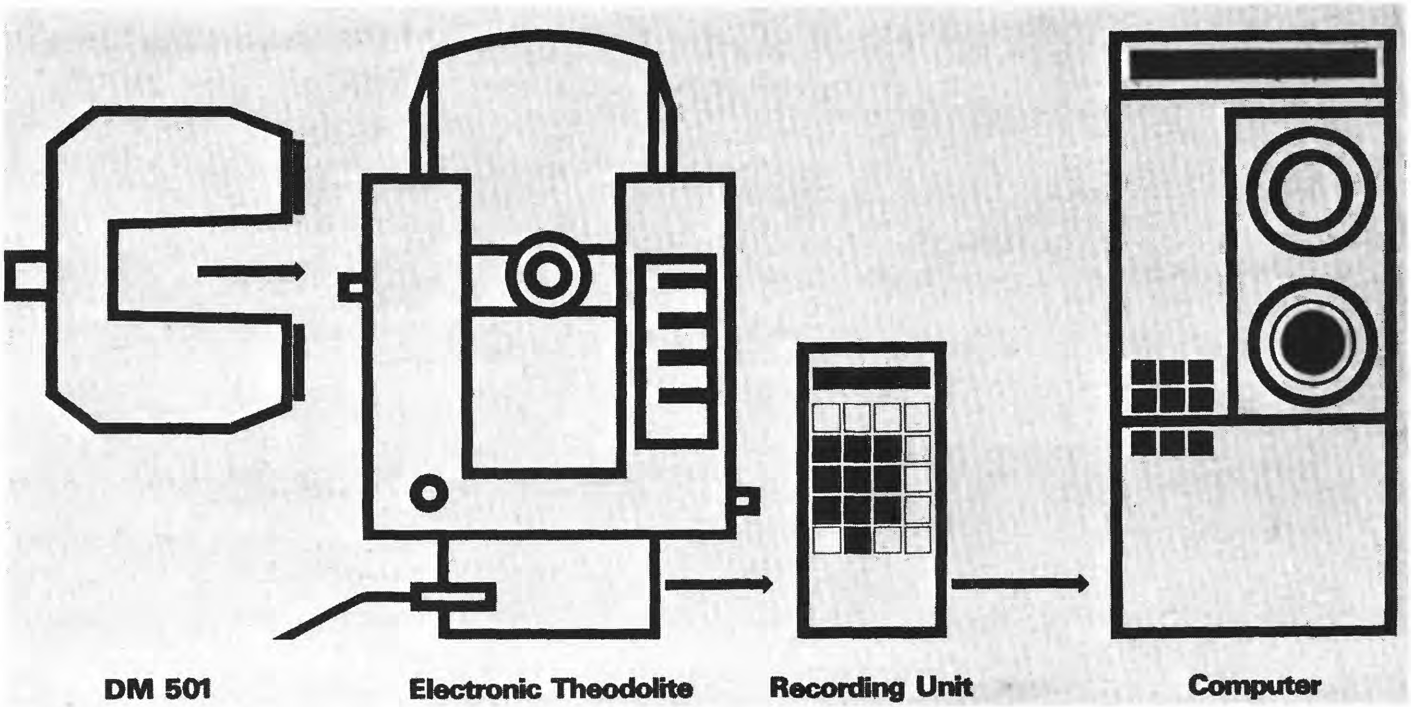


Figure 10*A* Semi-automatic system, Kern E1/2.

Figure 10*B* The Kern DM501 and a datastack attached to the Kern electronic theodolite. All measurement data are automatically stored in the datastack, while other information is keyed in manually. In the left figure the electronic theodolite is adapted only for automatic registration of angle measurement.

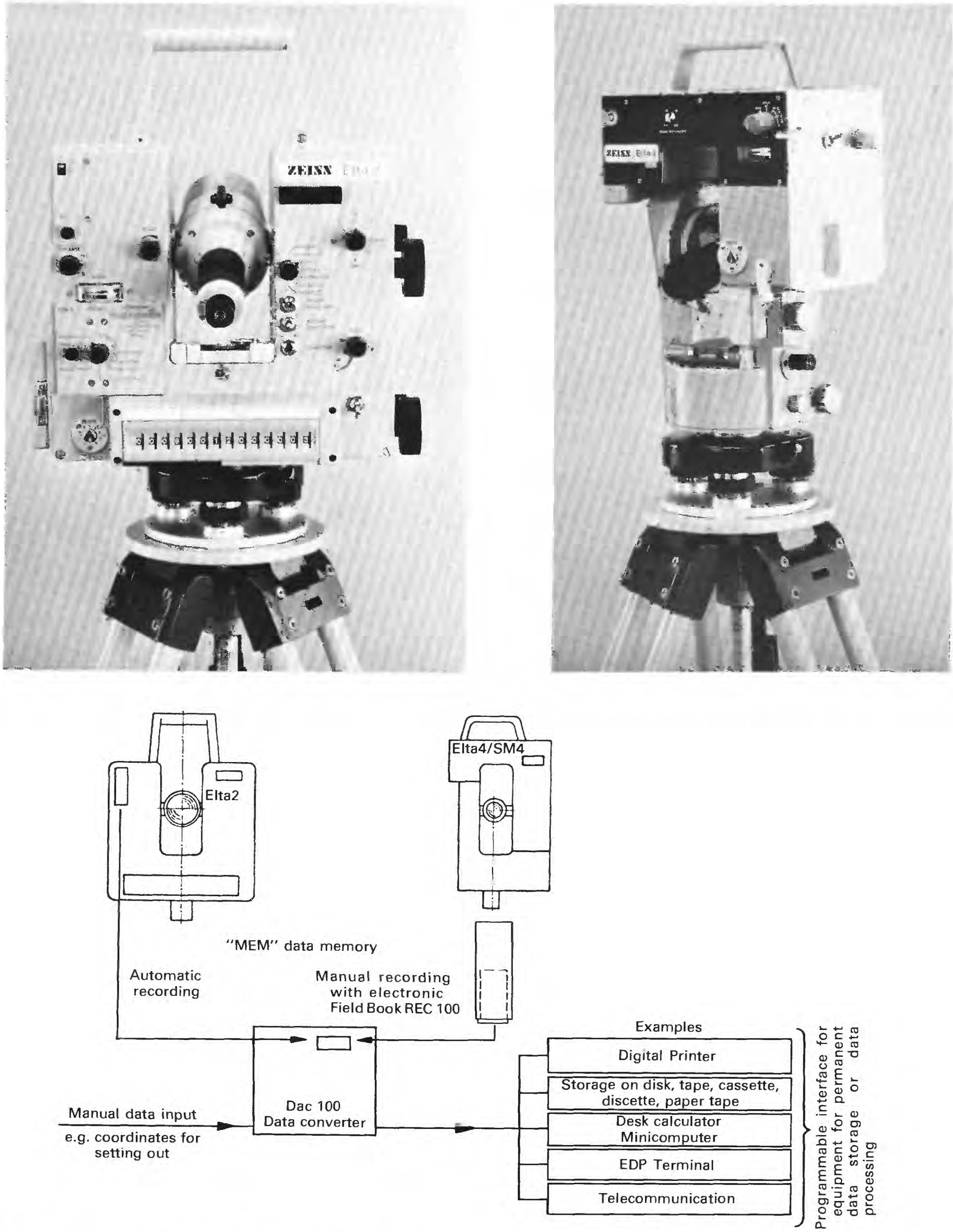


Figure 11 Semi-automatic system, Zeiss Elta-2 and the manual registration system Elta-4.

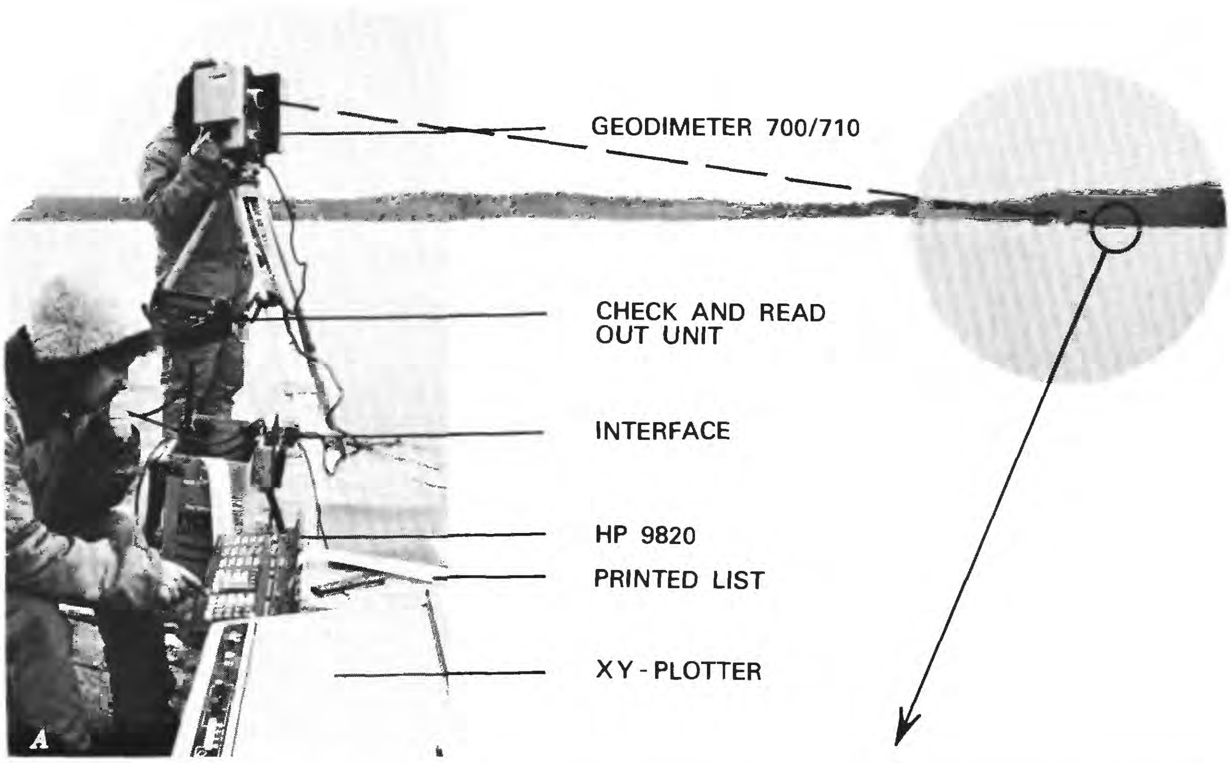


Figure 12 *A,* Geodimeter 710 connected via a cable to a desk top computer and an XY-plotter. The computer operator is responsible for controlling the function of the geodimeter and computer. He also communicates with the boat by radio. The alignments and each of the measured positions of the boat are mapped on the plotter. Printed out on the list are the input and the output data in the form of point number, X, Y, and Z coordinates and the perpendicular deviation from the theoretical alignments. *B,* A specially made boat equipped with instrumentation for measuring seismic reflexions within predetermined alignments. Computer operator communicates with boat by radio.

distance and height difference. Stored data can be recalled and presented on the display.

The recording unit acts as a terminal which transfers the stored data to the computer either directly or via a telephone line (fig. 10*B*).

Electronic Tachymeter Zeiss Elta-2 and Elta-4 (fig. 11): In the self-reducing tachymeter Zeiss Elta-2 all the components are built-in and form one unit free from connecting cables. The registration of the measured values is made in a datastack plugged into the electronic theodolite. Microprocessors steer the measuring process and computer data according to a selected program. Previously recorded data can be recalled and displayed. Moreover, the datastack (MEM) can be loaded at home as an electronic coordinate register. In conjunction with the layout program in the PROG program slide-in unit, this allows laying out by coordinates.

The interface between the Elta-2-MEM and the data processing center is the DAC-100 data converter, programmable data output of which allows adaption to existing systems.

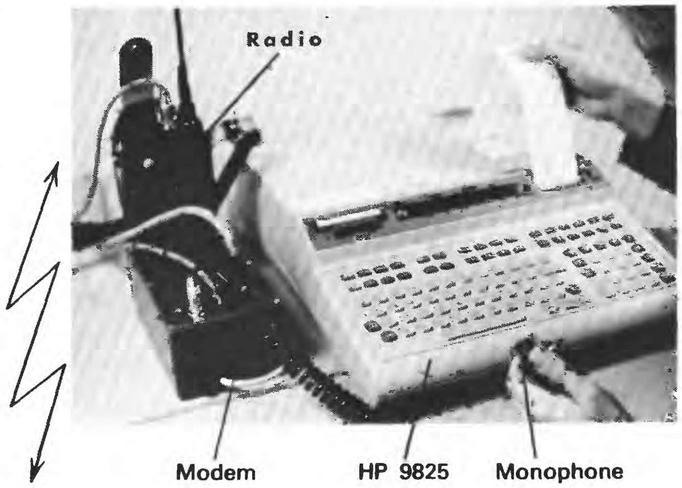
Total Stations

A total station can be arranged in two ways. The signals can be transmitted either via a cable (fig. 12*A*) or by coded radio signals (figs. 12*B* and 13). The data from the surveying unit are automatically registered and transmitted via a cable or by radio transmission to a computer provided with a plotting device. The computer transforms the data and the result can be stored in different ways and also graphically accounted for on the plotter. The plotting serves as a good check of the completeness of the surveying.

In practical application, the surveying instrument standing on a station in the field can broadcast surveying data to a computer located in an office building or in some other sheltered place. The calculation, data storage and plotting can then take place at the rate at which the data comes in via the receiver.

Before the surveyor leaves the station the completeness and the quality of the data can be effectively controlled. This possibility of getting a graphic display of the result of the surveying while being in the field, or close to it, is especially useful in surveying for civil engineering purposes over limited areas, as for road interchanges, measuring cross-profiles, or for industrial plants. It is also important when field surveying is used for filling photogrammetric gaps, as in measuring of digital terrain models.

In the near future we will probably have small desk-top computers with built-in screens, which can present both alpha-numeric values and graphic results. The picture on the screen can be saved by print-out on paper.



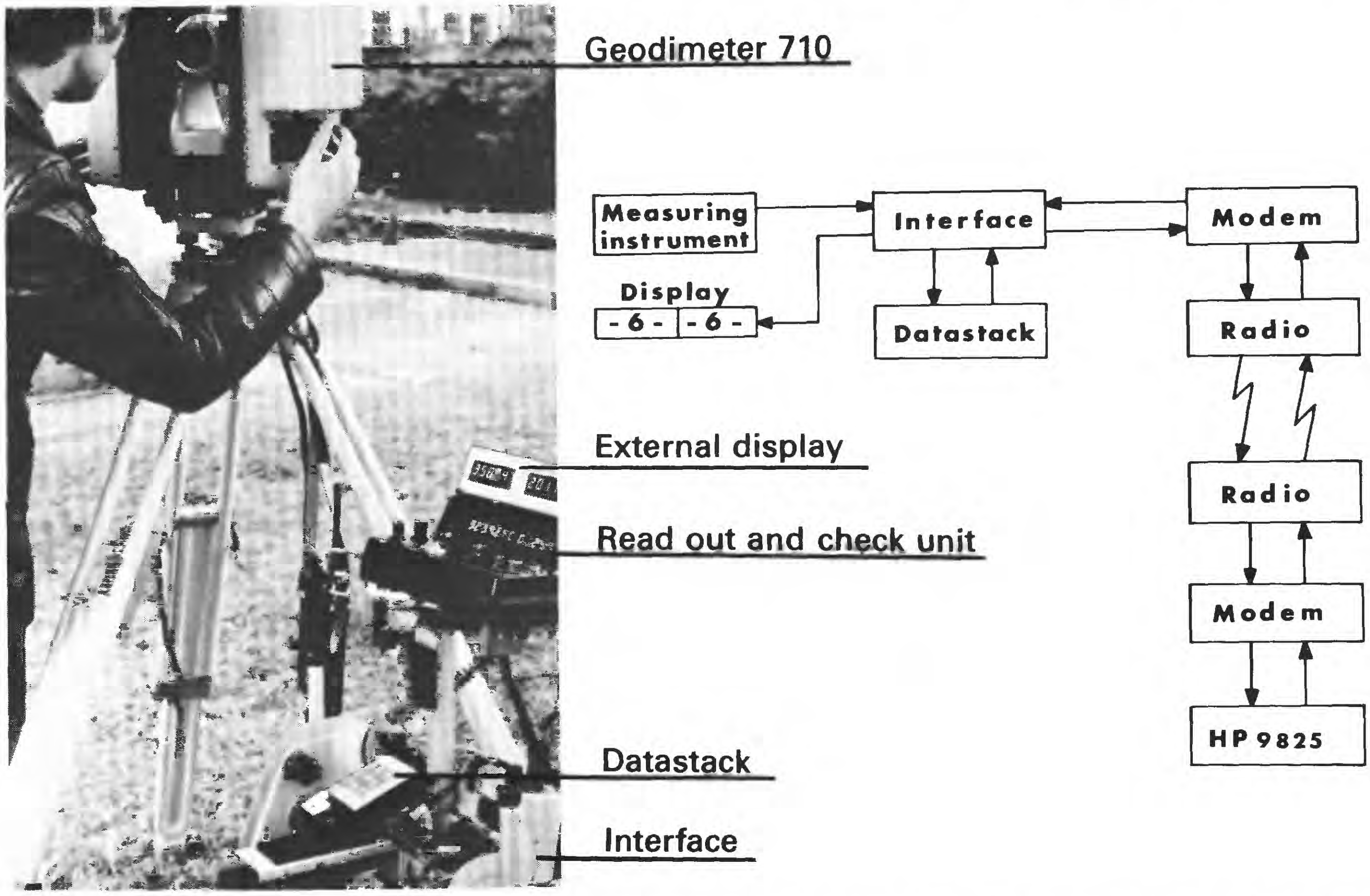


Figure 13 Geodimeter 710 connected to a desk top computer via coded radio communication. The two mobile radio stations use the frequency 439,850 MHz. The datastack is programmed to steer the operations in both directions.

SUMMARY OF AUTOMATION TRENDS

The most important result of the development of the recording of surveying data, which I have briefly described above, concerns the good possibilities of limiting the influence of the human factor on surveying technique. The possibilities of increasing the quality of the result and the completeness of the data are essentially better because of this development.

The instrument manufacturers seem to have understood this fact, and the trend of development goes in the direction of better recording for instruments without automation as well as for automated ones. We must keep in mind that it is not always necessary or possible to use the most advanced instrument for all types of surveying. It is, however, most necessary and important that there be correct recording of the data from measurements using the simpler instruments. The possibilities of strengthening the weakest link of the surveying chain are thus good. The development of automatic calculation goes on very rapidly and the trend toward stronger small computers or calculators is encouraging. The combination of fieldwork and calculation provides improved possibilities for advanced and economic solutions of the surveying problems. With new technical developments, there are many cases where field surveying is an excellent substitute for the photogrammetric technique.

The improvement of surveying instruments has an impact on the organization of the work and also influences the education and training of the personnel. Education in the basics of surveying is still very important—maybe more than before—as the great range of instruments and methods that is available today gives the surveyor many good possibilities of choosing the optimal method for the actual object. Today there are also good facilities available to train personnel in using the new technique. As an example the videotop can be mentioned. This tool for training means that the student can get the training easily and correctly with instruction adjusted for his background and ability.

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Discussion

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I think Carl has appropriately outlined the advances in instrumentation over the past 20 years and has zeroed in on the weakest links. As he pointed out, the weak links are the system of recording of the data and the human factor involved. Now, the human factor is very difficult to rate but he has pointed out the need for better trained personnel. We are now moving a bit from technicians towards professional people because these people must not only be technically trained in instrument operations, but they must know the theory behind each instrument. When Dr. Ternryd said that the weakest link is recording the information, was he talking directly about interactive graphics or graphical presentation or synthesis of data on an on-line basis? A person has to have the knowledge of which system to use. I'd like you to bear those two points in mind when we come to the discussion period.

I'd like also for you to look at it in a practical way and realize that you must have an information base available to start with. Think, how good are your geodetic values in North America, and what have you in secondary control? You know, the worst thing you can have is wrong information and if you start with wrong information it does little good to have all the instrumentation in the world. It only leads to what we always did in North America and I think we're still doing it—it's oversurveying. You must have good information to use interactive graphics or a synthesis of the field actions on an on-line basis.

I'd like you to ask questions. Do we have the basic information and knowledge to move into this field? If not, how do we move into it? The field is here, the instrumentation is here, and the modeling or interactive graphics to support it are here along with software that is readily available.

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Cartography Today

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INTRODUCTION

Cartography as a discipline is attractive, inspiring, and stimulating—attractive because it is work that provides opportunities for development and planning, inspiring because each case offers different regional characteristics which in turn demand different approaches, and stimulating because of the methods and techniques currently available for each particular project. If this were not true, probably many of us would not be here.

Without disregarding past achievements, we may say that the information systems—collecting, processing and distribution—have been highly impacted by technology in recent years. Cartography, which has a very special need for information, has not escaped this situation.

Since the early days when nomadic tribes hunted for food, people have had to know their own location, direction, and distance with respect to other people, resources, and phenomena. This fundamental need for information is still valid in our time, and it is this need that is the essence of cartography. Technology is the result of man's need to solve his problems more easily, with better coverage, or in more detail.

NEW CARTOGRAPHIC SYSTEMS

Practically all the cartographic work done between the 2nd Century B.C. and the first part of this 20th Century has entailed angle and (or) direct tape measurements. Since the 1950s, electronic distance-measurement equipment, satellites (both active and passive), and various inertial positioning systems have been developed and marketed for cartographic information gathering. There are still many countries that are considering incorporating such systems in their normal procedures, and while this is taking place, some of the systems will become obsolete. In the labs there is already new equipment for leveling; the global positioning system is almost operational; and experiments with very long base lines are offering good prospects. Unfortunately many countries cannot keep pace economically with these technological advances.

Most cartographic compilation in our day is done by photogrammetric techniques. Today, all major aerial survey agencies utilize black-and-white, natural-color, and false-color photography, along with modern techniques of automatic processing, electronic control of contrast, and so on. Probably these changes are difficult to realize because we have lived with them; but if we were to look back just 30 years, when the continental program was underway, we would see that in those days, with no trouble, 1:40,000 images were obtained and used to produce 1:500,000 maps. Today, images at scales of 1:80,000 or even smaller are used to compile maps at a scale of 1:20,000. Obviously the metric quality and the optical resolution of modern cameras are improving.

Aerial triangulation is a good example of how man devotes his efforts to cut down hard work. In 25 years, we have jumped from stereotemplets and graphic adjustment to a fully analytical process with bundle reconstruction and simultaneous space resections. Blocks of 500 models based on 40 points are not unusual, and results in terms of accuracy are so good that many agencies are now considering the process to densify the geodetic nets.

IMPACT OF COMPUTERS

Many of the achievements have been made possible by the revolutionary development of modern computers which have been part of the cartographic arsenal for some time. These machines, whether used for memory or processing, are the only capital goods whose price has decreased—a trend that will probably continue in the near future.

For many years map compilation, sometimes accomplished by pen-and-ink drafting and at other times by scribing, has been a labor-intensive handwork operation which has made it slow and expensive. Some applications in which a great amount of data is handled, such as aerial triangulation, cadastral surveys, or highway design, made feasible the use of electronic recording devices. Once the advantages of these devices were recognized, their use spread to other fields, and designs were improved using new electronic encoders for digitizing. In turn, this opened the door for direct interface with computers for direct processing of output information and control of some functions of the photogrammetric instruments. This was the beginning of the era of analytical plotters. With this automation of the photogrammetric process, information was provided in a suitable form for data banks or automatic editing.

Since the 1950s, scribing has been the preferred method of preparing separates for multicolor map printing. In the past we saw changes only in the materials used.

Only in recent years have we been able to obtain numerical information from plotters and thus to enjoy the benefits of interactive graphic systems. The storage, editing, and film plotting operations are now done with a high degree of automation, while human assistance is reserved for supervision, and correction of the final draft through the use of interactive display terminals.

With time, map editing will become more automated. This does not mean that we can work without the human being; on the contrary, each day we need personnel with better training. What will happen is that our map production capacity will expand, enabling us to meet the information requirements of our countries.

NEED FOR CARTOGRAPHIC PROGRAMS

Many countries have acute needs for food, housing, and energy sources, just to mention some of the most repeated problems. The solution to these urgent problems demands other types of cartographic information, in addition to topography. Resources inventories, dynamics of the environment, and land use are some of the programs that cartographic agencies are sponsoring. The production of thematic maps has greatly increased in recent years and their use in these programs has been highly beneficial.

We already have considerable experience in the human interpretation of aerial photographs; in fact, many maps have been produced using this technique. Now we also have available remote sensing data from airplanes and satellites which, with wide coverage and repeatability, lends itself to synoptic studies of regions or even entire countries. But there is still not a clear philosophy in regard to data processing. In most cases the information, which originally is in numerical form, is converted to a pseudocolor photographic image, probably to make use of the visual interpretation capability.

Even in cases where interactive processing systems are available, most of the effort for automatic interpretation has been based on spectral identification. Not much research has taken place using repeatability and almost none in form recognition, although form recognition is the basic concept used in identification. For example, there is nothing in this lecture room that we could not identify if shown such a form only in black and white. The implications for speeding up and improving features in mapping are obvious, of course.

There is much yet to be done in the field of remote sensing, but the results that we are already getting make it a useful tool.

With all this technology available one would think that the world would be surveyed and resurveyed quite often; unfortunately, this is not so. If we look at two popular scales for national series, medium scales (1:50,000 to 1:100,000) or smaller (1:250,000 to 1:500,000), we find that only 30 and 65 percent of the world, respectively, are surveyed. If we take into account accuracy or updating, these percentages drop to even lower levels. It makes us think, as cartographers, that our jobs are assured for many decades, but for others there is a more obvious problem affecting cartographic activities.

CARTOGRAPHY IN UNDERDEVELOPED COUNTRIES

The range of underdevelopment in the different countries is quite broad. In many cases, the capital investment necessary to establish a cartographic agency and to make it operational is either very limited or unavailable.

It may sound strange to us, but there are still countries where national series are done by means of planetable surveys—a way in which thousands of people can be gainfully employed instead of becoming unemployment statistics. Thus automation is not always acceptable in these countries: first, because of the labor-force situation; and second, because there is no capital for equipment purchases.

Frequently too, in these underdeveloped countries, the young technicians trained in foreign countries return to find unsuitable economic conditions at their sponsoring agencies. Sometimes they then go to work in private enterprises, where salaries are likely to be higher, and, in many other cases, they emigrate to more developed countries offering better opportunities.

Actually these problems and attitudes are not primary. They only reflect the main cause, and that is the low priority given by many governments to cartographic programs. Many of the mapping projects that get started are undertaken only as prerequisites to specific construction or development plans. With this type of policy, important projects are often delayed until basic surveys have been finished. The desirable alternative is to have the information in advance, not only to avoid delays, but more importantly to be sure that the solutions chosen are the best ones.

It is necessary that political authorities become aware that good planning can only be done with good information and, in many cases, cartography is a substantial part of that required information.

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Discussion

Lewis John Harris
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INTRODUCTION

At the beginning of my remarks, I am glad to have the opportunity on the centenary of the United States Geological Survey of saluting its distinguished past and of offering my best wishes for its future.

I had the good fortune to meet Director-General Villasana at an international conference on this site in 1976, and learned that our views on national topographical mapping, as far as our talks went, were in agreement. Therefore, I did not anticipate any differing views from him today. And I was not wrong. I shall develop a few points of his. My comments are directed towards the general question of achieving the right national policy, and the task of undertaking national mapping within the context of this seminar which is concerned with surveying, mapping, and cartography—its opportunities and perspectives in a world of shrinking resources and increasing environmental problems.

The primary consideration is to decide the purpose of the endeavor. And since the U.S. Geological Survey has been so involved with topographical mapping and cartographic presentation throughout its history, in the interest of time I shall mainly discuss these two aspects against the background of Villasana's paper.

MAPS IN A MODERN SOCIETY

The uses of topographic maps are manifold. They are used for land navigation; for the development of resources; for good administration; for scientific studies and operations; for constructional works; for search and rescue; for internal security, safeguarding the right of people and property; for national defense; for social, industrial, recreational and private needs; and for planning for the future.

Maps are an essential requirement of a modern society. At this time, when information systems are in our thoughts, it is advisable that we regard the map, the cartographic product, as a means of communicating information; and it is also worth emphasizing that the map is more than the presentation of all the individual features, for it enables the reader to obtain visually a synthesis of the features, and to make deductions from that cartographic synthesis, which would not be apparent from the study of the features individually and successively, or in list form.

The essential of good topographical cartography is a sufficient content of interpreted data which is accurately located, up-to-date, and easily readable by all. The artist, Whistler, one-time cartographic draftsman in the Coast Survey, has described the need for the right selection and the proper presentation in another context with the following words:

> Nature contains the elements, in colour and form, of all pictures, as the keyboard contains the notes of all music. But the artist is born to pick, and choose, and group with science, these elements that the result may be beautiful—as the musician gathers his notes and forms his chords, until he brings from chaos glorious harmony. To say to the painter that Nature is to be taken as she is, is to say to the player, that he may sit on the piano!

So it is in the compilation and presentation of maps.

Modern society by the complexity of its structure, and by the multiplicity of its demands, has augmented the content of maps; has given rise to an expanding range of thematic maps and overlays which are based on topographical maps and which give the additional information required by special users; and has directed attention towards the urgent need for adequate urban maps.

So the future seems to require that the generalized maps of medium scales be more informative; and that the urban maps of large scale be produced in a more orderly and plentiful manner. These requirements will have an influence on the mapping policies of a country, as we enter the age of computerised mapping, and on the degree of cooperation between map production centers at the different levels of jurisdiction or government.

Automated Cartography

Modern technology has offered computerised methods to facilitate the production of topographical and thematic maps, and to record and store the relevant digital data for subsequent retrieval, analysis, transmission, and usage. We must be masters of these methods, and not the slaves of the technology.

I believe it to be important as we move into the digital mapping era to take a holistic view of mapmaking; to maintain the close interrelationship between geodesy, photogrammetry, cartography, and map presentation giving each its full consideration; to recognise and accommodate the current development and deployment of information and graphical systems based on approximate and occasional geographical referencing, which may otherwise retard and undermine the establishment of homogeneous, comprehensive, and flexible computerised information systems for the use of all users; to review the accuracies of maps, the scales of mapping, the cost of mapmaking, and the production procedures; and to undertake the appropriate mapping of the urban areas.

Moreover, in the development of topographical information systems, a major interest will be the structuring of the data and the arrangement of the data in their hierarchies and associations. In this regard, the geometric pattern of linear features, clearly seen in medium scale topographical maps, can be the skeleton on which is arranged the complete topographical anatomy of the environment.

The cartographer, using the term in its broadest sense as mapmaker, needs to adapt modern technology and in particular computerised technology to the cartographic profession, not for innovation's sake but to serve the user and ultimately the payer (tax or private) more efficiently and more economically.

Automation in cartography has produced several trends:

- It has *moved* the focus of attention for deciding map accuracy away from the cartographic drafting and presentation, and directed the focus of attention on the practical accuracies achieved by the photogrammetric operator and surveyor.
- It has *augmented* the possible content and usage of maps and map data.
- It has *suggested* a practical separation of map production between the basic topographical data and the other data of a supplementary topographical or thematic kind in order to achieve more economical products.
- It has *generated* a possible reappraisal of the choice of map scale for a particular need.
- It has *emphasized* the requirement for an overall or holistic view to be taken of mapmaking.
- It has *necessitated* a continuous and critical assessment of the costs and responsibilities of production.

There is another reason for careful management. The attraction of instant maps may cause a lowering of cartographic standards of presentation, and may overemphasize the needs of particular specialisms, often governmental, at the expense of the general map user. Such happenings should be detected early, and contained to ensure overall progress.

Let us not permit the technology to debase the art of cartography. Automated cartography need not make Philistines of us. On the contrary, the promise of more refined drafting of higher accuracy should provide greater scope for the exercise of the science and art of cartography. It is to be hoped that the opportunity for such advancement will be seized.

Digital Cartographic Data

The general requirements of maps for road building have not altered in the change from traditional mapping to digital mapping. The examination of the topography, the preliminary siting of the road, the calculation of earthworks, the final siting and the setting-out are still required. However digital mapping has these advantages:

- It can produce graphical maps which are more accurate at a selected scale by reason of the more accurate machine-drafting.
- It can display all or enlarged portions of the map on display screens, on which tentative siting can be quickly superimposed for consideration and assessment.
- It can present on demand the coordinate data and other textual data of areas of interest shown on the display screen for the calculation of distances, areas, volumes of earthworks, etc., and for administrative information.

As with maps produced in the traditional era, the digital maps of an area which are available will be dependent on the value of the area or on the potential value of the area after development. The scale of the map and the accuracy and resolution of the digital data will decide the fineness of depiction of the roads and of the other cartographic features.

For example, the United States and Canada in their national topographic map production are working at the medium scales of 1:24,000 and 1:50,000, respectively. These are generalised scales, and the depiction of the roads is generalised. In the large-scale maps produced of urban areas, say at the scale of 1:1,000, the major features of a road are not generalised in the depiction, which differs appreciably from the depiction at the medium scales even after allowing for the change of scale. "With generalisation art enters into cartography."

It is also worth noting that using the set of digital data appropriate to the largest scale to produce the large- and medium-scale maps, say from 1:1,000 to 1:125,000, by automated cartography, will not only require the data to cover the area, but will also require certain editorial corrections to be made on the generalisation of the features, beyond the deletion and smoothing of features. As yet, these editorial corrections are most economically and effectively done by manual intervention on the proof copy or display screen.

Different agencies, offices and firms, public and private, are likely to become experts at the different map scales, and many banks or stores or bases of cartographic digital data will be created at the medium and at the large scales. As with maps, the digital data will have their range of uses depending upon their accuracy and resolution. Further data of interest to specialist users can be added if the data are of the appropriate accuracy. Many digital systems are likely to be created working at the same scale or accuracy, and also at other scales or accuracies. The exchange of data between such systems is a necessary aim to make the maximum and most economical use of the data collected. Common standards are therefore necessary for the definition of cartographic features and for the coding, structure and arrangement of digital data to enable the exchange of digital data—after further processing where necessary.

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Satellite Data Systems

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INTRODUCTION

As a member of the European surveying and mapping community, who has been asked to represent the European Space Agency at this meeting, I feel greatly honoured to help to celebrate the United States Geological Survey's one-hundredth anniversary and this for two reasons: First, the Geological Survey represents one of the largest mapping organizations in the world. We have discussed the status of surveying and mapping and its increasing progress and efficiency by modern technology, which only now makes it possible to map countries as large as continents in sufficient detail. The U.S. Geological Survey is one of the few organizations which have already proved that this is possible. Second, the Geological Survey in cooperation with the U.S. National Aeronautics and Space Administration is managing the Earth Resources Observation Program by satellites, which by no means is only an American program, but which is appreciated the world over, and has given the U.S. Geological Survey international recognition for its contributions in many disciplines.

It is not the applications of a satellite program to these disciplines that we are primarily concerned about in this session, but its suitability to gather map data. When I am to talk about satellite data systems I have a relatively short history to review. It only dates back 22 years when the Soviet Union launched Sputnik in 1957. In the meantime about 1,000 satellites have been launched by the United States alone—including over 350 by NASA—and about 1,400 by the Soviet Union. We remember well the achievements of both these nations in exploring the moon and our planets.

It is only relatively recently that other nations have ventured to enter space technology, establishing their own space programs. But this decision has been largely based on the experiences and the success of the space programs in the U.S.A. and the USSR.

The formation of the European Space Agency (ESA) was accomplished in 1974. It is based on the conviction that the countries of Europe do not have the resources to start their individual space programs, but that they can afford a joint program if they pool their resources.

In planning their own space program the countries of Europe have the advantage that they can concentrate on those space applications which have already been found to be indispensable in the U.S. and the USSR programs.

Applications which have so far become practical concern the following types of satellites:

1. Weather satellites, which today permit tracing weather conditions all around the globe.
2. Communications satellites, which have vastly improved intercontinental telephone connections and which make it possible to transmit live television programs around the globe.
3. Navigational satellites, which now permit the worldwide positioning of ships and planes. They have even revolutionized geodetic control survey techniques for developing countries.
4. Reconnaissance satellites, which are of indisputable military interest.
5. Satellites to explore geophysical parameters such as the contour of the Earth and its gravity distribution, the Earth magnetic field, or the parameters of the atmosphere.
6. Earth observation satellites, which give new data to a multitude of disciplines: on the topography of the Earth, geologic phenomena, the distribution and the state of vegetation, the cultivation of soil, the settled areas, the state of the oceans and coasts and the record of catastrophic events by flood, storms and fires.

IMAGE-GENERATING SATELLITES

Within this session on perspectives in surveying, mapping and cartography, we should restrict ourselves to satellite missions which are able to generate images for evaluation and interpretation. These are

1. The weather satellites.
2. The automatically operating Earth-resources satellites.
3. The reconnaissance satellites.
4. The manned orbital missions permitting Earth photography.

The weather satellites (table 1) were the first application satellites. The Kosmos series of the USSR and the TIROS series of the U.S.A. delivered space photographs of the Earth as early as 1960. The European Space Agency has operated its first meteorological satellite, Meteosat, since 1977. Meteosat is a geostationary satellite placed at a height of 36,000 km. It is one of the five such satellites planned in the international Global Atmospheric Research Program (GARP). Together with the U.S. Geostationary Operational Environmental Satellite (GOES) and the Japanese Geostationary Meteorological Satellite (GMS), it is part of the global weather watch.

Table 1 Meteorological satellites

NAME AND COUNTRY	OPERATIONAL PERIOD	ORBITAL ALTITUDE	SPATIAL RESOLUTION
TIROS 1-10, U.S.A.	1960–1965	700 km	3.5 km w/vidicon camera (visible)
ESSA 1-9, U.S.A.	1966–1969	1,500 km	3.5 km w/vidicon camera (visible and APT)
NOAA Series, U.S.A.	1970–	1,500 km	0.9 km (visible and thermal)
Kosmos 1–92 USSR	1959–1965	250 km	film capsule
Kosmos-226 USSR	1965–1969	600 km	Vidicon and IR
Meteor Series USSR	1970–		Vidicon, IR and APT
GOES U.S.A.		35,800 km	
Meteosat ESA	1977–	36,000 km	
GMS Japan			

It contains a rotating imaging radiometer capable of generating images in 3 bands:

1. The visible and photographic infrared (0.4 to 1.1 m).
2. The water vapour band (5.7 to 7.1 m).
3. The thermal (10.5 to 12.5 m).

Each picture contains 2,500 × 2,500 elements giving a picture element size of 5 km. The analysis of the images received every half hour to derive wind vectors for weather forecasting is done at the ESOC Center in Darmstadt. Meteosat has been the first goal achieved in the European Earth Observation Program from space.

Concerning the second group of satellite imaging systems, the Earth-resources satellites (table 2), the European countries—like the countries of Latin America, Africa, or Asia—have had the benefit of obtaining imagery from the American Earth-observation satellites, progressing from Nimbus to Landsat to Seasat.

Table 2 U.S. land observation satellites

NAME	OPERATIONAL PERIOD	ORBITAL ALTITUDE	RESOLUTION
Nimbus 1-6	1964–	1,000 km	Vidicon 1 km IR-scanner 8 km
ATS 1–4	1966–68	35,800 km	color
Landsat 1	1972–78	919 km	pixel size 79 m 4 channels
Landsat 2	1975–	919 km	
Landsat 3	1978–	919 km	pixel size 79 m 4 channels or pixel size 30 m 1 channel
Seasat 1	1978–	790 km	pixel size 35 m radar X-band

The advantage of Landsat is primarily the relatively high resolution in the 4 visible-near infrared bands. A pixel size of 79 × 79 m is obtainable of nearly every place on Earth every 18 days, if not covered by clouds. To talk about Landsat at the U.S. Geological Survey means carrying water to the ocean. Here is just an example: we use its digital processing capability, as other nations have, for land use mapping combined with a topographical map.

The European Space Agency operates its own satellite data reception and distribution network Earthnet. Within the Earthnet network the Italian station Fucino receives Landsat data while Seasat data are received by the British station Oakhanger and Nimbus data by the French station Mannion.

Seasat was of particular interest to cloud-covered Europe, but after about 100 days it ceased to operate its X-band imaging radar, which was capable of providing a 100-km-wide image strip from its 790 km height at a 20° inclination with 25 m pixels. The biggest problem with Seasat data is still that of data processing. To process the coherent radar data, available in holographic form, extensive digital filtering operations are required; so far this is not possible in a fast and economic manner.

Very little is known in Europe about the capability of military reconnaissance satellites (table 3) operating with cameras and film retrieval systems. Nevertheless we are convinced that they presently can produce the highest quality imagery from space.

Table 3 U.S. military reconnaissance satellites

NAME	TYPE	OPERATIONAL PERIOD	ORBITAL ALTITUDE	ESTIMATED SPATIAL RESOLUTION
SAMOS 1-80	film camera, c=90 cm	1962–1972	150 km	15 m
MIDAS	visible, IR, UV, c=90 cm	1967–	30,000 km geostationary	?
Big Bird	film camera, c=1.8 m	1973–	150 km	1-2 m

Table 4 History of manned missions space photography of the Earth since 1965

MISSION AND YEAR	CAMERA TYPE	ORBITAL ALTITUDE	FOCAL LENGTH	FILM FORMAT	RESOLUTION	GROUND RESOLUTION
Gemini 4–7 (1965)	Hasselblad, C. Zeiss-Optik	200 km	80 mm	5.7×5.7 cm	20 lp/mm	125 m
Gemini 10–12 (1966)	Maurer	200 km	80 mm	5.7×5.7 cm	20 lp/mm	125 m
Apollo 7 (1968)	R220 Maurer	225–420 km	80 mm	5.7×5.7 cm	35 lp/mm	70 m
Apollo 9 (1969)	Hasselblad, C. Zeiss-Optik	192–496 km	80 mm	5.7×5.7 cm	35 lp/mm	70 m
Skylab (S190A) (1973)	ITEK	435 km	152 mm	5.7×5.7 cm	29 lp/mm	99 m
Skylab (S190B) (1973)	ETC Action	435 km	460 mm	11.5×11.5 cm	25 lp/mm	38 m
SOYUZ 22–30	MKF-6, Jena	250 km	125 mm	5.5×8.1 cm	80 lp/mm	25 m

Manned orbital photography missions (table 4) on the other hand, such as those from Gemini, Apollo, and particularly Skylab, have given imagery that may be utilized to compare space photography with scanning and other automatic imaging systems.

The first photographic images from space, made available by the United States to many countries, were able to demonstrate what later automatic image acquisition systems with scanners—such as Landsats 1, 2, and 3—were able to achieve from 1972 onward. The Landsat program has especially made the countries of the world aware of the potential of space imagery for the purposes of thematic mapping of features such as vegetation, hydrology, and land use. It was soon realized, however, that the Landsats 1 and 2 spatial resolution whether of 79 m pixel size, or with Landsat 3 of 30 m pixel size, is much too coarse for reliable mapping to the standards of a topographic map.

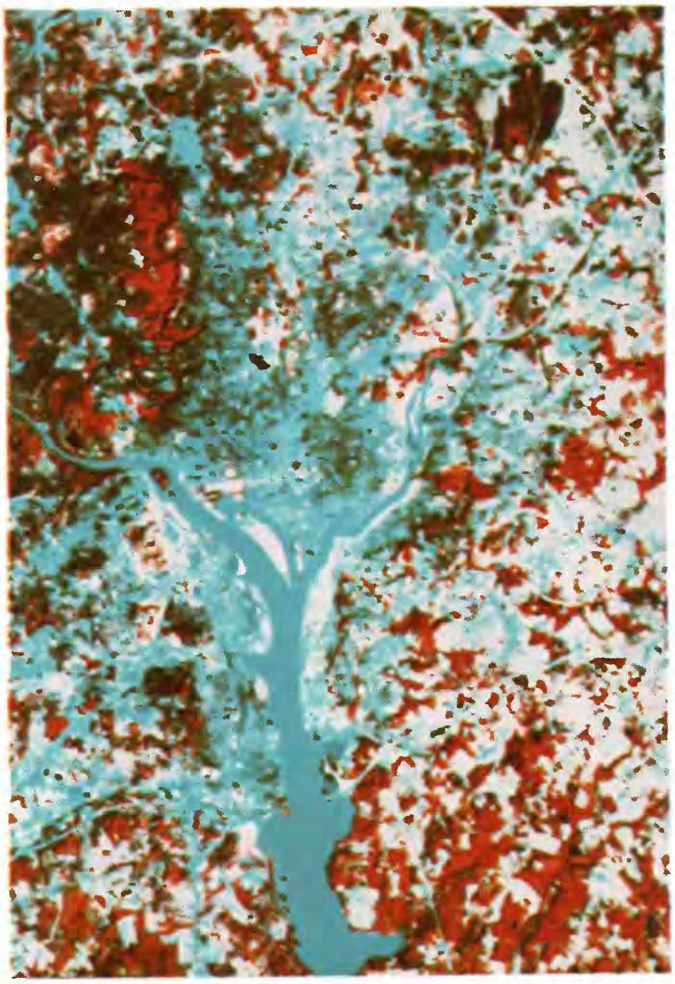
Both the U.S.A. and the USSR have demonstrated with improved camera systems in the missions Skylab (1973) and Soyuz (since 1976) that photographic resolutions between 25 and 40 m (corresponding to pixel sizes of about 10 to 15 m) could be reached. These cameras were photogrammetrically calibrated and they possessed image-motion compensation. The drawback of these space photography missions was that the missions were of relatively short duration, covering only isolated parts of the globe. Moreover, the formats of the images were not usable in standard photogrammetric plotting equipment. For that reason the capabilities of space photography could not be fully demonstrated to the mapping community throughout the world.

SATELLITE DATA FOR MAPPING

I cannot show images to be taken in the future, but I can show a few American examples, which help us find a viewpoint for a person engaged in mapping.

Most countries used Landsat images in analog form for photographic interpretation of geographical,

Figure 1 Digitally processed Landsat scene of the Washington, D.C. (U.S.A.) area magnified to about 1:200,000.



geological, hydrological, biological, or agricultural regional phenomena.

Much better interpretation results were achieved in multispectral classification of terrain features utilizing the 4 spectral channels of Landsat data in digital form. While digital treatment of Landsat data was demonstrated to be superior in every respect to analog interpretation, it was realized at the same time that digital processing of Landsat data is very time-consuming and very costly. For that reason all received Landsat images cannot be digitally processed at the moment to give optimal interpretation results.

At the same time the detectability of an object is limited to about 2.5 times the pixel size. Therefore Landsats 1 and 2 images are able to resolve objects with sufficient contrast with certainty only if they are at least 200 m in size. Figures 1 through 5 demonstrate this.

Figure 2 Equivalent image (see fig. 1) from Skylab with increased resolution.

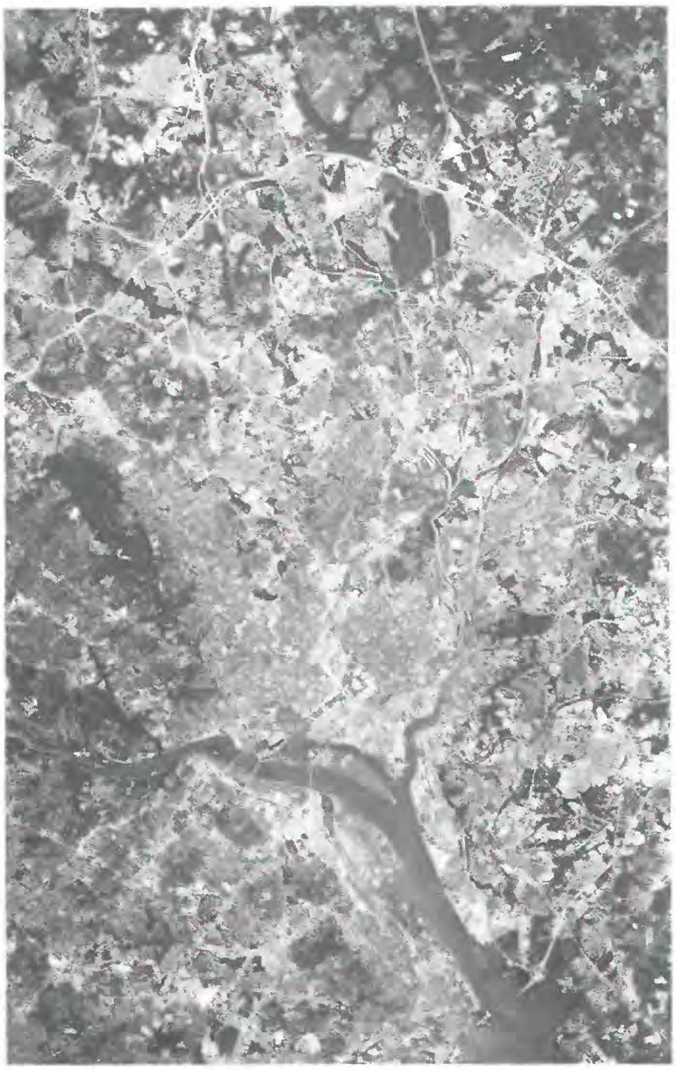


Figure 3 Landsat scene microscopic enlargement to 1:25,000 processed to limit on the laser recorder.

Figure 4 Same scene (see fig. 3) at 1:25,000 from Skylab.

Figure 5 This image of Cape Canaveral, Florida (U.S.A.), demonstrates the relatively higher resolution achieved by Landsat 3. It is, however, not yet comparable to camera resolution of Skylab.

Figure 6 Seasat radar image of Lake Geneva, Switzerland (portion at scale of 1:500,000). ▶

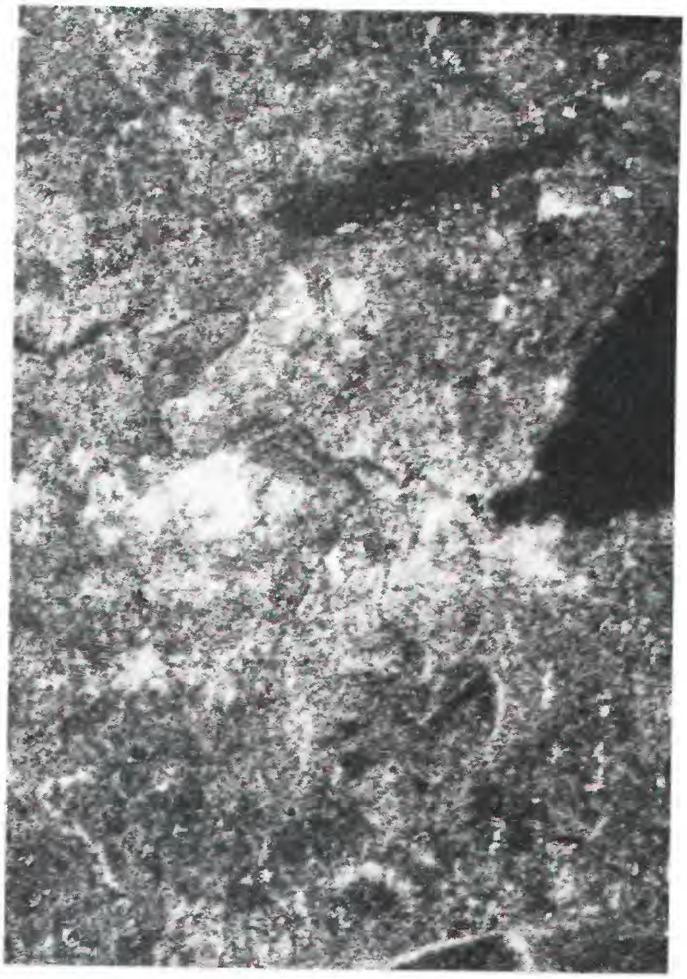
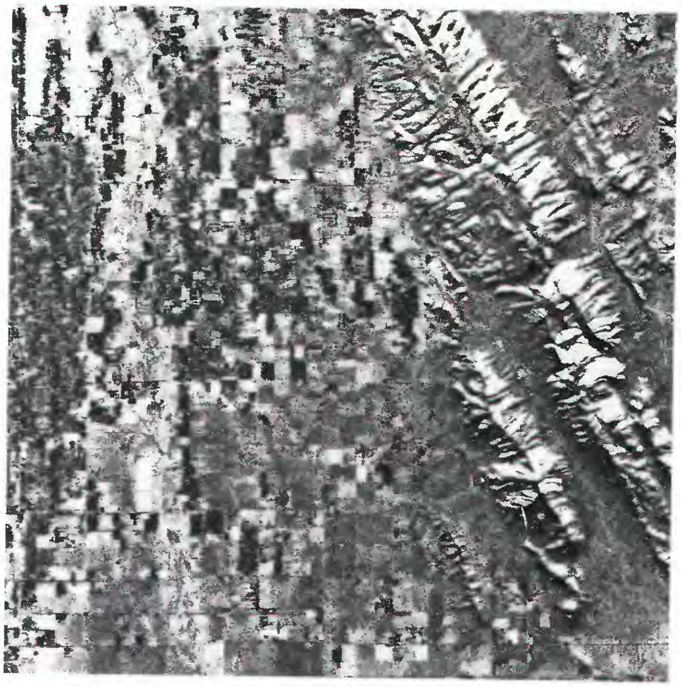
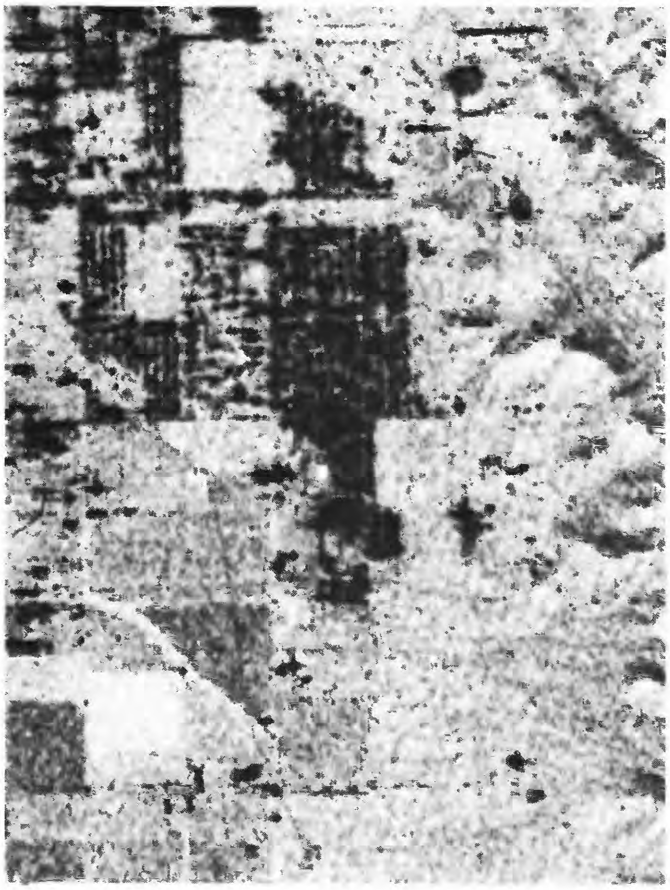


Figure 7 Enlargement of a superior Goodyear GEMO 1,000 aircraft radar image of Phoenix, Arizona (U.S.A.) (1:160,000). ▶



Reproductions in figures 6 through 9 demonstrate the capabilities but also the deficiencies of the radar imaging currently operational.



◀**Figure 8** Phoenix, Arizona, radar image (fig. 7) to about 1:30,000, shows that enlarging the scale of radar reflection images does not necessarily give better resolution.

Since many thematic and especially the topographic requirements call for detection of objects of a few meters in size only, future Earth-resources satellites (see tables 5 to 12) will be designed to achieve smaller pixel sizes. In the United States Landsat D is being designed for a pixel size of 30 m. Likewise France has decided on a pixel size of 10 to 30 m for the SPOT satellite. The U.S. proposals for the Stereosat satellite (15 m) of the European Space Agency (LASS and COMS, 30 m) and of Japan call for higher resolution than Landsats 1 and 2.

Table 5 U.S. remote sensing programs from space

Basic support programs	**Specifications and capabilities**
1. Space Shuttle	Reusable transporter.
2. TDRSS	Worldwide satellite communication system via geostationary satellites.
3. Multimission modular spacecraft	Various spacecraft.
Systems under construction	
1. Landsat D, 1982	Thematic mapper: 6 bands: 0.42–2.35 m, pixel size 30 m 1 band: 10–12.5 m, pixel size 120 m 85 Mbit/second data rate via TDRSS.
2. Shuttle Experiments	
a. Large-format camera	Orbit: 296 km circular 30 cm focal length 23 × 46 cm format 2,400-photo spool capacity.
b. Seasat radar	(X and L band).
Planned systems	
1. Mapsat (USGS)	Normal and convergent stereo 1 band, pixel size 10 m 2 bands, pixel size 20 m 45 Mbit/second data rate Orbit: 900 km circular.
2. Stereosat (Jet Propulsion Laboratory)	Convergent stereo 3 diode arrays Pixel size 15 m.
3. Multimission modular spacecraft with large-format camera.	Operational life 6–9 months Parking orbit: 900 km Mission orbit: 250 km.

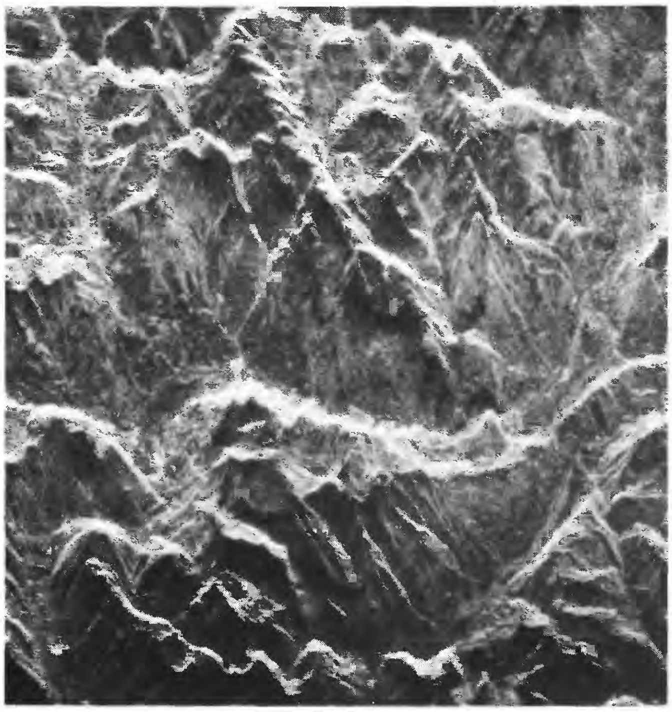


Figure 9 The high displacements of the Seasat image due to topography in Europe's Mont Blanc region render this radar image almost useless for a geographical reference.

Table 6 Other countries' remote sensing programs from space

USSR (Interkosmos)		
Soyuz	MKF.6	in use
France:		
SPOT on ARIANE		under construction
20 m pixel size	2 bands	
10 m pixel size	panchromatic	
250 images storage		
Japan		under construction and planned:
MOS (Marine Observation Satellite)		for 1983
50 m pixel size, visible and thermal		
LOS (Land Observation Satellite)		for 1987
30 m pixel size		
People's Republic of China		planned
Program of the Jen Hsi-Min Space Technology Institute		

Table 7 European Space Agency remote sensing programs from space

A. *Basic support programs*
1. Construction of Spacelab (by ERNO) for multipurpose use in Space Shuttle, the retrievable NASA space transporter
2. Construction of European rocket Ariane

B. *Systems under construction*
1. Spacelab 1 Experiment
   photogrammetric camera Zeiss RMK 30/23:
   3 films = 1,650 photos
   mission duration 1 week
   start up: April 18, 1982
2. Spacelab 1 Experiment
   microwave remote sensing models of operation:
   a. microwave scatterometer
   b. passive thermal sensor
   c. imaging radar in X-bands 25 m pixels, image width 9 km

Table 8 Spacelab camera-mission

Camera type:	Modified Zeiss 30/23
Orbit:	h = 250 km, i = 57°, 8 days
Film load:	3 rolls, 1,650 exposures
Film evaluation by:	IGN & CNES (France)
	IFAG & DFVLR (Germany)
	University of Milan
	University of Hannover

Table 9 Microwave experiment for Spacelab mission
[Joint construction project by Dornier of France and DFVLR of Germany]

Synthetic aperture radar	
X-band	9.6 GHz
Antenna inclination	45°
Sensitivity	1 db
Dynamic range	−30 db to + 10 db
Resolution	100 × 100 m (25 × 25 m required)

Table 10 European Space Agency plans for Earth-resources programs

1. LASS (Land Applications Satellite System)
   a. 30 m pixel diode array (6 channels)
   b. 60 m pixel scanner (refl.IR) (2 channels)
   c. 120 m pixel thermal scanner (2 channels)
   d. 100 m pixel synthetic aperture radar
2. COMSS (Coastal Ocean Monitoring Satellite System)
   a. ocean color scanner (7 channels, narrow spectral bands): f. Chlorophyll; visible 5; thermal 2
   b. synthetic aperture radar 30 m pixel
   c. microwave radiometer
3. Atlas program (see table 12)
   under study in Federal Republic of Germany: camera in space

One of the limiting factors to the achievement of the desired resolution suitable for topographic mapping is the data transmission rate. In a Landsat image 3,200 image elements are digitized every 50 m along the scan (yielding an equivalent pixel size of 79 m) with 8-bit gray level information for each of the 4 spectral channels. With one scan every 79 m with a velocity of 7.7 km/sec, a total of 97 scans must be made per second. To transmit these a data rate of 10 Mbit/sec is required.

For Landsat D a data rate of 84 Mbit/sec will be necessary. The present technological limit is 200 Mbit/sec, disregarding cost considerations. To reach the potential of current photography achievable with photogrammetric cameras, however, a data rate of 900 Mbit/sec would be required. During the next decade it does not appear to be feasible to reach this rate economically. Space photography therefore surpasses the capabilities of automatic sensors to provide data to solve cartographic problems at medium and small scales.

PLANNED AND SUGGESTED SPACE PHOTOGRAPHY MISSIONS

As surveys of world mapping progress published in "World Cartography" (no. XIV) indicate, current mapping methods utilizing aerial photography are progressing too slowly. That progress not only is a function of the area to be mapped but also relates to the number of photographs to be utilized for mapping. Systematic photographic coverage from space leads to utilization of far fewer photographs and to far fewer control requirements, and should therefore lead to a faster progress in mapping.

Requirements that can be achieved for this space photography are as follows:

1. A sufficient resolution to detect all objects of interest.
2. A specified positional accuracy commensurate with mapping standards.
3. A specified elevation accuracy commensurate with mapping standards.

These requirements vary for the different mapping scales and for different types of terrain. Based on these specific requirements a suitable space mapping system utilizing photographic cameras can be designed. The Institute of Photogrammetry at the University of Hannover, in collaboration with the German Space Agency (DFVLR), is engaged in a study of a suitable space photographic system in the so-called "Atlas Program." The technical realization of the project is being studied by the ERNO Company.

The Atlas Program is composed of three phases:

Phase A: Utilization of a standard mapping camera in space to acquire photographic imagery from a low orbit out of a pressurized manned cabin.

Table 11 The Atlas program
[Atlas A is under construction; B is under discussion; C is planned]

Atlas A		
Zeiss RMK 30/23 in Spacelab 1 for 1982		manned Spacelab module with 3 cassettes: 1,650 photos
Atlas B		
Alternatives (a *or* b *or* c):		
a. RMK 30/23 with image-motion compensation		pressure container on shuttle palette
b. RMK 60/23 with IMC		pressure container on shuttle palette with large magazine
c. TRb 60/24 with IMC 23×11.5 cm format.		manned Spacelab module
Atlas C		
New development alternatives (a or b or c):		
a. c=30 cm	23×23 cm format	pressure container on freeflyer with large magazine
b. c=60 cm	23×23 cm format	
c. c=75 cm	18×18 cm format	large magazine

Table 12 Performance specifications for the Atlas program

ORBITAL ALTITUDE	OPTICAL FOCAL LENGTH	FILM FORMAT	PHOTO AREA	OPTICAL RESOLUTION B/W	OPTICAL RESOLUTION COLOR IR
			Atlas A Mission		
250 km	205 mm	23×23 cm	189×189 km	40 lp/mm 21 m	254 lp/mm 33 m
			Atlas B Mission		
250 km	153 mm	23×23 cm	380×380 km	100 lp/mm 16 m	50 lp/mm 32 m
250 km	305 mm	23×23 cm	189×189 km	70 lp/mm 12 m	35 lp/mm 24 m
250 km	610 mm	23×23 cm	95×95 km	60 lp/mm 7 m	30 lp/mm 14 m
			Atlas C Mission		
516 km	750 mm	18×18 cm	380×380 km	60 lp/mm 12 m	30 lp/mm 24 m
480 km	610 mm	23×23 cm	189×189 km	60 lp/mm 13 m	30 lp/mm 26 m
360 km	610 mm	23×23 cm	95×95 km	60 lp/mm 10 m	30 lp/mm 20 m
360 km	305 mm	23×23 cm	380×380 km	70 lp/mm 17 m	35 lp/mm 34 m

Phase B: Use of an improved camera (optics image motion compensation) from a pressurized unmanned container.

Phase C: Use of the container in a free-flying retrievable unmanned satellite.

While phase B and C are at the proposal stage, phase A will be realized as an experiment during the first European Spacelab mission now scheduled to be carried into orbit in the NASA Space Shuttle Program in April 1982.

SPACELAB 1 METRIC CAMERA EXPERIMENT

The government of the Federal Republic of Germany has placed at the disposal of the European Space Agency a Carl Zeiss, Oberkochen, RMK 30/23 photogrammetric mapping camera, which has been modified at a European space facility to meet space requirements. While the experiment is funded by the government of the Federal Republic of Germany, the DFVLR is responsible for procurement and engineering carried out by Zeiss, ERNO, MBB and Kaiser Trethe to operate the camera electronically by ground commands and to accommodate it in the Spacelab module. ESA takes care of setting up the experiment proposal.

The response to announcement of the experiment was overwhelming. Over 100 institutions in all continents have expressed a worldwide interest in experimenting with the imagery. Based on these proposals a time table for areas to be photographed has been drawn up, subject to cloud cover conditions permitting photography.

Altogether, 3 film magazines with a total of 1,650 photographs can be exposed. In order to select the most suitable film types a joint cooperative test has been carried out utilizing high-altitude photography involving aircraft of the Institut Géographique National (IGN) France and the DFVLR. In the evaluation, the French Agencies CNES and IGN, the German agencies DFVLR and IFAG, as well as the Universities of Milano and Hannover, were involved. The tests are being carried out this fall (1979). They have already indicated that a photographic resolution of about 20 m (corresponding to a pixel size of 8 m) can be reached from Spacelab 1 utilizing black-and-white film. Infrared false-color films yield slightly lower, but still acceptable, resolutions, while the color films available cannot be recommended.

The photographs will be taken with 80 percent or 60 percent overlap. The proposals have indicated that the images will be subject to a wide range of investigations and methods ranging from topographic to thematic mapping in various disciplines such as geography, geology, forestry, land-use planning, agriculture, hydrology, coastal engineering, and oceanography. Concerning the methods to be used, all known mapping techniques are included: aerial triangulation, analog mapping, the use of analog plotters, rectification, orthophotomapping, and standard photointerpretation.

The experiments should give a clear indication over a wide area of the world as to whether further steps of the Atlas program should be pursued and with how much energy.

SUMMARY

There is a documented, urgent need for mapping on a worldwide basis for resource and social development. Present mapping techniques have been able to provide the required maps only in developed or in densely populated regions. However, a large part of the world still lacks such maps even at small scales. Present mapping techniques have been vastly improved but they are still not capable of providing the required maps in the next few decades. Satellite imagery from photogrammetric cameras offers a promising alternative, if resolution and geometric accuracy requirements can be met. Even where maps already exist there is a constant need to revise these maps. Also, satellite imagery may considerably accelerate the speed of updating those existing maps. For these reasons, a mapping camera has been placed on Spacelab 1 in order to demonstrate the possible advantages of mapping from space photography. If the experiment is successful a further development of a free-flying, serviceable satellite carrying a mapping camera is foreseen for the mid-1980s. This camera should contain a magazine carrying film for several thousands of photographs and, under control of weather satellite information, should be able to cover almost the total land area of the world in a few months' time. Careful estimates indicate that space photographing operations should be more economical and less time-consuming than mapping by aerial photography or even by automatic data acquisition systems, should such cameras become available at higher resolutions in the 1990s.

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Discussion

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A real joy for a professor is to see the success of his students; in no case is this better exemplified for me than by Gottfried Konecny, who has established an international reputation in photogrammetry and general comprehension of surveying and mapping matters. A brief comment on the wealth of material that Gottfried has presented is difficult.

There are two points, however, that I can make. One is the relative applicability of the telemetered data systems and the photographic film systems operating from space. I think it's quite clear that the photographic technology operating on film is at a much lower level than that required for telemetered satellite data. There is an anomalous situation where the film systems on the one hand can produce much higher resolution and more of the kinds of cultural information that we need for base mapping. In general such base-map information is not required in a very urgent time frame, and is therefore amenable to a system which can return data weeks or even months after it is collected. The telemetered data systems on the other hand operate at a much lower resolution but require a higher level of technology to determine the time-variant information which is critical for management of the Earth's natural resources. I don't see any real competition between these two kinds of approaches; they are both essential, and both should be implemented.

The other point that seemed to me to come out from Gottfried's discussion is the variety of systems which are being proposed or being implemented by the various countries. One of the primary characteristics of satellites is, of course, that they all operate on a worldwide basis. Everybody's satellite can cover the whole Earth. The systems which we have seen in Gottfried's paper being built by the United States, by the European Space Agency, by Japan, and by the USSR have a great deal of similarity in terms of spectral bands, ground resolution, and potential coverage patterns. It seems to me that one of the primary things that we need to get on with is to establish cooperation in these programs rather than competition, so that the systems of one country can complement the activities of another. There are many other things that I'd like to say about this, but I'm going to hold those until the panel discussion afterward.

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Opportunities and Perspectives in Digital Mapping and Automated Cartography

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INTRODUCTION

It is generally accepted that accurate and up-to-date terrain information is the foundation of orderly exploration and management of natural resources and the planning of urban centres, transportation routes, preservation of environment, and a host of other activities related to man's exploits on Earth. Since the beginning of civilization the map or plan has been, and still remains today, the most common method of portraying terrain information. Cartographic conventions have evolved over the centuries from an artistic portrayal of the terrain to a more technical or scientific representation of the Earth's surface. Today an increasing number of users demand terrain data in digital form in addition to, or in place of, the traditional graphics.

The developments in the last decade in computer technology, particularly in the field of computer graphics, have opened new vistas to those engaged in providing and managing terrain information. These developments have far-reaching implications, with effects on the storage, display and use of topographic information that are not yet fully appreciated.

In the traditional approach, the graphic manuscript or the reproduction negatives are the principal archival storage of the terrain information. In digital mapping the graphic manuscript is replaced by a digital data file, and the graphic data base is replaced by a topographic digital data base.

Digital mapping technology has the potential to greatly facilitate the use of terrain data by many other professions that are employing geo-referencing principles for the presentation and analysis of their own data, and are overlaying information peculiar to their disciplines upon a topographic map (or a skeleton of it) to display an almost infinite variety of themes. The use of "digital maps" in engineering applications is increasing steadily.

We now have the technology to create digital topographic data banks and data bases. But the degree of usefulness of digital terrain information and consequently the economic benefits of digital mapping will depend, to a large extent, on the degree of sophistication of the classification system of topographic features, an efficient reference system of all data and a file structure that provides for extensive data base management operations. Simple digitizing and encoding of terrain data for subsequent drawing by a computer-assisted drafting table will not satisfy the needs of most users of digital data. The system must not only provide capabilities to satisfy general cartographic data processing but must be capable of providing the base for geographically-referenced information systems. However, we must be cognizant of the fact that, despite great advances in digital mapping technology and data base management systems during the last decade, we have not yet reached the stage where the computer can efficiently provide answers to all questions related to the information contained in a digital data base. A human looking at a map immediately perceives the spatial relations between features but the computer performs dismally in this area and the associated computer costs are often extremely high.

COMPONENTS OF A DIGITAL MAPPING SYSTEM

Any digital mapping system consists of three basic components:

1. The data base management system.
2. The data input or data collection system.
3. The data output system.

The Data Base Management System

The data base management system is the most critical element of the total system. Its structure and sophistication will determine the degree of usefulness of the collected data. The structure and composition of data base management systems are being vigorously discussed and thoroughly investigated by senior officers of many national mapping programs, and I think it fair to say no consensus has as yet been reached. It is an adventurous person who attempts to describe the ultimate management system, so I will limit myself to describing briefly the data base structure employed at Topographical Survey of Canada. But before I begin, I would like to make the distinction between data bank and data base.

A **digital data bank** is a collection of data stored in files, which can be accessed and retrieved in an orderly manner. Just as books might be withdrawn from or replaced in a library by using the catalogue shelf number or book number, so can an item (e.g., a given contour) or file (e.g., file of all contours) be accessed or retrieved in a digital data bank. The action in both cases is independent from the intended use of the information contained in the book or in the digital file. It is a process of simple retrieval of information and there is no facility to relate information contained in files to each other or to answer questions about this relationship (i.e., number of houses above certain elevation).

On the other hand, a **digital data base** contains, in addition to the files, functions for the user to define in terms of a logical model the data elements and the particular association between these elements. The data base system, by means of appropriate software, accesses the data and brings them into association to fulfill the user's requirements, or to provide the answer to the question the user has asked.

The operation is similar to putting a question to a researcher in a library. The researcher would get the data from the books and bring them together for study to enable the question to be answered.

The access paths in a digital data bank and a data base are not the same. In the digital data bank the access paths are the file and the physical organization of the files. It is basically a file management operation. In the digital data base, however, the access paths within the computer system and storage are defined by the user's model for bringing the relevant or selected data into association. Since it is not feasible to foresee all possible applications of digital data, the data are collected without prior knowledge of all their subsequent possible uses. Therefore, data must be collected and stored in such a manner that their eventual use is not tied specifically to a single application, but is available for a variety of applications.

The Canadian Topographic Digital Data Base Management System: The digital topographic data base system of the Canadian Topographical Survey is feature oriented. To simplify the storage and management of the very large amounts of data required for mapping, an efficient means of referencing the data is necessary. The cartographic features are organized on the basis of map sheets, each of which will correspond to a file in a digital system. The sum total of the individual map sheet files constitutes a file system. At the file system level of data handling, there is a capability of data storage, data access and data retrieval, based on the knowledge of data content and data organization of the files. Each feature is classified according to its cartographic definition, i.e., roads, bridges, houses, contours, etc., and may be divided into as many segments as the user wishes. A feature (fig. 1) may have associated with it a number of attributes or characteristics; for example, a contour may be described in terms of its height, location (on land, ice or glacier) and type (normal, depression, approximate, auxiliary); a road in terms of its name, road type or construction, and so on.

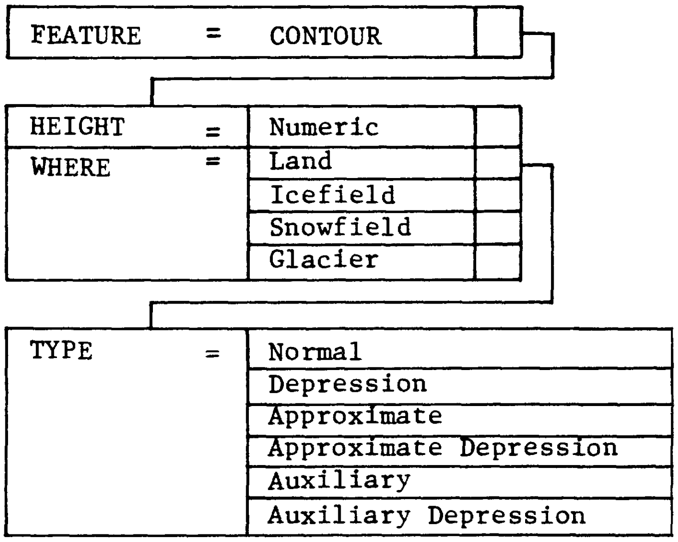

Figure 1 Feature attributes as classified by the Canadian Topographical Survey.

Each feature entity is described by a different set of attribute values that make the feature unique. Retrieval of any feature may be based on attribute values. The basis for all cartographic features is their position on the Earth's surface. Therefore, each feature is defined in terms of its Universal Transverse Mercator (UTM) coordinates. Textual information, such as names, is also included in the data base, but cannot be used for retrieval as this is unstructured information. Features of like type are grouped into classes and the classes are grouped to form a map (fig. 2).

Data Input System

The input to a topographical cartographic data base comes basically from two sources:

1. Digitization of existing graphics.
2. Direct digitization from air photography on a photogrammetric instrument.

The choice between one or the other method depends very much on local conditions and requirements. A county which has accurate up-to-date maps at different scales

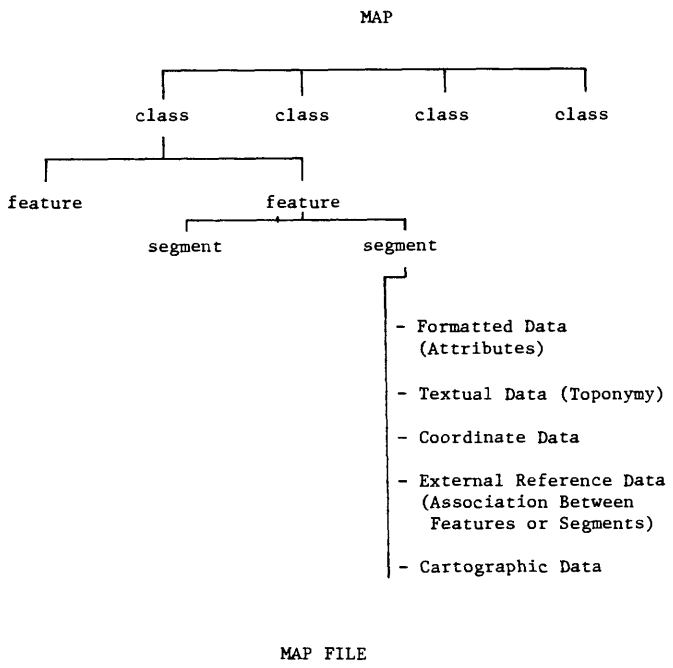

Figure 2 Classification of map features in digital topographic data base system of the Canadian Topographical Survey.

would most likely opt for digitizing of existing graphics by employing manual digitizers, semi-automatic line following such as the one developed by Laser-Scan of the United Kingdom, or Raster-Scan techniques.

The last two have made considerable progress during the last few years. The development of interactive (man-machine) graphic data collection and editing systems makes the digitization on photogrammetric instruments a practical proposition. It gives the stereoplotter operator unrestricted access to the digital data of the stereomodel he is compiling and of the surrounding stereomodels compiled by him or others (fig. 3). The operator may view these models at any scale on a CRT (cathode ray tube) and perform any necessary corrections or editing. He can tie in adjacent stereomodels and perform any required function on the digital data that he normally would on a penciled manuscript in the graphical compilation mode.

Instruments such as the Gestalt Photomapper 2 (fig. 4) generate a dense grid of terrain elevations which can form a part of a digital topographic data base.

Data Output System

Digital data offer the possibility of producing on demand an unlimited variety of outputs. However, in order to harness the full power offered to us by digital technology, we must re-examine our practices, concepts and traditions surrounding the cartographic conventions which were designed to a large degree to accommodate the abilities and limitations of the human draftsman. We must revise cartographic specifications to take full advantage of computer-assisted drafting systems and not attempt to make the computer slavishly duplicate human operations. However, we must not lose sight of the basic objective of making a map, that is to portray the terrain with clarity and fidelity in accordance with the needs of today's map users.

Since the geometric accuracy of terrain data is contained in the digital data, the positional accuracy of the graphics could be of secondary importance. One can foresee that future maps will be printed and distributed in a different manner than today. The production of printing plates directly from digital representation files would eliminate most if not all of the photo-mechanical processes. Organizations or even individuals could interrogate regional digital topographic data bases and view a map display on a CRT in their office or at home. They may even have the ability to produce the map of their interest in monochrome or in colour. The technology to accomplish this is now available.

SOME IMPLICATIONS OF DIGITAL TOPOGRAPHIC DATA BASES

The accuracy of the topographic data acquired by graphical mapmaking methods and then subsequently digitized is always constrained by the compilation scale. However, this is not the case when terrain data are digitized directly in the stereoplotter. Whereas in the traditional mapping process the original graphic manuscript compiled photogrammetrically at a given scale is the limiting factor governing the accuracy of topographic data, in digital map compilation the accuracy of the data is limited only by the scale of the photography, and the visual acuity and manual dexterity of the photogrammetric operator. The accuracy of the digital data is independent of map scale. There is no displacement of features to avoid crowding and no slippage of the scribing tool in following a different line. The digital data are always of higher accuracy than the resulting graphics. Thus maps at several scales can be automatically drawn from the same photogrammetrically obtained digital data to graphic accuracies that are standard for each scale.

When we speak of a map at a given scale we intuitively form a mental concept as to the accuracy and content of terrain information portrayed on that map. However, in terms of digital data, "scale" becomes meaningless. We have to develop and get used to a new concept applicable to the digital environment, which would be equivalent to the concept of "scale" in the graphical environment. This new concept would include standards of geometric accuracy, precision and level of topographical content of digital data. For example, at the lowest level of content a road may be defined by its centre line. At a higher level the

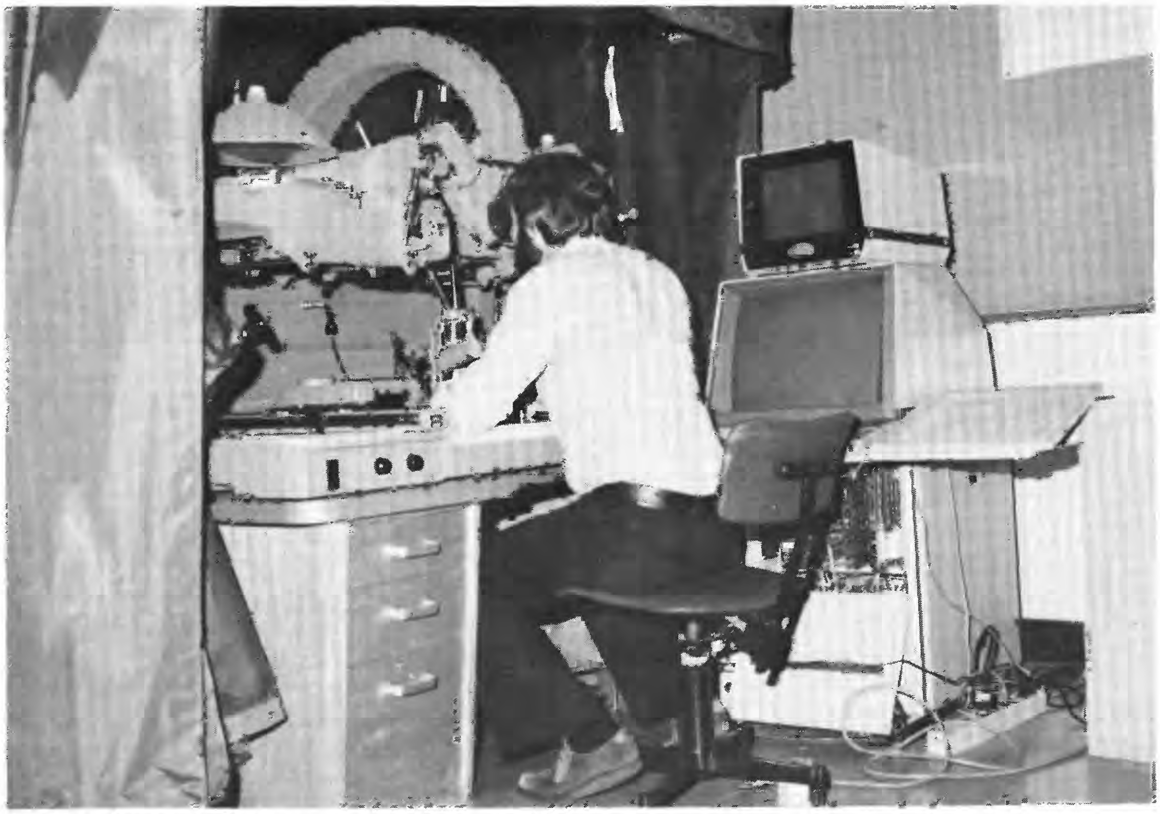

Figure 3 Wild B–8 with interactive digiting and editing unit.

Figure 4 Operator console of Gestalt Photomapper GPM–2.

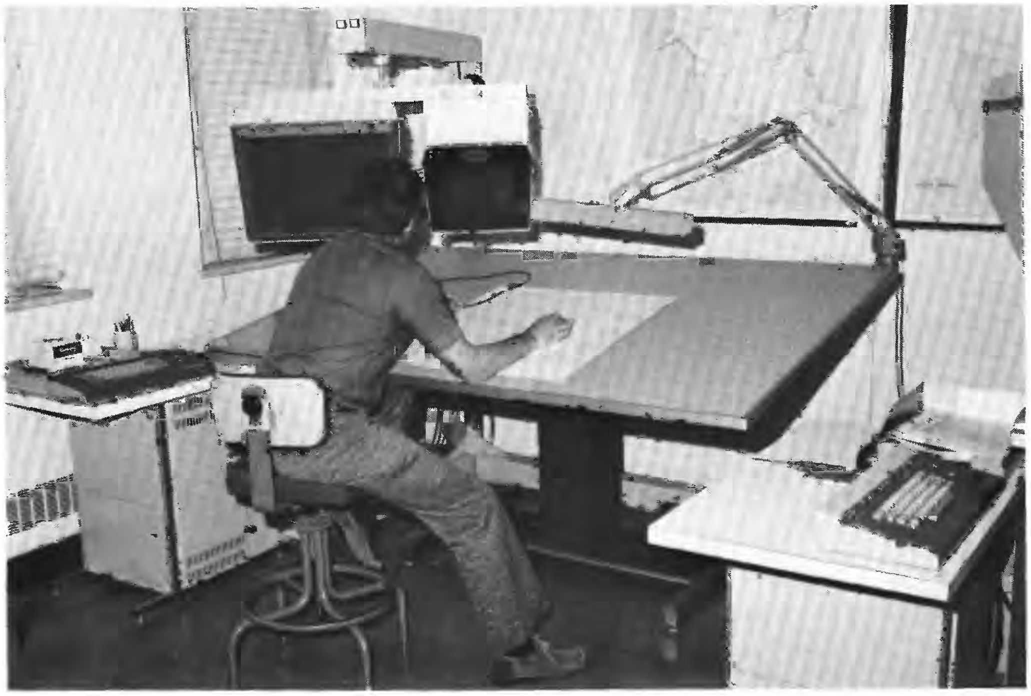

Figure 5 Interactive cartographic editing station.

road could become a "host feature" defined by the lines demarcating the sidewalk, shoulders, ditches and right of way.

Traditionally terrain elevation is represented by contours. This type of relief depiction is well understood by most map readers, but for computer applications the relief is best represented by a digital elevation model. It could be then argued that the digital topographic data base should contain digital elevation model (DEM) information and not contours. Contours at different intervals could be automatically generated on demand from the DEM's.

In digital mapping two basic types of digital files should be considered:

1. Position file.
2. Representation file.

The **position file** contains edited and checked data collected directly in digital form on a photogrammetric instrument or from large-scale plans where the position and shape of features is not distorted by cartographic representation. In this file all topographical features are recorded in their true geographical position without regard to cartographic symbolization.

The **representation file** is created by the cartographer for each scale of map from the position file. A computer-assisted interactive cartographic system permits the cartographer to displace or delete features (fig. 5), select appropriate symbols, and then issue appropriate commands for the automatic drafting of colour separation negatives.

On the surface it would appear that the creation of the position and representation files could be accomplished independently by the photogrammetrist and the cartographer without reference to one another. This, however, is not the case. The classification and referencing of topographic features, and the coding and organization of the digital files at the data collection stage, has an enormous influence on the software required for the cartographic treatment of the data. In fact, the classification and referencing governs the efficiency of the cartographic phases of map production and the whole data base structure. Therefore, development and operation of a digital mapping system which includes computer-driven negative scribing must be a joint effort of the photogrammetrist-topographer and the cartographer. The computer scientist is naturally an important member of the team, but he must remain subservient to the mapmaker.

The successful application of a digital mapping system in production depends not only on a thorough engineering development of the system, but to a large extent on clearly defined operational procedures and standards. Any deviation, however small, may render data useless, cause software systems to crash, or require costly manual intervention.

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Discussion

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I would like to consider the notion of scale in digital mapping. "Digital data files no longer have any scale." This statement is not acceptable in this absolute form. Scale remains a relative notion. One of the great merits of digital map files is that the same geometric data can be used in a variety of different map products.

The situation of computer-assisted cartography is a desperate one at the moment. Hopefully it will not be so desperate in the near future. There are considerable moves towards joint efforts to improve the situation, e.g., by exchanging experience in data structuring and feature standardization.

Benefits of computer-aided techniques in cartography are manifold. There is a large field of overlap and connection between traditional techniques and these new tools. The use of the computer forces one to tackle all graphic representation problems more logically and the results are more consistent maps. Also computer-assisted techniques in cartography are still closely tied to reproduction procedures. The U.S. Geological Survey has always been a leader in this field.

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Panel Discussion

Rupert Southard (USGS): We will now invite questions from the audience.

Lauro Sodre Neto (Brazil): Professor Ternryd, you talked about tacheometry and telemetry and showed us the latest developments in instrumentation and techniques. I would like to ask you if you have notice of any research going on towards the end of modifying the initial input from the optical system to an electronics system or even acoustical system as we did in fire-control instruments where the directors and range finders of optical type were replaced by electronic or acoustic equipment.

Carl Ternryd (Sweden): Maybe I have misunderstood your question, but as far as I understood it I cannot answer it.

Rupert Southard: Does anyone else on the panel think he can handle that question?

Ernst Spiess (Switzerland): If I understood correctly it was a question on whether acoustical principles and electronic principles could replace the optical ones. My own feeling would be that the acoustical principles would work fine in water; however, not in air. As far as the optical systems are concerned, also in the pointing, an optical device would be of a better directional quality than an electronic system. When it comes to distance measurement of course it is quite clear that the difference is not too large between the two.

H. J. Vojacek (Australia): I have a question for Dr. Zarzycki. If you have all your data in digital form and you have output at, say, 1:250,000, how do you overcome the generalization problem? Also, how do you maintain the geomorphological character of contours?

J. M. Zarzycki (Canada): I do not believe that in the foreseeable future we will have effective and economical software to accomplish generalization by computer. The way we do generalization is through interactive graphics. A cartographer will display on a CRT the original file as collected by the photogrammetrist and then will amend this file for each of the scales required employing an interactive graphic process. We cannot eliminate human judgment. Even the simplest operation of generalization done by computer is quite expensive and not reliable. As far as the contours are concerned, if the contours were compiled in a stereoplotter, their geomorphological character can be easily maintained in this process. If the contours are derived from a digital elevation model, then you may have problems in certain areas, particularly in flat areas and where contours enter drainage. The cartographer can make the necessary correction to contours employing interactive graphic procedures.

A. P. Colvocoresses (USGS): This question is basically for Mr. Zarzycki but perhaps for the other members of the panel also. To what extent is digital image information such as Landsat being incorporated into the so-called digital data bases which are basically, as I understand it, the digitization of line work? If you see a change in open water, urbanization, or land use or vegetation, what steps are being taken to incorporate that data directly into your data base or data bank?

J. M. Zarzycki: So far we have not done anything about incorporating digital data from Landsat into our data base. The data which we have in the digital topographic data base are basically line features and the data from Landsat give digital image information.

Ernst Spiess: There has been research work done in Germany in generalizing linear data and apparently there were many problems. The first thesis, for instance, just concluded in finding out how 7 high houses all in one row could be reduced to 3 houses all in one row, also on a wider road. As Dr. Zarzycki has said, you can have some programs which lead you a certain way along with generalization, but from a certain moment on, at the present stage of sophistication of the programs, you have to switch over to interactive techniques. How this goes on is a very difficult problem, mainly a storage problem. We found out that in many instances it is not ideal to store data in digital form. It is much better to produce a good output overlay and when you need it again you just play it back in the raster system. There was research work done also to switch over for generalization from line or vector systems to raster systems. It is a real challenge to determine when each of these different techniques (vector mode, raster mode) gives you an advantage.

A European group has done research on how to revise maps. All of you are aware of the common revision procedures by photogrammetric means, or by orthophotos, and one of the big problems we found was that change detection is a major problem. If some houses disappear that is much more difficult to detect than all the additional houses you have to put in your map. There I see some hope from the raster image side. Whether Landsat is the correct answer to this problem of revising large scale maps—there I would have quite a different opinion at the present moment.

Fred Doyle (USGS): I would like to comment also on the incorporation of digital image information into digital files. The Earth's land mass is about $10^{12}m^2$. If you were to make a digital image file for the entire land mass of the Earth at the pixel resolution on the order of 10 meters, it would require 10^{12} pixels. About 50 bits are required to document a pixel in three spectral bands, giving a total of 5×10^{13} bits. The largest available digital storage device can hold about 10^{12} bits. Thus fifty of those storage devices would be required in order to record the entire land mass of the earth at a reasonable resolution and put it into a digital file. It would take about four months to transfer the file from storage to the computer. I think it is much more reasonable to do the type of land-cover classification that Landsat has proven very good at doing and then to outline that information and store only the outlines and not the total digital file.

Lauro Sodre Neto: Brigadier Harris, I would ask if there is a possibility of considering simultaneously topographic information, geological information, and even jurisdictional information when designing a new road. It should be possible in digital mapping, I think.

Lewis Harris (United Kingdom): The general requirements from maps for road building have not altered in the change from traditional mapping to digital mapping. The examination of the topography, the preliminary siting of the road, the calculation of earthworks, the final siting and the setting-out are still required. However digital mapping can:

- produce graphical maps which are more accurate at a selected scale by reason of the more accurate machine-drafting;
- display all or enlarged portions of the map on display screens, on which tentative sitings can be quickly superimposed for consideration and assessment; and
- present on demand the coordinate data and other textual data of areas of interest shown on the display screen for the calculation of distances, areas, volumes of earthworks, etc., and for geological, soil, cadastral, and administrative information.

As with maps in the traditional era, the digital maps of an area which are available will be dependent on the value of the area or on the potential value of the area after development. The scale of the map and the accuracy and resolution of the digital data will decide the fineness of depiction of the roads and of the other cartographic features.

For example, the United States and Canada in their national topographic map production are working at the medium scales of 1:24,000 and 1:50,000, respectively. These are generalised scales, and the depiction of the roads is generalised. In the large scale maps produced of urban areas, say at the scale of 1:1,000, the major features of a road are not generalised in the depiction, which differs appreciably from the depiction at the medium scales even after allowing for the change of scale. "With generalisation art enters into cartography."

It is also worth noting that using the set of digital data appropriate to the largest scale to produce the large and medium scale maps, say from 1:1,000 to 1:250,000, by automated cartography will not only require the data to cover the area, but will also require certain editorial corrections to be made on the generalisation of the features, beyond the deletion and smoothing of features. As yet, these editorial corrections are most economically and effectively done by manual intervention on the proof copy or display screen.

Different agencies, offices, and firms, public and private, are likely to become experts at the different map scales, and many banks or stores or bases of cartographic digital data will be created at the medium and at the large scales. As with maps, the digital data will have their range of uses depending upon their accuracy and resolution. Further data of interest to specialist users of the types you mention, both numerical and textual, such as geological, cadastral, and jurisdictional, can be added to the digital data base and displayed or presented when requested in the required units or areas, provided the digital data base is suitably structured, and provided that the data are of the appropriate resolution and accuracy. The team responsible for such development should consist of members of a high professional quality and should be well balanced in their combined expertise. The cost-effectiveness of the digital data base system will be their major concern. Many digital systems are likely to be created working at the same scale or accuracy, and also at other scales or accuracies. The exchange of data between such systems is a necessary aim to make the maximum and most economical use of the data collected. Common standards are therefore necessary for the definition of cartographic features and for the structure and arrangement of digital data to enable the exchange of digital data—after "translating" by computer-processing into an intermediate common standard where necessary.

Carl Ternryd: I have quite a long experience in trying to develop the application of digital terrain models to road design and road planning. We have discussed how to design such a digital model in different layers; one of the layers should be the topography, others should be the geology, jurisdictions, and so on. From the technical and scientific points of view there are no problems. You can always get in as much as you like in a model, but the problem is how to get it out again, and how to use it. One must keep in mind when designing roads that it is not an equation; it is a compromise between different interests; the environment, the economy, the political point of view and so on. My recommendation is to take it easy if you are going to use it in the practical application. And I think that it is better to have the basic information first and then add more or less manually the other information. From a scientific point of view it is a very interesting approach but using it in practice is something else.

Clifton Fry (USGS): I have a general question for the panel dealing with occupational definitions. In your country, are you satisified with the current occupational definitions? Is there any on-going activity to update occupational definitions based on advancing technology?

Carl Ternryd: In Sweden, the status of the surveyor has always been a little bit questionable. It has been regarded more as a technician than an engineering profession. Today this is changing, I think because in this field the development of electronics and so on has come in with extremely high power. Now the status of the profession of surveyor is equal to the status of the profession of the civil engineer.

Willis Roberts (Canada): If we look back 25 years or so I would say that almost all surveyors in Canada were technicians and treated that way by the civil engineers and the foresters. We have made massive advances in education as well as in technology. The turning point was the creation of the Survey Engineering Department at the University of New Brunswick, under the direction of Dr. Konecny. Starting this fall, we now have four universities in Canada offering graduate and post-graduate courses in survey engineering. The graduates have been accepted by the professional engineering association in Canada and are eligible for registration as professional engineers. With that advancement in the professional field and the establishment of institutes of technology that are training technologists and technicians, there has been considerable progress in improving the professional status and the image of surveying and mapping in Canada.

J. M. Zarzycki: I'd like to comment on technicians, since most of the comment has been about professionals. In terms of Civil Service in Canada, we have a somewhat "Balkanized" system of classification. There are many job classifications performing surveying and mapping functions. In my organization, persons working as photogrammetric operators, cartographers, draftspersons, editors, and map checkers belong to the "drafting" category. They are grouped together with mechanical, civil or other engineering draftspersons. We are taking a new look at the job classifications with a view to devising a uniform system more suited to the surveying and mapping field. The need to interchange cartographers and photogrammetrists, particularly when new digital techniques are applied, makes the change in classifications more urgent. We have trained many cartographers to be photogrammetric operators. We are now developing new classification standards at the technical level for a topographical technician or technologist with different levels of competence. These people will be required to be proficient in photogrammetry and cartography with some knowledge of computers and field surveys. This will give us well-rounded technicians who can move from one area to another, as necessary. Our staff seem to like this approach because they see more opportunities for advancement and more diversified work.

Gottfried Konecny (Germany): May I say something from the viewpoint of the country that has had actually defined survey professions for at least 100 years. There now exists a surveying and mapping community of professionals in the Federal Republic of Germany, of a size of about 6,000 persons, so there is no question of recognition. But despite that relatively accepted standard, I think there are some new aspects which are now being considered within these professions. There is an increasing concern about land-information systems and the surveyor feels responsible for this field. On the other hand, he sees that he does not have the possibility of a total access to the information, nor is it established that he should actually maintain this information, so there is the updating question. The surveyor tends to limit his problem to cadastral information, but he is pressured also from other sides to accept more than he perhaps can handle. The same is true on the mapping side; there is the open question of where remote sensing fits in. What role should the mapper and the photogrammetrist take within remote sensing? I think he should play in both of these. It simply points out that the established traditions are becoming wider in their scope and that surveyors would like to cooperate on a broader basis with other professions.

Carl Ternryd: I'd like to make an amendment to what I said. I think that respect for the surveyor's profession is increasing as the requirements from industry development on control measurements and other measurements are increasing. They cannot do without this profession. I think that adds a great deal of respect to the surveyor profession, so we should not only talk about topographic information but also about other information and other measurements.

Ernst Spiess: Switzerland is a small country. We educate about sixty engineers, thirty technicians, one hundred and thirty apprentices and only eight cartographers annually. That gives a general background. The development in terms of what these people should be able to do is apparently the same as in the Federal Republic of Germany and in Sweden. Especially from the viewpoint of cartography we have seen that our surveyors are able to handle the necessities of using this modern equipment. There are some kinds of application engineers in the field who very much like to tackle new problems but when it comes to production they try to give it over to the technicians. They say all this is now an established technique, you go on and digitize; and they are looking for new items to do. I think it is a good attitude but it will have some effect on the way we will have to educate our people and where we will get people.

Alberto Villasana (DETENAL, Mexico): As you know, in Mexico we don't have much tradition in this field. We started ten years ago, which is nothing compared with your century of life. But we more or less know what salary has to be given to a good technician and I think we can always find a definition of this job that matches that salary.

Rupert Southard: I think it is important to comment on the situation here in the United States. There is some confusion, at least on the definition of surveyor versus the definition of cartographer and where the functions they are now performing may overlap. There are efforts being made on the part of the Civil Service Commission to come forward with a new set of standards for cartographers. These standards would at least bring the cartographer series into this century in terms of requirements for educational background and experience that one needs to function these days. The new requirements include particularly the addition of computer science and mathematical background to the former classical cartographer capability which was perhaps more in the geographic or small-scale-mapping spectrum. But the confusion still exists; it exists right here in this agency and we need to do something about it. Mr. Fry is chairman of a committee for the American Congress on Surveying and Mapping on position classification and statistics. It needs to proceed and it needs to dispel the argument between cartographers and surveyors over whose work is more important. This must be worked out because the work of both or either is extremely important to solve many problems of this country.

Robert Lyddan (retired, USGS): Rupert Southard has outlined for you the concern we have had here in this organization and in this country on these terms. I attended three United Nations conferences on cartography for Asia and the Far East spread over a period of about a decade and I noticed that at those meetings there was confusion and concern as to what the term "cartography" really meant. At the last meeting I attended, which was in Bangkok, the representative of the International Hydrographic Organization insisted that something that was being written should read "cartography and hydrography." He obviously felt that hydrography would otherwise not be sure of being included. The geodesists then said let us write it "cartography and geodesy." This kind of debate and confusion prevailed much of the time, and it was suggested near the end of the meeting that the United Nations group take another look at the term "cartography" and redefine it or emphasize more fully and clearly what the term really should cover. I am not sure that anything is being done, although it was agreed at that time that thought would be given to it.

My suggestion is that those of you who will be attending the next meeting, or those of you who are otherwise interested in this question, find out what is being done by the United Nations staff group in this connection. You might have an opportunity to influence what this term "cartography" means and how well and soon it will be established not only in this country but in others.

Rupert Southard: Some of us have just returned from a conference in Mexico, the Second United Nations Cartographic Conference for the Americas, where that question is still being debated, with no more light being cast on it than before. Some brilliant statements of position are being made. At Mexico City last month we had Professor Ormeling, president of the International Cartographic Association, and he explained to us without any doubt remaining what cartographers are and what they are not. The United Nations staff under Mr. Christopher seemed to hold to a looser and less encompassing definition that everything that has to do with mapping in any way is cartography, and that includes ground survey conducted for the purpose of making maps. Those conferences include a lot of input on geodesy, as well. It may be that it is more important for us to understand the differences and what the range of those differences may be. The study that Dr. Richard Dahlberg is doing with the support of ACSM and ASP and the Geological Survey on an inventory of courses in the mapping sciences will shed more light on all of this than any amount of conjecture on our part. The people who do the kind of work we do are coming from schools of engineering, schools of forestry, schools of geology, and particularly these days, they are coming from geography curricula again. Mappers by the dozens, hundreds even, are coming from the geography curricula which are being expanded and deepened to take care of that requirement. So I think the United Nations is not going to help us solve that problem; it is going to have to be solved here at home.

Lewis Harris: In this relatively small profession which has been weakened by its tendency to fragment into smaller specialisms, the professional in mapmaking should be educated in an exact science and then needs to have a basic grounding in the specialisms of geodesy, cartography including the graphic arts, and photogrammetry to ensure a balanced approach; to adjust to changing technologies; and to satisfy the new demands made on the profession. Experiences in World War II emphasize the need for the broad approach and the overall view, and exposed the danger of professional executives being limited in their perspective to one of the specialisms.

A distinction should be made between the professional and the technician. Nevertheless, the high quality and competence of the technician on production work in each of these specialisms should be recognised and be fully used to obtain efficient, economical, and maximum production. But the professional should have more than proficiency in techniques. The new university courses must guard against being limited in this way, for the courses would then be more appropriately taught in technical colleges. The professional takes his place alongside the other professionals in society; should have an understanding of the rightful place of the mapmaking profession in society not only for the good of the profession but also for the good of society; and have the future of the profession in keeping. Beyond being able to undertake the current types of work, professionals should be prepared to match their products with the usages, to augment the usages, and to accept future changes in requirements, in technology, and in conditions. Some professionals may, after their first years of experience, concentrate on one of the specialisms for which they have an aptitude and liking, but the majority of this small profession should remain flexible to meet the needs of management, production, and changing technologies.

The establishment of a postgraduate Institute of Geodetic and Cartographic Sciences for advanced and interdisciplinary studies, for research and development, for cultivating independent and responsible opinion, and for indoctrinating professionals in mid-career in new technological ideas and processes, is increasingly favored as the pace of advancing technology accelerates. A very high quality of staff is necessary in such an institute, and the concentration of the best talent in one suitably located national centre is indicated. The choice of title, it will be noted, avoids the use of the term "survey" which is not sufficiently specific and cannot be readily translated into other languages without some qualification. "Cartographic Sciences" would suffice if the broad definition of cartography is used—Ptolemy's Geographer. As this definition is not generally adopted at present in North America, the title has been expanded to Geodetic and Cartographic Sciences. "Cartographic and Geodetic Sciences" would be equally acceptable.

H.J. Vojacek: As a past president of the Australian Institute of Cartographers may I just add the views of the Australian. In Australia we do have cartographers and we do have surveyors and we do have photogrammetrists and at the moment the position is that if you are a photogrammetrist you can also be a cartographer. If you are a surveyor you can also be a cartographer. But if you are a cartographer you cannot be a surveyor or a photogrammetrist. And all the cartographers feel that this is somewhat not fair. So, at all meetings or federal council meetings of the Australian Institute of Cartographers we always have as an agenda item: "Cartography, what is cartography?" We also had a visit by Professor Ormeling and he enlightened us on what is cartography and what is not cartography. That was all very nice but when he left you know nobody believed it. As he said, "I will set this all right in Europe and in Australia not everything is upside down." So we do it differently anyway. At the moment we do have the same problems. They are trying to define cartography and what is a cartographer although we know what a photogrammetrist is or a surveyor. There are moves afoot to establish an institute that is all-embracing which we might call a mapping institute but I am sure we are a long way off. In the meantime we don't really know what a cartographer is, although we have an Institute of Cartographers.

Ted Albert (USGS): I wonder if the panel knows of any research being done in structuring of cartographic or spatial data, the data that we are talking about digitizing? I mean logically structuring them in a computer file. We have a tendency to take this kind of data and list it sequentially or put a meaningful number before it and that is all. Is anybody looking at new and perhaps esoteric or mathematical approaches to restructuring this kind of data so that it can be better related to other kinds of data: geologic, hydrologic, and so on? In addition, is there any pertinent research that anybody really is enthusiastic about in the area of mass storage?

J.M. Zarzycki: Substantial research is being undertaken in this very difficult field. I could provide the names of individuals involved in this research.

Gottfried Konecny: There is presently an effort going on in the Federal Republic of Germany to put the entire cadastre, not only the information on the owners, parcels, and rights, but also the boundaries, onto a computer system. It goes into the millions of parcels that need to be recorded. The software for this is in the design stage and one expects within a number of years, 3 or 4, to have test software available to handle this sort of thing. I can not give you detailed information, but this committee has regular publications in Germany where such questions are addressed.

Ernst Spiess: Again I might illuminate the situation a little bit from Switzerland, a small country where land surveyors are distributed in about 250 private offices. You can imagine that, having evolved in such a decentralized way, this system somehow interferes now with the necessity of centralizing data. In our university there is some research on what you can do on a small land-information system which will suit such a local survey. Apparently there are some possibilities but the big problems of course are: by what national organization you could back up such a small system; how you get your information from one body to the other; and how to update continuously. This goes under the general term of land-information system and there is quite a lot of current literature on this subject.

Carl Ternryd: In Sweden there is a lot of effort going on to try to provide a data bank concerning real estate parcels with different kinds of information overlaid upon each other. According to my experience concerning data banks, this is the most effective way of wasting money if you do not know what you are doing, if you are not careful, and if you are not conservative when building it up. So our experience in Sweden is very good but expensive.

Willis Roberts: I was in Sweden about 3 or 4 years ago with Carl and a few others looking at their data bank information and our own. The European cadastres have been established for a hundred years as mechanical file systems and what they are trying to do is automate them in a digital form. We are looking at it totally differently in North America in that we do not have a cadastre. We have no ownership maps or plans like theirs. Our assessment records, which are about 40 percent accurate, are about the best we have in a lot of places in North America. Fifty to sixty percent of North America does not even have that. So we have an opportunity here; we can grasp it and this is what they are trying to do at Guelph University.

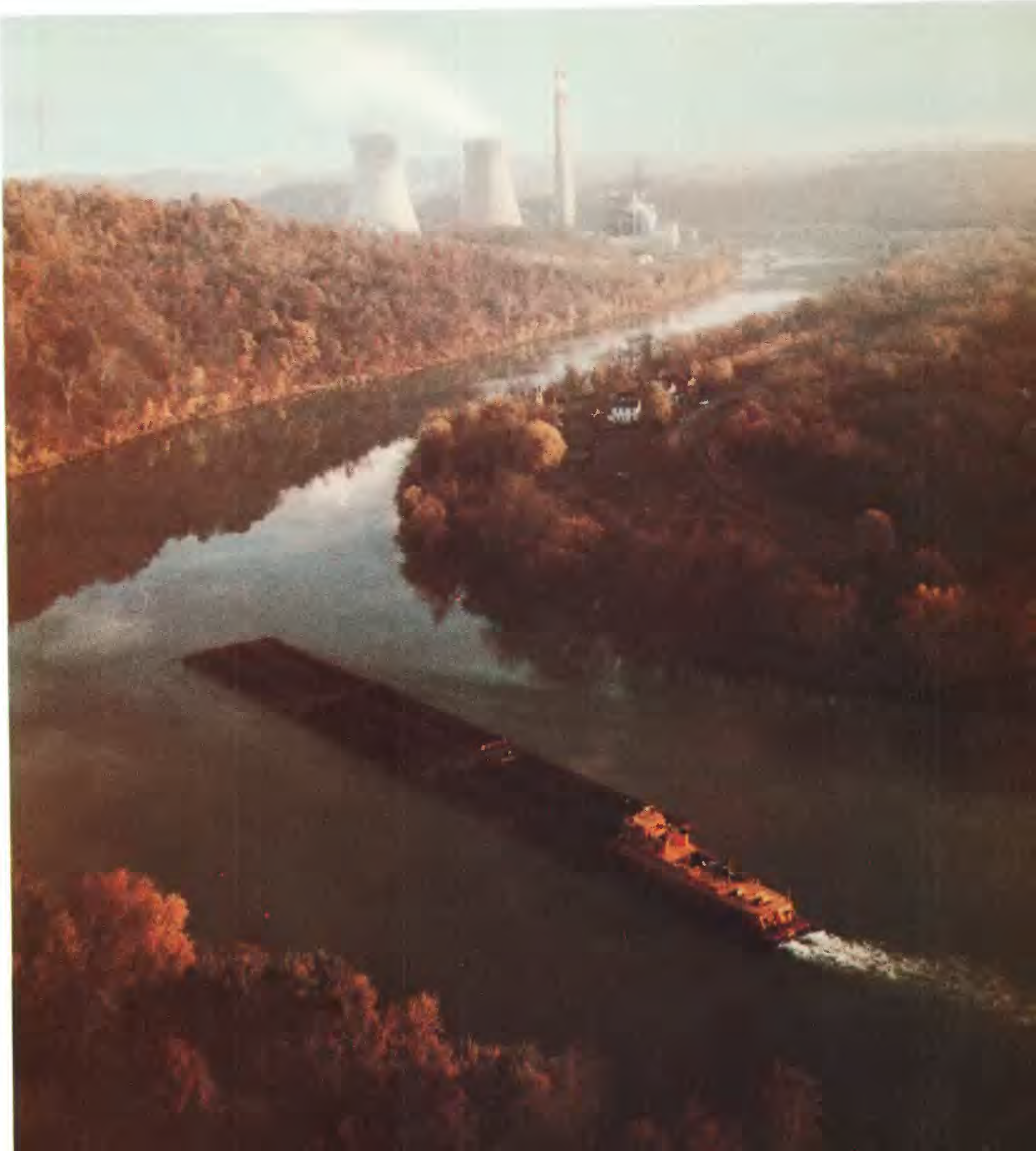
The idea is to set up a system that can be efficient and to this end I have been hammering at the cartographers quite a bit. We have got to cut across their structure of filing and their digital mapping. It is not worth anything to be able to call out map sheet so and so and all the contours on it, or print one contour of unknown location. What we want to operate with is in a unit basis: parcel base or even a breakdown of the parcel in the units of use. We do not want their structured file of going through it and then putting four models all together into one map sheet or grouping it some way with a code number and a menu. We have got to break that structured file so we can pick out what we want on a unit basis and that is a most difficult problem. We have been playing with it now for 3 years and we have all the cadastres on a unit basis. But to relate that to a topographic map and to geology and hydrology and climatology and the other basic seven factors—that becomes a different issue.

Carl Ternryd: I would like to make a little amendment to what I said. In my job I get questions about the building up of the data bank system and so on and I always tell them the following: "It is very easy to build up the structure to get the information in but that is not the interest. The interest is how to get the data out again, how to use them. That is the most important thing: before starting to get them in, you must know how to get them out."

Rupert Southard: I think that is a good place to stop. We must know how to get them out. I want to thank the panel very much on behalf of the Geological Survey for the superb contribution you have made to the celebration of our centennial.

Coal-laden barges on the Monongahela River in southern Pennsylvania, bound for a generating station shown in the background emitting steam. Photograph courtesy of Conoco, Inc.

Challenges and Problems Concerning Energy Resources



Sufficient Energy Raw Materials for Everyone?

F. Bender
President, Federal Institute for Geosciences and Natural Resources, Federal Republic of Germany

UNDISPUTED FACTS

It is commonplace knowledge that the availability of mineral resources is of great importance to the economy of a nation and that the resources themselves are finite and not regenerable. It is evidently quite normal human behaviour that such commonplace knowledge is realized by the public and by those responsible in the state as well as in trade and industry only when it is already too late or almost too late for the necessary measures.

However that may be, everybody talks meanwhile about energy raw materials, and that is little wonder. Efforts to secure supplies of energy raw materials have never before reached the present dimension. This is due to four undisputed facts:

1. the increase in price of petroleum, natural gas, and uranium;
2. the uneven regional distribution of energy raw materials;
3. the political and economic opportunities benefitting countries that have energy raw materials;
4. the political and economic risks to the countries dependent on the import of energy raw materials.

For many raw materials, "supply and demand" has largely lost its function as a price-regulating mechanism. The spread and growth of cartels and oligopolies and a worldwide trend to nationalization of the raw materials industry are clear indications of this evolution. This may be deplored or welcomed according to one's point of view, but to overlook these facts of life and not take them into consideration could become costly.

CONTROVERSIAL FINDINGS

So far, we have dealt with commonplace facts. Let us now turn to some very controversial views about global reserves and supplies of natural resources. According to "Limits of Growth" (Club of Rome, 1972), "With the present rate of growth in consumption most of the currently important and non-renewable natural resources will be extremely expensive in a hundred years, even with optimistic assumptions about deposits to be discovered, technical progress, recycling, and the use of suitable substitutes." This and similar subsequent studies not only provoked overdue reflections by the public about the finite character of mineral resources but also summoned up prophets foretelling the impending end of the industrialized countries, which would result from the presumably foreseeable exhaustion of important natural resources. Alarmingly short "life-times" were calculated for numerous raw materials and a "doomsday syndrome" spread among consumers.

It is obvious that these considerations have not taken properly into account either the knowledge of the geologist or his ignorance, as the case may be, of the actual natural resources potential of the Earth. No one has yet been able to even approximately quantify global resources, except perhaps the potential of recoverable oil. There, due to intensive and enormously expensive efforts, we do have an approximate conception, possibly correct within plus/minus 400 billion tce (metric tons of coal equivalent based on 7,000 kcal/kg). However, no one has any idea about the potential of metallic and nonmetallic resources; and with respect to the potential of solid and nuclear fuels, there are only vague conceptions. The reason for this deficiency is the fact that the Earth's crust has been explored only surficially so far, and even this superficially. If one were to compile a geological map for a depth of only 300 meters below the surface, on a global basis many millions of square kilometers would remain blank, because the geological situation at this depth is largely unknown. There are, however, no compelling geological reasons why the reserves potential of mineral ores and also of nuclear energy resources would not be increased by exploration at depths of 300 meters below the surface, using presently available or yet to be developed methods. There are also no reasons why those reserves would not be increased considerably by exploration down to 600 meters, perhaps by a factor of three in comparison to the presently known potential.

In view of these considerations, the "doomsday syndrome" is not quite understandable. In addition, pessimistic observers of the natural resources supply situation are inclined to overlook the fact that 30 years ago, the same as today, the demonstrated commercially recoverable reserves corresponded in each case to 20 to 200 times the annual production. In other words, in spite of a considerable increase in production it has always been possible to discover and develop sufficient new reserves to maintain the same proportion. There are also no *geological* reasons for the assumption that this will change basically in the next 30 years—except for hydrocarbons whose "static lifetime" will in all probability only diminish in the future.

THE ENERGY RAW MATERIALS RESOURCES OF TODAY

So far we have regarded the global raw materials resources situation which was controversial, is controversial, and will so remain until geologists succeed in precisely quantifying the raw materials resources of the Earth. This will probably take another 100 years or more and will certainly keep several generations of geoscientists fully occupied.

I would like to attempt to give a general account of the present state of knowledge on energy resources. Of course I am quite aware of the fact that the quoted figures may be suspect. They can only be based on the evaluation of information and data currently available.

A great deal of misunderstanding on the resources situation is due to the existence of different classification criteria. What one author classifies as "proven", "economic" or "hypothetic" is not necessarily the same for the other. The classification system commonly used by the U.S. Geological Survey and the U.S. Bureau of Mines is called the McKelvey Box. In this well-known system, the large box represents the resources, and within this box a much smaller one represents the reserves, or that part of the resources which is demonstrated and recoverable according to current economic conditions. For global assessments, this classification system involves some difficulties since economic conditions vary considerably from one country to the other. Nevertheless, based on information collected for the 1980 World Energy Conference (WEC) in Munich, we estimate the total world fossil energy resources at about 12,000 billion tons of coal equivalent, of which some 930 billion tons of coal equivalent are currently classed as reserves (fig. 1). This is less than 10 percent of the resources! The present annual world primary energy consumption is around 10 billion tons of coal equivalent. Provided there is no increase in consumption and no standstill in exploration and technology, these identified fossil fuel reserves alone could satisfy demand for almost a century.

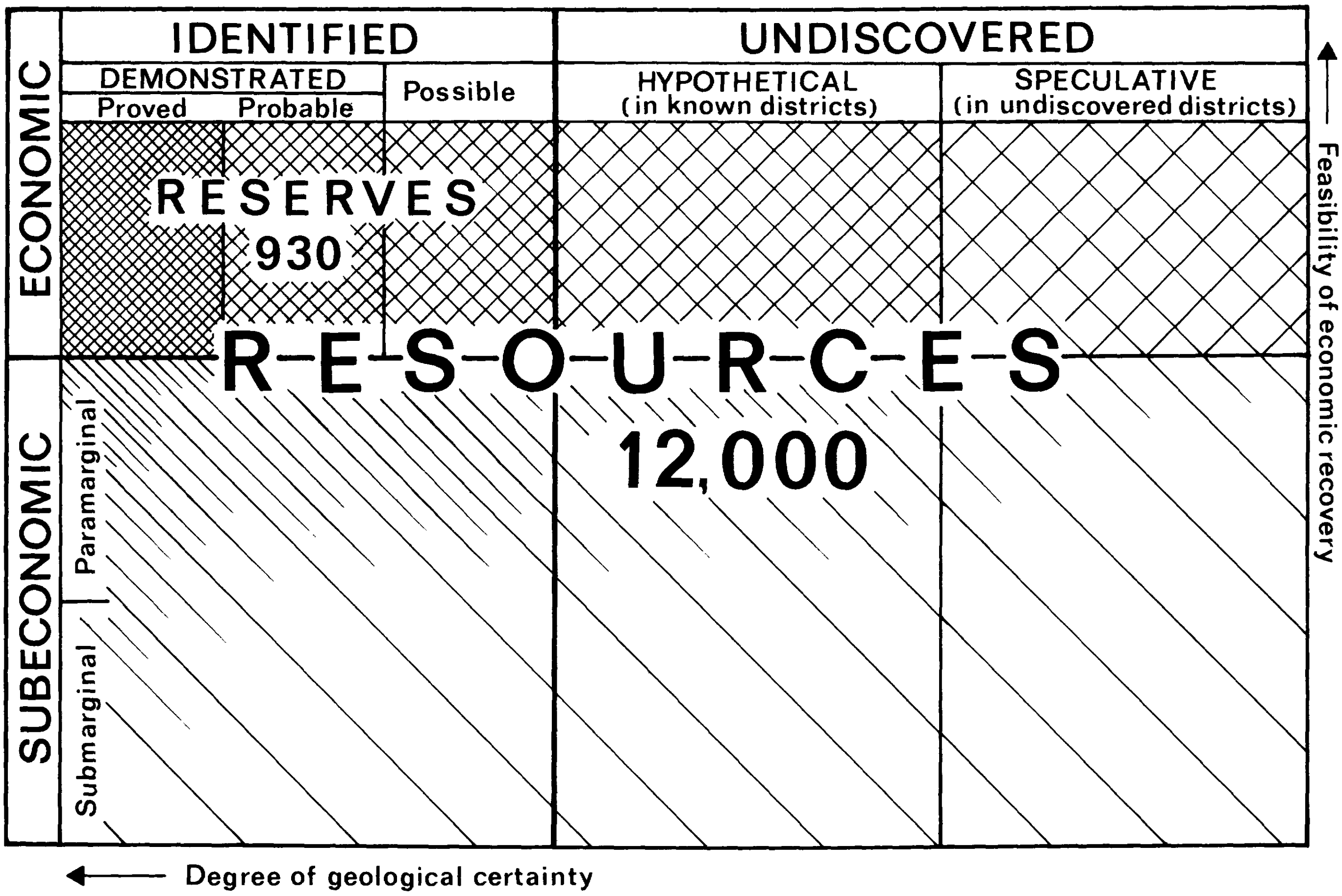


Figure 1 Estimates of world fossil energy resources. [Of the terms identifying economic reserves, "proved" equals "measured," "probable" equals "indicated," and "possible" equals "inferred." The direction of the arrow at the bottom left indicates increasing degree of geologic certainty; quantities are reckoned according to the USGS/USBM classification system in billions of tons of coal equivalent (10^9 tce).]

Distribution of Fossil Fuels as Resources and Reserves

The resources and reserves are distributed among the different fossil fuels according to our Institute calculations, as illustrated in figure 2 and compared in table 1. The dominant role of coal is demonstrated by the fact that it makes up about 85 percent of the world's fossil fuel resources and about 68 percent of the reserves. The planned economies or East bloc countries, including the People's Republic of China, have the biggest share of fossil energy resources. They are followed by the market economies (the industrialized countries of the Western World), with the developing countries, such as Brazil, Iran, and Mexico, in third place. Their regional distribution is compared in table 2 and illustrated in figure 3.

Nuclear fuels are classified in market economies and in most developing countries according to production costs. Together these countries have about 4.3 million tons of uranium recoverable up to a price of $130/kg U. We estimate that the planned economies have reserves in the same category of about 2 million tons, which is naturally a rough guess. This amounts to a total of 6.3 million tons of world uranium reserves. These reserves represent an energy equivalent of about 100 billion tons of coal equivalent when used in today's reactors, which only use about 1 percent of the theoretical energy content. It is estimated that in this category of nuclear fuels about one to two times this amount can still be found. In addition there are large quantities of low-grade ores with less than 0.1 percent uranium. Thorium reserves amount to approximately 4 million tons at present.

Table 1 Global resources and reserves of fossil fuels as estimated for the 1980 World Energy Conference (from WEC study)

	RESOURCES		RESERVES	
	10^9 tce	Percent	10^9 tce	Percent
Coal	10,125	85	636	88
Oil/natural gas	647	6	214	23
Oil shale/tar sand	[1]1,080	9	[2]84	9
Estimated totals	11,852	100	934	100

[1] Oil shale with an oil content of more than 40 liters per ton of rock.
[2] Economic recoverability still in question.

Table 2 Regional distribution of fossil fuels

	RESOURCES		RESERVES	
	10^9 tce	Percent	10^9 tce	Percent
Planned economies	6,790	57	316	34
Market economies	4,190	35	400	43
Developing countries	872	8	218	23
Total	11,852	100	934	100

Let us next take a look at individual fossil energy sources, beginning with coal, which is by far the largest reservoir of fossil fuel.

Coal: Bituminous coal and subbituminous coal, including lignite, together rank as the most abundant fossil fuel, and the distribution of the deposits is rather well known. Prospective areas can be defined quite well. This is demonstrated by the fact that estimations of coal resources have not varied very much over the last decades. Entirely unknown major coal deposits can hardly be expected.

Coal estimating is characterized by a huge difference between figures for resources and those for reserves (fig. 4). Total coal resources, according to World Energy Con-

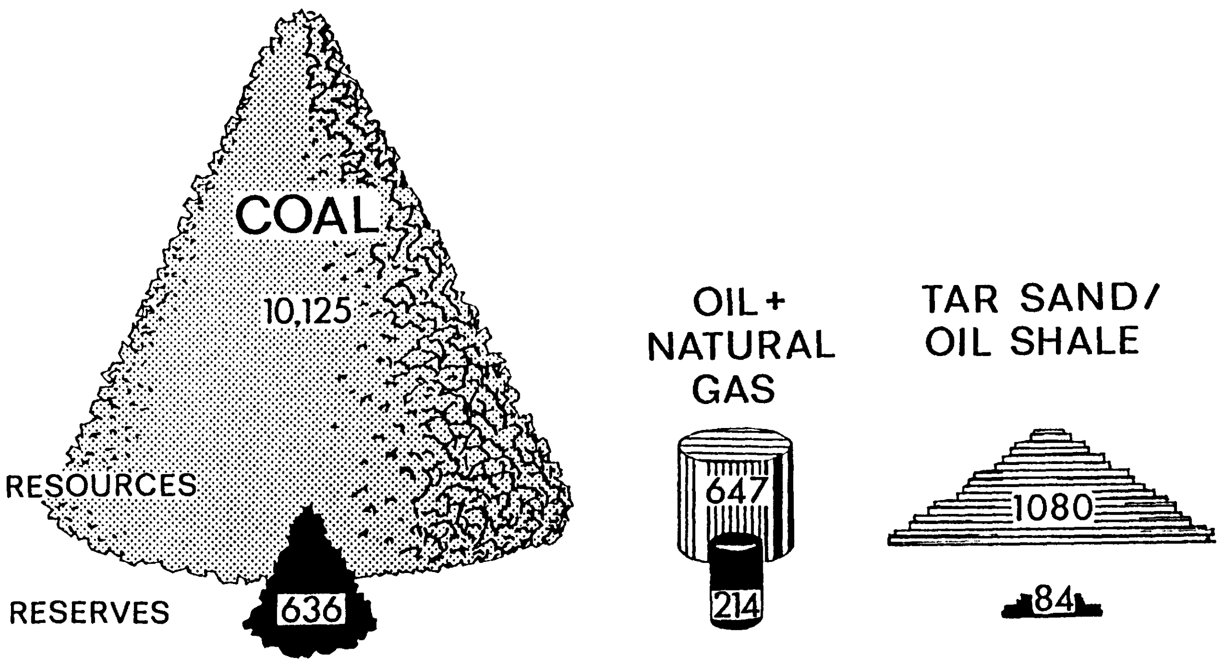


Figure 2 World distribution of fossil energy resources and reserves. (Fuel quantities are estimated in billions of tons of coal equivalent.)

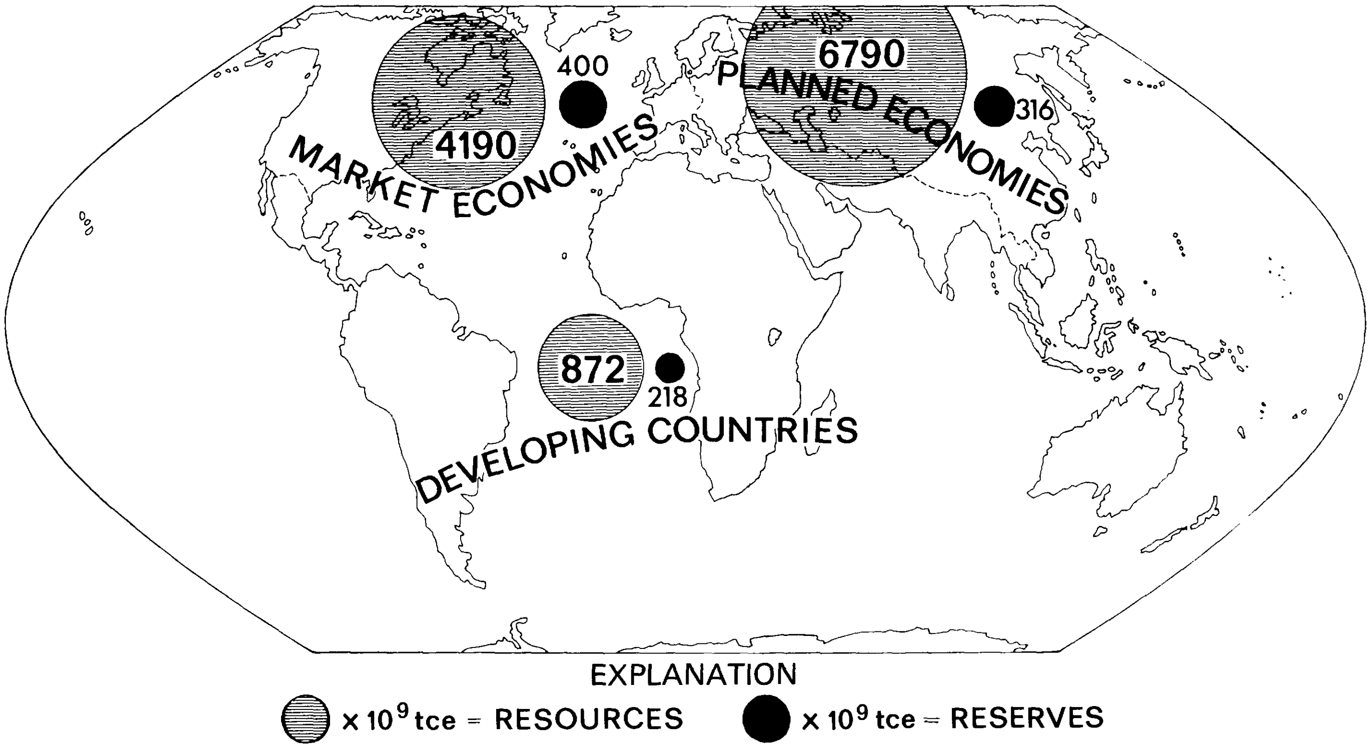


Figure 3 Regional distribution of fossil energy fuels. (Both resources and reserves are estimated in billions of tons of coal equivalent.)

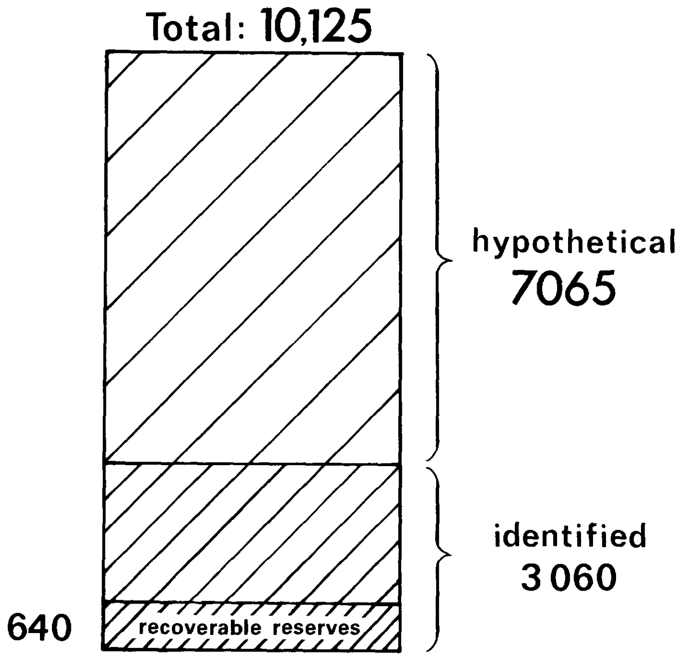


Figure 4 World coal resources and reserves. (Quantities are estimated in billions of tons of coal equivalent.)

ference data, are believed to represent about 10,125 billion tons of coal equivalent, of which 1,900 billion tons of coal equivalent are subbituminous coal, including lignite. Mobil Oil Company (1979) has estimated resources at 10,000 billion tons of coal equivalent, while the estimate of 11,716 billion tons of coal equivalent by the International Institute for Applied Systems Analysis is somewhat higher than the WEC value.

About one-third, or 3,060 billion tons of coal equivalent, of this 10,125 billion (the WEC tce total) is identified resources, meaning specific bodies explored by drilling and mine measurements. The remaining two-thirds of the resources are hypothetical, to be confirmed by exploration. Of the identified resources, again only about one-third or 1,130 billion tons of coal equivalent form the present reserve-base for mining. Taking into account the inevitable losses in mining, about 640 billion tons of coal equivalent are presently classed as recoverable reserves. Around 95 percent of coal resources are concentrated in ten countries. Reserves, however, are more widely distributed.

In 1977 world coal production was 2,988 million tons of coal equivalent, of which 2,538 million tons of coal equivalent was bituminous coal and 450 million tons of coal equivalent was subbituminous coal (fig. 5). Over the last ten years, the average annual increase in coal production has been 1.2 percent. With this annual increase factored in, present production could be continued for almost 100 years with the present reserves in the case of bituminous coal alone and for around 130 years with subbituminous coal.

Oil: While not the most abundant fossil fuel, oil is for many countries by far the most important energy base. In most industrialized countries it constitutes more than 50

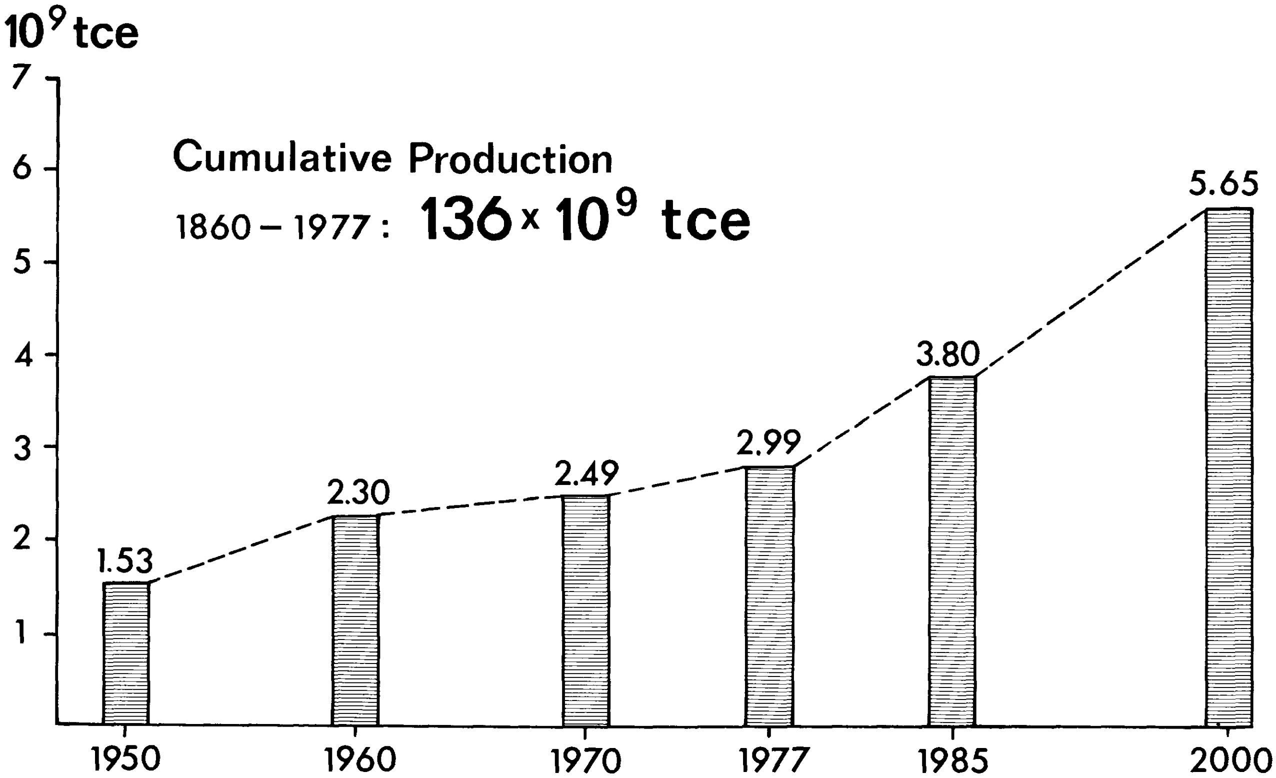


Figure 5 World coal production from 1950 to 2000. (After 1977, figures represent estimates by Bergbauforschung GmbH.; quantities are calculated in billions of tons of coal equivalent.)

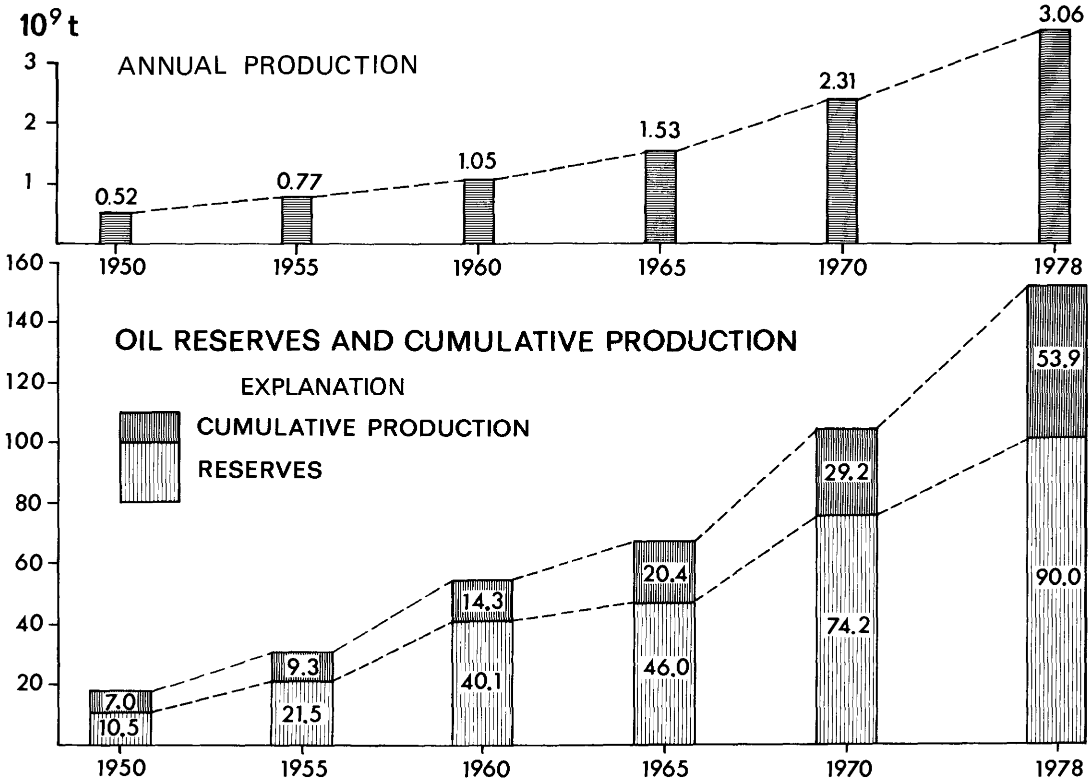


Figure 6 World oil reserves and annual and cumulative production from 1950 to 1978. (Quantities are calculated in billions of tons of coal equivalent.)

percent of the energy supply, and many other countries rely on it almost entirely. Several recent studies indicate that supply might fall short of demand in the 1980s, if the present rise in consumption continues. These include: "Energy Prospects to 1985" (Organization for Economic Cooperation and Development), "Energy—Global Prospects 1985 to 2000" (Workshop for Alternative Energy Strategies), and reports by Exxon, Caltex, Shell, Mobil, and the CIA, as well as the study "World Energy Resources 1985 to 2020" made by the Conservation Commission for the 1980 World Energy Conference. This shortfall is supposed to occur even if all the OPEC countries produce at full capacity; they do not, as we all had the opportunity to learn at the beginning of 1979.

Estimation of the total amount of recoverable oil in the world has been attempted by many different authors. Older evaluations have proved to be far too low. For example, in 1920 the entire recoverable oil resources of the Earth were estimated at 5.9 billion tons. Meanwhile, actual cumulative oil production is almost 55 billion tons and another 90 billion tons of proven reserves have been demonstrated (fig. 6).

The majority of estimates during the last 15 years lie between 200 and 300 billion tons of recoverable oil, with some evaluations approaching 500 billion tons. Several estimation methods have been used, including the amount of oil per volume of prospective basins, statistical probability, and basin analysis worldwide.

We estimate the total recoverable oil resources at 260 billion tons, based on a recovery factor of 40 percent or 650 billion tons of oil in place (Exxon and Shell estimate about 570 billion tons). Of this amount, about 90 billion tons are currently classed as proven reserves. These figures can be considered to be realistic in their order of magnitude because of the intensive petroleum exploration of the last few decades, which has significantly improved knowledge about prospective basins of the world and has allowed recognition of regularities in the regional distribution of petroleum fields. One important uncertainty remains: the possible prospectivity of the continental margins. The regional distribution of petroleum deposits is much more uneven than for coal. The Middle East with around 55 percent of proven reserves and around 35 percent of total recoverable resources is an unmatched phenomenon, a fact that understandably has a negative influence on worldwide availability (fig. 7).

World oil production was 3.048 billion tons in 1977; it increased only slightly to 3.055 billion tons in 1978. Theoretically, this level could be maintained with proven reserves for just over 30 years and with production of total

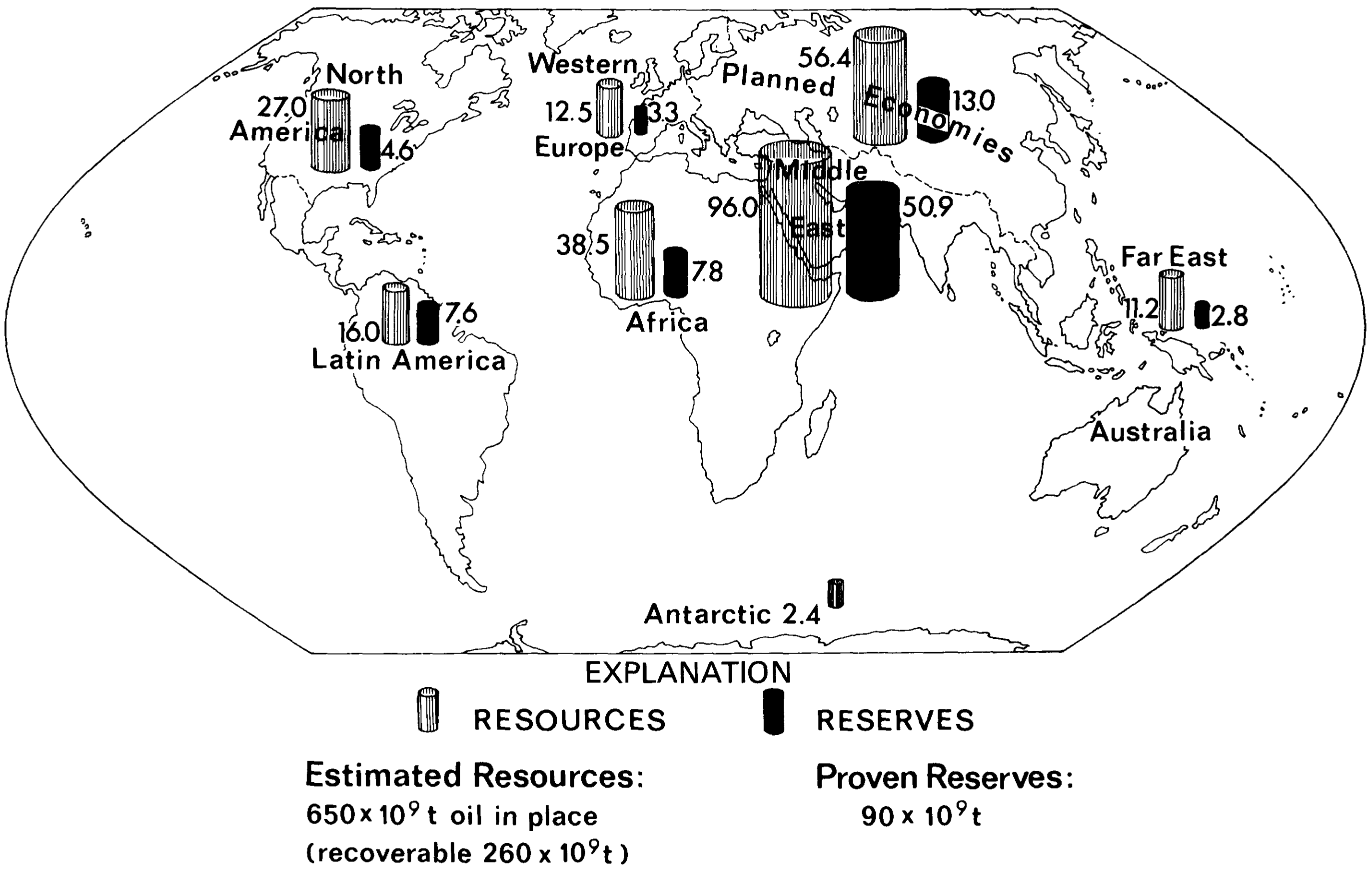


Figure 7 Regional distribution of world oil resources and reserves. (Quantities are calculated in billions of tons of coal equivalent.)

recoverable resources could be maintained for almost 100 years. If an annual production increase of 4 percent is assumed, these periods are reduced to around 20 to 40 years, respectively. Reserves in the last several decades have usually been equivalent to about thirty years of production. In spite of large production increases, additional new reserves were found to maintain this ratio. In 1976, the discovery rate of about 2 billion tons was lower than the year's production for the first time. New discoveries and especially higher evaluation of reserves in some existing fields, notably in Saudi Arabia, were responsible for the fact that in 1977 the reserve additions were bigger than the loss through production. This trend has continued, especially due to the finds in Mexico. According to Exxon (1979), new finds of more than 4 billion tons in 1978 more than made up for a production of 3.056 billion tons.

Natural gas: The use of gas in significant quantities began much later than that of oil and is restricted to fewer countries. Although consumption is expanding rapidly, considerable amounts of associated gas are still flared at some producing oil wells.

We estimate the total recoverable natural gas resources, including associated gas, at about 227 trillion cubic meters. Of this amount, 65 trillion m^3 are classed as reserves and 162 trillion m^3 are at present undiscovered resources. Ruhrgas (1978) and Mobil (1979) place gas resources somewhat higher (230 and 300 trillion m^3, respectively) than the WEC value that we have used. The 1979 figures of Shell and Exxon reserves are also higher (73.5 and 71.2 trillion m^3, respectively).

The regional distribution of natural gas resources is more even than in the case of oil; the planned economies play a leading role with 38 percent of the reserves and 32 percent of total recoverable resources (fig. 8).

Excluding flared and reinjected gas, net world production of natural gas in 1978 was about 1.435 trillion cubic meters. This means a static lifetime of around 50 years for the reserves and about 160 years for the total recoverable resources. If annual production increases of 4 percent are assumed, these life-spans will be reduced to around 30 and 50 years, respectively.

Oil shales and tar sands: Oil shales and tar sands represent huge hydrocarbon resources and have received increased attention, but despite technological and economic efforts, development is proceeding slower than originally planned and they are at present still of little importance as an energy source.

Recoverable oil in oil shale resources is estimated at 450 billion tons if only shales with more than 40 liters of oil per ton of rock are considered. Of this amount, 60 billion tons of oil are currently rated as "economically recoverable

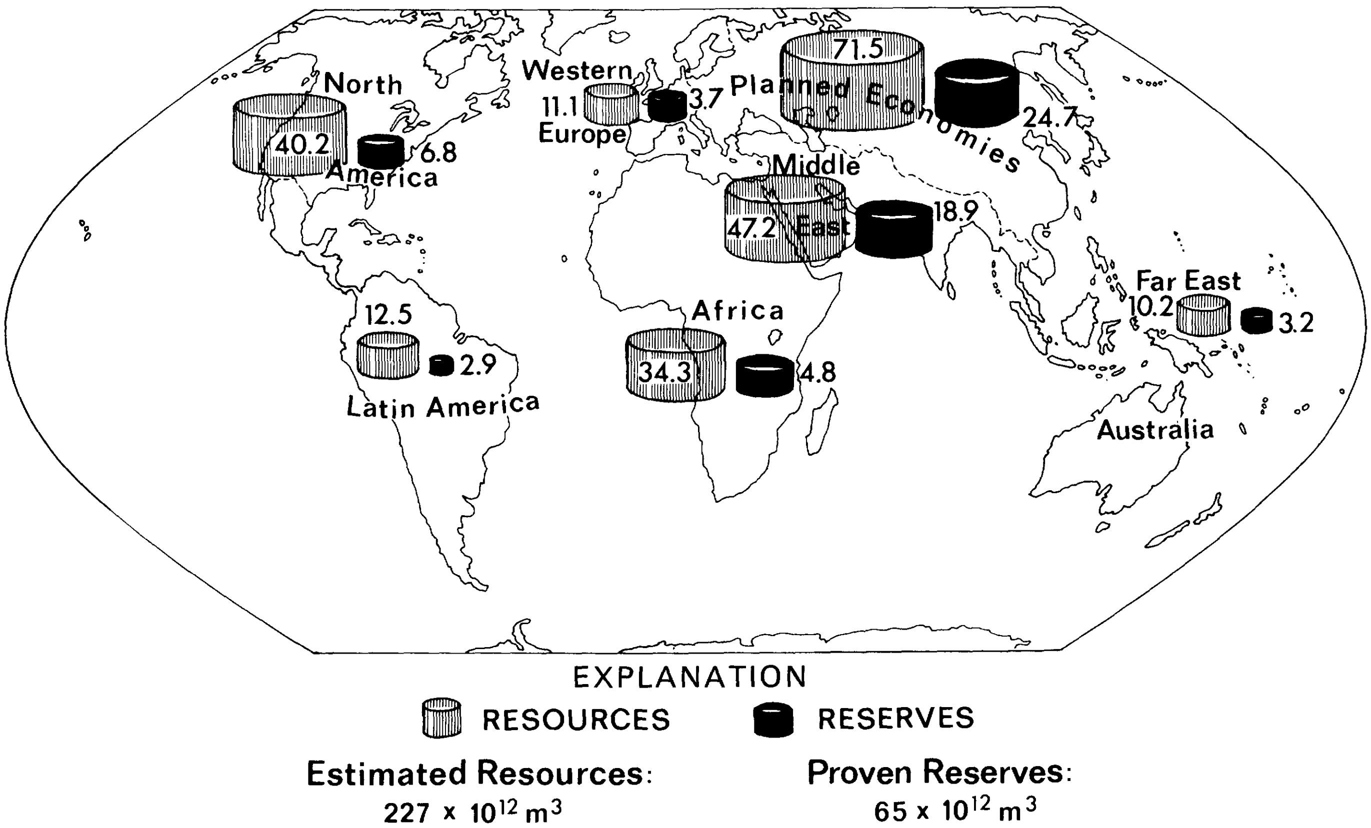


Figure 8 Regional distribution of world natural gas resources and reserves. (Quantities are calculated in trillions of cubic meters.)

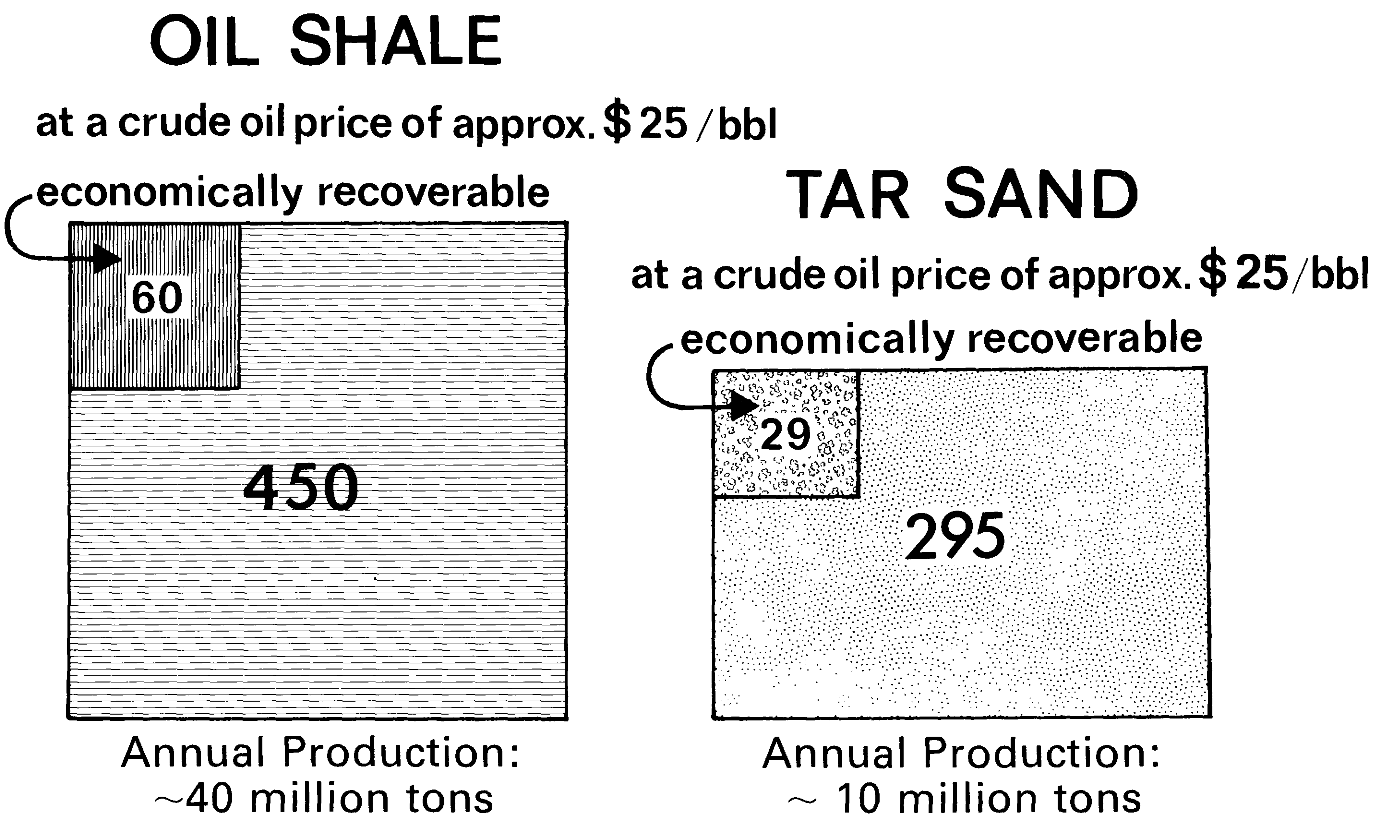


Figure 9 Estimates of world oil shale and tar sand resources. (Only shales containing more than 40 liters of oil per ton of rock are included in these figures; quantities are calculated in billions of tons of oil.)

resources" and could probably be transformed into reserves when the crude oil price reaches about $25 per barrel. The total oil resources in tar sands are estimated at about 295 billion tons, of which 29 billion tons are classed as reserves (fig. 9).

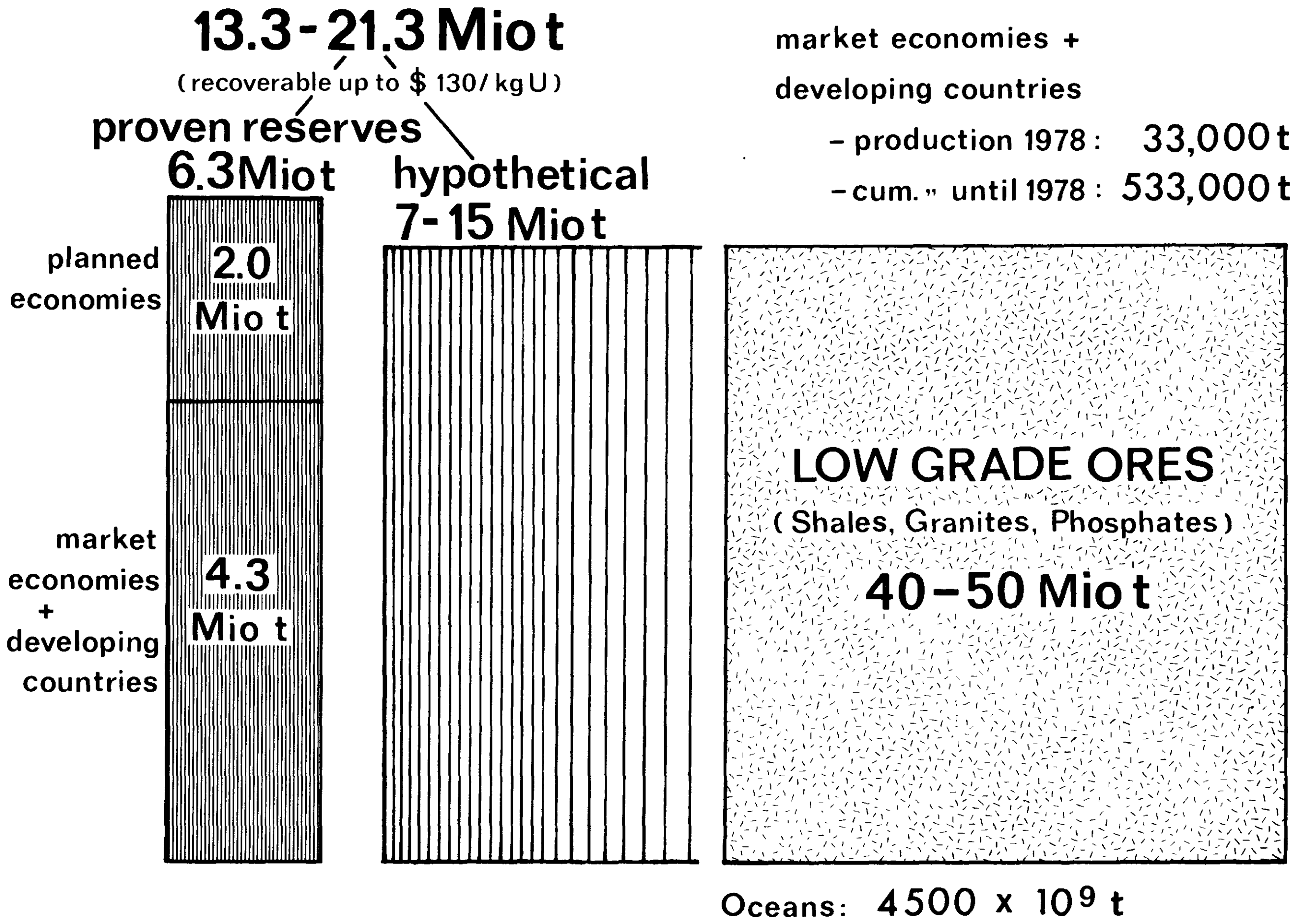
Shale oil production of some importance took place in 1976 in the Soviet Union and in China: the combined production is believed to be about 40 million tons of oil per year. Tar sands production in Canada reached about 9.5 million tons in 1978, mainly because of the increased production in the new Syncrude mine.

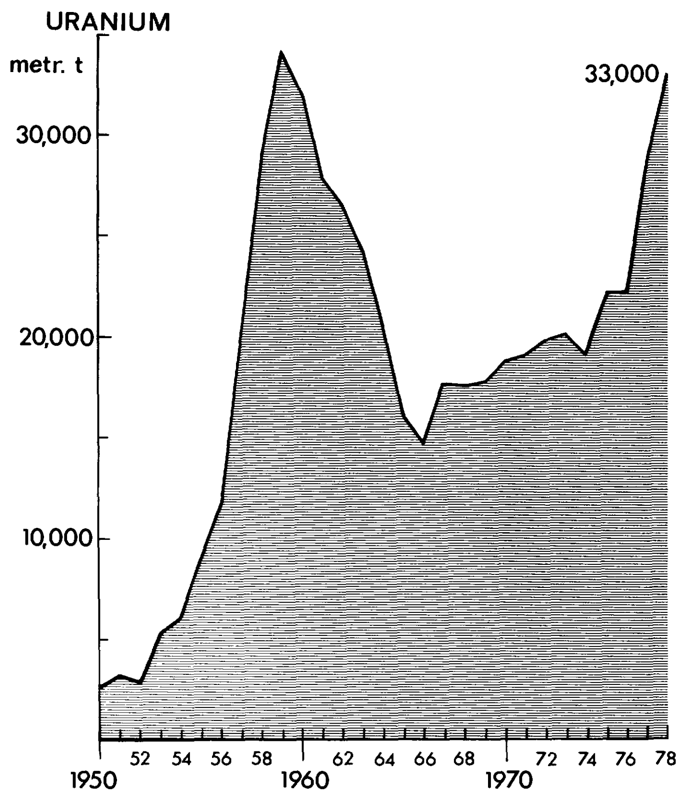
Nuclear fuels: Ten years ago, the energy planners saw nuclear energy as the way out of the difficulties in the energy supply. Rational calculations supported this assumption. The last few years have shown, however, that the irrational aspect of human behaviour must be included in such considerations.

The market economy countries plus developing countries have about 3.16 million metric tons "reasonably assured" uranium resources, plus "estimated additional reserves," recoverable at a price up to $80 per kilogram of uranium (= $30/lb U_3O_8). An additional 1.5 million tons is available in the range from $80 to $130 per kilogram of uranium (= $30–$50/lb U_3O_8), a total of 4.3 million tons. We estimate the reserves of the planned economies in this category at 2 million tons, giving a total of 6.3 million tons of world reserves, which is equal to around 100 billion tons of coal equivalent, if used in today's reactors (fig. 10).

Hypothetical uranium resources recoverable at a price up to $130 per kilogram of uranium are thought to be in the range of 7 to 15 million tons. The basis for this is "World Uranium Potential," an international evaluation of prospective, but little explored, areas (International Uranium Resources Evaluation Project, Paris, 1978). In addition, the so-called low-grade ores (phosphorites, euxinic shales, and certain granites with contents of 50 to 300 parts per million) are believed to contain between 40 and 50 million tons. The oceans with an average of 3 parts per billion are estimated to contain 4,500 million tons of uranium. Known thorium resources, which could partly replace uranium in a high-temperature reactor, are estimated at about 4 million tons.

In 1978, uranium production in the market economy countries and developing countries was approximately 33,000 metric tons (fig. 11). Their current production capacity is around 45,000 metric tons per year. Should the planned global expansion of the utilization of nuclear energy be realized—which at the moment seems questionable—all known uranium reserves today would be used up by the year 2000. Consequently, uranium exploration has been intensified in order to find and develop new resources.





▲ **Figure 10** Estimates of world uranium resources. (Quantities are given in millions of metric tons.)

◀ **Figure 11** Uranium production 1950 to 1978 for the market economies and developing countries. (Quantities are given in metric tons.)

Geothermal energy: Since the availability of energy resources is limited for geological and other reasons, the big hunt for the so-called alternative energy sources also intensified with the oil price escalation. Solar-, wind-, tide- and geothermal energy receive much attention. Only geothermal energy will be touched on here. It represents an almost unlimited energy potential, but its present utilization is still only of minor importance. The installed geothermal electricity capacity amounts to 1,500 megawatts in 20 power plants, the nonelectrical utilization amounts to about 6,500 megawatts (fig. 12). At present, the utilization of geothermal energy is limited to volcanic or tectonically active zones with natural occurrences of hot water or steam.

The so-called "hot dry rock technology," being developed mainly at Los Alamos in the United States, opens new perspectives for the future use of geothermal energy. The idea is to create a fracture system in deep-

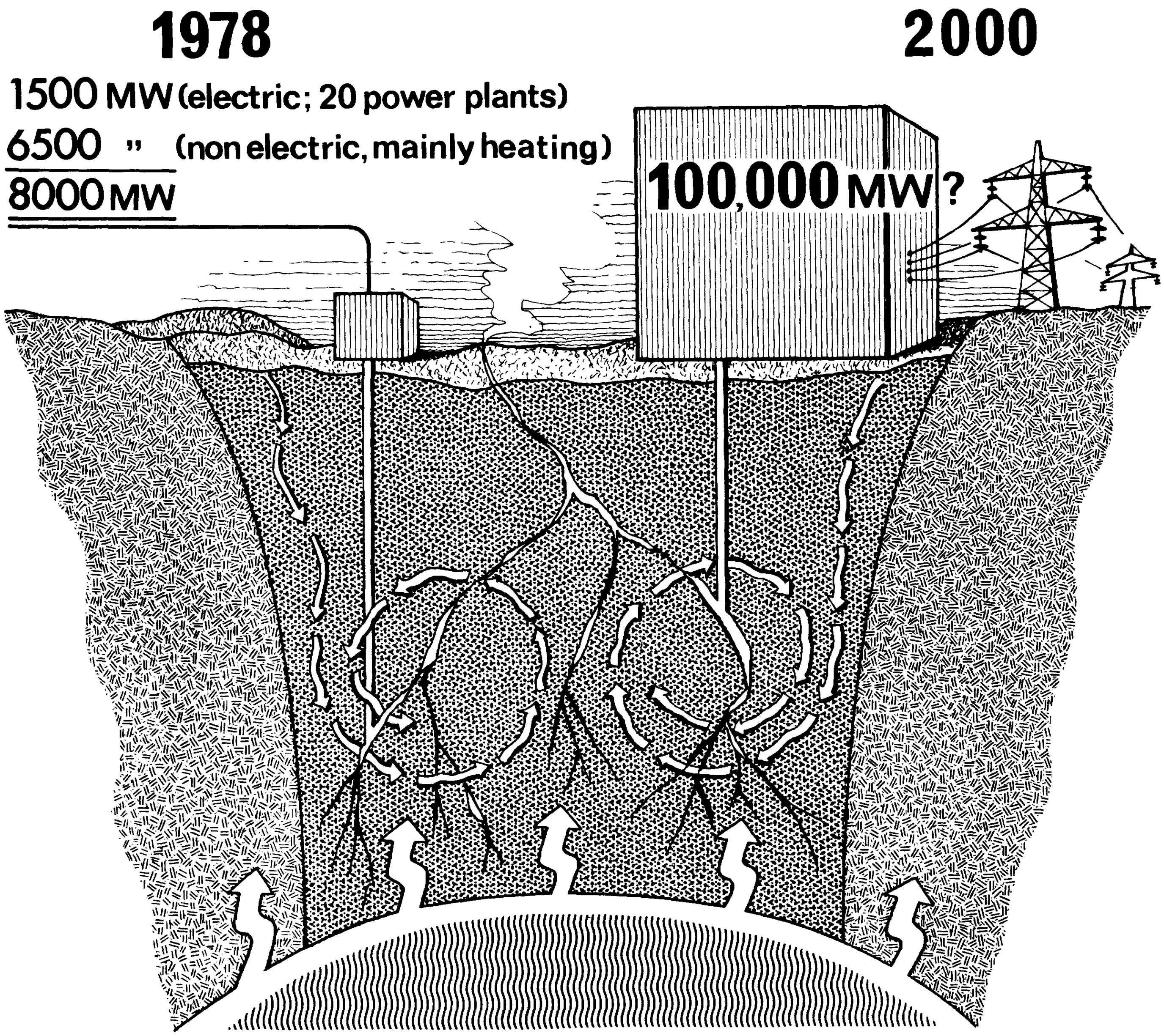


Figure 12 Geothermal energy figure for 1978 and projections for 2000. [Quantities are given in megawatts (MW).]

seated rocks where temperatures exceed 150° C. Water is pumped into this fracture zone through one well and is taken out through a second well after it has been heated. Tests so far have been promising. The advantage of exploiting hot dry rock is mainly that many more prospective areas are available, and therefore, geothermal plants could be constructed closer to places where such energy is consumed.

DIFFICULT FORECASTS

Forecasts on the possible proportions of the future energy supply contributed by the individual energy sources can be made from the figures given above. Since all such forecasts have proven to be incorrect after ten years at the latest, usually within two years, I wish to quote an old Chinese proverb for you: "To prophesy is extremely difficult, especially with respect to the future." So I want to venture from our present situation only as far as the beginning of the 21st Century, although this symposium is called "Resources for the 21st Century." In the last twenty years of the 20th Century there will already be enough difficulties providing for the supply of energy.

After taking into account the total of global energy resources and assessing that part of these resources which are convertible into reserves in the foreseeable future, the following can be projected for the period up to 1985:

1. **Oil** production may perhaps still rise to a certain extent, maybe up to 3.5 billion tons per year—but its relative share of energy consumption will definitely decrease;

2. the absolute, as well as the relative, contribution of **natural gas** to the energy supply can increase;
3. the favorable resources situation for **coal** permits its extensive utilization;
4. the reserve situation for **uranium** allows an increasing use of nuclear energy;
5. the contribution of **oil shales** and **tar sands** as well as of **geothermal energy sources** will remain limited.

Projections for world energy supply in the period from 1985 to 2000:

1. Production of **oil**, possibly also of **natural gas**, will have peaked;
2. **coal**, together with **nuclear fuels**, must provide the main share of the increase in energy consumption; there will be new ways of using coal, for example, by gasification in combination with high-temperature reactors;
3. hydrocarbons from **oil shales** and **tar sands** will become available on a larger scale;
4. there will be a rising contribution of **alternative energy sources**, such as **geothermal energy**;

Projections for world energy supply in the period beyond the year 2000:

1. Production of **oil** and **gas** and their importance as energy sources will rapidly decline further, but not their use as raw material for the petrochemical industry;
2. production of oil from **oil shale** and **tar sands** resources will now be mobilized on a large scale;
3. **coal** and **nuclear energy** will now satisfy the largest share of the demand. New reactor types with greater efficiency such as the fast breeder and the high-temperature reactor will allow the use of low-grade ores;
4. **alternative energy sources** will supply a substantial part of the demand.

It is clear that all fossil *and* nuclear fuels will be needed in order to avoid supply crises in the decades ahead, on the assumption that the energy demand will rise further and that the estimations of the resources situation are correct. Even so, all possibilities for using alternative energy sources, such as geothermal, must be developed rapidly because of the fast rising costs for exploration and exploitation of conventional resources.

SOLVABLE PROBLEMS

Our quantitative assessment of world energy resources on the basis of the present state of geoscience knowledge may be correct to within plus/minus 30 percent. Within 2, 5, or 50 years, we will know those quantities better. But with the present state of knowledge *one* statement can already be made now: energy raw materials are not becoming scarcer because their *physical* existence in the Earth's crust will come to an end within a few decades. The same is true for oil, although only if it is also recovered from oil shales and tar sands. After all, assuming an increase in demand of 4 percent, the demonstrated recoverable crude oil reserves will suffice for about another 20 years, and if one includes the inferred quantities, even for about 40 years. Taking the same increase in demand as a basis, the hydrocarbons contained in the presently known oil shales and tar sands may extend this lifetime considerably. Assuming a growth rate of 4 percent, presently known coal reserves will suffice for another 57 years, and the presently demonstrated uranium reserves (current price: $130/kg U) will suffice for another 50 years. Geothermal energy reserves are practically inexhaustable.

Nature has not yet confronted mankind with a foreseeable time limit for the physical existence of energy resources. Consequently, the problems of the supply of energy resources for everyone are theoretically solvable. Whether this is also true practically depends on all of us in the world. Whether rational and cooperative or emotional and egoistic behaviour will prevail among nations is a question whose answer will indisputably have a decisive influence on the future of mankind.

SUMMARY AND CONCLUSIONS

Logically, the further development of the lifetime of energy resources—this is, the identification of further resources and the conversion of resources into reserves—has become a task of supreme importance for all of us, especially for geoscientists.

The end of mankind is certainly not imminent because of the end of the physical existence of the energy resources as foretold by the "doomsday" prophets. Nobody has yet succeeded in definitely quantifying energy resources. This precision is still many years away. However, efforts to explore the Earth's crust should be considerably increased so as to know in more detail the raw materials, including energy resources, that are contained in it, and to improve their exploitation. Only facts can be used to curb the rapidly spreading and politically more and more dangerous hysteria about energy resources—facts that are substantiated by geoscientific findings and not by more or less disputable analyses and forecasts. Only then can the question "Sufficient raw materials for everybody?" be answered definitely and positively.

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An International View of Nuclear Raw Materials (Uranium)

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In response to the assigned topic, "An International View of Nuclear Raw Materials," one should obviously begin by defining from exactly where that view is taken. In this case, the viewpoint is from within the Secretariat of the International Atomic Energy Agency (IAEA) and the subject is restricted to uranium.

The concept of the IAEA was inspired by President Eisenhower's significant speech to the United Nations General Assembly on 8th December 1953, the significant quotation being: "I therefore make the following proposals. The governments principally involved, to the extent permitted by elementary prudence, should begin now and continue to make joint contributions from their stockpiles of normal uranium and fissionable materials to an international atomic energy agency. We would expect that such an agency would be set up under the aegis of the United Nations." Subsequently, the International Atomic Energy Agency came into being on 29 July 1957.

The IAEA is an autonomous member of the United Nations family of organizations with its own programme approved by a Board of Governors and its own budget financed by contributions from 110 Member States. Its main objectives are to "seek to accelerate and enlarge the contributions of atomic energy to peace, health and prosperity throughout the world * * * and to provide assistance to Member States * * * that is not used to further any military purpose." With headquarters in Vienna, Austria, it has a total staff of about 1,500 persons and its annual budget is currently about 76 million dollars.

The IAEA, from its relative youth of 22 years, therefore greets and offers its respects and good wishes to the United States Geological Survey on this, the occasion of its 100th anniversary celebration. The opportunity is also taken for noting some of the interests which the two organizations have in common: for example, the development of nuclear techniques in mineral exploration, the use of isotopes in hydrological surveys, the use of satellite imagery in geological data, and bilateral and international technical assistance to developing countries in relevant geological subjects. However, the strongest common interest is perhaps in nuclear raw materials, the subject of this paper, and primarily in uranium in the context of national and international requirements, especially for the 21st Century.

[1] Deceased April 2, 1980.

PART I: SOURCES OF INFORMATION ON NUCLEAR RAW MATERIALS

IAEA Activities Concerning Uranium

Among the many concerns of IAEA are world uranium resource estimates and all matters relating to the geology, exploration, development, and production of uranium in all its Member States. It also administers technical assistance aid programmes that assist developing countries in any of these matters.

The IAEA staff group dealing with uranium subjects is small, being only part of a Section in one of the Divisions of the Department of Technical Operations, itself one of five Departments in the Agency. The work of the uranium group follows two main channels, (a) General Divisional Programmes and (b) Technical Assistance.

The general divisional programmes are mainly fulfilled in the encouragement of information interchange by organizing scientific meetings and by publishing their proceedings for the benefit of all Member States. A list of the proceedings of meetings and technical reports published by the uranium group in the last ten years is given in Annex I. (*See* the appendix to this chapter.)

In addition to the meetings and publications arranged within IAEA's general divisional programme, much of the information gathered and disseminated is done through cooperation with other organizations, most notably the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD). With headquarters in Paris, France, the NEA has only 22 Member States, all of them industrial countries. Thus, mainly through cooperation with IAEA, the Nuclear Energy Agency (NEA) obtains access without difficulty to information from many of the important uranium countries in the world.

There are, at present, four permanent joint NEA/IAEA committees on uranium subjects:

1. Working Party on Uranium Resources, Production and Demand.
2. Steering Group on Uranium Resources.
3. Group of Experts on Research and Development in Uranium Exploration Techniques.
4. Working Group on Uranium Extraction.

In addition, a Working Party on Nuclear Fuel Cycle Requirements is supported by IAEA's Economic Section in the Division of Nuclear Power and Reactors and not by the uranium group, because it is mainly concerned with reactor strategies, nuclear fuel inventories, and the like, rather than with resource estimates, exploration, or extraction.

All these groups are staffed by experts nominated by their own Governments which are Member States of one or both of the two Agencies.

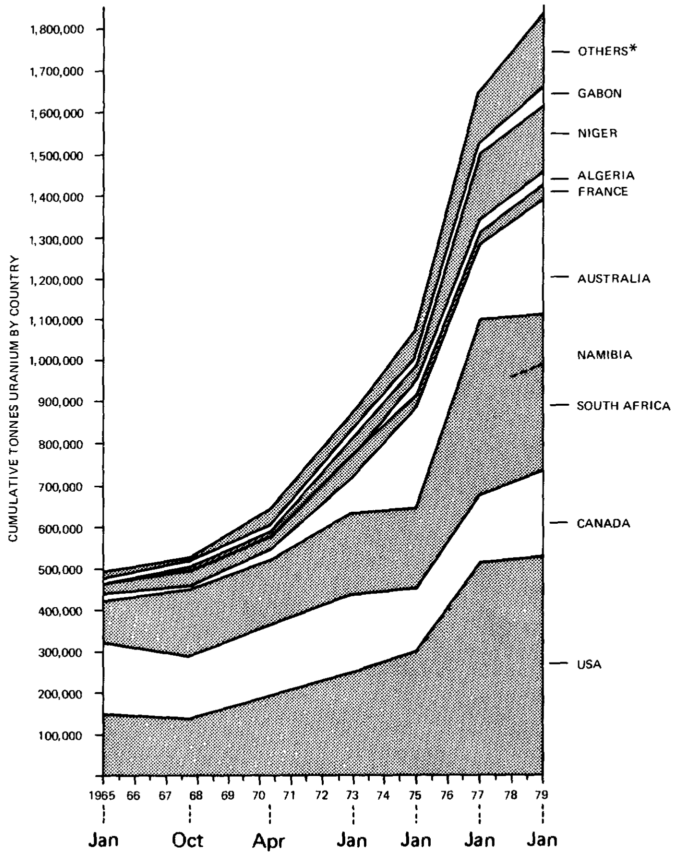
Other fruitful international cooperation takes place with the United Nations Development Programme (UNDP), the United Nations Centre for Natural Resources, Energy and Transport (CNRET), International Institute of Advanced Systems Analysis (IIASA), Commission of the European Communities (CEC), The Uranium Institute, International Geological Correlation Programme (IGCP), and on a direct basis with uranium organizations in Member States such as the Department of Energy and the Geological Survey in the United States.

Uranium Resources, Production and Demand Reports

Since 1965 the NEA and the IAEA have been responsible for publishing the so-called "Red Book" reports that are entitled "Uranium Resources, Production and Demand," roughly at two-year intervals (OECD, Paris). These reports are generally accepted as the most authoritative statements presently existing on these subjects in the World Outside Centrally Planned Economies Area (WOCA).

At the beginning of each two-year exercise or cycle, the permanent NEA/IAEA joint Working Party and the permanent NEA/IAEA joint Steering Group together issue a questionnaire (revised at the beginning of each biennial exercise) to all the Member States of both Agencies who are known to have any interest in uranium. [These joint committees consist of representatives appointed by Member States which produce and (or) consume radium.] After the completed questionnaires are received, a joint Working Party meeting is convened to which representatives of the countries returning questionnaires are now invited. This expanded, entire Working Party then reviews relevant resource definitions, cost ranges, availability, constraints on exploration and production, demand, additional sources of supply and the resource estimates. Each national representative is a full member of the joint Working Party and may be asked by the other members to explain or defend the figures submitted by his country. The views expressed at this international discussion are consolidated by the scientific secretaries of the two agencies into a draft text which is normally reviewed at least once at other meetings of the entire NEA/IAEA Working Party and of the NEA/IAEA Steering Group.

The number of countries reporting uranium resource figures to the Working Party has risen from 20 initially in 1965 to 32 in 1979. Similarly countries reporting uranium production have risen from 9 in 1969 to 15 in 1979. The resource estimates for 1979 are given in tables 1 and 2. Figure 1 shows the changes in estimated resource figures over the last 14 years.



* Other designates: Argentina, Brazil, Central African Empire, People's Republic of the Congo, Denmark (Greenland), Federal Republic of Germany, India, Italy, Japan, Mexico, Morocco, Portugal, Spain, Yugoslavia, Zaire.

Source: NEA/IAEA Joint Working Party on Uranium Resources.

Figure 1 Growth in market-economy and developing countries of reasonably assured uranium resources from 1965 to 1979. [Quantities of ore are shown in metric tonnes for the following production cost categories: 1965, 1967, 1970 at $10/lb U_3O_8 ($26/kg U), 1975 at $15/lb U_3O_8 ($39/kg U) and 1977 and 1979 (projected) at $30/lb U_3O_8 ($80/kg U); resources for 1979 are projected. Namibia's reserves are distinguished from South Africa's in the reporting period indicated.]

It must be emphasized that these reports are the result of voluntary cooperation and while the figures may be challenged by other members of the joint Working Party and may have to be explained or defended by the national representative, it is ultimately each Government's approved figures which are accepted and published.

The Working Party also concerns itself with additional sources of supply such as higher cost uranium, by-product uranium, and very low-grade uranium resources.

Table 1 Estimates of WOCA uranium as reasonably assured resources, as of mid-1979
[Quantities are given in 1,000 tonnes U]

	COST RANGE IN 1979 U.S. DOLLARS		
WOCA COUNTRY	<$80/kg U (reserves)	$80–130/kg U (other assured resources)	Total recoverable resources up to $130/kg U
Algeria	28	0	28
Argentina	23	5.1	28.1
Australia	290	9	229
Austria	1.8	0	1.8
Bolivia	------	0	0
Botswana	0	.4	.4
Brazil	87.5	0	87.5
Canada	172	17	189
Central African Empire	18	0	18
Chile	0	0	0
Denmark	0	27	27
Egypt	0	0	0
Finland	0	2.7	2.7
France	39.6	15.7	55.3
Gabon	20	0	20
Germany, Federal Republic of	4	.5	4.5
India	29.8	0	29.8
Italy	0	1.2	1.2
Japan	7.7	0	7.7
Korea, Republic of	0	4.4	4.4
Madagascar	0	0	0
Mexico	6	0	6
Namibia	117	16	133
Niger	160	0	160
Philippines	.3	0	.3
Portugal	6.7	1.5	8.2
Somalia	0	4.6	4.6
South Africa	247	114	391
Spain	9.8	0	9.8
Sweden	0	301	301
Turkey	2.4	1.5	3.9
United Kingdom	0	0	0
U.S.A.	531	192	723
Yugoslavia	4.5	2.0	6.5
Zaire	1.8	0	1.8
Total	1,807.9	745.6	2,553.5
Total (rounded)	1,800	750	2,550

The International Uranium Resources Evaluation Project Steering Group on Uranium Resources (IUREP)

Apart from jointly guiding the "Red Book" exercises, the main task of the Steering Group in recent years has been to carry out the International Uranium Resource Evaluation Project (IUREP). Recognizing that the "Red Book" exercises did not constitute complete appraisals of the world's uranium resources, the joint Steering Group undertook a follow-up study "to better define the possible extent and location of further undiscovered uranium resources, referred to as 'Speculative Resources' exploitable at costs less than U.S. $130/kg U."

In contrast to the "Red Book" exercises, this IUREP Phase I evaluation of Speculative Resources did not rely on Government estimates and submissions but on evaluations arising from bibliographic studies by a group of approximately 30 international consultants. Their work was in turn evaluated, finalized and endorsed by the 14 members of the joint Steering Group. In December 1978 it was co-published by NEA/IAEA as "World Uranium Potential: An International Evaluation" (OECD, Paris).

Group of Experts (R&D) in Uranium Exploration Techniques

In 1976 a Group of Experts was set up as one of the permanent NEA/IAEA Committees. Composed of technical representatives from 12 Member States and International Organizations interested in, and actively involved in, research and development in uranium exploration techniques, the Group recommended that a series of workshops be convened to select subjects for collaborative research and development. These workshops were to enable experts to exchange information on the state of current research, and to identify areas or sectors in which international cooperation in research and development could be expected to lead to the early discovery of new uranium deposits. Proposals were formulated and workshop subjects were selected so as to further international collaboration in four major sectors:

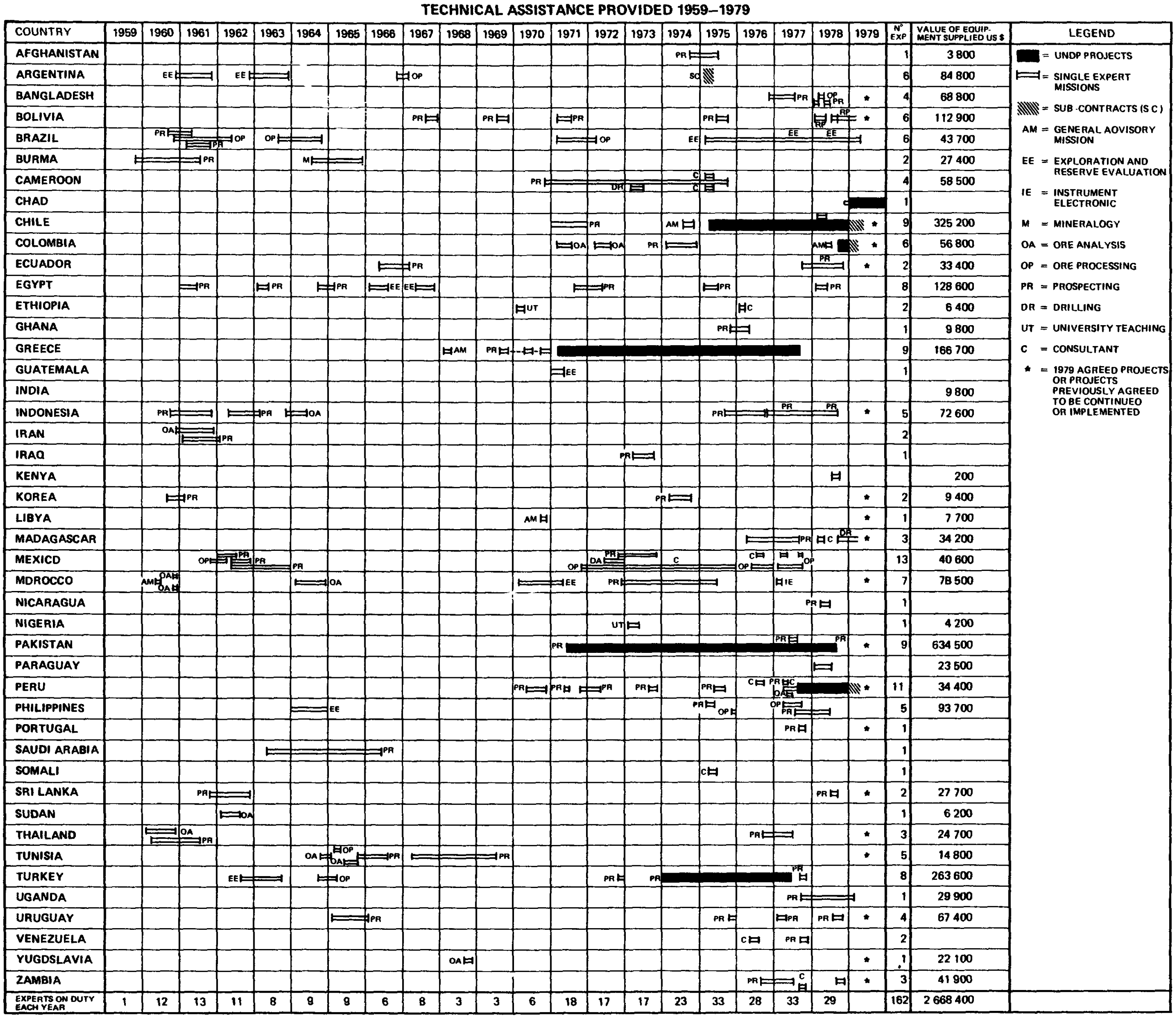
1. Dissemination of existing knowledge.
   a. Exploration case histories.

Table 2 Estimated additional resources of WOCA uranium as expected occurrences, as of mid-1979
[Quantities are given in 1,000 tonnes U; figures for Canada are from STI/PUB/148 (Vienna, 1966); for Austria, Bolivia, Gabon, Madagascar, the Philippines, Yugoslavia, and Zaire are from STI/PUB/198 (Buenos Aires, 1968); for Mexico from STI/PUB/227 (Vienna, 1970); all other figures are from the Joint NEA/IAEA Working Party on Uranium (Paris, 1977) and additional information up to mid-1979.]

	COST RANGE IN 1979 U.S. DOLLARS		
WOCA COUNTRY	<$80/kg U (reserves)	$80–130/kg U (other additional resources)	Total recoverable resources up to $130/kg U
Algeria	0	5.5	5.5
Argentina	3.8	5.3	9.1
Australia	47	6	53
Austria	0	0	0
Bolivia	0	.5	.5
Botswana	0	0	0
Brazil	106.3	0	106.3
Canada	404	302	706
Central African Empire	0	0	0
Chile	5.1	0	5.1
Denmark	0	16	16
Egypt	0	5	5
Finland	0	.5	.5
France	26.2	20	46.2
Gabon	5	5	10
Germany, Federal Republic of	7	.5	7.5
India	.9	22.8	23.7
Italy	0	2	2
Japan	0	0	0
Korea, Republic of	0	0	0
Madagascar	0	2	2
Mexico	2.4	0	2.4
Namibia	30	23	53
Niger	53	0	53
Philippines	0	0	0
Portugal	2.5	0	2.5
Somalia	0	2.4	2.4
South Africa	54	85	139
Spain	8.5	0	8.5
Sweden	0	3	3
Turkey	0	0	0
United Kingdom	0	7.4	7.4
U.S.A.	742	393	1,135
Yugoslavia	5	15.5	20.5
Zaire	1.7	0	1.7
Total	1,504.4	922.4	2,426.8
Total (rounded)	1,500	920	2,420

2. Improvement of data quality.
   b. Measurement of natural gamma radiation.
   c. Data handling and interpretation.
   d. Instrument technology.
3. Identification of potentially productive regions.
   e. Uranium provinces.
   f. Rock geochemistry.
   g. Uranium deposit genesis.
   h. Airborne radiometrics in mountainous areas.
   i. Uranium favourability by mineral analysis.
4. Discovery of concealed mineralization.
   j. Borehole logging.
   k. Gases in uranium exploration.
   l. Subsurface geophysical exploration.
   m. Biogeochemistry.

Seven of the workshops had been held as of October 1979, and project proposals were formulated for international cooperation and for jointly funded research and development. The first proposal on Exploration Case Histories culminated at a meeting in Vienna where documented case histories were presented on at least twenty major deposits that were discovered and explored within the last twenty years. They will be co-published by NEA/IAEA. It is hoped that the other projects will be eventually fulfilled through similar international collaboration.



COUNTRY	N° EXP	VALUE OF EQUIPMENT SUPPLIED US $
AFGHANISTAN	1	3 800
ARGENTINA	6	84 800
BANGLADESH	4	68 800
BOLIVIA	6	112 900
BRAZIL	6	43 700
BURMA	2	27 400
CAMEROON	4	58 500
CHAD	1	
CHILE	9	325 200
COLOMBIA	6	56 800
ECUADOR	2	33 400
EGYPT	8	128 600
ETHIOPIA	2	6 400
GHANA	1	9 800
GREECE	9	166 700
GUATEMALA	1	
INDIA		9 800
INDONESIA	5	72 600
IRAN	2	
IRAQ	1	
KENYA		200
KOREA	2	9 400
LIBYA	1	7 700
MADAGASCAR	3	34 200
MEXICO	13	40 600
MOROCCO	7	78 500
NICARAGUA	1	
NIGERIA	1	4 200
PAKISTAN	9	634 500
PARAGUAY		23 500
PERU	11	34 400
PHILIPPINES	5	93 700
PORTUGAL	1	
SAUDI ARABIA	1	
SOMALI	1	
SRI LANKA	2	27 700
SUDAN	1	6 200
THAILAND	3	24 700
TUNISIA	5	14 800
TURKEY	8	263 600
UGANDA	1	29 900
URUGUAY	4	67 400
VENEZUELA	2	
YUGOSLAVIA	1	22 100
ZAMBIA	3	41 900
EXPERTS ON DUTY EACH YEAR	162	2 668 400

	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
EXPERTS ON DUTY EACH YEAR	1	12	13	11	8	9	9	6	8	3	3	6	18	17	17	23	33	28	33	29	

Figure 2 Summary of technical assistance in uranium provided by IAEA to developing countries from 1959 through 1979.

IAEA Technical Assistance to Developing Countries in Uranium Exploration, Development and Production

The fourth permanent NEA/IAEA Committee serves as the Working Group on Uranium Extraction. All Member States of the Agency are eligible for technical assistance provided under the Regular Programme and both Member and non-Member States are eligible for assistance from the Agency under the United Nations Development Programme funding, provided that they are economically developing and are members of the United Nations or of the specialized agencies. The IAEA advises governments on uranium exploration, development and production programmes and provides field experts and equipment and training to their nationals who are professionals and technicians.

Figure 2 summarizes the IAEA technical assistance programme in uranium subjects from 1959 to the present. The first, a single-expert mission, was to Burma in late 1959, and since that time IAEA has fielded approximately 140 separate projects in 45 countries, engaging 162 field experts and including 7 large-scale UNDP financed projects with teams of experts. To support these projects, equipment worth U.S. $2,668,400 has been supplied.

At the end of each project the chief field expert must write a report of his activities, with recommendations to the recipient Government for further action. These reports are the exclusive property of the host government, but governments are asked to de-restrict the reports and make them available to other IAEA Member States after a period of three months. Thus these reports are usually also available to IAEA staff as information for the international data base on world uranium geology, exploration and development that is being assembled at IAEA headquarters.

International Nuclear Fuel Cycle Evaluation Project

As set up separately by IAEA at an organizing Conference in Washington in October 1977, Working Group No. 1 of the International Nuclear Fuel Cycle Evaluation Project had among its responsibilities the estimation of needs for nuclear energy and the related needs for and availability of uranium. Sub-Group B (Nuclear Fuel Resources) of INFCE Working Group No. 1 was closely linked with the joint committee studies undertaken by the NEA/IAEA Working Party and Steering Group on uranium resources. But in addition to assessing the available information on uranium resources Sub-Group B gave greater emphasis to high-cost, low-grade resources as possible future sources of uranium.

INTernational URanium GEOlogy Information System (INTURGEO)

Both through the various advisory and technical aid programmes outlined above, and through many other direct contacts with uranium geologists in Member State governments, with geologists in international organizations, and with geologists in industry, the IAEA has acquired a large collection of maps, technical papers, reports and news clippings about uranium all over the world. The global scale of such a mass of information mandated a computer data base able to store and disseminate the essentials of this information to all Member States.

Accordingly, the International Uranium Geology Information System (INTURGEO) was designed in April 1978 by four leading science information experts, including one from the U.S. Geological Survey. Implemented in February 1979, INTURGEO is stored on discs of an IBM model 370–3350 computer and is maintained by ADABAS, a commercial data management system. The organization of INTURGEO reflects IAEA's five-fold approach to uranium resource analysis, since it consists of five specialized data files:

The Regional Reference File or RRF systematically stores information on the geology of a region so that the characteristics favourable to uranium mineralization can be determined. Other pertinent data on the region are also stored in this file.

Exploration Activity File or EAF contains the data that characterize the uranium exploration for a specific region, so that the uranium favourability of the region and need for further exploration can be assessed.

Deposit/Occurrence File or DOF stores those geological data that characterize uranium ore deposits or occurrences so that deposits can be compared and classified. The IAEA wishes particularly to acknowledge the consulting service of Virginia Byers of the U.S. Geological Survey, who acted as consultant and incorporated data on the principal uranium deposits of the world that had been collected by the USGS over the last several years. As a result the DOF now contains 325 records.

International Summary File or ISF summarizes uranium information on a country or political region. This includes a country's uranium resources and its known attitude toward uranium resource development.

Ore Processing File or OPF is presently being developed.

Except for OPF, the system is fully operative, although with a limited amount of data at present. (The main components of the first four files are shown in figure 3.) In a paper read at the IIASA meeting held at Laxenburg, Austria, in July 1979, Linda Trocki and Maurice Hansen of the IAEA staff provided a description of INTURGEO for the Conference on Systems Aspects of Energy and Minerals Resources. The conference was sponsored by the International Institute for Applied Systems Analysis. Eventually, INTURGEO will cover world uranium geology,

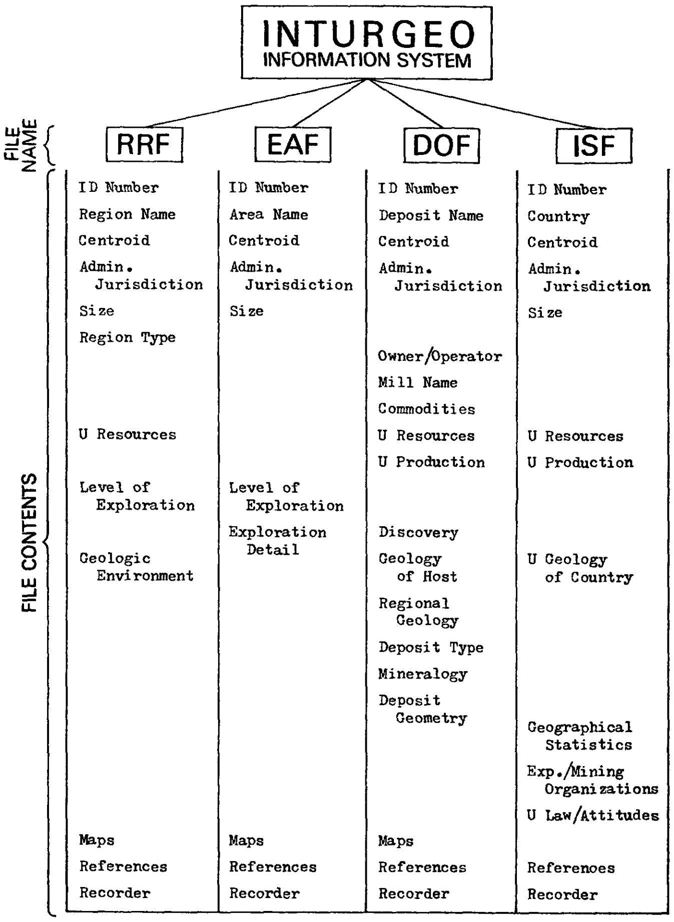


Figure 3 Organization of four of INTURGEO's five data files illustrate similarities of information. (Items occurring on the same line have similar structures.)

exploration, resources, and production so that information application for atomic energy uses can and will be as diverse as the users. The most obvious application is simply the collection, systematic storage, and retrieval of vast amounts of geologic data. World-wide dissemination of uranium resource information is another application of high priority in IAEA. INTURGEO will also provide users with a rapid method for intelligent resource appraisal. In summary, the five-fold INTURGEO approach to world uranium resources data is unique and the possibilities for scientific and economic applications are unlimited.

With the support of its Member States, the IAEA will maintain the most complete uranium geology file in existence, available to participants for the cost of a time-sharing terminal and a telephone call. Up to now the project has been supported by IUREP and thus indirectly by the U.S. Department of Energy, but it will require a steady source of other funding, such as contributions from more Member States, to ensure technical stability and maintenance of the data bank. It is a pleasure to acknowledge a pledge of financial support from the U.S. Geological Survey, but additional funding will still be required. Besides giving such financial support, the scientific support of Member States will be of great help in coding and verifying data on their own countries.

PART II: SOME CONSIDERATIONS TOWARD THE 21ST CENTURY

Uranium Demand

Any forward view of the uranium exploration and production industry, international or national, will be determined by uranium demand both in the latter part of this century and in the 21st Century. In fact, any planning for the future is first of all related to the overall world energy demand and the mix of fuels necessary to meet that demand. The world energy demand in the next century will be dependent on a large and complex number of factors such as predicted population growth, economic growth, technology related to the supply and utilization of all fuels, resource availability, environmental considerations, health and safety, national and international policies, and war and peace. As these factors are undeniably interdependent, the problem of predicting overall energy demand and the mix of fuels making up that demand is obviously extremely complex.

Energy utilization in the latter part of this century and in the 21st Century could follow an almost infinite number of options within very wide boundaries related to the extremes of either total economic collapse or of buoyant growth.

Taking a reasonable view of the future as from mid-1979 it would seem that nuclear power must play some significant role in the future energy scenario, even though the amount will depend on world economic growth and all the other factors mentioned above.

At the present time, the consensus of experts involved in forecasts is that any attempt to specify the most probable level of installed nuclear capacity for the long term is virtually impossible. The best that can be done is to try to establish the most probable high and low limits, while allowing that the actual capacity is most likely to lie between them. But installed nuclear capacity may even prove to be outside that predicted range.

Many experts, including those in the Joint NEA/IAEA Working Party on Nuclear Fuel Cycle Requirements, in the International Nuclear Fuel Cycle Evaluation project, in the International Energy Agency, and in the World Energy Conference have predicted a nuclear capacity range of 1,000 to 1,800 gigawatts electric (GWe) in the year 2000 and a much higher range for the year 2025. These experts based their predictions mainly on responses obtained from questionnaires sent to national authorities.

In the period before the year 2000, predictions for reactor mixes and fuel cycle strategies are based on national replies to questionnaires and while reliable to that extent nevertheless cover a very wide range for lifetime uranium requirements for reactors committed through the year 2000. Estimates range from 2.9 million tonnes of uranium at the low end to 8.4 million tonnes of uranium at the high end.

For the period after the year 2000, the picture is not at all clear either. The experts had to view the situation from the standpoint of current and future technology, such as fast breeder reactors with 100 percent high uranium utilization, in order to quantify high and low uranium requirements. The cumulative net demand for uranium up to the year 2025 has been estimated to be between 3.60 million tonnes of uranium at the low end and 12.00 million tonnes of uranium at the high end. However, if the lifetime requirements for committed reactors up to the year 2017 is included—that is, eight years before the start-up of the reactors—the range is from 4.00 to 20.00 million tonnes uranium.

The uranium requirements from the present up to some point near the middle of the 21st Century will, most probably, fall within this range, and it would be difficult to assume that any one point in this range is inherently more likely than any other. Furthermore, few expert assessments have attempted to make predictions of nuclear power beyond the year 2017 or 2025 for lifetime reactor commitments, but it seems improbable that reactor commitment and installment would come to an abrupt end on those dates. Some substantial demand for uranium would seem to be a reasonable assumption for the rest of the century in addition to that required by reactors committed up to the year 2025.

It is thus the author's view that the uranium geologists and the uranium exploration and development industry in the countries of the World Outside the Centrally Planned Economies Area (WOCA) should be setting a target for discovery, exploration, and development of 20 million tonnes of uranium as they approach the start of the 21st Century, despite the fact that this figure could be considered to be at the high end of the expected demand range. I realize that fulfillment is likely to be very difficult and it may therefore be all the more important and prudent to keep this target figure of 20 million tonnes U in the forefront of the planning by this and the next generations of geologists and explorationists.

Uranium Supply

Tables 1 and 2 summarize the WOCA uranium resources as of mid-1979. The reasonably assured resources (Reserves) (table 1) available at a cost less than U.S. $80/kg U in 1979 amount to approximately 1.80 million tonnes of uranium as estimated from the figures published by the Joint NEA/IAEA Working Party on Uranium Resources, Production and Demand (1977) plus additional information available up to mid-1979. In addition, the Reasonably Assured Resources within the cost range of U.S. $80 to $130/kg U amount to 0.75 million tonnes of uranium, making a total of 2.55 million recoverable tonnes up to the limiting cost of $130/kg U.

Over and above this reasonably assured supply, the Estimated Additional Resources up to the limiting cost of U.S. $130/kg U total 2.42 million tonnes of uranium (table 2). However, the definition of estimated additional resources states that this refers to uranium that is *expected* to occur, mostly on the basis of direct geological evidence in extensions of well-explored deposits, little explored deposits and undiscovered deposits believed to exist along a well-defined geological trend with known deposits. In other words, estimated additional resources are subject to confirmation by exploration.

If the target of 20 million tonnes uranium for the next century is acceptable, then there are at present only 1.80 million tonnes, or 2.55 million tonnes if higher costs are acceptable, to set against it at the present time. All the difference, 17.45 to 18.20 million tonnes, is dependent on future exploration.

There is no doubt that additional, as yet undiscovered uranium resources will be identified and brought into use some time in the future. But we must ask, is it reasonable to predict that resources of an order of magnitude of 17.5 to 18.20 million tonnes of conventional type, relatively low-cost uranium resources, can be found in the unexplored or incompletely explored parts of the WOCA countries?

Meanwhile, lower grade, higher-cost resources are being identified. For example, it is calculated that 15.0 million tonnes of uranium occur in the world's marine phosphate deposits and in shales, granites, and other disseminated deposits. These subeconomic reserves could be exploited technically if demand generates a price that would make them commercially attractive to the mining industry.

Thus, the nuclear power industry and the uranium industry face a twofold question as the 21st Century approaches. Should support be given to geologists and explorationists to help them find conventional type low-cost uranium in unexplored areas over the world? Or should support be given to chemists, mill technologists, and engineers to ensure uranium supplies from such known sources as phosphates, black shales, granites, and sea water? For geologists there is no doubt that the first half of the question posits the more attractive option, although it would be prudent to give some emphasis to research on recovery of uranium from low grade sources, as eventually they may have to make an important contribution—especially in the next century.

International Uranium Resources Evaluation Project

With this as background, the Joint NEA/IAEA Steering Group on Uranium Resources launched the International Uranium Resources Evaluation Project (IUREP) in early 1977 to better define the possible extent and location of further undiscovered uranium resources exploitable at costs less than U.S. $130/kg U (in 1979 dollars) which were called "Speculative Resources." Speculative Resources refers to uranium, in addition to Estimated Additional Resources, that is thought to exist mostly on the basis of indirect evidence and geological extrapolations, in deposits discoverable with existing exploration techniques. Deposits envisaged in this category can generally be specified only as located somewhere within a given region of geological trend.

As the term implies, the existence and size of such resources are highly speculative. In Phase I of the IUREP project completed in June 1978, studies of 185 countries covered general geography, geology in relation to potentially favourable uranium bearing areas, past exploration, uranium occurrences, past production, present states of exploration, and the potential for new discoveries. For each of these 185 countries, a judgement was made of the order of magnitude of their additional potential. To facilitate the process of judging the relative favourability of each country's uranium potential, the Steering Group devised a ranking scheme: low, moderate, moderate to high, high, high to very high, and very high. For the purpose of obtaining an aggregate measure of this potential, the Group also applied ranges of tonnages to the rankings. The Speculative Resources derived by this method for the world excluding the People's Republic of China and the eastern part of the USSR, and for continental divisions, are shown in table 3. This 1978 report was summarized in the NEA/IAEA publication "World Uranium Potential" (1978) which is available from OECD, Paris.

Table 3 Speculative uranium resources listed by continent, excluding People's Republic of China and the eastern part of USSR

[The potential shown here is "Estimated Total Potential" and includes an element for "Reasonably Assured Resources" and "Estimated Additional Resources" although those data were not available in 1978 to the Steering Group.]

CONTINENT	NUMBER OF COUNTRIES	SPECULATIVE RESOURCES (IN MILLION TONNES U)
Africa	51	1.2– 4.0
North America	3	2.1– 3.6
South America and Central America	41	.7– 1.9
Asia and Far East	41	.2– 1.0
Australia and Oceania	18	2.0– 3.0
Western Europe	23	.3– 1.3
Total	177	6.5–14.8
Eastern Europe, USSR, People's Republic of China	8	3.3– 7.3

These IUREP totals are not meant to indicate ultimate resources of uranium since the Steering Group's perspective was restricted by current knowledge which is in turn severely limited in many areas of the world. For this reason judgements of Speculative Resources may change as cumulative geological knowledge increases. It is important also to emphasize that even if these Speculative Resources exist, as presumed, there is no guarantee that the resources will be discovered or if discovered that they can be made available. The estimates imply nothing about *discoverability or availability*. It is essential that the tonnages of Speculative Resources should not, under any circumstances, be used for nuclear power programme planning purposes. They should be viewed as a qualitative measure of the present state of geological knowledge and simply be regarded as both a target for future exploration efforts and a guide for establishing priorities for subsequent evaluations.

From these figures it may be assumed that even if the high "Speculative Resources" totals could eventually be converted to Reserves—and this may be a very wild assumption—it would still leave a considerable gap between that and the stated target of 20 million tonnes uranium for the 21st Century. Either the geologists of the future must do better than the IUREP estimates or from 20 to 30 percent of the stated target should come from higher cost low-grade sources.

In addition to aggregating the Speculative Resource tonnages by continents, the 185 WOCA countries were also grouped from highest (I) to the lowest potential (V), depending on how the Steering Group viewed their future potential for uranium resources. The 8 countries in the Centrally Planned Economy Area (USSR, People's Republic of China, and Eastern Europe) were simply listed together as Group VI. Figures for speculative resources in that group may be considered mainly conjectural. (See table 4.)

Group I, with the highest Speculative Resource potential of between 5.1 and 9.9 million tonnes uranium, is formed by the 20 countries whose geological potential is undoubtedly good and where exploration is obviously to

Table 4 Speculative world uranium resources listed by category

[Categories I to V includes the WOCA Countries; category VI includes the USSR, the People's Republic of China, and 6 countries in Eastern Europe.]

CATEGORY	NUMBER OF COUNTRIES	SPECULATIVE RESOURCES (IN MILLION TONNES U)
I	20	5.1– 9.9
II	11	1.0– 3.0
III	26	.4– 1.4
IV	43	.0– .4
V	77	.0– .1
VI	8	3.3– 7.3
Totals	185	9.8–22.1

be encouraged. But in these, international assistance is unnecessary or inappropriate as the exploration is well directed, intensive, and likely to continue to be so. This category includes Australia, Canada, France, Federal Republic of Germany, Italy, Namibia, Niger, South Africa, Spain, the United Kingdom, and the United States of America.

Group II, with the second highest potential of between 1.0 and 3.0 million tonnes uranium, consists of 11 countries with good geological potential, but where exploration is presently inadequate. These all warrant further exploration and evaluation. They are Algeria, Angola, Argentina, Brazil, India, Libya, Mali, Mexico, Somalia, Zaire and Zambia.

Group III consists of 26 countries whose geologic potential is similar to that of Group II but whose speculative potential is considered to be less than in Group II for a total ranging from 0.4 to 1.4 million tonnes of uranium. Bolivia, Botswana, Cameroon, Central African Republic, Chad, Colombia, Congo, Ethiopia, Gabon, Indonesia, and Madagascar are among those assigned to this group.

Group IV consists of 43 countries considered to have limited potential but some geological interest which may warrant international assistance in uranium exploration. The total speculative potential assigned to this group was 0 to 0.4 million tonnes uranium. Countries such as Afghanistan, Bangladesh, Kenya, Liberia, Paraguay, Uruguay, and the two Yemens were assigned to this category.

Group V includes 77 countries that are considered to have a very small potential for the discovery of uranium and were assigned in aggregate a range from 0 to 0.1 million tonnes uranium. Such countries as Bahrain, Benin, Fiji, Lebanon, Luxembourg, Nepal, Qatar, Timor, and Upper Volta are included in this category.

Group VI consists of 6 non-WOCA countries of Eastern Europe, and the USSR and the People's Republic of China. No comment can be made on these 8 countries, except that they were tentatively assigned speculative uranium resources in a range from 9.8 to 22.1 million tonnes.

The selection and categorizing of the 185 WOCA countries (Groups I to V) was not influenced by any political or access situation nor on whether they are advanced industrial countries or developing countries. The only matters considered were their geological potential for further uranium resources and their exploration capability and history.

Clearly the greatest future potential lies in the Category I countries. These are the countries which already contain 90 percent of the world's Reasonably Assured Resources and Estimated Additional Resources; therefore the IUREP group may have been somewhat biased by the extent of the existing information on uranium resources. Nevertheless it was and is felt that the greatest promise for additional uranium lies in these countries and that the exploration problem is likely to be adequately taken care of by Government organizations and private industry acting on the spur of demand and price incentives.

However, these are also the countries where depletion and exhaustion of deposits will first occur. There is also the possibility that the IUREP estimates are wrong and that the highest Speculative Resources do not occur in the Group I countries. For these reasons it is very important that the Group II and Group III countries receive adequate exploration attention at the earliest possible date so that they can make their contribution to world uranium supply in the 21st Century. The following very brief summaries of the 37 developing countries in Group II and III are therefore presented to give small glimpses of the geological potential and the exploration requirements which, if fulfilled, might make a contribution to the uranium resources of the 21st Century (fig. 4).

Information Summaries on IUREP Selected Developing Countries

Group II and III Countries with Good Uranium Potential

Algeria is believed to have moderate to high uranium potential. Additional uranium-bearing veins could be discovered in the Precambrian rocks of the Hoggar and, possibly, in the Eglab (Reguibat) massif. Large areas of Tassili Series and also continental Cretaceous sediments, outcropping around the fringes of the Hoggar and Eglab massifs and in the Tindouf syncline, probably have uranium potential. A stratiform deposit, which is being evaluated at the present time, has been discovered at the base of the Tassili on the southern side of the Hoggar.

Angola has moderate to high uranium potential. Proterozoic unconformity deposits could be present in the middle Proterozoic Oendolongo Series. The Bembe System is probably a correlative of the cupriferous and uraniferous Katanga Group of Zaire and Zambia. Karroo, Cretaceous and Tertiary (Kalahari sands) continental sediments are present in the interior of Angola. Calcrete uranium development is possible within the Kalahari sands. Uranium mineralization could be associated with known carbonatites.

Argentina is considered to have a high potential for additional uranium resources. The majority of the known uranium deposits in Argentina occur in Permian and Cretaceous sediments especially in Mendoza Province. Exploration to date suggests that such sediments, which are

Figure 4 IUREP-selected developing countries with good potential for uranium. (Speculative potential estimated to be between 1,400,000 and 4,400,000 tonnes uranium.)

exposed in many areas in the Cordillera of western Argentina, are the most promising for the discovery of new deposits.

The Comisión Nacional de Energía Atómica (CNEA) is actively exploring, initially by aerial radiometric surveys, many areas of the Cordillera but much potentially favourable ground remains to be covered.

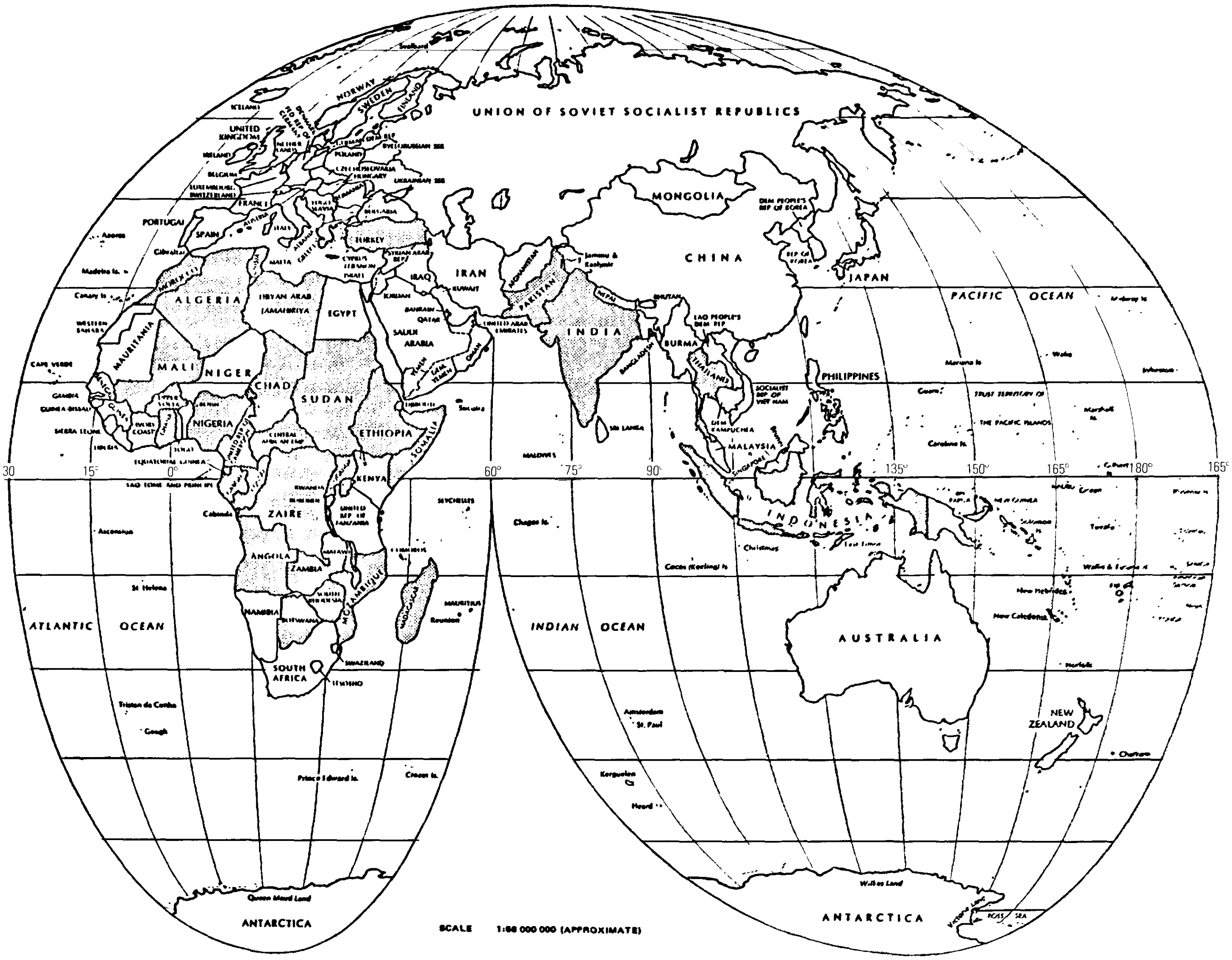
Bolivia is thought to have a moderate potential for additional uranium resources. Although no uranium reserves are credited to Bolivia, there are geologic possibilities for several types of deposits. Large areas of eastern Bolivia are underlain by Precambrian rocks of the Guapore massif and these should be investigated for the presence of quartz-pebble or Proterozoic unconformity-related deposits.

In addition, vein occurrences are known in the Central Cordillera and many radiometric anomalies have been detected within the Tertiary sedimentary succession in the Altiplano. The Tertiary volcanics in the Altiplano are also attractive targets for further study.

The Comisión Boliviana de Energía Nuclear (COBOEN) has been active in several areas together with outside agencies, in particular with Azienda Generale Italiana Petroli (AGIP).

Botswana has moderate to high uranium potential as most of the exposed sedimentary and metamorphic environments are geologically capable, including the Transvaal and Waterberg Supergroups, which could have quartz-pebble conglomerate uranium deposits; the late Proterozoic platform sediments of northwestern Botswana; the Karroo Series, in which uranium occurrences are known; and the Kalahari sands, where both sandstone uranium and "Yeelirrie-type" calcrete deposits could have been formed. Some uranium occurrences are known both in the Karroo and in Kalahari calcrete.

Brazil has a high to very high potential for additional uranium resources. The area of Brazil is large and its geology is favourable in various places for every known



type of uranium deposit. Significant uranium deposits have been found in sediments of the Parana Basin, and this huge basin should be prospected further. Several occurrences of uranium associated with quartz-pebble conglomerates are known and, although none of these are economically viable deposits, the potential for such deposits exists within the Precambrian shield areas. Uranium is also known in the form of disseminated and vein occurrences in the Precambrian rocks of the Serido geosyncline. The similarities of this area in Brazil to that containing the Rosasing deposit in Namibia is most encouraging. The full potential of the recently discovered Itataia phosphate-uranium occurrences in the south has yet to be realized. While a very considerable national and bilateral effort is being undertaken, the country is so vast and the geology of such favourable potential that much ground remains to be covered.

Burundi and Rwanda have both been assigned to moderate uranium potential. A UNDP airborne survey in 1963 detected between 70 and 80 anomalies in the two countries. A random survey over the Tertiary rift valley sediments found high radioactivity at the contact of these sediments and basement rocks just north of Lake Tanganyika in Burundi. Further to the north in Rwanda, radioactive water has been found in springs along the same alignment. In the extreme southeast of Burundi, a relatively small area of upper Proterozoic platform sediments merits attention to determine if they are "Copper Belt" facies and, if so, to examine them for reduced zones or faults.

Cameroon is thought to have a moderate potential for the discovery of uranium resources. Uraninite occurs at Goble in northern Cameroon as thin coatings on fault planes and fractures at a Precambrian syenite-schist contact. The middle Proterozoic Lower Dja Series, which has been correlated with the uraniferous Francevillian Series of Gabon, is present in the southern part of the country. Cretaceous continental sediments (Garoua sandstones) are exposed in the northern part of the country (uranium occurrences are known in the Cretaceous of Niger). The belt of "Younger Granites" (Tertiary?) could have uranium potential. In fact, a UNDP project is evaluating a recent vein uranium discovery in one of these "Younger Granites" in southwestern Chad. The intrusive straddles the Chad-Cameroon boundary.

The Central African Republic is thought to have a moderate potential for additional uranium resources. The Bakouma deposits in this country are unusual, if not unique, and probably the best hope for finding additional uranium in the Central African Republic would be under similar geological conditions in the south-central part of the country. The possibility also exists for finding unconformity-related deposits near or at the contact of upper Proterozoic and older Precambrian rocks. The several areas of Cretaceous and Tertiary continental sediments are also prospective for uranium.

Chad is believed to have a moderate uranium potential. Precambrian rocks are present in the Tibesti massif in the northwestern part of the country; in the east-central part of Chad; and in the south. Lower Palaeozoic sandstones (Tassili Series?) rest upon Precambrian in the Tibesti area. Stratiform uranium occurrences are present at the base of the Tassili Series on the south side of the Hoggar massif of Algeria. Recently discovered uranium occurrences in southwestern Chad, in veins cutting a "Younger Granite" (Tertiary?), are being evaluated at the present time. Continental Cretaceous and Tertiary sediments outcrop in the southern part of the country and dip northward into the subsurface of the Chad Basin.

Colombia has a moderate potential for uranium resources. There are numerous unpublished reports on uranium occurrences in Colombia which are catalogued in libraries in Bogota. Large areas of Colombia have not been mapped. This is particularly true of the eastern part of the country which is underlain by Precambrian rocks of the Guyana massif, which must be regarded as an area of good potential for uranium deposits. The Santander and Garzon massifs of the Cordillera Oriental are areas which contain uranium occurrences in veins and may also contain disseminated and, possibly, Proterozoic unconformity-related deposits. Areas of the Cordillera Central should also be examined as they may also contain vein or disseminated deposits. Mesozoic sediments in the Cordillera Central and the Cordillera Oriental have some potential for sandstone uranium deposits.

The Instituto de Asuntos Nucleares (IAN) is working together with MINATOME and Empresa Nacional del Uranio S.A. of Spain (ENUSA) in prospecting central and northeast Colombia. Other companies have also explored in Colombia but no data are available.

Congo has no known uranium resources but is thought to have moderate uranium potential. The middle Proterozoic Mayumbe System is a possible correlative of the Francevillian Series of Gabon, in which several uranium deposits have been discovered and are in production. The West Congo System of upper Proterozoic age is an equivalent of the Katanga Group of Zaire and Zambia, which is notable for the Copper Belt mines and some uranium occurrences. In fact, in western Zaire, immediately to the south of the West Congo System outcrops in Congo near Mindouli, small deposits of copper, lead, zinc, arsenopyrite and uranium are known. The continental sandstones of the coastal plain region are all prospective for uranium.

Ethiopia appears to have moderate uranium potential even though no uranium occurrences are known. The country has not been adequately explored, even in a preliminary manner. The Wadera Group (middle Proterozoic?), consisting of arkoses and shales with subordinate quartzites, was deposited in a shallow basinal environment unconformably on a basement of para- and orthogneiss and metamorphosed granites. Geosynclinal zones and the Mozambique mobile belt subsequently developed on the above-described basement during the upper Proterozoic and possibly the lower Palaeozoic. Major unconformities exist within the Proterozoic and also there are numerous fracture zones and carbonaceous and graphitic sequences. These conditions could be conducive to the formation of uranium deposits. The Adigrat Sandstone is a possible partial correlative of the Karroo of southern Africa, and radioactivity of 3 or 4 times background has been noted locally. The Upper Cretaceous partially continental Jesomma Sandstone of the eastern Ogaden is prospective for uranium. A search should be made for "gypcrete" uranium deposits in southeastern Ethiopia similar to the secondary uranium deposits of the Mudugh Province of Somalia.

Gabon has a moderate to high uranium potential. Several sandstone uranium ore bodies have been discovered in the middle Proterozoic Francevillian Series of the Franceville Basin, which are in production and, possibly, there are more to be discovered. The upper Proterozoic West Congo and Noya Systems should also have potential for uranium as they are generally correlative with the Katanga Series of Zambia and Zaire and the Damara of Namibia and Botswana. The continental or marginal marine sequences of the coastal basin of Gabon are favorable for uranium.

Ghana has a moderate possibility for the discovery of uranium resources. Sandstone uranium deposits could be present in the Tarkwaian System of the intracratonic Voltaian Basin. The Tarkwaian System consists of fluviatile, deltaic, marginal marine and lacustrine clastic sediments, including arkosic sands, and was deposited on a dissected basement. Pyrite has been observed and uranium anomalies in stream water (up to 180 ppb) have been found along the Voltaian scarp. Another prospective area, in which uranium veins might be found, is the contact zone between the West African Craton and the Katangan-Damaran mobile zone.

India has a high potential for additional uranium resources. In peninsular India, the Indian Shield contains known viable deposits of uranium: some areas have not as yet been explored, so a potential for extending known deposits and discovering new ones exists, particularly disseminations in sheared metamorphic rocks, but also perhaps quartz-pebble conglomerate deposits. Basins of Gondwana continental sediments and some of later age resting on the Shield have shown some promise—particularly the Upper Cretaceous of Meghalaya—and are a favourable environment for sandstone deposits. Perhaps the most favourable and certainly the most extensive strata in which such deposits may be found are those of the Siwalik System, which outcrop in the Sub-Himalaya Belt (Himalaya Front Range). Calcrete deposits may be present in the deserts of northwest India.

Indonesia is regarded as favorable for uranium deposits on the larger islands of Sumatra, Java, and western Kalimantan—and possibly also on Timor, Bangka, and Billiton (Belitung). The sedimentary rocks throughout the geological column are marine except in much of Sumatra (especially the central and western parts), central and western Java, and southeastern Kalimantan, where coal and lignite deposits occur in some Tertiary strata. These should be investigated for lignitic or sandstone uranium deposits. In the mobile belts of the larger islands mentioned above, carbonaceous shales and other strata are invaded by granites, and uranium-bearing disseminated deposits or veins may occur in or near the granite bodies.

Libya has moderate to high uranium potential. There are two extensive basins in southern Libya, the Murzuk and Kufrah Basins, which contain continental facies ranging in age from Cambrian through Cretaceous. For example, continental Carboniferous sediments, similar to the uraniferous Carboniferous of Niger (to the south), are located on the flanks of the Murzuk Basin.

Madagascar has a moderate potential for the discovery of additional uranium resources. Such uranium would probably be discovered in the Antsirabe area in the Neogene lacustrine basin; in the Fort Dauphin area (uranothorianite); and in the Karroo sedimentary areas of the west and northwestern parts of the country.

Mali probably has moderate uranium potential. It could occur in veins similar to the Algerian vein deposits of the Hoggar (Ahaggar) in the Adrar des Iforas region of northeastern Mali. It is also possible that uranium could be found in the continental clastic facies of the Cambro-Ordovician, Carboniferous and Cretaceous Systems. There are large areas underlain by such rocks. A stratiform occurrence of uranium has been discovered on the south side of the Hoggar massif in Algeria at the base of the Cambro-Ordovician Tassili Series, and also in Cretaceous continental sandstones at Azelik in Niger.

Mexico has a moderate to high potential for additional uranium resources. The known uranium deposits occur in Mexico as dissemination and fracture fillings in volcanic rocks, at the eastern edge of the Sierra Madre Occidental, and in sandstone beds of the Gulf Coastal Plain. Large areas of Mexico are covered by acid volcanic rocks and these should be examined for further deposits of the disseminated type. Also, in addition to the continental sediments of the Pacific Gulf Coast, marginal marine and continental sediments occur in many of the states of Mexico and these should be studied, especially as many of them are spatially related to good source rocks.

Uranium exploration has been in progress in Mexico since 1957 and activity has recently been substantially increased. The Instituto Nacional de Energía Nuclear (INEN), which is responsible for all exploration, is active in many areas, in particular the states of Tamaulipas and Chihuahua. The geology is favourable and the areas so large that increased exploration is justified.

Morocco is thought to have moderate uranium potential. Prospecting was carried out in the country first by the Commission d'Energie Atomique (CEA) and later by SOMAREM (a joint Moroccan-French-American company) beginning in 1946 and terminating in 1956. Pitchblende occurrences were discovered at Azegour in 1949 and uranium mineralization has been discovered in various granites. Several Hercynian granitic intrusions of the Atlas are considered to be "fertile" (uraniferous). Radioactivity was noted in association with cobalt ores at Bou Azzer. Uranium mineralization occurs in the Permian formations at Beni Maden, apparently associated with lead, zinc, and copper. Upper Jurassic sandstones of the Middle and High Atlas regions are anomalously radioactive locally. Uranium is also present in the marine phosphate deposits of Morocco.

Mozambique has a moderate potential for the discovery of uranium resources. Refractory uranium minerals are abundant in Precambrian rocks but it is doubtful if much uranium could be recovered from such sources. The occurrences suggest, however, that the Precambrian is somewhat "fertile" and that vein or unconformity-related uranium occurrences could have been formed within the country under the proper geological conditions. A good possibility for finding uranium is in the Karroo Series in the western part of Mozambique, where the stratigraphic successions seem quite similar to the Karroo of South Africa, Zambia, and Madagascar in which there are numerous uranium occurrences.

Nigeria probably has moderate potential for the discovery of uranium resources. Past exploration by the

United Kingdom found pyrochlore occurrences in granite in Kano Province and in the Jos Plateau. It should be noted, however, that these are refractory in nature. A private company conducted airborne radiometric surveys in the Sokoto Basin and found some anomalies. No information is available concerning follow-up work. The "Younger Granites" which intrude the Precambrian, and the Jurassic (?) alkaline ring dike complexes seem to be uraniferous (up to 120 ppm). Vein occurrences associated with these "Younger Granites" are being explored in Chad at the present time. Cretaceous continental sediments are present in the eastern and northwestern parts of the country. Uranium occurrences are known at Azelik in Niger in the same sequences.

Pakistan has a moderate potential for additional uranium resources. The most favourable environment in Pakistan for the formation of uranium deposits is in the sandstones, siltstones, and conglomerates (with some interbedded clays) of the Siwalik System. These beds are traced across the northern part of the Indus Basin, and down its west side, almost to Karachi. The age ranges from upper Miocene to Pleistocene. Similar beds of equivalent age occur in the Makran Coast Range. In northern Pakistan, Carboniferous "Karakorum" shales outcrop extensively. These carbonaceous shales may bear syngenetic uranium deposits similar to those of the Alum shales of Scandinavia, or, where invaded by granitic rocks, vein or disseminated deposits might be induced.

Peru has a moderate potential for additional uranium resources. There are no known uranium deposits in Peru but this is probably a result of the low level of exploration activity and the limited knowledge of the geology of the country. Uranium does occur in association with exploitable deposits of silver, copper, lead, and zinc that are already being mined. The Mesozoic continental sediments, in particular those of the sub-Andean belt, together with Permian sediments along the Maranon-Mantaro-Apurimac-Urubamba geanticline and the Tertiary red bed sediments of the sub-Andean region appear to be favourable hosts for uranium deposits. There is also some potential for disseminated and vein deposits in the Cordillera Oriental and along the eastern slopes of the Andes.

An initial three- to five-year plan has been begun in order to define the sedimentary areas most favourable for uranium exploration. The IAEA is participating in this programme.

Saudi Arabia has a moderate potential for uranium resources. In the Arabian Shield area of Saudi Arabia, disseminations in granitic and syenitic rocks are the most likely types of uranium deposits to be found—particularly in pegmatitic facies, or in carbonatites and fenites associated with alkaline or peralkaline rocks, where they may be associated with niobium. The Phanerozoic succession is almost entirely marine, except for a few, mainly thin, nonmarine beds in the Permo-Triassic.

The areas mapped as Nubian sandstones might also be looked at, unless the arid conditions there preclude the possibility of mining and milling. Also, the Neogene deposits, especially in northeastern Saudi Arabia, may contain favourable continental beds; the less arid parts of desert basins should be investigated for possibility of uraniferous calcrete deposits.

Somalia is thought to have moderate uranium potential. The Bur area may have some possibilities for finding additional uranium deposits but it should be realized that the uranium minerals discovered to date are refractory in nature. Nevertheless, the best possible region for finding additional uranium deposits is probably the Mudugh which is underlain by favourable rocks of the Merca Series. Carnotite deposits are present in "calcrete-type" deposits in this Series. Much of the Mudugh Plateau is unexplored.

Sudan probably has a moderate possibility for finding uranium resources. At present, several international companies are engaged in uranium exploration, and uranium minerals (torbernite and uraninite) have been identified in Precambrian schists and conglomerate. There are numerous similar areas of granitic intrusions into schist in Sudan. Another favourable geologic environment would be that of the younger granite and syenite intrusives which exhibit ring structure. Occurrences of uranium have been found recently in Chad in veins cutting Tertiary "Younger Granites." The continental Nubian sandstones, which cover the northwestern part of the country, certainly are prospective for uranium.

Thailand has a moderate potential for uranium resources. The continental beds of Jurassic, and possibly Cretaceous, age of the Khorat Group, which is exposed mainly in the Khorat Plateau of northeast Thailand, appear to be the most favourable rocks for uranium deposits. In the southern part of peninsular Thailand there are at least eight basins containing lignite-bearing continental beds of the Tertiary Krabi Group. Source rocks of these sediments are probably, in part at least, gneisses and granites. Some of the latter are tin and tungsten bearing; some are anomalously radioactive so that the Tertiary strata should be favourable for lignitic or sandstone deposits, or both.

Turkey has a moderate potential for additional uranium resources. To date all uranium resources have been found in Tertiary rocks, mainly in Neogene sandstones, but also some in Eocene basal conglomerate and in volcanics. Numerous anomalies have been found in these, and in plutonic and metamorphic rocks. Past exploration achievements should be reviewed for the purpose of developing a new plan for further assessment of the uranium potential for Turkey.

Uganda is considered to have moderate uranium potential. Based on the general geology of the country, it is thought that its southwestern part, which contains Proterozoic arenites and Mesozoic-Cenozoic volcanics and sediments, is the most favourable for the occurrence of uranium. This supposition is supported also by the fact that most of the radioactive anomalies found in Uganda are located in that region.

Venezuela has a moderate to high potential for uranium resources. There are no known uranium deposits in Venezuela, but the Precambrian rocks there, which have been little studied, are considered to be very interesting with, in particular, the possibility for discovering Proterozoic unconformity-related deposits below the Roraima Series. The geologic conditions above and below the sub-Roraima unconformity are very similar to those found in northern Saskatchewan, Canada, and in the Northern Territory of Australia. The Guyana massif may also contain economic deposits of uranium in quartz-pebble conglomerates. In addition, there is a more limited potential for sandstone, disseminated, and vein uranium deposits in the Andean areas.

Zaire is rated as having a high uranium potential. Uranium occurrences are known in the upper Proterozoic platform sediments of Katanga in the Copper Belt and were worked at the famous Shinkolobwe Mine. Correlatives of the middle Proterozoic uraniferous Francevillian Series of Gabon are known in Zaire. Mesozoic continental clastic sediments of the Congo Basin are thought to have uranium potential and the same can be inferred regarding the Tertiary Kalahari sands.

Zambia is believed to have a moderate to high potential for discovering additional uranium resources. Such resources could be found in the Katanga and Karroo Systems where uranium occurrences are already known. In the Kalahari sands both sandstone uranium deposits and uraniferous calcrete deposits could be found.

Zimbabwe-Rhodesia is considered to have a moderate potential for the discovery of uranium resources. The principal area of interest would be the northwestern one-third of the country, to some extent in the upper Proterozoic low-grade metamorphosed Lomagundi "Copper Belt Type" platform sediments, but more particularly in the extensive areas of poorly exposed Karroo sediments.

Factors Affecting Future Nuclear Development

First, it is important to repeat that, for those countries listed as having Speculative Resources of uranium, there is no guarantee that these resources will be discovered or, if discovered, that they can be made available. Serious constraints may well arise on many fronts.

Restriction of access to the favourable areas for the purpose of exploration may come about in many ways. Some governments have not yet formulated a uranium development policy and are unsure of how to negotiate with international mining organizations. Governments that do have plans for their own nuclear power programmes are often unwilling to open their country to exploration by developers from the advanced countries until their own uranium needs are guaranteed. In both instances, inaction can delay the realization of the full potential of some favourable ground. Geographic constraints are also very great in many countries. Desert conditions clearly exercise grave constraints on exploration and development, but they can be overcome if the predicted rewards are progressively confirmed, as has been shown in Arlit, Niger. Tropical jungle or rain forest conditions are even more difficult to overcome and in both desert and jungle the time required for exploration and development is very much greater than it is in regions with more accessible and milder terrain. Inadequacies in uranium exploration techniques and the lack of trained manpower in many countries will be an obvious and serious constraint for many years. Conflicts in land use where discoveries have been already made is an obvious problem, not only in developing countries but in other countries where such constraints, publicized by environmental groups, have delayed systematic and well programmed development. The incentive to explore will be strongly influenced by the forecasts of market prices for uranium. Although showing a spectacular rise between 1974 and 1976, uranium prices have since levelled off, so that in the last two years the rate of rise of uranium prices has not matched the world inflation rate. If this continues, it will be an increasing constraint on exploration.

Many areas favourable for uranium discoveries are obviously in developing countries, many of which do not have the resources to adequately evaluate their potential. Compared to the more industrialized countries, the extent of exploration effort in most developing countries is very small. Increased assistance to such countries for the development of uranium resources should contribute to their economic development. Increased international and bilateral cooperation between industrially advanced countries and developing countries, and the encouragement of investment by industrial companies or by joint ventures, would enhance the exploration and production of uranium resources in the developing countries. Such actions would also contribute to the mutual satisfaction of the power requirements of both developed and developing countries in the 21st Century.

Another factor that should be considered as the 21st Century approaches is that at present approximately 85 percent of the world's Reasonably Assured and Estimated Additional Resources of uranium are in Australia, Canada, France (and French controlled sources), South Africa and the United States of America. Therefore, unless there is the international and bilateral cooperation necessary for finding and proving resources in developing countries, knowledge of reserves may remain incomplete because these countries also have very high Speculative Resources. In any case, the power-energy world political situation in the 21st Century, based on uranium-nuclear power, might well be very different from that of today, based, as it is, largely on petroleum.

CONCLUSIONS: URANIUM FOR THE 21ST CENTURY

It is assumed that the total cumulative world demand for uranium to the middle of the 21st Century will be up to a maximum of 20 million tonnes. At the present time an apparent deficit, beyond known resources, of some 17 to 18 million tonnes exists; this might be the target for the world's geologists and explorationists as the 21st Century approaches.

Thus, two principal lines of policy seem to be indicated: (1) intensification of the search for new conventional type, low-cost uranium deposits in geologically favourable areas of the world and (2) concentration on developing economically acceptable technology for extracting uranium from the known low-grade uranium sources.

The Phase I IUREP study indicates that substantial areas in both the industrialized and the developing countries are geologically favourable for making new discoveries of uranium deposits. Therefore, despite the many technical, economic, and political constraints that presently exist, the top priority must be given to exploration, and much of it should be done in developing countries. Exploration lead times are so great that action is required immediately.

The total world power-energy requirements up to the middle of the 21st Century are, however, so great that it would also be prudent to give considerable emphasis to research and development of improved processes for the recovery of uranium from low-grade sources.

Based on the evidence of the past record of both geologists and mineral recovery technologists there is every reason to be hopeful that the target for the 21st Century can be achieved – provided that, starting immediately, sufficient effort and expenditure are employed.

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ANNEX I

List of IAEA publications relevant to uranium subjects

(1) PROCESSING OF LOW-GRADE URANIUM ORES
Panel Proceedings Series – STI/PUB/148
Proceedings of a Panel held in Vienna in 1966

(2) NUCLEAR TECHNIQUES AND MINERAL RESOURCES
Proceedings Series – STI/PUB/198
Proceedings of a Symposium held in Buenos Aires in 1968

(3) URANIUM EXPLORATION GEOLOGY
Panel Proceedings Series – STI/PUB/277
Proceedings of a Panel held in Vienna in 1970

(4) THE RECOVERY OF URANIUM
Proceedings Series – STI/PUB/262
Proceedings of a Symposium held in São Paulo in 1970

(5) URANIUM EXPLORATION METHODS
Panel Proceedings Series – STI/PUB/334
Proceedings of a Panel held in Vienna in 1972

(6) RADON IN URANIUM MINING
Panel Proceedings Series – STI/PUB/391
Proceedings of a Panel held in Washington, D.C. in 1973

(7) FORMATION OF URANIUM ORE DEPOSITS
Proceedings Series – STI/PUB/374
Proceedings of a Symposium held in Athens in 1974

(8) RECOMMENDED INSTRUMENTATION FOR URANIUM AND THORIUM EXPLORATION
Technical Reports Series No. 158 – STI/DOC/10/158

(9) THE OKLO PHENOMENON
Proceedings Series – STI/PUB/405
Proceedings of a Symposium held in Libreville in 1975

(10) URANIUM ORE PROCESSING
Panel Proceedings Series – STI/PUB/453
Proceedings of an Advisory Group Meeting held in Washington, D.C. in 1975

(11) RECOGNITION AND EVALUATION OF URANIFEROUS AREAS
Panel Proceedings Series – STI/PUB/450
Proceedings of a Technical Committee Meeting held in Vienna in 1975

(12) EXPLORATION FOR URANIUM ORE DEPOSITS
Proceedings Series – STI/PUB/434
Proceedings of a Symposium held in Vienna in 1976

(13) RADIOMETRIC REPORTING METHODS AND CALIBRATION IN URANIUM EXPLORATION
Technical Reports Series No. 174 – STI/DOC/10/174

(14) DISCUSSIONS OF THE URANIUM GEOLOGY WORKING GROUPS
Technical Reports Series No. 183
Proceedings of discussions held in Sydney (IGC) in 1976

(15) GAMMA-RAY SURVEYS IN URANIUM EXPLORATION
Technical Report Series No. 186

(16) EVALUATION OF URANIUM RESOURCES
Panel Proceedings Series – STI/PUB/507
Proceedings of an Advisory Group Meeting held in Rome in 1976

(17) GEOLOGY AND EXPLORATION OF URANIUM DEPOSITS IN AFRICA
Panel Proceedings Series – STI/PUB/509
Proceedings of meeting held in Lusaka, Zambia, November 1977 (in press)

(18) URANIUM GEOLOGY OF LATIN AMERICA
Panel Proceedings Series
Proceedings of meeting held in Lima, Peru, December 1978 (in press)

(19) URANIUM ORE RESERVE ESTIMATION MANUAL
Technical Report Series (in press)

Discussion

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As former General Director of the Mineral Research and Exploration Institute of Turkey (MTA), I should like to congratulate the United States Geological Survey personnel on the Centenary of the Geological Survey. In taking this opportunity, I should like also to thank you for the technical assistance of the USGS to the MTA during the last 20 years in providing consultancies and training programmes and for the assistance in the establishment of new sections and in the strengthening of the organization. This cooperation between the two organizations also has created a good friendship among the personnel of each. On this very happy occasion I should like to wish all the people of the U.S. Geological Survey good luck and success for the future.

With regard to the technical papers, I should also like to congratulate Mr. Bender and Mr. Cameron on the excellent presentations of their very interesting papers which I enjoyed hearing.

There is a great need for natural resources in the future, that is to say, in the 21st Century. Yet I believe that if we consider the whole world with regard to natural resources exploration, we have literally only scratched the surface of the Earth. In fact, most areas have been only superficially surveyed. We not only have to know the Earth's surface but we also have to explore in depth from the surface of the Earth, that is, down to 1,000 meters.

Geologic prospecting and exploration are difficult in many parts of the Earth. Some areas are covered by sea, lakes, swamps, forests, or thick vegetation; some areas are very broken up by tectonic forces and, in some cases, this rough terrain handicaps exploration work. For instance, most of eastern Turkey is covered by a lava layer about 80 m (200 ft) thick, which currently prevents mineral prospecting and exploration. Therefore, in general, there is a need for improved exploration techniques and methods and for larger equipment and more sensitive instrumentation. Then more thorough prospecting and exploration of our natural resources could proceed under varying conditions.

Controversy always surrounds calculations of world resources based on figures from our present information collection systems. In order to maintain cumulative data for evaluation and thus produce sound and reliable information, it is essential that a world-wide Data Center be established. At such a Center it would be possible to collect all available scientific information, such as geological and geophysical data. Then digital commodity maps, such as a world oil map, a world coal map, or a world uranium map could be prepared by evaluating all the geoscience data stored in the computer systems. It might be possible to indicate new geologically favourable areas on these maps by interpretation of statistical data. Possibly this sound information and these digital commodity maps could also serve for making long-term national programming, as well as indicating national or international investment possibilities for states or private enterprises. Such maps could be revised about every 5 years for that purpose. World-wide cooperation in free collection of data is, of course, requisite for the success of such a Geodata Center.

Coal: With resources of 12,000 billion tons, coal seems to be the world's most promising energy resource for the next century and may meet world demands for the next 100 to 130 years. However, there is still a lot of work to be done to prove these resources and also to discover new coal or lignite resources in lesser known parts of the Earth, especially to explore underground coal or lignite seams. As coal and lignite are the most plentiful of the known resources, it is important to make full use of coal. That in turn means that technology for the utilization of coal by gasification and liquefaction becomes very important. That is to say, many coal projects and new investments and much drilling equipment is needed.

Oil: The present known world oil reserves of 260 billion tons of recoverable resources, of which 90 million tons have been proven, are just about enough for the next 20 to 40 years. The discovery of new oil fields, therefore, is the most important aspect of work that geoscientists can do now for the world's future. There is always a tendency to explore in the vicinity of well-known oil producing areas. Although that is normal procedure in this type of exploration, I feel that it is time to try to discover new oil fields outside the well-known onshore and offshore areas by using the most advanced exploration technology and geoscience.

The industrial world and all mankind are facing serious energy shortages. It is therefore necessary for all nations to combine their efforts and to cooperate in the discovery of new oil fields. In this respect, a broader outlook, complete cooperation, and civilized understanding are essential. We have to consider not only one nation's need but those of all mankind.

Geothermal Energy: The present geothermal energy contribution of 1,500 MW of electricity and 6,500 MW equivalent of nonelectricity is insignificant. We must assume that there is hidden potential energy stored underground and we must use improved methodology and technology to study and identify such hidden energy sources, including possibilities in the volcanic areas. In this respect, volcanology studies may prove useful. Also, dry hot rock technology should be pursued.

Uranium: Based on differing figures, known world uranium reserves are said to range from 2.25 to 6 million tons. Assuming the larger identification is correct, the projected world demand for 23 million tons in the 21st Century leaves a 17-million-ton gap. If we then consider that only about 3 million tons of uranium have been discovered in the past 30 or 40 years, we may assume that it will be very difficult to close the demand-supply gap—perhaps almost impossible. However, it is also possible to make new discoveries in the less known areas. Years ago, there was a gold rush and, according to my interpretation, there was also a uranium rush in 1940 and again in the 1950s. Now what we need is another uranium rush in the coming years.

I feel that some national governments do not give high priority to uranium exploration; first, because they do not have a programme for nuclear power plants; second, because they consider uranium a strategic commodity and not a commercial commodity that will meet the immediate economic needs of the country and, third, because some of these countries lack professional workers and equipment.

In the case of the question put forward by Mr. Cameron, that is, whether we should concentrate our efforts only on the discovery of new uranium resources or whether we should confine ourselves only to up-grading the already known low-grade ores, I should like to say that we are not in a position to make choices. We should explore and discover new ore deposits as well as evaluate the known low-grade uranium resources.

To achieve the aim of closing the foreseen gap, it is necessary:

1. To draw the attention of the governments to the importance of uranium exploration and training;
2. To give high priority to long-term national exploration programmes;
3. To prepare training programmes for national professionals;
4. To ensure cooperation for the exchange and collection of information amongst nations and international organizations;
5. To further the improvement of exploration technology and to introduce new and more precise instruments for the detection and evaluation of deeper zones;
6. To promote extensive technological research for the concentration and evaluation of low-grade uranium ores by the International Atomic Energy Agency or by countries having advanced technology or to establish an entirely new international research center specifically for this purpose.

With regard to nuclear energy sources, it is, of course, also necessary to consider thorium resources. The improvement of reactor building technology and the introduction of fast breeders may open the way for the introduction and use of thorium in nuclear-energy production, thus possibly closing the nuclear fuel gap. Thorium exploration and evaluation, in this respect, should not be neglected.

Conclusion: In closing, I should like to point out, once again, that there are of course potential resources but, also, that a tremendous task lies ahead for us—to identify these resources and to make them recoverable, proven reserves. In addition we must discover new resources and reserves. To evaluate what nature provides for us is, therefore, an urgent matter of time, money, skill, effort and close cooperation amongst nations and international organizations. There is plenty of work, not only for geologists, but also for all geoscientists who will be required to accomplish this great task of putting the potential resources of nature into the service of mankind.

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Discussion

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Let me begin by thanking Dr. Bender and Dr. Cameron for their kind remarks about the U.S. Geological Survey and especially for their comprehensive and authoritative analyses of their respective subjects. Both speakers have submitted much longer and more detailed papers for publication in the proceedings of this symposium than could be presented here. We thank them on the one hand for making the fuller versions available for the record and on the other hand for their good efforts in summarizing their salient points here today.

I sympathize with the great uncertainties expressed by Dr. Cameron with respect to the projections as to future demand for uranium. Not only are there ordinary uncertainties encountered in making forecasts of future consumption—and these are difficult enough—but there are two others that are extraordinary. The first relates to the public's appraisal of the risks associated with nuclear energy, posing the very real question as to whether or not the public will wish or permit any significant production of nuclear energy, regardless of what may be the shortage from other sources. The second question is an extension of the first, namely will the breeder reactor—which holds the potential for a many-fold increase in the fuel value of uranium—be judged safe enough for development, and if so can it be brought into commercial use in time to effect a significant reduction in the demand for uranium ore. Depending on the outcome of these uncertainties, the future demand for uranium might be less than the high forecast, but I am inclined to agree with Dr. Cameron that it is prudent for geologists to assume that the opposite will be true and to take the high demand forecast as a target for exploration. Inasmuch as geologic research and exploration costs are usually only a small fraction of development and production costs, such an assumption will not be costly to the public if it proves unwarranted.

Although the gap between known, recoverable uranium resources and the high forecast of cumulative demand to the middle of the next century is huge—calling for the discovery of about 6 to 9 times as much ore as is now known—I am impressed that uranium geologists have been able to identify as targets for exploration speculative resources several times larger than those already known. For many minerals the most imaginative estimates of undiscovered resources fall into a much lower ratio with respect to known deposits. The demand for uranium, however, is still relatively new compared to many other minerals and perhaps exploration targets are easier to identify for uranium than for minerals long sought after. This is supported by Ralph Erickson's estimate—based on the crustal abundance method that I suggested some years ago—that world potential recoverable resources of uranium may be on the order of 90 million tons. Dr. Cameron stressed that the speculative estimates he reported should not be used for planning purposes and even more caution is called for in the use of the estimate based on crustal abundance. What is significant is that there are reasonable bases for suggesting that undiscovered minable deposits remain to be found and that further exploration is worthwhile.

This observation also applies to all of the fossil fuels and to geothermal energy, as Dr. Bender has indicated. Even with respect to petroleum, which, as Dr. Bender indicated, is a more fully explored resource than most others, undiscovered resources have a potential that justifies exploration. And, as the recent discoveries in Mexico show, in some areas the undiscovered potential may prove to be larger than can be "guesstimated" now. As earth scientists, we can see both challenge and opportunity for years to come in adding to usable resources through research and exploration. But we cannot think that success in our efforts alone will satisfy future world needs for energy. Dr. Bender has pointed out how much more quickly our fossil fuels will be depleted if consumption grows at 4 percent annually instead of remaining at present rates. I like to put this in even more dramatic terms by pointing out that a billion-year supply of anything, if used at present rates, would be exhausted in a mere 584 years if used instead at only a 3 percent rate of annual increase. Clearly, help in meeting our energy needs for the future must come also from other sources, in particular from the development of the means to achieve more efficient and conservative use of energy, to use other forms of energy that are now beyond economic reach, and to stabilize world population. Nevertheless, research and exploration do have major contributions to make in meeting future needs for resources if they are vigorously pursued.

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Problems of Energy Development in India During the 21st Century

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INTRODUCTION

It has been estimated that man has consumed about 18 quintillions of energy ($Q = 2.93 \times 10^{14}$ kWh $= 2.52 \times 10^{17}$ kcal) from the 1st Century A.D. until the middle of the 20th Century and that half of this energy has been used during the last 100 years alone (Kashkari, 1975). Moreover, it has been estimated that the total energy requirements of the world will accelerate to 100 Q during the next century (Majumdar, 1979).

Independently, a United Nations Committee has estimated that the known reserves of energy are only on the order of 24 Q. Even taking into account the possible, probable, marginal, and submarginal fuels, the world's total energy resources may not exceed 50 Q. It is, therefore, evident that man will run short of conventional energy fuels by the middle of the next century.

The current energy crisis has, therefore, been a blessing in disguise for the world community as a whole. It has afforded an unique opportunity for individual nations to have a closer look at indigenous resources as well as to assess and harness any new energy sources that may substitute for fossil fuels. There is a growing realisation that the future of mankind will depend, not on one or two energy sources, but on a "basket" of them. Energy is available everywhere in a variety of forms, and sooner or later it should be possible to exploit that variety in a manner suited to the needs of all people.

It is in this context that we present an outline of India's energy resources and the problems and challenges of the energy situation that we will meet in the next century.

AVAILABILITY OF ENERGY RESOURCES

Commercial Energy

India is among the few countries in the world that is endowed with coal, oil, natural gas, nuclear fissionable material and hydel (hydroelectric) potential. The presently known quantity of commercial energy sources is given in table 1.

Table 1 Known quantities of nonrenewable and renewable commercial energy sources in India, 1978
[Indian coal has an average heat value of 5,000 kilocalories per kilogram.]

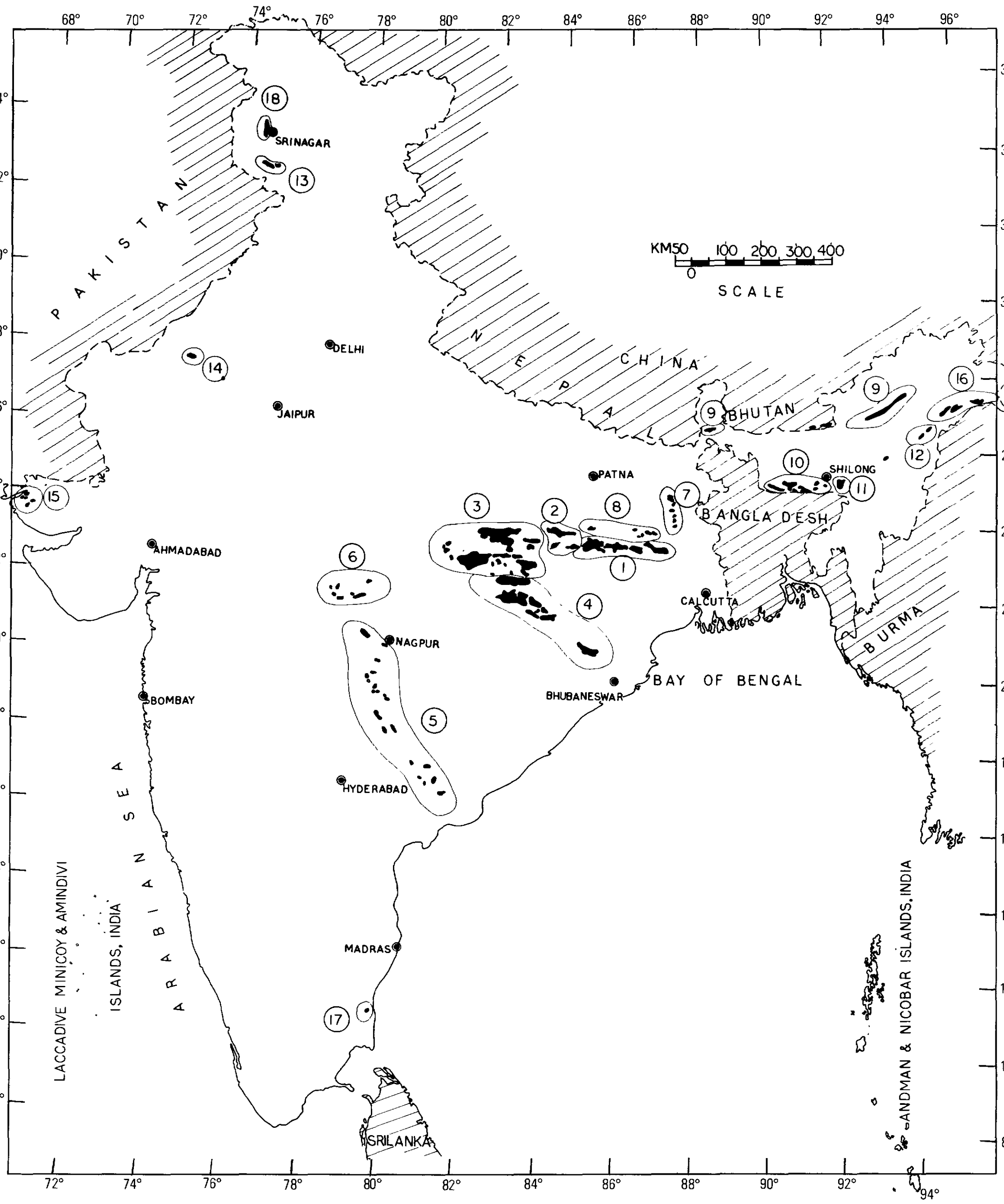
RESOURCE	PROVED	POTENTIAL	ESTIMATED TOTAL	COAL EQUIVALENT IN M. TONNES
Nonrenewable				
Coal (metric tonnes)	26,300	85,500	111,800	112,850 (coal and lignite)
Lignite (metric tonnes)	1,870	230	2,100	
Oil (metric tonnes)	1,500	4,700	6,200	12,400
Natural gas (billion m³)	-----	-----	6,500	11,700
Nuclear (billion kWh)	-----	-----	2,200,000	2,200,000
Renewable				
Hydel (billion kWh)	-----	-----	700	700

Coal: Estimates of the resource position indicate that coal will make a significant contribution not only to our growing needs for direct energy but also to the gas, chemical, and metallurgical industries. The major workable coal deposits occur in two stratigraphic horizons: (1) the Lower Gondwanas of Permian age, and (2) the coal and lignite deposits of Tertiary age (fig. 1). About 97 percent of the reserves occur in the Gondwana deposits of peninsular India.

A 1978 estimate (India, Geological Survey) puts the resources at 114 billion tonnes of coal and lignite in seams more than 0.5 metres thick, occurring to a depth of 1,200 metres. Of this, a total reserve resource of 88,527 million tonnes has been estimated in seams 1.2 metres or more in thickness, occurring to a depth of 600 metres, which are currently regarded as workable. Of these 88,527 million tonnes, only 30 percent is under the "proved" category (Geological Survey of India, 1971). The balance will have to be established for exploitation by further exploration.

Oil and Gas: Sedimentary basins occupy an area of about 1.4 million square kilometres (about 42 percent of India's total land area). Additionally, the offshore sedimentary basins have an area of 0.32 million square kilometres with a water cover to 200 metres deep (fig. 2). Altogether the prospective areas in the basins occupy 1.0 million square kilometres onshore and 0.32 million square kilometres offshore.

Prasad's 1977 studies indicate that the undiscovered resources in place are on the order of 6.20 billion tonnes of oil and 6,500 billion cubic metres of gas, equivalent to 6.50 billion tonnes of oil. Including the offshore areas, 59 percent of the potential occurs in the western part of the country, 38 percent in the eastern part, and 3 percent in the



PERMIAN (Lower Gondwana)

1. Damodar Valley
2. Koel Valley
3. Sone Valley
4. Mahanadi Valley
5. Godavary Valley
   a. Wardha Valley
   b. Singareni area
6. Satpura Basin
7. Rajmahal
8. Deogarh Hazaribagh Group
9. Darjeeling and N.E.F.A.

EOCENE (coal fields)

10. Garo Hills
11. Khasi Jaintia Hills
12. Mikir Hills
13. Jammu

EOCENE (lignite fields)

14. Rajasthan Palana
15. Gujarat (Kutch)

OLIGOCENE THROUGH PLEISTOCENE

16. Upper Assam
17. Neyveli Lignite
18. Kashmir Lignite

Figure 1 Location of major workable coal and lignite deposits in India.

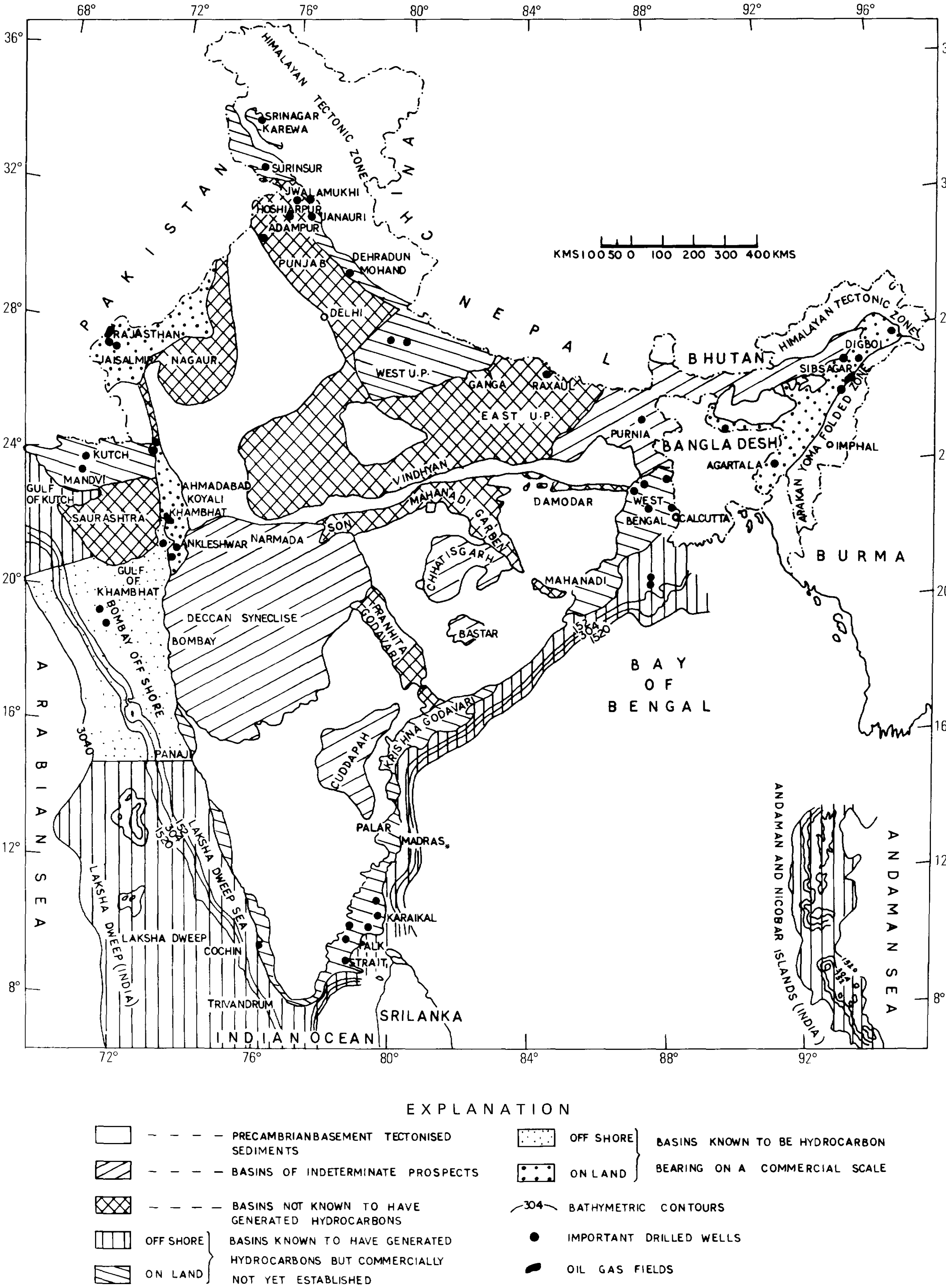


Figure 2 Onshore and offshore sedimentary basins of India.

northern part. The prognostic recoverable reserves are, however, estimated at 1.5 billion tonnes of oil and 4,500 billion cubic metres of gas. Of this, the location of nearly 0.5 billion tonnes has been established so far. The present annual production of oil is about .011 billion tonnes. So far as gas is concerned, recoverable reserves amounting to 160 billion cubic metres have been established. Of this, about 15 billion cubic metres of gas have been produced so far. The current production of gas is on the order of about 2.6 billion cubic metres of which about 40 percent is flared.

Nuclear Energy: Reasonably assured uranium reserves in India are on the order of 22,000 tonnes U_3O_8 with an additional inferred reserve of 24,000 tonnes U_3O_8. Besides, there are thorium reserves of about 0.45 million tonnes, which are the largest in the world. The presently known proved and inferred reserves of uranium would support only 10,000 megawatts of installed nuclear capacity for 30 years, based on the current type of nuclear reactors. If fast breeder reactors are operating by the turn of the century, the potentially available energy from the presently known proved and inferred reserves of uranium would increase substantially to support 1,000,000 megawatts of installed capacity for 30 years (yielding energy amounting to 200×10^3 billion kilowatt hours of electricity) and that from the thorium reserves would be practically unlimited generating electricity to the amount of 2.0×10^6 billion kilowatt hours (Fuel Policy Committee, 1974). The currently installed nuclear capacity is about 640 megawatts annually.

Hydroelectric Power: Based on a 1953-58 survey, India's total hydroelectric potential was estimated at 41,155 megawatts at 60 percent load factor (Fuel Policy Committee, 1974). This potential is distributed in the different regions of the country as shown in figure 3 and table 2.

Table 2 Estimated hydroelectric potential of India by region

REGION	MW AT 60% LOAD FACTOR	BILLION kWh	PERCENT OF TOTAL POTENTIAL
Eastern	2,694	14.2	6.5
Northern	10,731	56.4	26.1
Western	7,189	37.8	17.4
Southern	8,097	42.6	19.7
Northeastern	12,464	65.4	30.3
Total	41,155	216.4	100.0

There is scope for possible upward revision of the potential in the Himalayan area (region 2, table 2). In fact, investigations carried out by some of the Northern States have shown that the potential is likely to be much higher. Moreover, the "seasonal" energy potential that would be available largely at the sites of the multi-purpose projects in peninsular India has not been included in the above estimate. In view of these additional factors, a later estimate puts the potential at 80,000 megawatts at 60 percent load factor (Parik, 1976). Of this, only about 11 percent (9,000 megawatts) has been developed and capacity for another 5,600 megawatts is under development. Thus a total potential of 14,600 megawatts is likely to be developed by the end of the Sixth Plan Period (1982-83).

Noncommercial Sources of Energy

Over 75 percent of India's population lives in villages where enormous quantities of firewood, vegetable waste, and cow dung are burnt for the supply of domestic energy. (The rural energy economy is also largely nonmonetised.) Even today about half of the total energy consumed in the country comes from such sources. This undisciplined fuel consumption brings in its trail indiscriminate deforestation that leads in turn to the removal of precious top soil—along with large quantities of plant food—and to the silting of river beds and storage reservoirs. It deprives the soil of valuable organic manure as well.

Firewood: About 23 percent of India's land mass is forestland: less than the desired goal of 33 percent. The estimated potential of wood is not more than 2,000 million tonnes. The reckless use of this free forest wealth by the rural population for domestic energy requirements has not only created a serious ecological imbalance but has also set in motion the process of desertification. This hazardous trend must be checked, and to achieve this objective it is essential that social forestry be adopted on a wide scale, as recommended by the National Commission on Agriculture.

Cow Dung: With a large cattle population (230 million head as per 1966 census), cow dung is an important potential source of energy for the production of both improved fuel in the form of bio-gas, and as fertilizer. The estimated annual production of dry dung was 170 million tonnes in 1966 which increased to 324 million tonnes in 1975-76. The present estimated production of dry dung is on the order of 350 million tonnes per annum (equivalent to 1,750 million tonnes of wet dung). This is capable of generating 70 billion cubic metres of gas annually in bio-gas processing plants. Even if only 25 percent of this is really available (keeping in view the limitation of collection and utilisation), the potential gas generation could be on the order of 17.5 billion cubic metres. This is equivalent to 9.6 billion cubic metres of natural gas. With higher utilisation of cow dung, the actual potential would be much higher.

Vegetable Waste (Bagasse): This includes sawdust, paddy husk, coconut shells, dry leaves, and other vegetable refuse. There is not likely to be any constraint in its availability in view of the projected increase in our agricultural output. Its consumption as fuel was about 38 million tonnes in 1970-71. Plant residues from the biomass such as bagasse, which is widely used as fuel, can be even better utilized, both in the domestic and in the industrial sectors—at sugar mills, for instance. About 14 percent of all sugar cane that is crushed in India is produced as bagasse, and its availability as fuel was estimated at 14 million tonnes in 1973-74.

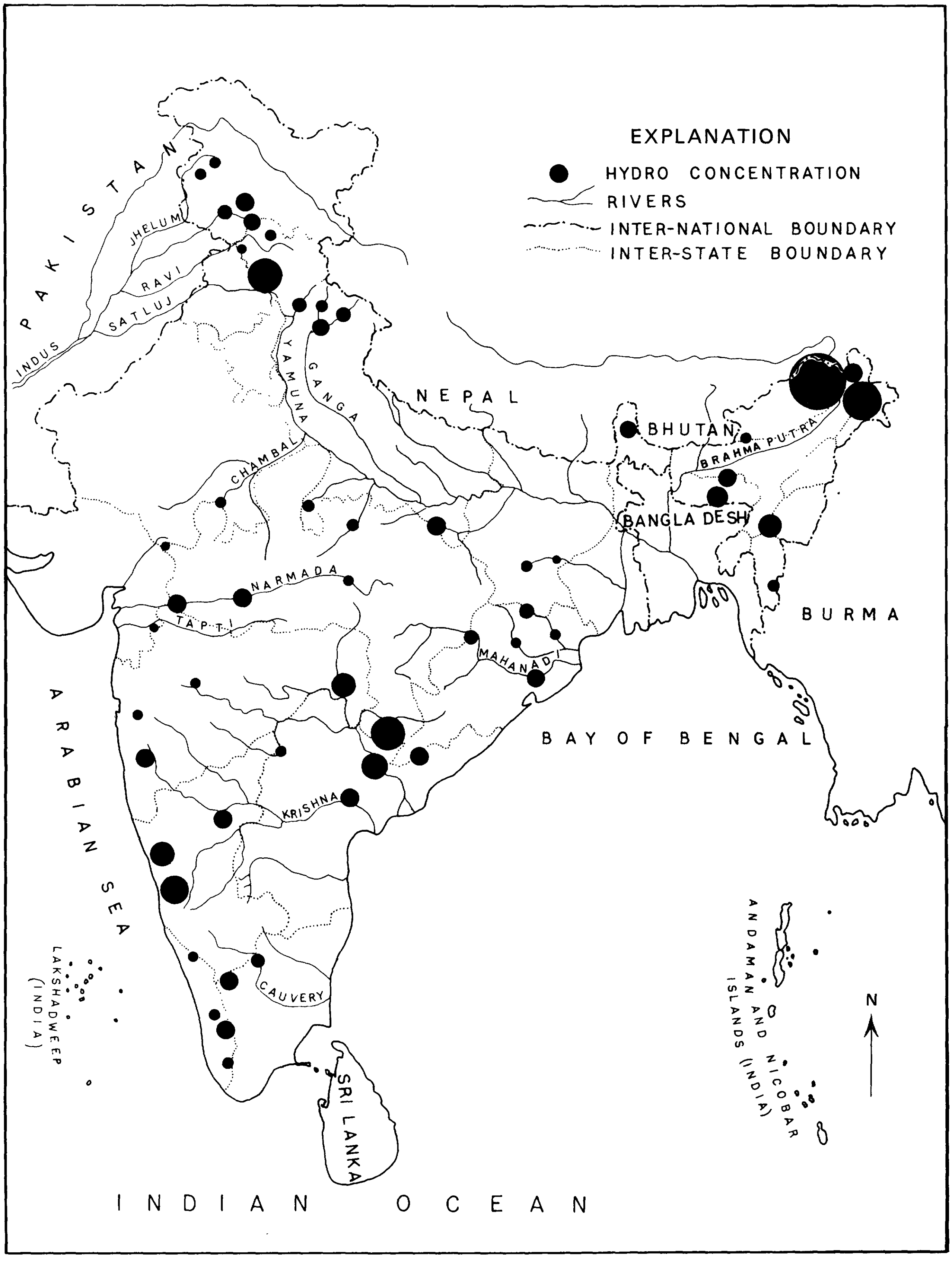


Figure 3 Distribution of hydroelectric resources of India by region.

Nonconventional Sources of Energy

These sources include solar energy, geothermal energy, tidal power, and windmills. Such resources are either renewable or virtually inexhaustible and are nonconventional in the sense that they are not yet in widespread commercial use.

Solar Energy: In a tropical country like India where the sun shines brilliantly for nearly 300 days in the year, the harnessing of solar energy has tremendous potential. The average intensity of solar radiation received on the ground in India is some 600 calories per square centimetre per day or about 10 billion kilowatt hours per square kilometre per year. This works out to an energy delivery equal to 2.5 million kilowatt hours per square kilometre per day. Even with only 10 percent efficiency of conversion to electricity, this would mean that each square kilometre would yield 0.25 million kilowatt hours per day. Total generation of electricity in 1979–80 is expected to be on the order of 112 billion kilowatt hours. Conceivably this could be generated from solar energy received in an area of about 1,120 square kilometres, that is about 0.035 percent of India's total land area of 3.2 million square kilometres. The potential is, therefore, enormous.

Solar energy can be either (1) harnessed directly as thermal energy, or (2) converted to electricity through the photovoltaic process, or (3) converted to biomass as fuel by stimulating biological processes. Significant developments have already taken place in all these areas. Applications of solar energy include water heating, desalinization of sea water, food drying, cooking, manufacture of salt, energizing of solar cells, refrigeration, air conditioning, water pumping, and conversion through plants into liquid and solid transportable fuels.

Geothermal Energy: Hot springs, which are sources of geothermal energy, occur in four regions of the country. But out of a total of 253 springs, only 103 have a temperature above 37° C. Although the total power generation potential is negligible, some of the sources are in advantageous localities, as in the northwest in the northern latitudes. This geothermal potential cannot possibly be ignored in the northwest, but it will not, however, have any impact on the nation's overall energy requirement.

Tidal Power: Despite the fact that India has a very long coastline, there is potential for power generation in only three areas, where the tidal range exceeds about 5 metres. The total potential may not exceed about 1,000 megawatts and the actual energy that can be exploited economically would be much less. Therefore, this also will not have any significant impact on our overall energy requirement.

Windmills: Extensive windmill data available in the Indian Meteorological Department from over 400 meteorological stations indicate that such mills can be installed in certain parts of the country where wind speeds over 10 kilometres per hour are prevalent; for example in parts of the coastal regions, Rajasthan, Gujarat, Maharashtra and Karnataka. Studies at Hindustan Aeronautics Ltd. (HAL) indicate that 10,000 kilowatt hours of electricity can be generated annually at stations with an annual mean wind speed of 13 to 17 kilometres per hour (Krishnan, 1976). Those with wind speeds of 9.5 to 12.5 kilometres per hour and 6.5 to 9.5 kilometres per hour are estimated as likely to generate 8,000 kilowatt hours and 4,500 kilowatt hours a year respectively. Today, the wind power used is insignificant compared to that from other conventional energy sources. Windmills can become a significant source of pollution-free energy production in rural India, particularly in the tracts where there is a potential for development of water pumping systems for irrigation. So far the problems of cost and energy storage have prevented full-scale development of wind power.

Chemical Sources

A major thrust in research and development efforts has been directed toward assessing the potential in chemical sources of energy, particularly of those that could lead to reduced dependence on petroleum products like motor gasoline, high speed diesel oil (HSDO), and kerosene. Nonconventional sources of energy are also being evaluated. The potential R&D areas that have been identified are

1. Battery-powered vehicle (initially based on lead-acid battery technology)
2. Development of fuel cells for rural electrification including
   a. The sodium sulphur battery
   b. The metal air cell
   c. The H_2O_2 cell
   d. The lithium cell

PLANNING FOR PRODUCTION OF COMMERCIAL ENERGY UP TO THE YEAR 2000

Long-term forecasting of energy requirements is beset with difficulties, and besides, such a forecast is not likely to be accurate because of unforeseen circumstances—political, economic, or social. However, an attempt has been made to forecast the likely requirements for commercial energy up to the year 2000. No attempt has been made to forecast non-commercial energy requirements by 2000 A.D. in view of the possibility that any production rise in this sphere is not likely and may even come down with the passage of time as conventional sources penetrate the rural sector.

Figures on the actual production of commercial energy in 1973–74 and 1978–79 and the production programme envisaged up to the year 2000 are based on formal and informal estimates, as shown in table 3.

Table 3 Production figures for commercial energy in India, 1973 to 2000

[Oil and gas production in the first year column is given only for the 1973 calendar year and the hydel and lignite figures for 1978–79 are provisional.]

SOURCES	1973–74	1978–79	1982–83	1987–88	1999–2000
Coal (M.T.)	77.87	102.06	150.00	208.00	370.00
Lignite (M.T.)	3.3	3.9	6.5	10.7	12.0
Oil (M.T.)	7.2	11.0	16.5	22.0	30.0
Gas (billion m^3)	1.6	2.6	11.2	15.8	43.6
Hydel (billion kWh)	29.0	48.0	77.0	89.0	105.0
Nuclear (billion kWh)	2.4	3.2	8.2	8.8	10.5

Coal: The Working Group on Coal and Lignite, constituted by the Government of India in 1978, has estimated the requirement of coal up to 1987–88 and, keeping in view the latest trend in production, the figures have recently been modified to some extent. It is expected that a large number of projects now under construction and in which investment has been or is being made will yield good results and a high level of growth by the end of the Sixth Plan, that is, by 1982–83. During the Seventh Plan, the growth rate is likely to be less spectacular and may not exceed 7 percent—against a little more than 10 percent during the Sixth Plan period. With a growing economic base and because of difficulty in providing staff for technical infrastructure, a growth rate of 5 percent has been presumed during the period 1987–88 to 2000 A.D. The estimate of coal production thus arrived at broadly agrees with the estimates prepared by other authorities on the subject.

The growth rate for India has been forecast at 3.8 percent by the end of this century in "World Energy Resources, 1985-2020" (Petres and Schilling, 1978), and for the World as a whole at 2.1 percent during the first 20 years of the 21st Century. Keeping in view the efficient utilisation, the conservation, and the large investments that are required, the same growth rate of 2 percent has been assumed for the development of Indian coal resources during the next century.

Oil: Without any change in present energy policy and assuming a high economic growth rate, India's total requirement of oil will be on the order of 90 million tonnes by 2000 A.D. Assuming that 30 million tonnes of domestic oil will be available, the imports will be on the order of 60 million tonnes. This will be a serious burden to the national exchequer (Rs. 1,60,000 million) assuming that present costs double by the end of the century. The country cannot possibly afford to spend so much in foreign exchange for oil imports. A short-term plan for oil production from already established reserves is in effect now, and it is expected that India's oil production will reach a level of 24 million tonnes in the early nineties and may reach about 30 million tonnes by the end of the century, thus limiting consumption to a level of 60 million tonnes. Keeping in view the prognostic reserves (which are still to be established), production may have to be pegged downward at a level of 30 million tonnes during the next century. So far as natural gas is concerned, it is proposed to raise the present production of 2.6 billion cubic metres to as high as 44 billion cubic metres by the end of the century. But this forecast for the future is, in fact, less an estimate of production and more a projection of needs. The prognostic reserves of gas onshore in Gujarat and Assam, in association with oil in Bombay High, and of free natural gas in offshore Bassein are so large that it should be possible to use gas for some of the purposes for which oil products like LPG, kerosene, fuel oil, and maybe naphtha are presently used. Substitution of gas for oil is proposed in 3 stages; 25 percent by 1982–83, 30 percent by 1987–88, and 44 percent by the year 2000. This could be achieved if concerted efforts are made from now on to work out a strategy for exploration and exploitation of this resource. Prognostic reserves of oil and gas suggest that the levels of production of oil and (or) gas mentioned above should be achievable. However, large investments are required for exploration, exploitation, and distribution. The alternative to this—importing oil and oil products—would mean a severe drain on our foreign exchange reserves. Apart from this, the question of availability from outside sources may pose a serious threat to India's economy.

Hydroelectric Power: At the beginning of India's Sixth Plan in April 1978, installed hydroelectric capacity was more than 9,000 megawatts and considering the projects already under execution, this capacity is likely to be little higher than 14,600 megawatts by the end of 1982–83. Furthermore, considering the fact that hydroelectric projects have long gestation periods and require heavy investments, it may not be possible to create capacities of more than 16,000 to 17,000 megawatts by 1987–88 and 20,000 megawatts by 2000 A.D. Additionally, a large hydroelectric potential exists in the northeastern region of the country, which is also earthquake prone and has a low load factor. On this basis, the availability of power from hydroelectric sources has been cautiously estimated.

Nuclear Energy: As outlined in the 1978–83 Draft Five Year Plan, nuclear capacity will be increased to 1,565 megawatts by 1982–83 from the present level of 640 megawatts (India, Government Publication, 1978). However, considering present difficulties with such technological problems as radiation leakage from the generating plants and nuclear waste disposal, nuclear capacity may be developed to only 2,000 megawatts by 2000 A.D.

RESOURCES AVAILABLE AT THE BEGINNING OF THE 21st CENTURY

Considering the present potential of India's various nonrenewable resources and the probable consumption rate during the remaining years of the 20th Century, the resources available at the beginning of the 21st Century are estimated in the quantities indicated in table 4.

Table 4 Estimates of nonrenewable resources available in India for the 21st Century
[Coal, lignite, and oil are figured in millions of tonnes; natural gas in billions of cubic metres. Recovery has been assumed as follows: coal at 50 percent; lignite at 90 percent (opencast only); oil at 25 percent; gas at 70 percent.]

NONRENEWABLE RESOURCE	TOTAL AS OF 1979	DEPLETION BY 2000	BALANCE AS OF 2000
Coal	111,800	9,789	102,011
Lignite	2,100	225	1,875
Oil	6,200	2,340	3,860
Natural Gas	6,500	628	5,872

Estimates on both the availability and consumption of resources have been prepared with a bias for the 21st Century. That is, a very conservative estimate for consumption during the 21st Century has been assumed, while a very liberal view as to availability of existing resources has been taken. Even on the basis of these assumptions, India's coal resources may not last beyond the '60s of the 21st Century, although the prevailing and widely-held view is that such resources will last for about 200 years, especially for noncoking coals. Similarly, we think that oil resources are likely to be exhausted by the end of the first quarter of the century, but that gas resources may see us through the middle of the next century. The estimates are rough and the duration of supply may vary, depending on the rates of production and consumption, but the fact remains that these resources will be exhausted well within the 21st Century. This, therefore, highlights the need for an aggressive and sustained programme to develop alternative renewable sources of energy so that these can be widely used by the time the fossil fuel resources will have been largely exhausted.

PROBLEMS AND CHALLENGES OF ENERGY DEVELOPMENT DURING THE 21st CENTURY

Since energy is essential for society's sustained growth, demand has been rising rapidly in developing countries like India. However, if the present trend continues—of placing more reliance on conventional energy, that is, the nonrenewable resources—and higher consumption rates are pursued, these resources are not likely to last beyond the first quarter of the next century. Even with a nominal growth rate of 2 percent or so in the next century, our resources are likely to be exhausted by the 2060s. The magnitude of the problem in terms of conventional energy has to be realised, therefore, and appropriate steps have to be initiated without delay in order to meet the challenges of the 21st Century. A strategy must also be evolved for better energy management. Briefly, action is called for in the following areas:

1. Promote efficient development and rational use of finite resources and intensive search for additional resources other than those known presently;
2. enhance recovery percentages of the fossil fuels by resorting to improved technology;
3. conserve the nonrenewable resources by resorting to efficient exploitation and utilisation as well as by inter-fuel substitutions and by restricting use of conventional fuels to "key" sectors that cannot do without them;
4. develop new technology for efficient and economic utilisation of nuclear resources;
5. maximize our hydroelectric potential, which is a renewable form of conventional energy;
6. carry out intensive research and development work for economic commercialisation of major nonconventional energy sources and interlink these with the other forms of energy; and
7. make efficient and rational use of the noncommercial forms of energy.

By adopting some of the above measures, it will be possible to extend the economic life of the nonrenewable forms of energy. The time gained in this process must then be fully utilised to develop the nonconventional sources of energy. In this context, it may be mentioned that "although calendar-wise there might appear to be a great deal of time for this transition, technology-wise there probably is not. Research and development of nonconventional energy sources must be greatly expanded and accelerated; even if practical new energy sources become available before being needed, it will be far better to have them in reserve ready for use than to be too late" (Partridge, 1978). It should, therefore, be obvious that mankind will have to rely more on the nonconventional than on the conventional sources of energy and must opt for an efficient and rational use of noncommercial sources. This is particularly important for India since 75 percent of the population lives in villages and relies primarily on noncommercial energy for cooking and heating.

In order to develop a successful strategy for the 21st Century, no time should be lost in deciding the priorities, charting a course, and making hard decisions. For India and other developing countries, the following measures are strongly recommended:

1. Hydroelectric power, a major renewable conventional resource, should be tapped to the maximum in order to conserve the nonrenewable fossil fuels. Latest estimates placed hydel potential at 80,000 megawatts (with 60 percent load factor). Of this, only about 9,000 megawatts have been tapped so far.
2. Noncommercial energy sources, such as firewood, cow dung, and vegetable waste, should be used efficiently and rationally for maximum fuel efficiency. The reckless use of our forest wealth to meet the domestic energy requirements of the rural population should be stopped. Moreover, abundant cow dung has immense potential for increased efficiency if it is processed in bio-gas

plants. Not only can it generate clean fuel, but the residue can be used as fertilizer. About one-fourth of the dung is itself consumed in the generating process, but there is about 20 percent more usable heat from the gas than is obtained by direct burning. The gas thus produced can be used both for cooking and lighting and has the added advantages of hygienic operation, absence of smoke and soot, convenience in burning, and as its byproduct, a rich fertilizer. There are about 575,000 villages in the country and only about 45,000 bio-gas plants operating today (Commerce, 1977). There is, therefore, a tremendous potential for development. Studies have indicated that community-size bio-gas plants would make processed cow dung our least expensive renewable source of energy.

3. Development of "energy plantations" on a large scale should be established, particularly for the fast growing plant species suitable for biomass conversion by anaerobic digestion, fermentation, and other biochemical processes. Biomass production of liquid and gaseous fuels, such as ethanol and methane could also constitute an important fuel source for a developing country. Sugar cane, an unusually high yield plant, holds a lot of potential in this regard. For instance, India, like Brazil, could go a long way toward reducing gasoline consumption significantly with an aggressive programme of ethanol production from sugar cane.

4. Amongst nonconventional sources, solar energy is the only promising source for supplementing the world's energy demands indefinitely. Unlike the finite fossil fuels, solar energy will be available for all time to come. This is a highly attractive primary source because it is available, clean, socially acceptable, and pollution-free. Thus solar energy holds immense possibilities for both low-temperature and medium-to-high temperature applications. Low-temperature thermal conversion techniques are now fairly well developed and can be introduced in the rural sector to provide energy for cooking, lighting, hot water, and—possibly—for irrigation. The applicability of solar energy for medium- to high-temperature use in the industrial sector should be given the highest priority with the objective of eliminating dependence on the conventional sources. A technological breakthrough in cost reduction would have a profound impact on the energy needs of the 21st Century.

5. Other nonconventional energy sources like tidal, wind, geothermal, and chemical power should be harnessed to the maximum and utilised in suitable sectors of the economy.

6. Hydrogen, the commonest of all elements, has the highest energy content on a pound-for-pound basis of any of the fuels. It holds out immense prospects as a replacement for oil and natural gas because it can be transported by pipelines, potentially stored cheaply for years in a gaseous form or more expensively stored in liquid form. Hydrogen can be produced by thermochemical means, by photolysis, or by electrolysis. Moreover, solar energy systems "can be designed for the production of hydrogen as well as for electricity. It has been recently reported that hydrogen can be phased into energy systems of the world in a manner compatible with existing technologies and used to provide virtually all the needs of industrialised societies (including air-transport)" (Auer and others, 1978). As a universal potential source of energy, hydrogen will play a significant role in the world's future, and appropriate R&D efforts should be geared up right now.

7. Economic production of fusion power is one of the most challenging scientific and technological endeavours of our time. The basic nuclear fuel in the fusion reaction is deuterium, an isotope of hydrogen, which is available in sea water. The energy required to separate deuterium atoms from sea water is small and negligible compared to the energy released by fusion. One gram of deuterium can yield 10,000 kilowatt hours of energy or about 10 million times the energy released by burning one gram of fossil fuel (Mathew, 1977). If this same fusion reaction (which releases vast amounts of energy in a hydrogen bomb) can be controlled, virtually unlimited energy can be obtained. Research and development work is going on in many institutions all over the world, and extensive efforts are also underway to provide the scientific/engineering base that will make the concept commercially viable. Furthermore, it is reported that vigorous and adequately funded programmes could bring thermonuclear fusion to the laboratory-reactor stage by the 1990s. The pace must be accelerated so that 50 years from today in 2030, fusion power will flow into every home.

CONCLUSION

The very fact that the oil resources are likely to be exhausted by the 2020s, and the seemingly large resources of coal and of gas as well by the 2060s, poses a formidable challenge for those meeting the energy needs of the next century. Apart from large scale exploration that will establish the potential resources of the fossil fuels as early as possible, all conceivable steps must be taken for conservation, efficient utilisation, interfuel substitution, improvement in mineable recovery, and development of new technology, in order to stretch the life of the world's fossil fuels. It would appear also that other forms of energy like solar, biomass, bio-gas, and the rest will have to play a significant role in meeting energy demands during the next century, in addition to nuclear reactors (including fast breeder reactors) and hydroelectric plants. Windmills and tidal and geothermal power should also be developed wherever feasible. It is imperative, moreover, that these newer sources be in wide use before or by the time fossil sources will have been largely exhausted. It must be remembered that any new technology, which can be developed commercially and made economically, environmentally and socially attractive, takes a very long time to make any worthwhile penetration into the energy scenario. Therefore, all steps, including R&D, must be initiated right now in order to develop and (or) perfect commercially viable new technologies that will give renewable energy sources a significant role by the end of this century. The matter needs concerted action by all concerned. We can ill afford to have the luxury of a casual approach.

Energy, which is vital to the well-being and prosperity of all mankind, should be treated on a global basis. It is, therefore, important that all the world work together for the sound development and use of energy. It is suggested that new technologies developed and (or) being developed by the advanced nations for the commercial use of renewable energy sources should be made available freely to the developing nations so as to facilitate selection and adoption of the technologies best suited to them.

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World Oil Resources: Their Assessment and Potential for the 21st Century

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Oil has acquired a dominant position with respect to the world energy supply. This is not due to its long term abundance prospects. It is because of the outstanding ease of its utilization, and also because of an *exceptional* low cost of production owing to *exceptional* geological and political conditions. In fact, these conditions, which led to the post-World War II oil boom, were restricted to a small region (2 percent of the world's surface area) and to a mere decade, the 1960s: an instant in human history.

So the reality looks like this: our civilization depends heavily on oil. Because of the difficulties and the time needed to shift to other energy sources, it is of the utmost importance that we assess how long the oil era will or *can* last. This paper expresses a few thoughts on the subject.

Before analyzing oil resources assessments and potential for the 21st Century, we would like to put forthcoming estimates in a special perspective: How much oil or liquid fuels will, or would, we need? This is indeed not an easy question. In trying to answer it, we are confronted with a great many uncertainties. First of all, we should know how many people will be on Earth 50 or 100 years from now, and what their life-style will be like. Although the whole problem is a fascinating one, we are in fact concerned here mainly with the specific aspect mentioned above: How much oil, or liquid fuels, could be needed? Basic assumptions which we have made at IIASA in order to attempt to give a preliminary answer are: first, that the world population will be stabilized (say, at *less* than 12 billion people or 3 times the present level; possibly between 7 and 9 billion people); second, that energy needs also be stabilized, or increasing very slowly (this is in contrast with some other forecasts of ever increasing energy demand); and third, that oil and other liquid fuels will be reserved for transportation (there will be a limit to the number of cars and potential mileage), petrochemicals (but other raw materials, such as coal or biomass, will compete), and development phase of the Less Developed Countries.

It is often mentioned that "oil must be reserved for transportation and petrochemicals." In fact, with a progressive shift to the supply of heavier crudes, it is not clear what the maximum yield of light or intermediate products could be.

All in all, we came to a consumption figure of between 3 and 5 billion tons of oil per year. This seems a reasonable value. However, more of other liquid fuels (synfuels) could be produced and consumed because of their convenience or preference for them. Curiously, this consumption figure is also an often quoted maximum for world oil production supposed to occur in the 1990's (the Central Intelligence Agency of the United States, the Workshop on Alternative Energy Strategies) and in most oil companies' studies as shown in figure 1.

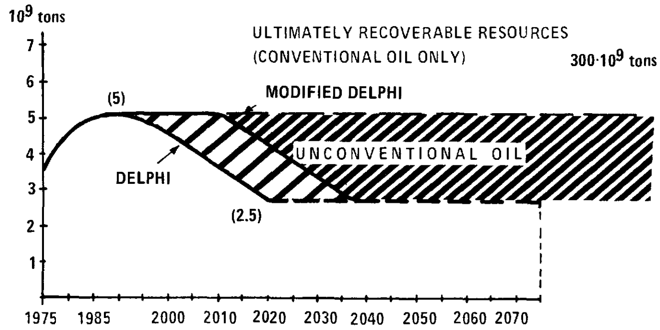

Figure 1 Potential world oil production curve, in billions of tons.

Our point of view for looking at the oil resources and (or) liquid fuels is thus to consider how long resources could allow a plateau of oil production and consumption to continue (fig. 1) and, in view of potential resources, what should possibly be done to maintain such a level of production. In other words, we challenge the bell-shaped production curve shown in figure 1.

ASSESSMENTS OF CONVENTIONAL WORLD OIL RESOURCES

We do not have good tools with which to tackle our problems. Unfortunately, world oil resources are very poorly known. Because so many important energy policy decisions are founded on so fragile a basis, it is important to understand why and, hopefully, to aim to correct this uncomfortable situation to make the poorly known well-known.

We have emphasized, as shown in figure 2, some of the differences between reserves and resources that can help us to understand better why we know so little about resources. Generally, the interest in reserves has been very great, but there was, until recently, little or no interest in resources. The time horizon for reserves is between 10 and

[1] Part of this work has been performed with the support of the Electric Power Research Institute.

	RESERVES	RESOURCES
Interest in	Great	None in the past, now emerging
Time horizon	10–30 years	Long or very long term
Economic aspect	Must be profitable	Non-profitable today, "science-fiction" technology
Estimated by	Industry	Member of industry *or* government (institutions)
Data	More or less reliable, conservative, "proprietary," and exploitation-oriented	Uncertain or speculative, but scientifically oriented
Methods	Industrial work (expensive): exploration, drilling, and measurements	Paper or computer work: "geological", "historical"

Figure 2 Reserves compared to resources.

30 years, and for resources it is long or very long term. What we, at IIASA, call the long or very long term is at least from 20 to 50 years after the year 2000, say until the year 2050 or even later, clearly into the 21st Century.

From the economic point of view, reserves must be "profitable". This is a very important point because, in fact, we have not redefined, since the oil crisis of 1973, the meaning of the word "profitable". Is a reserve "profitable for industry" (which was essentially the case up to now)? Is a reserve "profitable for a country"? This question can have a big influence on the revision of our estimates of reserves and (or) resources. Traditionally and by definition, resources are either not profitable or are unknown, and estimates even sometimes rely on what industry calls "science-fiction technology," that is, technologies still to be developed and matured. However, the border line between reserves and resources is sometimes very thin. For instance, if the British Government were to change its taxation policy only slightly and find it "profitable" to do so, so-called "marginal reserves" (currently in the 50 to 100 million barrels range) would become commercially producible.

Estimates of reserves are generally made by industry (they are its daily bread). Estimates of resources have been made by members of the industry (most often on a hobby basis, because it is not their main occupation) or by government or scientific institutions. It follows that estimates of reserves are more or less reliable, conservative, proprietary, and exploitation oriented. Methods of obtaining these data are expensive and include exploration and drilling. On the other hand, resource estimates are uncertain or speculative, more theoretically oriented, and based on paper work, now also on computer work.

If we look at these many differences, I think that we already understand why the reserves are much better known than the resources. Starting from this point of view, we at IIASA have devoted much attention to the various world oil resources assessments and have tried to understand them better. A summary of our studies was first presented at the meeting of the American Association of Petroleum Geologists in Houston, Texas, April 1–4, 1979.

Some lists of world oil resources assessments during the past 25 or 30 years have been published. We have also made our own list of these mostly well-known estimates (fig. 3). We have listed only the results we have been able to find in published papers, because sometimes reference is made to an estimate we are not able to document. Our tabulation gives the name of the estimator and his company, which is an often underestimated factor. Where applicable, we have also put the estimate for the United States. When two values are given with a slash it is because the estimator himself has given two values. For instance, Weeks has generally calculated two values, for "primary"

ESTIMATOR, AFFILIATION, AND YEAR	ESTIMATE OF TOTAL BARRELS	U.S. PART OF TOTAL	U.S. PART OF PERCENT
Duce (ARAMCO, 1946)	500	100	20
Pogue (N.A., 1946)	615	---	--
Weeks (JERSEY, 1948)	617	---	--
Levorsen (STANFORD, 1949)	1,635	---	--
Weeks (JERSEY, 1949)	1,015	---	--
Weeks (JERSEY, 1958)	1,500/3,000*	240	16
Weeks (N.A., 1959)	2,000/3,500*	270/460*	14
Hendricks (USGS, 1965)	1,984/2,480*	320/400*	16
Weeks (WEEKS, 1968)	2,200/3,550*	---	--
Hubbert (USGS, 1969)	(1,350–2,000)**	---	--
Moody (MOBIL, 1970)	1,800	---	--
Warman (B.P., 1971)	(1,200–2,000)**	---	--
Weeks (WEEKS, 1971)	2,290/3,490*	---	--
Jodry (SUN, 1972)	1,952	190	10
Odell (UNIV, 1973)	4,000	---	---
Kirby, Adams (B.P., 1974)	(1,600–2,000)**	---	--
Moody (MOODY, 1975)	(1,705–2,030–2,505)** 95 percent 5 percent	242	12
Grossling (USGS, 1976)	(1,960–2,200–3,000–5,600)**	182–250**	8
Klemme (WEEKS, 1976)	1,600	---	--
Parent, Linden (Institute of Gas Technology, 1977)	2,000	---	--
DELPHI (Desprairies) (Institut français du Petrole, 1977)	2,200/2,500**	---	--
Moody (MOODY, 1978)	2,030	300	15
Nehring (RAND [CIA], 1979)	(1,700–2,300)**	---	--

* Estimator gives primary, then secondary values.
** Estimator gives range, sometimes with a mean value.

Figure 3 Major published estimates of world oil resources. (Barrels are calculated in billions.)

and "secondary" recovery respectively. Values in brackets correspond to a range of values, sometimes with a mean value. Altogether, there have been about two dozen estimates since 1946.

Some experts have used similar tables to analyze potential trends of world oil resources estimates. Odell (1973) for instance, has made a curve, which is well-known, of the linear regression of the estimates, and has shown that the estimates generally increased with time. In addition, it is possible to see from such graphs, even adding the most recent estimates, that the uncertainty or, one might say, the spreading of the estimates did *not* decrease with time. In fact, if we take all the values listed in figure 3, the picture appears as shown in figure 4. Even if many values tend to increase, it is in fact difficult to draw a regression line through the estimates. At best, there appears to be a magic line or "magic figure" of 2,000 billion barrels, at which many of the estimates are "knocking."

Analyzing these various estimates after a careful reading of the documents, we can summarize thus:

In 1947, there was the introduction of estimates of offshore oil which first boosted the estimates (Pratt, 1947; Levorsen, 1949).

In 1958, Weeks introduced the first estimate of broad regional distribution.

In 1962, Hubbert introduced the first "estimate of estimates."

In 1965, Hendricks estimated "discoverable" oil in-place.

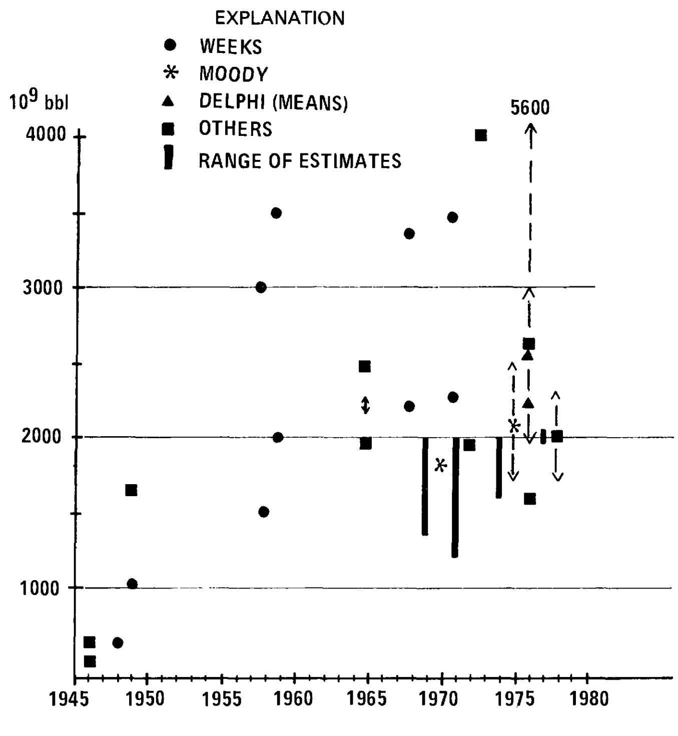

Figure 4 Evolution of estimates of ultimate world oil resources. (Barrels are calculated in billions.)

In 1969, analyzing previous estimates, Hubbert stated that the uncertainty of world estimates was between 1,350 and 2,000 billion barrels.

In 1970, Moody stressed the importance of giant and supergiant fields.

In 1975, Moody published what remains one of the best (and most influential) estimates, and introduced probability distribution.

In 1977, the extremely important DELPHI study was issued (Desprairies, 1977).

In 1978, Nehring was the first to disclose the method and the data used to perform an estimate.

Concerning the study by Nehring, it is worth pointing out that previous estimates were, in fact, calling mostly upon our "faith," because if the method was, at best, suggested, the data used to arrive at the estimates were never cited. Here we refer to world estimates and not estimates for the United States, for which the situation was different. This means that from the scientific point of view, it was not possible to check whether world assessments were good or not.

As a next step, it is interesting to investigate the relative independence of these various estimates. Levorsen's, for instance, is not independent because he combined those of Pogue (1946) and of Weeks (1948), and added the offshore estimate of Pratt (1947). Weeks has made a lot of estimates but, of course, they are mere revisions and are not independent of each other. Hendricks was apparently independent. Hubbert, as we mentioned, made the first "estimate of estimates." This last process has more or less continued until the present day. To cut short this long story, figure 5 summarizes, using the horizontal axis for independent estimates and arrows for connections, a thirty-year period, from 1946 to 1976, for which we have found about six independent world oil resource estimates.

Then, in 1977, the very important DELPHI study by Pierre Desprairies of the French Petroleum Institute was published. It was prepared for the Conservation Commission of the World Energy Conference held September 1977. More than forty experts were consulted: 27 answered the first set of questions, 22 of them confirmed or revised their answers in the second round. We can, however, question, by referring to the above, whether all of these 22 estimates are really complete, independent estimates.

Figure 6 summarizes the main findings of the DELPHI study. Ultimate world oil resources remaining to be produced (to which must be added 300 billion barrels of past cumulative production, to make these figures comparable with others given previously) would be 1,900 billion barrels, excluding deep offshore and polar areas, and 2,200 billion barrels if these are included, assuming the recovery rate were raised from today's average 25 percent to about 40 percent at the end of the century. (In fact, the

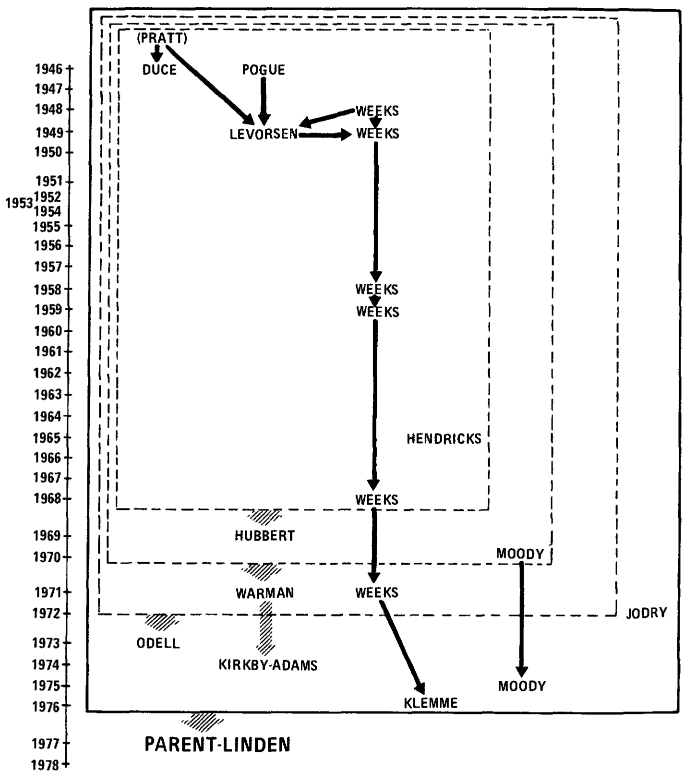

Figure 5 Source relationships between oil resources estimates.

• Ultimate world oil resources remaining to be produced ("consensus")	:	1.900 × 10⁹ bbl (260 Gt) or 2.200 × 10⁹ bbl (300 Gt) including deep-offshore and polar areas

- 45 percent offshore
- Recovery increasing from present 25 percent to 40 percent in the year 2000
- Increasing contribution of enhanced recovery: 55 percent of gross increase in 2000
- slowing down of annual rate of growth of reserves: Back to 20×10^9 bbl/yr in 2000

Figure 6 Main findings of the WEC-DELPHI study published for the 1977 Conference.

limits imposed on the study were the year 2020 and a production cost of less than $20 per barrel, in 1976 dollars.) These are the values proposed by the estimator. The DELPHI study also concluded that the increasing contribution of enhanced recovery would account for 50 percent of the gross increase in the year 2000. By that year, the annual rate of growth of reserves would slow down to 20 billion barrels per year.

It is interesting to look at the degree of consensus. In the following paragraphs, we use billion metric tons of oil, which were the original units of the DELPHI study, instead of billions of barrels. In figure 7, the 27 "first" answers are plotted—each respondent number appearing on the vertical scale and his corresponding individual estimate on the horizontal scale. It may be seen that the answers, in fact, cover a broad range, from about 170 billion to 750 billion tons (the latter is an average for the 550 to 950-billion-ton range). It is interesting to remark that, even when extreme estimates are eliminated, the estimates of the consensus group (fig. 7), show some appreciable disagreement on the potential future role of deep offshore and polar areas. Figure 8 shows another way of presenting the same results.

Finally, in relation to our IIASA studies to assess potential future world oil production, it is interesting to try to establish values on regional distributions of world oil resources according to the DELPHI study experts. Figure 9 shows, in a similar fashion to figure 8, the answers for North America. We find the known phenomenon of the broad ranges of estimates (answers re-converted to billion barrels in figures 8 and 9). And figure 10 shows for major regions the minimum estimates, the maximum estimates and the averages for the totality of answers from the experts, or only for the answers of the "consensus" in the global range of 200 to 300 billion tons. The 1975 Moody values and the 1978 Nehring values fall into the same ranges, and more especially into the consensus ranges. However, this no longer applies to the range of estimates, generally and understandably much broader if all the answers are taken into account. But even in the consensus range, and although agreement on the global value is plus or minus 20 percent, there is no clear convergence of estimates at the regional level. The ratios between higher and lower values in the 200 to 300 Gt range vary from 2 to 4. Estimates of socialist countries, which do not publish statistics, are difficult to evaluate. For the Middle East, the factor of 2 represents a very big difference of 80 billion tons, which is roughly equivalent to present known world reserves. The highest disagreement of opinion among the experts is related to deep offshore and polar areas. It is fair to say that the DELPHI study in fact occurred about at the turning point: concerning deep offshore, the original optimism of the mid-1970s has now been succeeded by an (exaggerated?) pessimism.

This is where we stand with regional estimates for world oil resources and the material with which we are working. It seems appropriate to say that, from the scientific point of view, our knowledge is very, very poor.

ASSESSMENTS OF WORLD UNCONVENTIONAL OIL RESOURCES

We can assess estimates of unconventional oil resources in the world by saying that the situation is still much worse than for conventional oil resources.

True, there are some very large deposits, more or less well known—and curiously, located on the "oil ring" described by Nehring (1978) (Athabasca Tar Sands, Colorado Oil Shales, Orinoco Heavy Crudes). The aggregate in-the-ground resources of these very large deposits are considerable, at least 800 billion tons, of which about 150

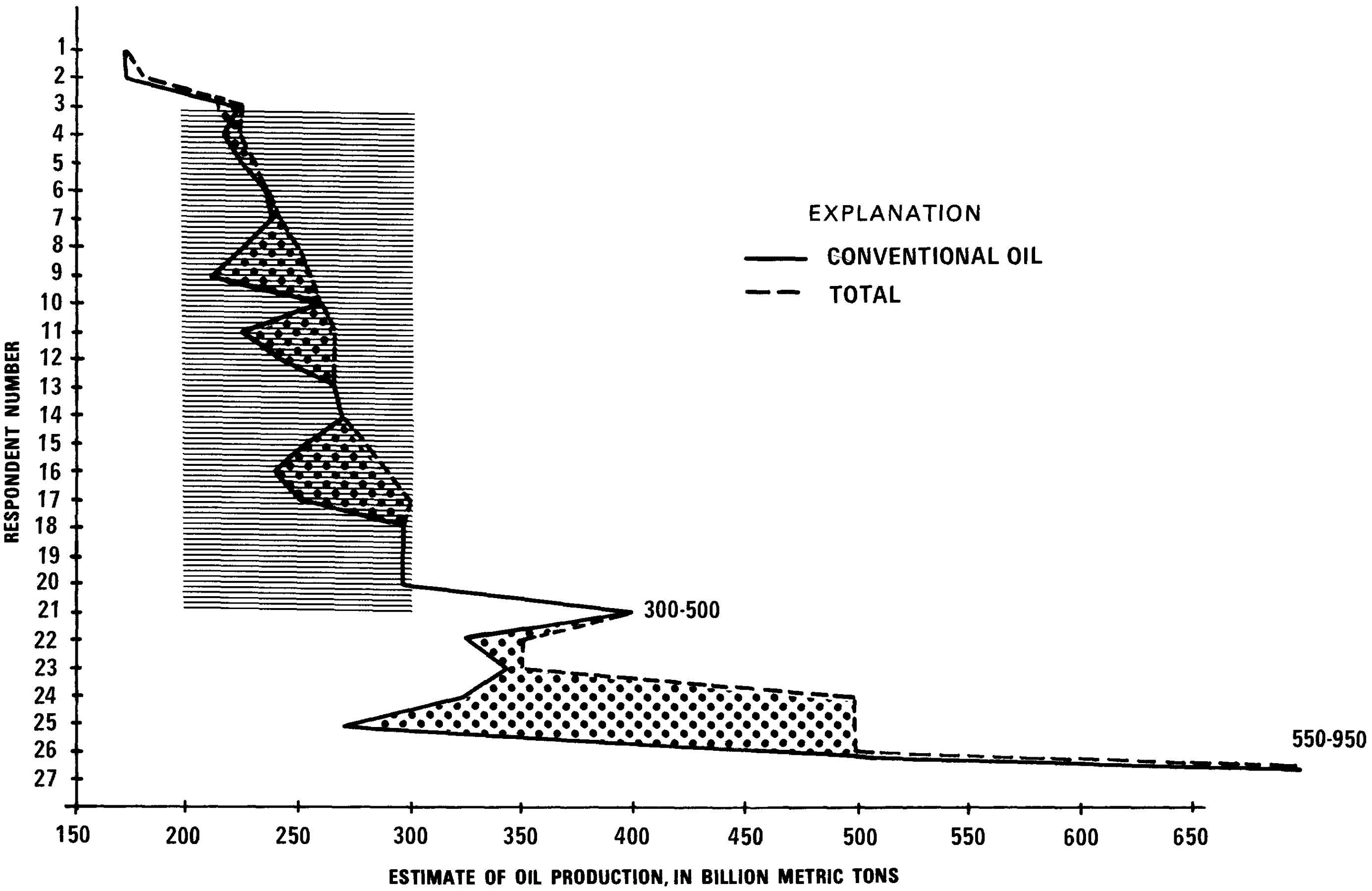

Figure 7 Analysis of answers to DELPHI questions. Shaded area: 18 answers regarded by Desprairies (1977) as representing a consensus. Values on the left are figures without polar and offshore areas, where applicable; values on the right include polar and offshore areas.

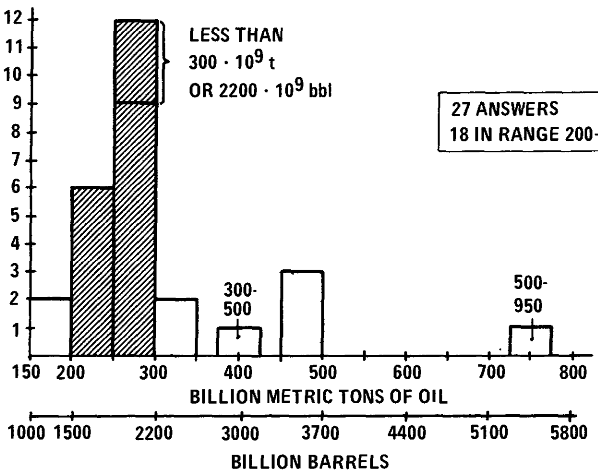

Figure 8 World oil resources remaining to be produced (DELPHI study). Vertical scale: number of answers for the various ranges of the horizontal scale; shaded area: 18 answers regarded by Desprairies (1977) as representing a consensus.

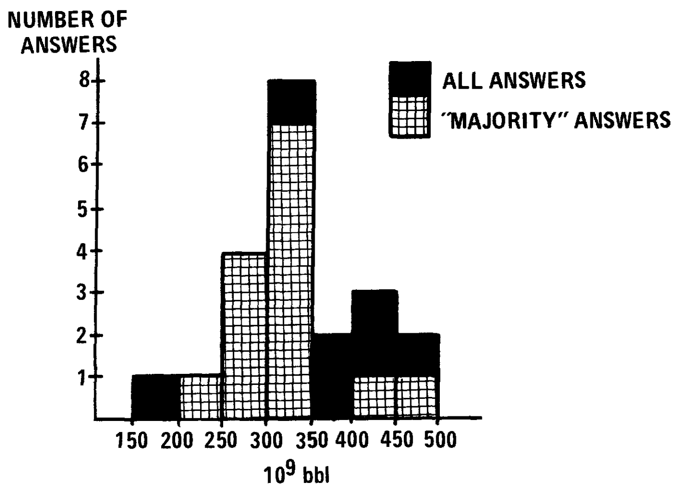

Figure 9 Ultimate oil recovery in United States and Canada (DELPHI study). (Estimates are calculated in billions of barrels.)

billion tons are presently considered to be recoverable (fig. 11), which has to be compared to the 900 billion tons of conventional oil originally in place, if we accept the DELPHI values. But our main concern is to answer this question: what may possibly exist at a global level beyond these huge deposits; that is, what is the potential regional

	RANGE PROJECTED IN ALL VALUES			VALUES "IN CONSENSUS" 200-300 Gt RANGE*		
	MINI-MUM	MAXI-MUM	AVER-AGE	MINI-MUM	MAXI-MUM	AVER-AGE
Socialist countries	27.3	96.3	54.9	40.3	83	54.9
U.S.A. and Canada	6.2	50	28.5	15.6	45	26.1
Middle East and North Africa	54.8	300	109.1	76	156	101.9
Africa South of Sahara	2.7	40	11.3	4	13.4	8.8
Western Europe	5	22	11.2	5	22	11.1
Latin America	7.9	55	22.9	12.5	36.9	20.9
East and South Asia (includes Japan, Australia, and New Zealand)	5.5	30	15.1	6	25	13.6
Deep offshore and polar regions	0	230	38.7	0	50	21.2

*Of the 18 values in the 200 to 300 Gt Range, four do not give details by regions.

Figure 10 Regional distribution of DELPHI estimates. (Figures are calculated in gigatons.)

distribution of these unconventional oil resources? Because of a lack of economic interest until now (let us recall: reserves must be profitable), very little effort has been made to assess these unconventional resources in most countries.

As we showed at our 1976 IIASA-UNITAR Conference on the "Future Supply of Nature-Made Petroleum and Gas", sources of global data are generally very few and very old (Barnea and others, 1977). Contrary to what was expected, the first United Nations sponsored Conference on Heavy Crudes and Tar Sands held at Edmonton, Alberta in 1979 (United Nations Institute for Training and Research, 1981) did not really improve the data situation. Most improvements were related to Canada and, to a lesser extent, to the United States and Venezuela. Many of us, in the energy community, had expected that a serious reassessment would get started after the 1973-74 oil crisis. Apparently (we will come back to this matter later) and unfortunately, this did not happen, except in the three above-mentioned countries plus, possibly, in a very few other places.

That is why the International Institute for Applied Systems Analysis has launched its own survey of unconventional oil resources, through questionnaires and interviews. Our study is about midway so that it is premature to present final results and (or) conclusions. However, some of our progress will be reported.

Heavy Crudes and Tar Sands

At the already-mentioned international conference in Edmonton, Meyer and Dietzman of the U.S. Geological Survey presented a global estimate of resources and possibly recoverable reserves of heavy crudes and tar sands (fig. 12). Recovery rates for tar sands were generally very conservatively estimated at 10 percent or less (paper given in June 1979).

We, at IIASA, consider these figures somewhat misleading inasmuch as they aggregate rather good data—for Canada, the U.S.A., and Central America (essentially Venezuela)—with poor to very poor data for the other regions.

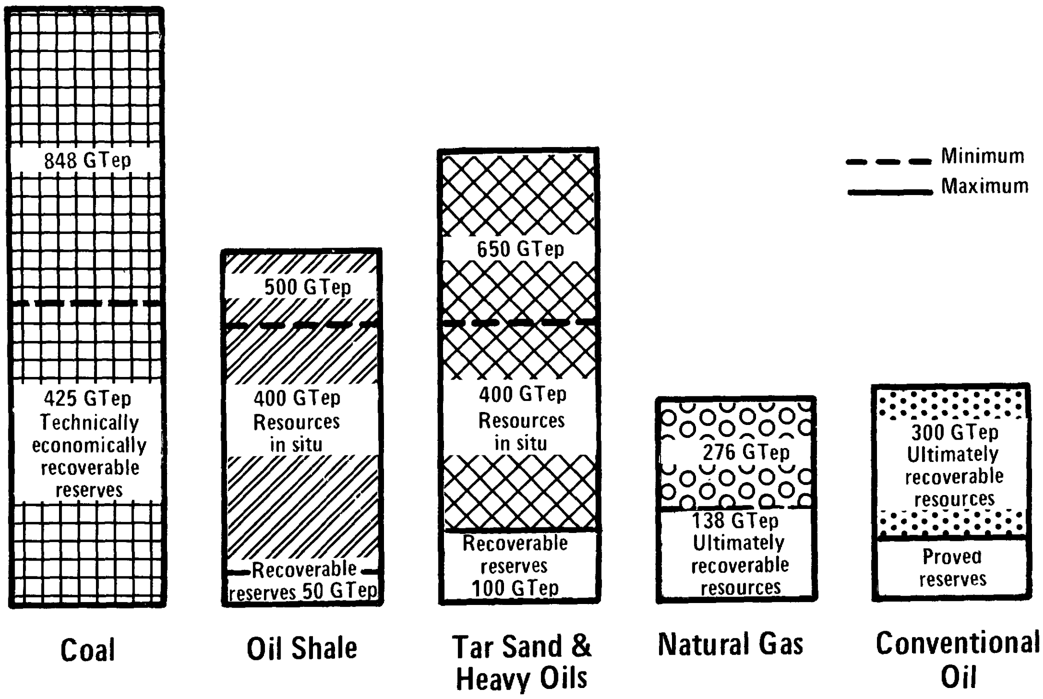

Figure 11 Fossil fuel reserves and resources. (Estimates are given in billions of tons; GTep = gigatonnes (billions of tons) of oil equivalent.)

	MEDIUM CRUDE OILS 20≤ °API≤25	HEAVY CRUDE OILS °API<20	DEPOSITS*	TOTAL
Canada	119	69	333,010	333,198
U.S.A.	2,271	2,254	2,512	7,057
Middle America	108	331	______	439
South America	8,376	5,654	100,012	114,033
Europe	154	734	______	6
Africa	4,197	89	175	4,461
Middle East	32,759	3,528	______	36,287
USSR/Asia	660	97	16	773
Total	48,664	12,747	435,731	497,122

*In this table Meyer uses the word "deposits" to refer to crude oil which does not occur in conventional reservoirs.

Figure 12 Estimate of heavy crude and tar sand reserves (10^6 barrels) (from Meyer and Dietzman, 1979).

It is interesting to point out that, in known areas and the ones, in fact, where knowledge has increased further, there has generally been an increase in the estimates.

Athabasca tar sands: 627 billion barrels estimated in 1976 (Canada, Ministry of Energy, Mines, and Resources, 1977); 869 billion barrels estimated in 1979 by Mossop and others (Alberta Research Council) who referred to a 1978 study by Outtrim and Evans.

Lloydminster (Alberta) heavy crudes: Two probabilistic estimates, one for 1976 and one for 1979, are shown in figure 13. See also McCrossan and others (1979).

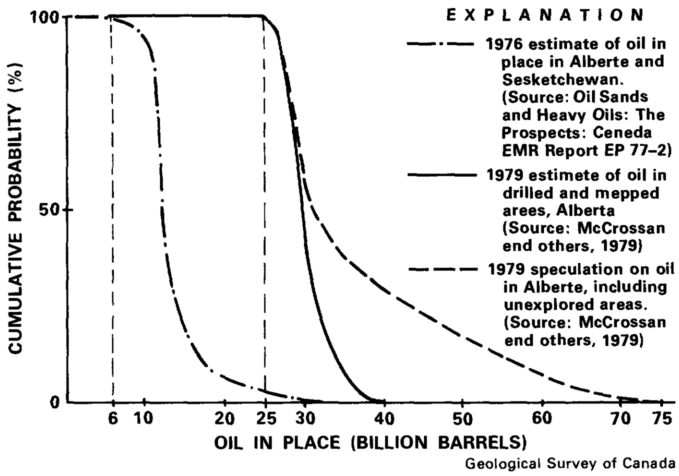

Figure 13 Lloydminster-area heavy oils.

California tar sands: Estimates have increased from 270–323 million barrels in 1965 (Ball Associates, Monograph 12) to 966 million barrels in 1979 (Hallmark paper given at International Conference, Edmonton) through the addition of new deposits, not including two large but conjectural deposits.

Utah tar sands: Estimates have grown from 2.0–4.3 billion barrels in 1965 (Ball Associates, Monograph 12) to 22.4–29.2 billion barrels in 1979 (Ritzma, 1974 and 1979).

An important question is, of course: Can this upward revising be expected to be a general phenomenon? That is, were deposits very conservatively estimated in the past (sometimes, a long time ago, as much as a few decades) and will more recent and better assessments upgrade them? It is premature, and unfortunately not possible, to give a definite answer to this question. However, three examples outside North America, among the few we have at hand, give some preliminary information.

In Madagascar, an unpublished 1954 British Petroleum study (Kent, 1954) that was used in Meyer and Dietzman's 1979 assessment had estimated tar sand resources at 1.79 billion barrels; but a 1962 survey by Andrianasolo and others for the Malagasy Oil Company arrived at a possible estimate of 22 billion barrels or 3 billion tons.

For Italy, the 1979 Meyer and Dietzman estimate referred to 50 million tons (about 360 million barrels) of recoverable heavy oil. The most recent Azienda Generale Italiana Petroli (AGIP) assessment by Dalla Casa and others mentions 350 million tons of heavy oil originally in place in developed fields and 1,200 million tons in discovered but not yet developed fields. Assuming a low-recovery factor of 10 percent because of technical difficulties, this represents about 155 million tons or 1,100 billion barrels of recoverable oil.

For Peru, based on previous estimates, Meyer and Dietzman reported 60 million barrels of recoverable reserves. But at the Edmonton International Conference, A. A. Pardo (Petroleos del Peru) mentioned that in-place reserves of heavy crudes for the Maranon Basin are estimated at 1,500 million barrels. A low 10 percent recovery rate would yield 150 million barrels.

The few examples cited above illustrate, if at all necessary, the difficulties but also the potential for evolution of such reserves and resources estimates of heavy crudes and tar sands.

Oil Shales

World oil-shale resources were given by J. R. Donnell (1977) at the 1976 IIASA-UNITAR Conference, as shown in figures 14 and 15. In fact, most of these data originate from the excellent 1965 U.S. Geological Survey Circular 523 by Duncan and Swanson, itself a collection of old to very old data. The various tables by Meyer, Duncan,

CONTINENTS	RECOVERABLE UNDER PRESENT CONDITIONS	MARGINAL AND SUBMARGINAL
Africa	10	90
Asia	24	84
Australia and New Zealand	___	1
Europe	30	46
North America	80	2,120
South America	50	750
Total	190	3,091

Source: By J. R. Donnell; modified from Duncan and Swanson.

Figure 14 Known oil shale resources of the world land areas (billions of barrels).

SMALL RESOURCES

	$10^6 m^3$	10^6 barrels
Chile	3	18.9
Israel	3	18.9
Jordan	7	44.0
Tasmania	3	18.9
Turkey	3	18.9
	10^6 tons	10^6 barrels
Austria	1	8
Malagasy	4	32
Poland	6	48

MEDIUM RESOURCES

	$10^6 m^3$	10^6 barrels
South Africa	20	125.8
Argentina	60	377.4
Australia	40	251.6
Bulgaria	20	125.8
Spain	40	251.6
France	70	440.3
Luxembourg	110	691.9
New Zealand	40	251.6
Thailand	130	817.7
Yugoslavia	30	188.7
	10^6 tons	10^6 barrels
Morocco	74	592

LARGE RESOURCES

	$10^6 m^3$	10^6 barrels
West Germany	320	2,012.8
Burma	320	2,012.8
Brazil	127,320	800,842.8
Canada	7,000	44,030.0
People's Republic of China	4,430	27,864.7
Zaire Kinshasa	16,000	100,640.0
U.S.A.	250,000	2,000,220.0
Great Britain	160	1,006.4
Italy (Sicily)	5,600	35,224.0
Sweden	400	2,516.0
USSR	17,000	112,591.0

Figure 15 Estimates of oil shale resources by country.

Swanson, Donnell, and others are, in fact, the first tentative assessments of the global existence and (or) availability of unconventional oil.

Our IIASA survey permits an additional perspective; continuing again with a few examples:

In France, in 1954 there were 440 million barrels of known oil shale resources according to J. R. Donnell (1977). A three-year study (1974–1978) by R. Breton and others (1978) included 35 core drillings over a broad area east of Paris plus 10 core drillings in a selected area within that broad area. The broad area survey indicated about seven billion barrels, and the intensive survey of the smaller area identified more than 400 million barrels with contents between 40 and 100 liters of oil per ton of rock (restricted to an overburden ratio of about 2).

In Morocco, Duncan and Swanson (1965) gave no oil shale estimate; but in 1974, A. K. Matveyev estimated about 600 million barrels. Today, known resources are estimated at 1.6 billion barrels and total resources can possibly reach 5 billion barrels, according to recent IIASA survey findings.

In contrast to these two important upward revisions, our survey has also revealed downward revisions, such as for Italy, the United Kingdom, and New Zealand. The final figure for Italy is not yet known, but it is foreseen, on the basis of the IIASA survey, that it will be lower than the previous figure of 35 billion barrels. For Great Britain, where data are most uncertain, and interest is very low, a pilot study in the Kimmeridge Clay apparently downgrades occurrences. For New Zealand, no figures are available, but a statement, based on 20 core drillings, reports that resources are smaller than previously estimated and are of no economic importance (personal commun., IIASA Survey).

Most studies indicate that at present there is little or no interest in oil shale resources. In fact, it is clear that most if not all the deposits are relatively smaller and of a lesser oil content than the Colorado oil shale deposits, and that probably no effort will be made elsewhere before the United States really begins to exploit their huge oil shale reserves, apart maybe from the special case of Brazil.

THE THREE PATHS TO COSTLY OIL

There is no doubt that the cost of oil (we are not speaking here of its sale price!) shows a rising trend regardless of what production route is followed. We summarize this in figure 16.

The first path is the historical one: the oil industry, especially onshore, shifts production progressively from supergiant and giant fields to medium-size fields and, finally, to small fields. The supergiants or fields larger

GIANT FIELD → MEDIUM FIELDS → SMALL FIELDS

($5 \cdot 10^9$ bbl) ($700 \cdot 10^6$ t) — ($500 \cdot 10^6$ bbl) ($70 \cdot 10^6$ t) — $50 \cdot 10^6$ bbl) ($7 \cdot 10^6$ t) — ($5 \cdot 10^6$ bbl) ($0{,}7 \cdot 10^6$ t)

ON-SHORE → OFF-SHORE → DEEP-OFFSHORE

"GOOD" OIL (80–25° API) → DIFFICULT OIL (25–10° API) → "BAD" OIL (10–7° API, TAR SANDS) KEROGEN, OIL SHALES)

Figure 16 The three paths to costly oil.

U.S.A.	2,219	Venezuela	41	Burma	20	Japan	14
Canada	241	India	40	Abu Dhabi	19	Malaysia	13
Mexico	174	United Kingdom	34	Peru	19	Turkey	13
Algeria	101	Iraq	29	Trinidad	19	Italy	12
Argentina	73	Libya	28	Nigeria	18	Austria	11
Indonesia	61	Germany	25	Netherlands	17	Australia	10
Brazil	54	Saudi Arabia	24	Syria	17	Colombia	10
Iran	53	Yugoslavia	22	Egypt	15	Pakistan	10

Figure 17 Summary of world rig activity in 1978 (excluding socialist areas), given as number of rigs by country. Besides the 3,456 rigs listed, another 30 countries have from 1 to 9 rigs, for a total of 120.

Oil rigs by region	Number operating	Prospective Areas in square miles by Grossling (1976)	by Ivanhoe
North America [1]	2,460	4,421,400	-------
Latin America	402	4,804,600	1,819,300
Europe	142	1,394,000	-------
Middle East	193	1,344,800	-------
Africa	182	5,034,590	-------
Asia	186	-------	-------
South Pacific	13	-------	-------
Total	3,578		

[1] Includes United States and Canada but not Mexico. Total number of rigs by region does not necessarily agree with enumeration by country.

Figure 18 Number of rigs by regions and by estimated size.

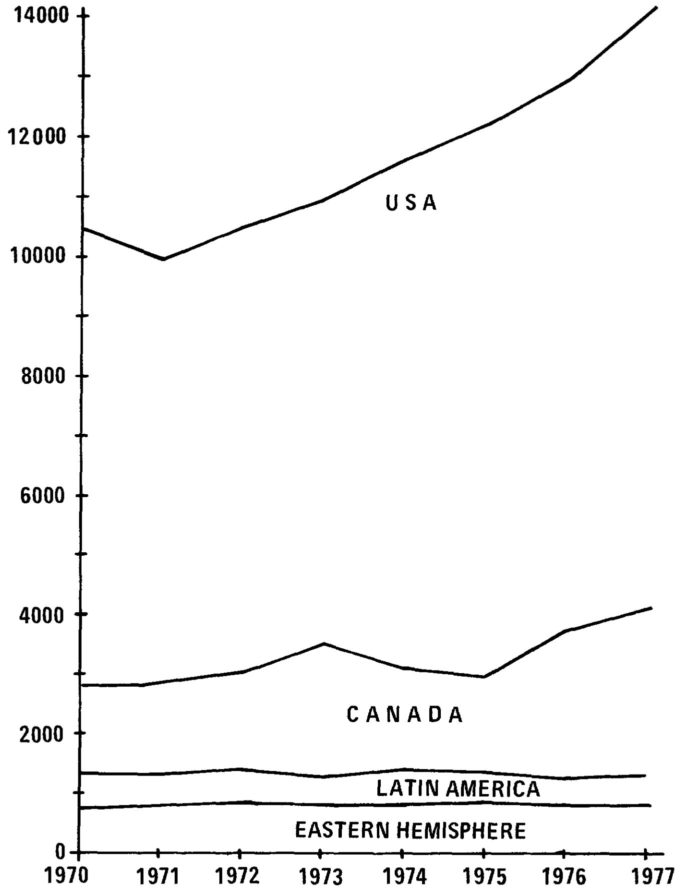

Figure 19 Free world total exploratory well completions.

than 700 million tons or 5 billion barrels were eagerly searched for all over the world and the giants, those larger than 70 million tons or 500 million barrels, were both the most profitable, and still account for more than 70 percent of world oil production.

Small fields already account for 15 percent of United States production. It is sometimes argued that this could only happen in the United States because of the special situation where the wealth underground belongs to the owner of the surface: thousands and thousands of farmers have taken the risk; a few became millionaires. This only means that in other countries—if the same result is to be achieved—other or new types of incentives will have to be found. We are confident that, since it will take a long time before a substitute for oil is found, these incentives will indeed be developed. Nationalized oil companies will probably be the first to benefit from them.

A review of world petroleum history makes clear that there is an enormous variation in the size of drilling efforts, as brilliantly shown by B. F. Grossling in his article, "Window on Oil" (1976). Regarding the prospects for finding more oil, we at IIASA agree qualitatively with Grossling, but not "quantitatively" in the sense that we find him somewhat optimistic. But we are convinced that there is still a lot of oil to be found.

Curiously, it is interesting—but somewhat disappointing—to see how the Western World has reacted to the 1973–74 crisis. This is illustrated by the data for rig activity (figs. 17 and 18) and for exploratory drilling completions (fig. 19). Two conclusions can be drawn: (1) There is a continuous—and even increasing—difference between drilling by the United States and Canada on the one hand and the rest of the Western World on the other hand: and (2) only the United States and Canada have dramatically increased their search for oil and gas since the oil crisis.

From the DELPHI study, a tentative supply curve can be drawn for the 300 billion tons of oil remaining to be produced (fig. 20). Incidentally, a similar curve was mentioned by Shell representatives in a May 9, 1979 lecture by K. R. Williams. This means that a good part, about two-thirds of these 300 billion tons of oil, was considered to be producible at less than $12 per barrel (in 1976 dollars), with corresponding investments of less than $10,000 per barrel per day capacity. Let us recall that the greater part of oil today (in 1979) is still produced at costs probably not higher than $2 per barrel per day.

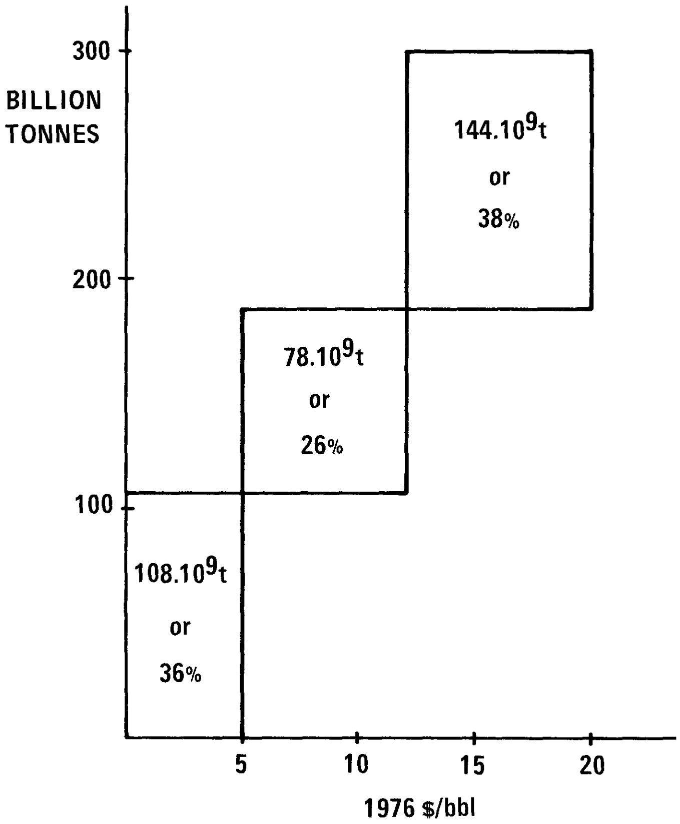

Figure 20 World oil supply curve, according to DELPHI study (1977).

For these reasons, we think that, on a global basis, this path will remain the preferred one in coming decades, and will probably be used reasonably far into the 21st Century. It can provide sufficient time—taking into account that world consumption and (or) production of oil will increase much slower than previously forecast—for a timely penetration of unconventional oil into the market, provided a few countries pave the way; for example, the United States with the Synfuel program and Canada with tar sands.

The second, or offshore path, began with a technological extension of onshore exploration and production, and was further encouraged for political reasons. The North Sea was especially suitable for offshore development because of its highly appealing political stability. Here the most impressive technological progress has been achieved. Unfortunately, the progress has been accompanied by parallel and dramatic cost increases ($10,000 to $12,000 per barrel per day capacity). Moreover, there is some disappointment with U.S. Atlantic offshore explorations, for instance with regard to the Baltimore Canyon. This, together with discouraging results up to now in deep offshore areas, has somewhat slowed down the race to deeper and deeper water, and has led some experts to revise downward their previous hopes for deep offshore potential. Higher and higher costs are obvious, but the resources—if any—are elusive. Curiously, this path is counter to the first: because of increasing costs, unfortunately, going deeper and deeper obliges oil operators to concentrate only on the biggest deposits. That means that giant fields are needed for normal offshore production (as mentioned above for North Sea "marginal" fields) and probably that supergiants are needed for deep offshore production, unless new production methods are developed.

The third path would be from "good oil" to "bad oil" (oil shales) passing through "difficult oil" (heavy crudes and tar sands). Such a production evolution is highly technology-dependent and will really occur—if it occurs at all—as a result of a political determination and only in a few countries at first. These few countries, including presumably Canada and the United States, have the double incentive of high oil consumption *and* imports and of owning the largest deposits presently known. They also have the advantage of possessing oil producers competent at the highest technological levels. A problem whose solution is not yet clear, but which could be highly important at the world level, is to understand whether path 3 will resemble path 1 or path 2 as far as sizes of deposits are concerned. Because of the immature state of development of the technology of "difficult" and "bad" oil, it is hard to anticipate whether only large to very large deposits will be producible or whether small deposits will also be producible, possibly through different methods. With our present knowledge, investments for path 3 are the highest among the various steps of the three paths: for example, $25,000 to $30,000 per barrel per day capacity for new tar sand projects in Alberta.

These very high capital costs (for production from tar sands, deep offshore, oil shales, etc.) and the huge size of deposits and (or) production facilities point to a necessary and permanent role for major oil companies, with the hope that the necessary steps will be taken to encourage them, or simply to keep them alive.

CONCLUSION

We are hopeful that the necessary amounts of liquid fuels can be produced, according to our curve proposed in figure 1, with a progressive—and well-planned—penetration of unconventional oil. (We do not underestimate the possible role of liquids from coal, but this question is outside the scope of this paper.)

Two final comments by way of conclusion:

1. The three paths that lead to costly oil also lead, in fact, to a new dimension in oil history, because of the dramatic increases not only in costs in monetary value but also in costs of natural (and human) resources. Impacts on, and requirements for, other

natural (and human) resources will become greater and greater for producing these new sources of energy. So much so, in fact, that energy resources can no longer be considered in isolation from other resources such as water, land, materials, and manpower, these same resources being discussed during this U.S. Geological Survey Centennial Symposium. To understand these systems aspects better, we have developed the WELMM approach (Water, Energy, Land, Materials and Manpower) at IIASA and summarized our opinion in the slogan: Man does not consume energy, but WELMMITE. A lot remains to be done to achieve a better understanding in this direction.

2. Much will depend on what will happen in the next decade in North America. If the North Americans are successful, their efforts will open the way to new resources, not only for North America, but all over the world. It is with some melancholy that I must confess that Western Europe, the region depending the most on oil and, unfortunately, on imported oil, has restricted itself to a wait-and-see position.

ACKNOWLEDGMENT

I should like to thank especially Jean Michel Merzeau, of IIASA, for his very efficient help on unconventional oil resources with the preliminary results of the survey he is performing and for stimulating advice and discussions.

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Discussion

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First of all, I would like to congratulate Dr. Grenon for his candid critique of the various estimates that have been proposed for world petroleum resources. In his paper, he refers often to consensus points of view. As it turns out, he has developed a consensus of consensuses. Now I will highlight some of the points made in that paper.

His starting point is how critically important are the remaining world petroleum resources, because to reach the energy alternatives of the 21st Century, we will need those oil resources for the remainder of this century and the early part of the next. If that oil is not available, we simply will not reach the 21st Century.

The paper gives a useful estimate of the annual amount of oil that will be needed for the next several decades to sustain the world economy, before the other energy alternatives are able to make an important contribution. The estimate is three to four billion tons of oil per year.

In the paper Grenon further states that only Nehring had disclosed the method used in making the estimates, which is not exact. For instance, both Hendricks and Grossling, and perhaps others, have also disclosed in full their estimation methods and the supporting data.

The paper traces the interrelationships of the various estimates, and shows that most of them are not independent. To display these relationships, family trees of estimates are presented. It can be seen that there are few "ancestors"; rather, most of the estimates are "cousins."

When examining the numerical range of the various estimates one is struck by how widespread they are. Also, no definite time trend is apparent—the data show neither an increase nor a decrease of the world estimates as a function of the time when the estimate was released. Moreover, the spread of the data does not appear to decrease with time. Thus from that point of view the latest estimates do not appear to be closer to the truth than the earliest were.

Commenting on the methods and data which have been used, he terms the existing knowledge to be "very, very poor." I would suggest that we change it to "very, very, very poor."

Dr. Grenon outlines three patterns that future oil developments could follow: (1) trend to heavier oils, (2) trend to smaller fields, and (3) trend to offshore fields. I have a reservation with respect to the trend to smaller fields. It does not seem to me that the majority of the giant fields have already been discovered in the world. Rather, it would appear that the greater number of the giant fields, scattered over the world's prospective petroleum area, are yet to be found.

I agree with Dr. Grenon's skepticism about current estimates of world petroleum resources. One should question the apparent sole reliance or bias of decision makers toward conventional or consensus views. The amount of petroleum we will finally obtain is what worldwide exploratory efforts are able to ultimately get, and not a so-called "expected value," based on current perceptions. The underlying uncertainty function of these methods of estimation is really unknown. Because of these considerations I feel we should prefer to continue scanning the full range of the published estimates, as Dr. Grenon has done.

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Comments from the Floor

H. W. Menard (U.S. Geological Survey): There is no way to define a scientific prediction system. It is rather striking that there is not an enormous range in the estimate of undiscovered oil. That is because there is rather general agreement as to how much oil remains to be discovered in Alaska and the continental shelves. We have detailed information from oil countries. The more information you have, the wider the range of estimates.

M. Grenon (International Institute for Applied Systems Analysis): Price is one of the crucial parameters. Unconventional natural gas could become competitive, but at the same time a lot of conventional natural gas has been put on the market. We delay on unconventional natural gas because it is much more expensive. There is a trend of OPEC to always increase the oil price. New countries are now entering the oil price increase game. Egypt has been exploring for the last few years and along with Mexico is now producing oil on the market. India is another example of another country that cannot afford to pay high prices for oil and therefore will start exploration. Between $20 and $25 per barrel means a lot of oil can come on the market and many people will not be able to buy it.

E. Bittner (Office of Resources, U.S. Department of State): On the question of whether one can bring oil onto the market if it only goes up high enough, one has to consider the energy cost of bringing in difficult oil. In Venezuela with heavy oil, with today's technology it costs more energy in terms of a barrel of oil than one would get from a barrel of oil. In addition to a price, we must consider an energy balance. The technology is a restraint.

M. Grenon: We have created such an energy imbalance. If you look at oil shale in the United States, the balance is still very positive. We are now studying about when the balance will become negative if you go to decreasing content. Oil shale still maintains a positive balance. If you consider water pumping power, the energy balance is negative, but the economical balance is positive. You have to look at the economic balance as well as the energy balance.

The Growing Oil Scarcity and the Challenge of Future Discoveries

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The world price of gold has, over the last four months, increased from $240 an ounce to more than $400, showing a rise of 67 per cent. If this latter price is compared to a base price of $35 per ounce which existed immediately prior to the first devaluation of the U.S. dollar in 1971, the resulting percentage increase would be more than 1,000 per cent. Over the same two periods of comparison, the average price of oil (or black gold) has gone up by 38 per cent and 775 per cent respectively, a rise considerably lower than that of gold. The reason put forward by the press for this dramatic rise in the price of gold is the growing distrust of individuals in world currency markets as well as their reaction to the prospects of high inflation and recession in world economies.

Apart from what the press and other media say about gold, people buy gold as a store of value for protection against future hazards. They also buy it for its utility as jewelry, and here it has an intrinsic value to them as individuals. But for the economy at large, buying gold is an investment with a very low return. Its contribution to productivity and GNP growth is almost nil except for a few countries who control its world production. Nonetheless, people at all levels tend to accept a price increase of gold as a fact of life. There is little dispute between nations as to whether such an increase is exorbitant or normal. There is even less dispute as to whether its price is controlled by a few sellers who stand to reap huge profits from its sale at times of high prices.

When it comes to oil, it is an entirely different story. It is a well-known fact that its discovery, its reserves and production, its utilisation and trade attract the greatest interest and controversy among all sorts of people including in particular economists, politicians, journalists and academicians; and the reason for this should not escape our notice. Unlike gold, oil productivity is in contrast immeasurable, for it is involved in almost every phase of human activity, by day and night, at factory and at home, in motion and at rest. It is not an overstatement to say with confidence that it is the geologist and then the driller, who, by discovering it, have paved the way for this all-pervasive contribution to the advancement of mankind. We in Saudi Arabia do pay tribute to those teams of American geologists and drillers who, armed with the best of technology and a zest for achievement, have been instrumental in the well-timed discovery of our giant oil fields. They have also contributed a great deal towards the exploration and development of mineral resources now under way. Although it is premature at this stage to evaluate our mineral potential in a precise manner, we do hope that by the turn of this century we may assume an effective role in world trade of other minerals like that played by oil. After these great discoveries were established, the management and disposal of those resources were transferred by geologists and their trade partners to the business managers and their associates in both the private and public sectors. I hope that these other categories of human beings will perform as good a task as did the geologist, who in our world of irrational conflict today has become the real unknown soldier.

As far as oil is concerned, it should be inscribed in the annals of history that the greatest contribution made was that of the geologist. Undaunted by inhospitable climates of prospective areas, be they the hot deserts laden with awkward sand storms, or the cold and icy polar areas extremely hazardous to health, the geologist has struggled, finding the huge reservoirs that contain this precious hydrocarbon liquid needed by man to preserve and enrich world civilisation. Hundreds of billions of barrels have been found so far. However man, in his quest for a better life, has, since the inception of oil discoveries during the 19th Century, used up about 427 billion barrels out of a worldwide discovered recoverable reserve of 1,120 billion barrels, i.e., about 38 per cent.

The geologist, more than anyone else, knows how many years current world reserves will last if the world continues to consume oil at existing levels, and how many fewer years they would last if higher rates of consumption were necessary to maintain higher economic growth. He, more than anyone else, knows how much oil is ultimately available for recovery from conventional fields and from those that may be discovered elsewhere in the next ten to twenty years. I hope that as geologists your outlook on the future is optimistic, because my own is grim indeed. I do not have to repeat the same numerical prognosis which I have so many times introduced before audiences as distinguished as yours, in order to prove my point. Suffice at this stage to cite some figures that depict the dramatic, if not wasteful, rise in world consumption on a disaggregated basis during the last ten years. The American individual on average consumed 3.2 tonnes of oil in 1968. In 1978 he raised his consumption to 4.1 tonnes, reflecting a rise of almost nine-tenths of one tonne or 284 American gallons. His consumption of total primary energy including oil during the same period went up from 7.74 tonnes (of oil equivalent) to 8.73 tonnes, a rise of almost one tonne. But while, as I have already demonstrated, per capita consumption of oil increased by nine-tenths of one tonne, average consumption of all other sources of energy increased at the same time by only one-tenth of one tonne of oil equivalent.

Per capita consumption of oil in Western Europe went up from 1.45 tonnes in 1968 to 1.87 tonnes in 1978, a rise of 0.42 tonnes, or 132 US gallons. Average primary energy consumption including oil increased from 2.65 tonnes of oil equivalent to 3.25 tonnes of oil equivalent, i.e., a rise of six-tenths of one tonne. Again, the greatest part of this rise in energy consumption, or 70 per cent, was accounted for by oil. Per capita consumption of oil in Japan grew over the same period from 1.35 tonnes to 2.32 tonnes, reflecting a rise of about one tonne or 315 US gallons, whereas per capita consumption of primary energy, including oil, increased from 2.1 tonnes to 3.2 tonnes of oil equivalent. Once more it is evident that the greatest part of such growth or 90 per cent was accounted for by oil.

Although per capita consumption in the less developed countries in much lower than that of the industrialised countries, much of the growth in energy consumption has stemmed also from oil and its derivatives. Per capita consumption of oil in the Middle East and South America went up from 0.45 and 0.46 tonnes in 1968 to 0.85 and 0.62 tonnes in 1978 respectively. In Asia and Africa, per capita consumption of oil is the lowest in the world. It grew however from 24 and 35 US gallons in 1968 to 44 and 45 US gallons in 1978 respectively.

In the Sino-Soviet bloc, per capita consumption of primary energy went up from 1 tonne in 1968 to 1.65 tonnes of oil equivalent in 1978, whereas that of oil had risen from 0.26 tonnes to 0.56 tonnes respectively, accounting for 47 per cent of total energy growth from all sources.

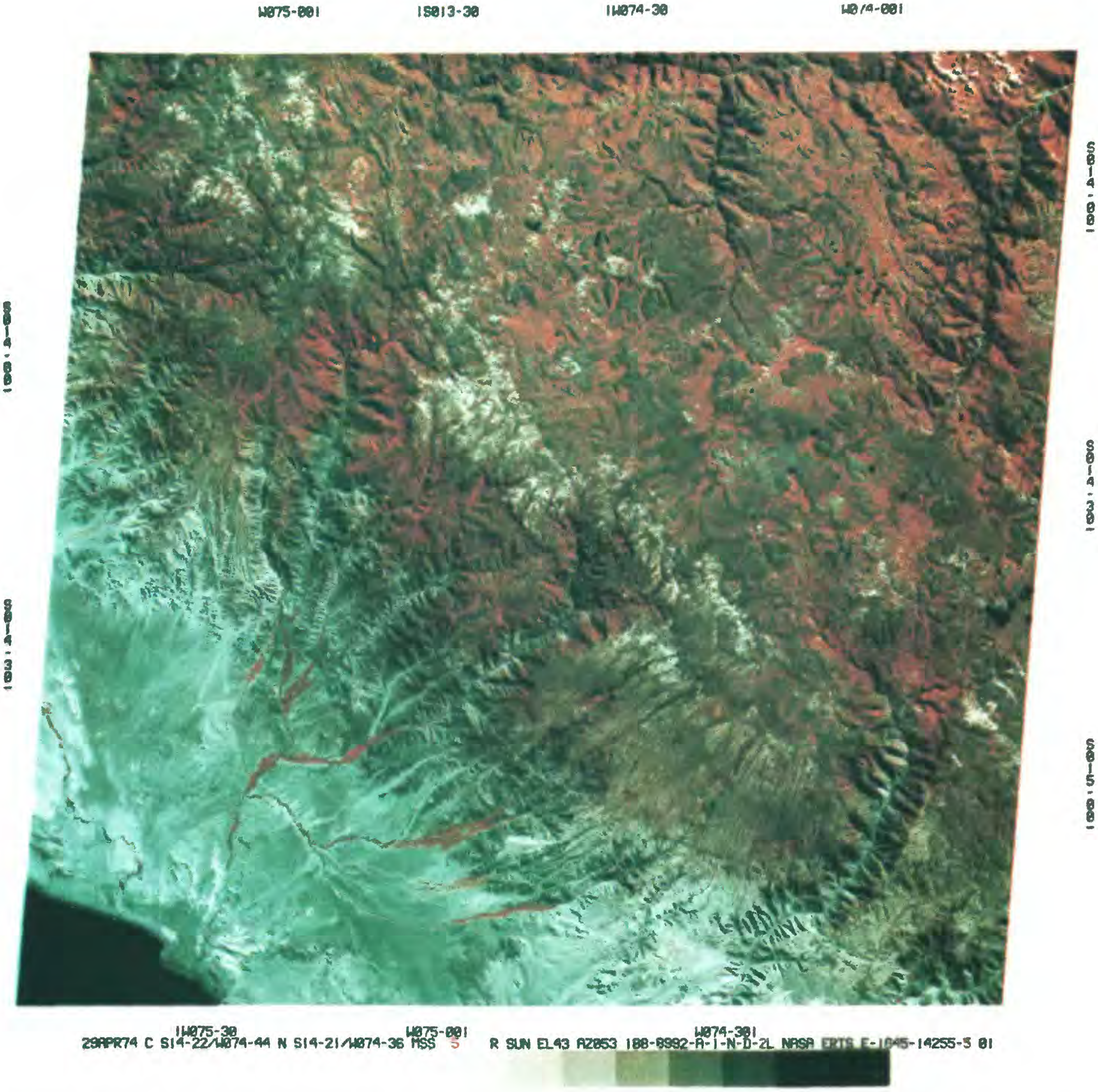
Thus the rise in per capita consumption of oil in the USA between 1968 and 1978 was greater than the absolute level of per capita consumption of oil in the Middle East in 1978. The rise in per capita consumption of oil in the USA over the last ten years was more than six times the absolute level of per capita consumption of Asia and Africa in 1978. These figures highlight four important facts:

1. The consumption by many industrialised countries of much more than their fair share of world energy supplies.
2. The continued reliance by all world communities on oil as a major source of energy, during the last ten years.
3. The need to expedite the rate of finding new reserves, and to improve the rate of recovery of oil in place.
4. The necessity to rationalise the use of oil.

It is a well-known fact that the declining price of oil in real terms over the twenty-year period 1950–1970 was responsible for the stagnation of drilling activity in the USA and many other areas with good prospects for oil. Only new areas where unusually prolific reserves existed such as Libya and Abu Dhabi could have been developed under these circumstances. The disincentive entailed in the then prevailing low price of oil was more than offset by the prolific nature of those oil fields themselves, a God-bequeathed attribute. There, the high cost of exploration and development was counterbalanced by the low unit cost of production resulting from the exceptionally high production rates per well. But even prolific fields have their own limitations. The world still needed more oil than those fields could produce. Once again, the law of supply and demand had, out of necessity, manifested itself as a market force after being obscured over a long period of artifical suppression. In early 1971, the long-term downward trend in the world price of oil was finally reversed and prices had commenced their upward course, following the application of the Tehran Agreement reached in February that year between the oil producing countries and the oil companies. Thus, geological and drilling activities elsewhere were given a fresh impetus as a result of the changing economics of utilisation. But the real momentum was provided when the oil prices were substantially raised in 1973 and 1974. Drilling activities worldwide have picked up discernibly following those price increases. In the United States, which accounts for the largest part of world drilling, the number of wells drilled since 1974 has about doubled. In 1978 alone, they increased by 13 per cent. Many oil and gas fields with sizeable reserves were discovered in the lower 48 States. Development of oil fields in Alaska, the North Sea, and Mexico was greatly intensified and the salutary effect on the world economy of such development is well recognised. It remains to be seen, however, whether this new trend will be sustained or thwarted by similar disincentives as those which prevailed in the nineteen-fifties and nineteen-sixties. The rate of drilling in the United States for 1979 is expected to decrease by 5 percent from that of 1978, following an average rate of growth of 12.6 per cent obtained over the previous five-year period. I hope that this reduced rate does not mark the beginning of a new cycle of lethargy in drilling activity as a reflection of the new surge in world inflation, which would erode the benefits arising from higher oil prices. World oil resources are finite. The amount of oil reserves discovered so far represents about 60 per cent of the world total. In order to locate the remaining 40 per cent, great effort will have to be exerted mainly by the geologist, in co-operation with the industrialist and the petroleum engineer, to overcome the formidable obstacles that lie ahead. But although the main task of discovery is that of the geologist, others should also create the suitable climate for him to function efficiently.

Market conditions should be coherently restructured in such a way as to permit a reasonable degree of predictability, and to ensure stable conditions of investment for the planners, as well as the manufacturers of necessary equipment and new technologies. This is an essential concomitant to geological and drilling activities. The problem of finding more reserves, and new supplies for that matter, is more of a geological and economic one rather than of a political nature. Nonetheless, it seems that certain quarters find it expedient to project the problem in a political framework and consequently call for a political solution. The so-called political solution cannot increase world oil reserves by one single barrel. On the contrary, it will have the effect of reducing supplies by impeding the development of reserves. The problem is simply geological and economic, and can only be alleviated through geological and economic solutions. An effective measure through which reserves can more immediately be increased is to promote ways and means of enhanced recovery systems. Oil recovery methods applicable at present allow only about 30 per cent of the oil in place to be produced, leaving 70 per cent of this precious liquid in the ground. I am of the opinion that geologists in close co-operation with petroleum engineers can, if given the necessary incentives, devise new methods of recovering an additional 10 to 20 per cent of the oil on top of the 30 per cent now extracted. By doing so, world reserves could be augmented by no less than 200 to 400 billion barrels. Thus, the life expectancy of world recoverable reserves may be extended by about 10 to 20 years.

World oil exports are determined by three factors: the rate of world consumption, the rate of reserve discovery or additions, and the price. Under all circumstances exporters have in the past done their best to provide the world with its requirements on a long-term basis. They have done so at times when the price of oil was extremely low, when it was increased, and also when it declined in real terms. Apart from a certain amount of oil reserves that may be termed or declared as "National Reserve" and thereby apportioned for the consumption needs of future generations in the producing countries, the bulk of our reserves will ultimately be earmarked for export to the importing countries. Additions to our reserves are therefore looked upon simply as an automatic means of increasing supplies to the importing countries. Reduction or stagnation of those reserves means lesser availability to the consumer. Whilst the price of oil can go up, it can fall in real terms. Whatever effect pricing has in determining supplies, the deciding factor, ultimately, is the actual amount of oil reserves in existence. For under conditions of diminishing reserves, no matter how high the price will be, it will certainly fail to induce additional supplies simply because the producing capacity is not there. The role of price as a stimulus to additional discoveries, and also as a determinant of base-load supplies will, however, continue to be effective. But the major roles in determining future incremental supplies in an adequate manner will be those of the consumer and the geologist, the first by rationalising his consumption, the second by discovering more reserves.



Peruvian Andes (upper right) and coastal plain (lower left), 320 km southeast of Lima. The potential for discovery of new mineral deposits in the Andes is excellent. Approximate scale 1:1,000,000. National Aeronautics and Space Administration, Landsat image 1645–14255, April 29, 1974.

Challenges and Problems Concerning Mineral Resources

Organizing a National Assessment of Mineral Resources

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INTRODUCTION

I am pleased to have this opportunity to address the U.S. Geological Survey on its one-hundredth anniversary. We in Chile are especially grateful to the Survey, since its technical cooperation was material in the creation of the Chilean Geological Survey in 1957. Also, I am grateful for the invitation to participate in this symposium on Resources for the Twenty-first Century. I hope that my contribution will be of some value for the organization of mineral assessments in developing countries.

ORGANIZING A NATIONAL ASSESSMENT OF MINERAL RESOURCES

Assessment of the mineral resources of a country involves the evaluation or estimation of its ultimate mineral resources, and, therefore, requires an estimation of both identified resources and undiscovered resources. Whereas the identified resources can be assessed with an acceptable degree of accuracy, the evaluation of potential or undiscovered resources is controversial, because it is based on speculative concepts and on more or less incomplete data of the geological environments of the mineral deposits. In spite of this uncertainty, it is worthwhile to evaluate the potential of yet-to-be discovered resources as an approximation that can be progressively refined as knowledge of the mineral deposits and their geologic settings becomes more complete.

The importance of an assessment of potential mineral resources is twofold, on one hand for the country itself, because this knowledge is essential for planning long range mining programs, and on the other hand for the world as a whole, because no country is self-sufficient in the minerals needed for economic development. In all phases of development—industrial, agricultural, social—minerals are the basic elements on which everything else is dependent.

The development and organization of an entity devoted to the national assessment of mineral resources is the subject of this presentation. I believe that the most effective entity for this purpose is a national geological survey that not only carries out direct studies of mineral deposits but also undertakes geological, geochemical, and geophysical mapping to establish the environment of the deposits and to locate new deposits.

An evaluation of the mineral potential of a nation requires basic knowledge as to the types, distribution, and environments of known mineral deposits, which underpin any estimates of the total resource potential of the national mineral resources. In discussing such an evaluation I would like to use our Chilean experiences as example, bringing to your attention the methods used in the assessment of some of our key mineral resources. I also would like to discuss some of the problems of organizing a national geological survey in a developing country, which is a prerequisite for the assessment of the mineral resource potential. Again this discussion is based on my own experiences with creation of the Instituto de Investigaciones Geológicas de Chile (Chilean Geological Survey).

Without any doubt, the basic geologic knowledge of the country is fundamental to the assessment of its mineral resources. The most effective way of gaining this knowledge is by systematic geological mapping at medium to small scales such as 1:50,000, 1:100,000, and 1:250,000, the last scale to be used in areas where previous mapping is scant or absent, the condition of most developing countries until the past 2 or 3 decades. Larger scale quadrangle maps, at scales of 1:25,000 or greater, such as those now being produced in North America and Europe, are a luxury that few of the developing countries can afford. When geologic mapping has progressed to the point that the major stratigraphic, structural, and plutonic elements are recognized, it is desirable to compile (with additional small-scale mapping as required) a small-scale national geologic map. In Chile, we found it possible to prepare such a map at the scale of 1:1,000,000 after only about 10 years of systematic larger scale mapping.

Inasmuch as only part of the country was covered by larger scale maps, it was necessary to augment the data in these maps with reconnaissance mapping and extrapolating of geologic information to unmapped areas. Photogeologic interpretation of aerial photographs was essential to such extrapolation. Satellite images, which have been available since the early 1970s, have proven to be of invaluable assistance in interpretative geological mapping. Aerial photographs are particularly useful because they give a relatively detailed view of the geology, whereas the satellite images give a broader picture of the regional distribution of the larger geologic units which commonly are masked by details shown in the larger scale photographs.

In this way it is possible to construct a national geologic map that, although surely having many inaccuracies in a first issue, will prove to be very useful and can be progressively refined, as more geologic information becomes available.

With a national geologic map completed, a second phase of investigations, directed toward mineral resources assessment, is preparation of a metallogenic map showing the locations and types of known mineral deposits on a simplified geologic map. Such a map gives a birdseye view of the different types of deposits as well as the interrelation of mineral deposits and the geologic environment. This map may serve to identify targets for mineral exploration, for example, areas lacking mineral deposits in belts or lines of abundant deposits, and for estimating the potential for undiscovered mineral deposits.

Preparation of a metallogenic map requires study and compilation of available information about the known mineral deposits, including significant occurrences that do not presently constitute economic mineral deposits. Information about each deposit may be compiled on specially designed cards that can be used either to develop a computer file wherein the various parameters may be evaluated or can be manipulated by less sophisticated mechanical methods. The following data concerning each deposit are essential:

1. Accurate geographic location, including elevation above sea level.
2. Host rock or rocks, including lithology, structure, and age. If the deposit is associated with an intrusive body, it is advisable to obtain chemical analyses and radiometric ages of the igneous rock in this body.
3. Morphology and attitude of the deposit—does it occur as a vein, manto, stockwork, dissemination, or massive ore body; what is the strike and dip; is it related to folds, faults, or bedding in stratified rocks.
4. Types and distribution of hydrothermal alteration.
5. Mineral paragenesis and zoning of both hypogene and supergene mineralization.
6. Size and extent of the deposit—available information about resources and reserves should be noted as well as historical data about production, which together give an idea of total quantity of ore present before mining began.
7. Genesis of the ore deposit, which may be determined by making comparison with similar though better-known deposits.

In a country such as Chile, which has had a long history of mining, a large part of the information about mineral deposits can be obtained from available mine reports. However, even here considerable effort must be directed to field checking this information and to reconnaissance investigation of deposits for which data are not available.

Once the desired information about the known mineral deposits is obtained, the next step is to plot the mineral deposits and occurrences on the national geologic base map, either on transparent overlays or directly on the map. For most developing nations, map scales of 1:1,000,000 or 1:2,000,000 are appropriate. However, in Chile we found the scale of 1:1,000,000 to be the best for the national metallogenic map. The geologic base map should preferably be a simplified version of the national geologic map. Such a map is prepared by grouping of geologic units that apparently provided similar favorable metallogenic environments as well as those that were unfavorable or that represent post-mineral cover. The geologic base map should also show major tectonic features, especially those having obvious relation to mineral deposits.

Map symbols representing the mineral deposits should be designed in such a way as to show, as clearly as possible, the main characteristics of the deposit, such as

1. Most important metal or metals contained.

2. Size and morphologic type of deposit.
3. Type and age of host rock.
4. Age of the mineralization.
5. Probable genetic type of deposit, be it epigenetic, syngenetic, contact metamorphic, lateritic, evaporitic, placer, or other.

The final step in preparing a metallogenic map consists of the grouping and delineation of the mineral deposits into metallogenic provinces or mineral belts. The designation of these metallogenic units is accomplished by grouping deposits according to dominant metal or metals, genetic types, paragenesis and minor metal associations, age of mineralization, and age of host rock. Once these metallogenic units have been delineated, their limits may be traced on the overlays. The simplified geologic map showing mineral localities designated by informal symbols, and overlays showing mineral or metallogenic provinces, constitutes the metallogenic map of a country. Such maps should be periodically refined as new information about mineral deposits and regional geology becomes available.

The metallogenic map constitutes the fundamental document for the assessment of the mineral resources of the country, especially for the evaluation of the so-called undiscovered or potential resources. Nevertheless, in order to have a better basis for evaluation of these resources, it is advisable to complement the metallogenic map with regional geophysical and geochemical surveys, which might indicate more specifically the probable existence of undiscovered deposits between known mineral districts or clusters of deposits.

Climatic conditions must be considered in the evaluation of the undiscovered resources of a country. For example, the existence of lateritic deposits depends on tropical climate, whereas supergene deposits of base and precious metals are most prevalent in areas of arid to semi-arid climate, and evaporites are characteristic of areas having an arid climate.

Geomorphologic studies are important to resource evaluation. They may give a clue to areas favourable for the preservation of secondary enriched zones over primary sulphide deposits or for accumulation and preservation of placer deposits.

The other component of the national mineral resource potential, identified resources, includes reserves and resources of both economic and subeconomic materials. The quantification of mineral resources, that is, the determination of cutoff grades and reserves, is generally made by mining companies rather than by national geological surveys. However, this information is critical to an accurate national mineral resource evaluation, and it should be made available to the national geological survey or other entity responsible for the evaluation. Such proprietary company data can be utilized in the resource evaluation without disclosing the source or the mines to which they refer. Not only are these data essential to evaluating the deposits and districts to which they apply but also to less known though similar deposits and districts.

By using information about reserves and resources obtained from the mining companies together with that obtained by analysis of metallogenic maps, it has been possible to make a preliminary assessment of some mineral resources of Chile. A good example is copper contained in the porphyry copper deposits, which probably account for more than 90 percent of the Chilean copper resources.

Most of the porphyry copper deposits of Chile are distributed in a narrow longitudinal belt located on the western slope of the high Andes at altitudes between 1,000 and 4,500 m. This belt extends from the Chile-Peru border in the north, at latitude 18° S, southward to approximately latitude 39° S, a length of about 2,300 km. Porphyry copper deposits in actual or past exploitation are Chuquicamata, El Teniente, El Salvador, Potrerillos, Andina, Disputada, and Andacollo. Two of the three largest copper deposits of the world (the third being the Bingham deposit in central western United States) are El Teniente and Chuquicamata, each containing several thousands of millions of tons of ore and an estimated several million tons of contained copper. In addition to these deposits that have been exploited there are many other porphyry copper deposits in the belt that are in various stages of exploration. These include the deposits at Mocha, Cerro Colorado, Quebrada Blanca, El Abra, Pampa Norte, and Los Pelambres. Most of the deposits, other than El Teniente and Chuquicamata, probably have less than 5 million tons of contained copper.

The size and shape of the El Teniente and Chuquicamata ore bodies can be used to estimate the vertical extents of the deposits and the amount of material stripped by erosion. These parameters can then be applied to less well-known porphyry copper deposits to assist in estimating their size and depth of mineralization. The ore body at Chuquicamata is oval-shaped, being 3,600 m long and having a maximum width of 800 m. Exploration has demonstrated that the vertical extent of mineralization is more than 1,000 meters. At El Teniente, the ore body is roughly circular, with diameters varying between 1,500 and 2,500 m, and the known vertical extension is more than 1,200 m. Lowell and Guilbert (1970) reported that porphyry copper columns may have vertical extents of as much as 3,000 m. Considering the size of El Teniente and Chuquicamata, it would seem that the original ore bodies had at least this maximum vertical dimension, and it may be estimated that the erosion levels in these are between the middle and uppermost parts of the porphyry copper column.

The host rocks of the porphyries are of Mesozoic to Tertiary age. Post-mineral volcanic and sedimentary rocks of Late Tertiary and Quaternary age, which extend over part of the area occupied by the main porphyry copper belt, undoubtedly cover some deposits that, like the known deposit, had previously been exposed by erosion. In the northern half of the porphyry copper belt between 40 percent and 70 percent of the area is covered by the post-mineral rocks, and about 40 percent of the entire belt is covered by post-mineral rocks.

The copper resources contained in most of the known porphyry copper deposits and prospects of Chile have been calculated on the basis of information provided by the largest operating porphyry copper mines, by geologists in charge of exploration at developing mines, and by geologic reports of several prospects. The results are as follows:

Reserves or identified economic resources

Demonstrated	6,012,000,000 tons of ore.
Inferred	3,253,000,000 tons of ore.

The average grade of the reserves (identified resources) is 1.02 percent Cu, and therefore the fine copper contained is approximately 94,500,000 tons.

Identified paramarginal and submarginal resources

Paramarginal: 1,970,000,000 tons of ore, average grade 0.51 percent Cu.
Submarginal: 4,625,000,000 tons of ore, average grade 0.24 percent Cu.

The fine copper contained in these resources is estimated at 20,900,000 tons.

In addition to these identified resources, the copper companies have estimated hypothetical resources in the vicinity of or at depth in the operating mines at 4,500,000,000 tons of ore, of 0.76 percent Cu, containing some 34,200,000 tons of fine copper.

Estimation of the resources within the remaining area in the porphyry copper belt is more difficult. In view of the fact that the belt is far from having been completely prospected, it is likely that many deposits remain to be found. The resources in these deposits may be classified as hypothetical. As stated above, 40 percent of the area of the belt is covered by post-mineral rocks, and it is probable that approximately the same percentage of the total copper resource of Chile remains in undiscovered buried deposits. On the other hand, part of these undiscovered deposits may have an overburden too thick for them to be economically exploited at this time. Of the remaining 60 percent of the porphyry copper belt, where pre-mineral rocks are exposed, it may be estimated that more than half has not been adequately prospected.

In accordance with this reasoning, the resources computed for the known deposits, about 150 million tons of fine copper, are in approximately one-third of the area of the porphyry copper belt. This tonnage figure is believed to be conservative. If the deposits in the remainder of the porphyry copper belt, including areas covered by post-mineral rocks and those inadequately exposed (including blind deposits not exposed by erosion) it is likely that total resources are at least three times the identified resources. Therefore, it is estimated that the resources of the Chilean porphyry copper belt are approximately 450 million tons of contained copper, of which 100 million tons are reserves.

ORGANIZATION OF A NATIONAL GEOLOGICAL SURVEY

As the final part of this presentation, I would like to mention the challenges and problems encountered in the creation of a national geological survey.

Without doubt, the most difficult obstacle is the lack of understanding by governments and by the public of the important contributions that such an entity can make to economic development. Because developing countries have so many urgent problems whose solution requires funding from the national budget, it is difficult to convince authorities to support a national geological survey whose impact is long term in contrast to, for example, social reforms that may have an immediate impact on the well being of the people. The only way to alleviate this difficulty is through a long and patient campaign to explain to the authorities that a national geological survey can provide the basic resource data essential to long-term planning and economic development of the nation.

Another problem, commonly encountered in developing nations, is the proliferation of small geological organizations that dissipate energy and funds that would be more effective in a single organization. It is therefore necessary to demonstrate to the authorities that a centralized national geologic survey is the most effective type of organization for undertaking a mineral resource evaluation.

Government authorities must also be convinced that a major objective of a national geological survey is systematic geologic mapping of the country. Such mapping is fundamental to all types of geological, geophysical, and geochemical mapping, to mineral resource investigations, and to studies of natural hazards such as earthquakes and landslides.

NEED FOR GEOLOGIC EDUCATION

Finally, it may be said that a problem often encountered in developing countries is the lack of well-trained geologists. It is here that technical cooperation between the developed and developing nations can be most effective, as was the case in Chile. In fact, between 1954 and 1966, a technical cooperation program between the U.S. Geological Survey and the Government of Chile, under the auspices of the technical aid program of the Government of the United States, led to the formation of the Instituto de Investigaciones Geológicas, the first national geological survey of Chile. A broad program of geologic investigations was developed and high-level work standard established. A major part of the effort of the U.S. Geological Survey was in the training of Chilean geologists, both in Chile through demonstration geologic mapping and in the United States through university level post-graduate study.

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Mineral Industry of Pakistan

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INTRODUCTION

The unique position of Pakistan between the Indian shield or plate in the east, the Eurasian mass in the north and the Iran-Afghanistan microcontinent in the west makes for a fascinating geological province in which there has been considerable interest during the decade since the plate tectonic theory was first defined. In 1960, the Hunting Survey Corporation Ltd., Canada, mapped the geology of the southern part of Pakistan at 1:250,000 scale and described its geology in some detail. In 1964, the Geological Survey of Pakistan published a geological map of Pakistan at the scale of 1:2,000,000. However, at this time, interpretation of geological features was based on geosynclinal theory. Subsequently, when plate tectonics replaced geosynclinal theory as a working model, the geologic and tectonic position of Pakistan generated new interest, particularly with respect to the country's potential in mineral resources.

Very broadly Pakistan can be divided into Baluchistan in the west and northwest and Indus plains in the east; the two areas are separated by an approximately north-south trending calcareous zone designated as the Indus Basin, which is also called the main axial belt of Pakistan. The northern mountain zone lies north of this axial belt. The Baluchistan Basin is mainly underlain by arenaceous and volcano-sedimentary rocks with large masses of calcalkaline volcanics and intrusives. On the basis of the Ispikan conglomerate of Tertiary age and the sino-diorite ophiolitic complexes of Ras Koh, the Baluchistan basin has been sub-divided into the following secondary belts:

a. South Mekran belt—arenaceous zone lying south of Ispikan conglomerate.
b. North Mekran belt—arenaceous zone lying north of Ispikan conglomerate up to Ras Koh complex.
c. Ras Koh belt composed of sino-diorite and ophiolitic complexes.
d. Chagai belt lies north of Ras Koh belt and is composed of calcalkaline volcanic and intrusive rocks with porphyry copper deposits and an intervening basin of volcano-sedimentary rocks designated as the Dalbandin synclinorium.

The ophiolitic complexes are largely confined to the northern and western part of the main axial belt.

The main axial belt representing the Indus basin is divided into the Kirthar, Sulaiman and Kohat-Pothwar Provinces. The mountain zone north of Kohat-Pothwar is underlain by igneous, metamorphic and mafic intrusive rocks of Tertiary age and metamorphic and sedimentary rocks of Precambrian to Tertiary age.

The central axial belt, which unequally divides Pakistan lengthwise, is a complex anticlinorium that started to develop some time during the Cretaceous. Some of the major ophiolites of Pakistan occur on the western flank of this belt near Las Bela, Muslimbagh, Fort Sandeman (Zhob) and Waziristan. The Ras Koh belt, Chagai district, again west of the axial belt, consists primarily of calcalkaline magmatic rocks with subordinate ophiolites and volcanics ranging in age from Cretaceous to Miocene(?).

Powell (1979, p. 5) envisages three stages in the tectonic development of Pakistan: (1) Rapid northward movement of India from Late Cretaceous to early Eocene; (2) small counterclockwise rotation of India during the Eocene; and (3) slower northward movement from the Oligocene to the present. He also envisages two convergence zones: a northern one, the Alburz-Hindukush and a southern one, the Zagros (Central Iran)-Chitral zone. It is generally considered that the ophiolites along the central axial belt were emplaced during the Cretaceous when India was rapidly moving toward the north.

Only ten years ago Pakistan was considered to be a country possessing industrial mineral resources only. Table 1, which gives estimates of mineral reserves as of the end of 1970, is inaccurate and incomplete. For example, chromite reserves have been grossly exaggerated as there is no real basis for many of the reserve estimates.

Table 1 Proven reserves of minerals in Pakistan as of 1970 (unit: millions of tons)

Barite	1.99
Celestite	.30
China clay	6.13
Chromite	3.00
Coal	442.00
Fire clay	17.00
Limestone and dolomite	45,000.00
Magnesite	5.00
Marble	very large
Gypsum and anhydrite	2,020.00
Iron ore (mostly low grade)	500.00
Rock salt	over 1,000.00
Sulphur	.125
Vermiculite	11.50

Intensified geological investigations during the last two decades, particularly since the discovery of the Saindak Porphyry Copper deposits in the early 1960s, have demonstrated that Pakistan has a sizeable potential for metallic minerals, particularly copper, lead, zinc, molybdenum, silver and perhaps tin. After a brief review of the existing mineral industry in the country, I propose to discuss the mineral potential of Pakistan as it appears today. It should be pointed out that due to a lack of detailed knowledge of the geology of the country the ideas presented here are not well documented.

At present 15 mineral commodities are being mined in Pakistan. Of these, five are being exported (tables 2 and 3). As can be seen the total mineral production of the country is small and the contribution to the earning of foreign exchange rather insignificant. The mineral industry receives only about 0.5 percent of the annual development plan allocations and its contribution to the GNP is of the same order. This, of course, does not include contributions of mineral-based industries such as cement, ceramics, glass and fertilizer.

MINERAL OCCURRENCES OF PAKISTAN

Antimony

Mining of antimony ores containing stibnite (Sb_2S_3) and boulangerite ($Pb_5Sb_4S_{11}$) has only been carried out in the Lutkho area of Chitral State. The oldest mine is at Krinj (fig. 1), about 13 miles north of Chitral town, where stibnite occurs in quartz veins in Palaeozoic slates 150-300 ft below their contact with overlying Cretaceous limestone. The maximum thickness of the veins is about 4 ft. Ore is extracted by small inclined workings along the veins. Annual production is 150-250 tons. Hand-sorted ore contains about 20 percent Sb. The ore is roasted at a small plant near the mine to convert the Sb_2S_3 to Sb_2O_3. Another deposit at Avirath Gol, about 5 mi west of Krinj, consists of veins of boulangerite as much as 3 ft thick at the contact between Palaeozoic slate and Cretaceous limestone. The veins are irregular, and only a few hundred tons of ore containing as much as 40 g of gold and 75 g of silver per ton has been extracted. Total reserves at both these deposits probably are not more than a few thousand tons.

Stibnite-bearing quartz veins have been reported from Qila Abdullah (fig. 1) as occurring in the hanging walls of faults cutting slates of probable Oligocene-Miocene age. About 50 tons of ore reportedly have been mined. Reserves have not been estimated. Similar occurrences reported in the surrounding areas have not been studied.

Barite

Only small scale mining of barite is being done in Pakistan and annual production during the past decade has ranged between 1,800 and 16,400 tons per year (table 2). About a dozen occurrences of barite have been described in the literature (Ahmed, 1969, p. 55-60) but only the major deposits are described here.

Table 2 Production of selected minerals from 1971-72 to 1977-78 (unit: thousands of tons)

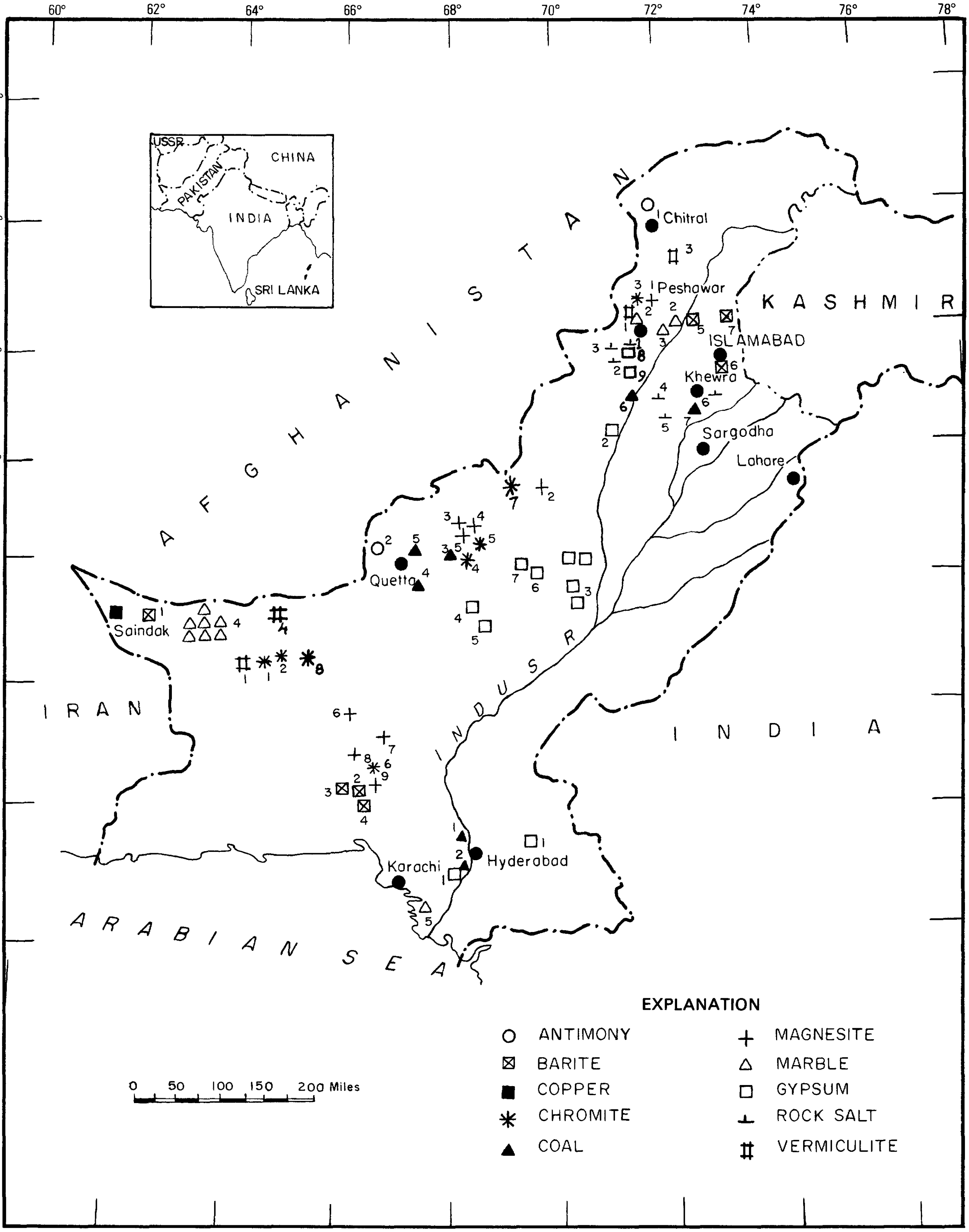
	1971-72	1972-73	1975-76	1976-77	1977-78
Aragonite/marble	15	31	25	35	34
Barite	1.80	1.9	7.15	15.606	16.414
Celestite	2.58	1.15	9.57	2.70	NA
Chromite	34	18	12	8.0	9.47
Coal	1,255	1,204	1,108	1,113	1,164
Dolomite	NA	NA	.356	.270	.274
Fire clay	22	19	41	39	50.471
Gypsum	22	132	299	287	175.02
Limestone	2,628	2,846	3,249	4,927	4,184
Fullers earth	13	16	20	12	11.15
Magnesite	1.03	2.504	2.660	1.245	4.288
Rock salt	358	354	427	336	610
Soapstone	4.225	6.239	5.314	7.596	7.84

NA – Not available.

Source: Pakistan Statistics Division.

Table 3 Principal minerals exported (quantity in tons; value in thousands of Rs.)

	1974-75		1975-76		1976-77	
	Quantity	Value	Quantity	Value	Quantity	Value
Marble/aragonite	1,357	1,451.8	232.7	285.5	100	178.2
Marble, grey	54	89.8	89.4	94.3	188	169.7
Marble, onyx	8,461	9,865.4	1,407.2	1,969.9	6,624	12,783.1
Limestone, unworked	2	2.2	568.0	224.0	414	319.3
Sandstone and porphyry stone	----	----	----	----	1,213	149.9
Rock salt	2,118	915.4	4,189.2	911.5	7,904	1,214.0
Chromium ores and concentrates	26,690	9,398.7	15,536.4	9,488.7	23,991	9,543.5
Total	38,682	21,723.3	22,022.9	12,973.9	40,434	24,357.7



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Peshawar
ISLAMABAD
Khewra
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Quetta
Saindak
Karachi
Hyderabad
0 50 100 150 200 Miles
EXPLANATION
ANTIMONY
BARITE
COPPER
CHROMITE
COAL
MAGNESITE
MARBLE
GYPSUM
ROCK SALT
VERMICULITE

Three barite deposits occurring in the Khuzdar area are the Monar Talar deposit, the Shekhran hills deposit, and the Bankhri deposit. The Monar Talar deposit is exposed along the foot of the Monar hills about 3 mi SSE. of the Gunga village (latitude 26°46′N.; longitude 66°31′E.). The barite is interbedded with limestone and is generally impure. Thickness of the barite varies from 10 to 20 ft at the southern end of the deposit to about 50 ft at the northern end. The deposit is about 4,000 feet long. Reserves estimated to an arbitrary depth of 100 ft are 850,000 tons (Hunting, 1960, p. 409). The Shekhran hills deposit, about 12 mi W. of Khuzdar and 1-1/2 mi NE. of Shekhran hills, is in an area noted for lead mining about a century ago. The barite occurs as replacement of a 2-ft bed of sandy limestone of Jurassic age. The deposit has a strike length of 60 ft, and it exhibits characteristics suggesting that it may be at the same stratigraphic horizon as the Monar Talar deposit. The Bankhri deposit consists of a vein 100 ft long and 3-9 ft wide, which strikes N. 28° E., and is in quartzitic rock of Jurassic age. The deposit is being exploited and more than 2,000 tons of ore, the amount of the original reserve estimate, has already been mined.

Klinger and Ahmad (1967) described the Khuzdar deposits as occurring in the Zidi formation of Jurassic age. The barite occurs as a series of tabular lenses parallel to and confined to the lower thinly bedded limestone. The footwall rock appears to have been leached, silicified and oxidised (Klinger and Ahmad, 1967, p. 10). At places this altered rock is more than 100 ft in thickness. The barite zone is about 4,500 ft long, and barite lenses in the zone are 10–80 ft thick and 270–1,200 ft long. Typical analyses are given in table 4, sample Ba-1 and Ba-2. Reserves are estimated to be about 1.3 million tons.

Table 4 Selected analyses of barite

SAMPLE NO.	WEIGHT PERCENT						
	$BaSO_4$	SiO_2	Al_2O_3	$CaCO^4{}_3$	Fe_2O_3	MgO	Sp.gr.
Ba-1	91.86	2.48	2.73	0.98	0.02	1.63	---
Ba-2	95.92	1.84	.02	.49	.03	.67	---
PR-45	88.42	2.55	---	5.78	.15	---	4.21
PR-47	92.76	1.91	---	2.64	.09	---	4.35

Ba-1, Ba-2 – Barite sample from Khuzdar area.
PR-45, PR-47 – Barite sample from Kohala area.

Source: Ahmed 1969, p. 57 and 59.

The Kundi barite deposits (latitude 26°24′ N.; longitude 66°36′ E.), also in the Khuzdar area, are concordant replacement bodies in folded fossiliferous limestone of Jurassic age. The limestone unit is exposed for 1,800 ft but barite is confined to the western one-third of the area. Five beds of limestone, 1–5 ft thick, have been partially replaced by barite. Grades are estimated to be 30–98 percent of $BaSO_4$. According to Klinger and Richards (1967, p. 36), reserves to a depth of 25 ft are 14,000 tons.

In the north of Pakistan the most important barite deposit is that of Kohala (fig. 1) occurring as dilation veins and lenses in Hazara slates of Precambrian age(?). The barite occurs as coarse-grained aggregates of interlocking crystals and is quite pure. The deposits now being exploited are estimated to contain 30,000 tons of ore. Typical analyses of the ore are given in table 4, sample nos. PR-45 and PR-47.

Chromite

Alpine type chromite deposits are widely distributed in Pakistan (fig. 1). In the north, lenses and at places veins of chromite associated with dunite, harzburgite and pyroxenite are found at several localities in the Malkand district. The chromite here is of variable grade (table 5, samples 31–34), and the deposits are mostly small, none containing more than 3,000–4,000 tons. An interesting feature of the deposits is the range of chemical composition wherein some of the ore is actually chromian magnetite (Cr_2O_3 as low as 8 percent and a Cr/Fe ratio of 1:11.5). Another locality in north Pakistan (not shown on map) is at Waziristan (approx. 33° N., 70° E.) where small lenses (containing not more than a few hundred tons) of high grade chromite (48 percent Cr_2O_3, Cr/Fe ratio of 3:1) have been found in a terrain having extensive outcrops of ultramafic rocks. Small lenses of refractory grade chromite also have been mined in an area 10–12 mi north of Fort Sandeman (now Zhob) but here again no significant deposit has been found. The chromite in this area is usually high in alumina (table 5, samples 29–30).

The largest and best developed chromite deposits occur south of Muslimbagh (formerly Hindubagh) where chromite has been mined since 1903. The chromite occurs

Figure 1 Index map of Pakistan showing the principal mineral occurrences.

Explanation

Antimony deposits: 1, Krinj; 2, Qila Abdullah. **Barite deposits:** 1, Dabbar; 2, Monar Talar; 3, Shekran Hills; 4, Bankhri; 5, Chhatti; 6, Tepra; 7, Kohala. **Chromite deposits:** 1, Bunap, Kalat Division; 2, Raya Valley, Kalat Division; 3, Hari Chand, Peshawar Division; 4, Khanozai, Quetta Division; 5, Muslimbagh, Quetta Division; 6, Lasbela; 7, Fort Sandeman; 8, Kharan. **Coal deposits:** 1, Lakhra; 2, Meting-Jhimpir; 3, Khost-Sharigh-Harnai; 4, Mach; 5, Sor Range-Degari; 6, Makerwal; 7, Salt Range. **Copper Deposits:** Saindak Porphyry Copper. **Gypsum and anhydrite deposits:** 1, Hyderabad area; 2, Saidu Wali; 3, Dera Ghazi Khan; 4, Spin Tangi; 5, Khattan; 6, Chamalang; 7, Barkhan; 8, Kohat; 9, Daudkhel. **Magnesite deposits:** 1, Sakhakot; 2, Zizha; 3, Nasai; 4, Spin Kan; 5, Sra Salawat; 6, Karka; 7, Loya na Pani; 8, Baran Lak; 9, Sinchi Bent. **Marble deposits:** 1, Khyber Agency; 2, Mardan District; 3, Nowshera; 4, Chagai; 5, Braudadbad. **Rock salt deposits:** 1, Jatta; 2, Karak; 3, Bhadur Khel; 4, Kalabagh; 5, Warcha; 6, Khewra. **Vermiculite deposits:** 1, Kalat Division; 2, Mohamand Agency; 3, Swat State; 4, Chagai.

Table 5 Chemical composition of Pakistani chromites selected to show range of composition, expressed in weight percent

	1	2	3	8	17	20	21	25	29	30	31	32	33	34
Cr_2O_3	58.1	58.7	59.1	56.1	57.7	52.5	53.9	57.0	44.7	44.8	34.27	35.21	41.51	7.94
Al_2O_3	11.8	11.8	10.2	12.7	10.7	14.9	15.1	10.7	21.0	21.3	10.32	24.08	12.67	5.38
Fe_2O_3[1]	2.97	2.97	4.16	3.20	3.84	4.95	3.36	4.35	4.7	4.7	5.33	5.71	4.32	57.16
TiO_2	.37	.30	.26	.21	.22	.30	.43	.29	.23	.23	.12	.07	.10	.29
V_2O_5	.06	.08	.07	.06	.05	.08	.12	.10	ND	ND	ND	0.06	.04	.01
FeO	11.4	11.53	10.46	13.60	13.35	12.10	13.19	13.60	13.1	13.30	13.38	13.03	14.93	24.22
NeO	ND	ND	ND	.16	ND	ND	.10	ND	.18	.22	ND	.10	.11	ND
MgO	14.6	14.5	15.2	13.9	13.0	14.50	13.80	13.10	15.3	14.80	34.78	21.51	25.01	3.61
MnO	ND	ND	ND	.18	.09	.19	.02	ND	.19	.18	.05	.03	.05	ND
CaO	.06	.05	.05	.07	.08	.08	.08	.24	ND	.08	.96	.17	.79	ND
SiO_2	.52	.24	.21	.38	.22	.28	.15	.42	.55	.39	ND	ND	ND	.42
Total	99.88	100.17	99.71	100.56	99.25	99.88	100.43	100.30	100.00	99.21	99.81	99.81	99.53	99.03
Cr/Fe	3.44	3.45	3.47	2.84	2.86	2.65	2.77	2.71	2.15	2.13	1.57	1.62	1.84	.87

[1] Total iron determined as FeO.
No. 1-30 Zhob Valley Chromites (Bilgrami, 1968, table 1, p. 142).
No. 31, 32 Samples from quarries 1.3 and 1.5 miles northwest of Landi Raud Banda Harichard areas, respectively.
ND Not determined.
No. 33 Sample from Quarry 1.5 miles southwest of Sakhakot, Harichard area.
No. 34 Sample from chromite dump at Takht-e-Bhai Railway Station.

in lenses, pods, veins, and bands (Bilgrami, 1961, 1964, 1968; Ahmed 1969). It is generally friable. Annual production has averaged about 20,000 tons a year, the maximum being 39,000 tons. Since most of this chromite is exported, the production has varied with international demand, and the current level of production is only about 10,000 tons a year. High grade metallurgical chromite (Cr_2O_3, 48 percent; Cr/Fe ratio of 3:1) as well as medium grade chromite (40–46 percent, Cr/Fe ratio of 2.6:1) are being produced. Typical ore grades are shown in table 5, samples 1–25.

Smaller chromite deposits, mostly high grade, have also been worked at Khanozai, about 35 miles northeast of Quetta (fig. 1). These deposits are smaller than those of the Muslimbagh area. Scattered occurrences of chromite, found in the Chagai district, at Kharan, and in the Bela-Khuzdar area (26–28 N., 67 E.), have not had any significant production. Reserves at Kharan are estimated to be 20,000 tons.

Coal

All Pakistani coals are lignitic to sub-bituminous and of early Tertiary age. Coal deposits of the Punjab and Baluchistan have been affected by orogenic movements, and coal beds in these areas have been folded, faulted and in places squeezed into lenses. Coal seams range in thickness from a few inches to several feet. Most of the coals are non-coking and are high in ash, volatiles, and sulphur. They crumble to powder on drying and are liable to spontaneous combustion. The chemical composition of the coals is highly variable, not only within the same coal field but also within the same coal bed, from one area to another. Selected analyses from various coal fields are shown in table 6. The seven major coal fields of Pakistan are described briefly.

The Lakhra coal field (fig. 1), which extends over an area of more than 150 sq. mi, has 3 lignitic coal beds of Paleocene age. The coal-bearing formations have been folded into an open anticline in which beds on the flanks dip less than 10°. The main coal bed is 2.5 to 12 ft thick and extends through an area as much as 12 mi long and 5 mi wide. It lies 150 feet below the surface. The other two beds are much thinner (9 in to 2 ft) although the coal is of the same quality as that in the main bed. Reserves are estimated to be 2,540 million tons of which 160 million tons are proven reserves. The chemical composition of coal from this field is given in table 6.

The Meting-Jhimpir coal field (fig. 1) extends over an area of more than 350 sq. mi, where two coal seams occur in sedimentary rocks of Paleocene age that have been subjected to minor faulting. The seams are 9 in to 4 ft thick and occur at depths of 50–120 feet below the surface. The coal is lignitic and characterised at places by a resin content as high as 0.5 percent. Analyses of coals from this area are shown in table 6. Reserves are estimated at more than 30 million tons.

Table 6 Chemical composition of Pakistani coals. Source: from Ahmed, 1969, p. 173–176.

NO.	COAL FIELD	MOISTURE PERCENT	VOLATILE MATTER PERCENT	FIXED-CARBON PERCENT	ASH PERCENT	SULPHUR PERCENT	CALORIFIC VALUE (BTU)
1	Lakhra coal fields	31.8-35.7	28.0- 0.9	26.8-30.0	7.4-10.5	3.3- 6.0	7,010- 7,660
2	Meting Jhimpir coal field	15.4-29.8	29.8-39.8	31.0-36.3	8.2-14.6	3.4- 7.4	7,400- 9,800
3	Khost-Sharigh-Harnai coal field	4.0-11.4	34.8-45.3	25.3-43.6	9.3-34.8	5.0- 7.1	8,500-12,400
4	Mach coal field	7.1-12.1	34.5-39.4	32.4-41.5	9.6-20.3	3.2- 7.4	9,200-10,300
5	Sor Range-Degari coal field	15.9-18.7	33.5-39.6	36.0-42.0	3.0-13.0	.5- 5.6	9,000-11,000
6	Makerwal coal field	4.2- 6.8	37.1-44.9	36.0-46.0	7.0-21.0	4.0- 5.6	9,500-11,850
7	Salt Range coal field	3.2- 7.6	26.3-38.8	29.8-44.8	12.3-37.7	3.5-10.7	7,100-11,100

The Khost-Sharigh-Harnai coal field (fig. 1), which extends over an area of more than 300 sq. mi, has three workable seams ranging in thickness from a few inches to 8 ft. The coal bearing formations trend northwest and crop out intermittently along a ridge for a distance of about 35 mi. The coal beds at places dip steeply and have been faulted. The coal, which is bituminous, is characterised by high volatile matter, has washable ash, and possesses coking properties. Analyses of coal from this field are shown in table 6. Reserves are estimated to be more than 40 million tons.

The Mach coal field (fig. 1) extends over an area of 16 sq. mi and has three workable coal seams as much as 4 ft thick. The coals are in strongly folded and at places faulted sedimentary rocks of Eocene age. The coal is of inferior quality, having intercalations of shale and a high sulphur content. On drying, it crumbles easily to powder and is liable to spontaneous combustion. Analyses are shown in table 6. Reserves are estimated to be 2 million tons to a workable depth of 150 feet.

The Sor Range-Degari coal field (fig. 1) is ten miles north of Quetta and covers an area of about 20 sq. mi. The coalbearing sedimentary rocks are of Eocene age, and the coal beds crop out in the western parts of a syncline that has been cut by a fault of large displacement. The beds generally dip at angles of more than 45°. The coal is of sub-bituminous grade, has comparatively low ash and sulphur (table 6), and large-size lumps can be extracted. Systematic development of this coal field has been undertaken by several private and public-sector companies. Estimated reserves to depth of 2,000 ft down dip are more than 20 million tons, although the actual reserves may be several times this amount.

The Makerwal-Gullakhel coal field (fig. 1) is located about 8 mi west of Kalabagh (longitude 32°55′ N., latitude 71°32′ E.), and extends over an area of about 10 sq. mi. A single coal bed in the area occurs in an anticline that has been locally faulted. The western part of the anticline is less disturbed and the strata on this limb dip at angles of about 30°. The coal is blocky, and mining yields lump coal that is sold at a premium. It is high in volatiles, ash, and sulphur (table 6). Reserves of all categories are estimated at about 20 million tons.

The Salt Range coal field (fig. 1) is about 100 sq. mi in area, extending from 15 mi northeast of Khewra to about 20 mi north of Khushab. The coal beds occur in folded Patala shales of early Eocene age overlain by Sakesar limestone. The coal crops out in bold scarps at the edge of a plateau. Only one coal bed, ranging in thickness from a few inches to 5 ft, is being worked. The coal is of high-volatile bituminous grade, having high ash and sulphur content and being liable to spontaneous combustion. Analyses of coals from this field are shown in table 6. Reserves are estimated at 100 million tons.

In addition to the above coal fields, there are more than 15 other smaller fields being worked in Pakistan. However, the interest in coal mining in these fields is limited because most of the coal is used for firing of brick kilns, and demand is small. Use in thermal power plants, such as that which the government plans to construct at Lakhra, may greatly increase the demand for Pakistani coal.

Copper

Even though copper deposits have been reported to occur widely in Pakistan, the recently discovered porphyry copper deposits in the Sulphide Valley near Fort Saindak (fig. 1) offer the best potential for development.

Sulphide Valley is a shallow north-northwest trending depression between latitudes 29°14′ and 29°18′30″ N. and longitudes 61°35′40″ and 61°37′ E. The valley intersects the northwest trending Mirjawa mountain range near its junction with the sand-covered desert plain that extends to the border with Afghanistan. The Fort Saindak area was the site of volcanic activity during Paleocene to Oligocene time and is marked by a belt (Chagai belt) of widespread calcalkaline stocks about 300 mi long in an east-west direction, about 85 mi in maximum width. Several porphyry-copper type deposits have been found in this belt in Pakistan and its extension into Iran where the large Sar Chashmah copper deposits occur.

The Saindak region is underlain by volcanic rocks, sedimentary rocks consisting chiefly of marine shales, and fluviatile or deltaic siltstones and sandstones. These rocks are intruded by stocks of tonalite, granodiorite and adamellite of Oligocene age. Sulphide Valley is traversed by the east trending Saindak fault, to the south of which is a zone of potassic alteration in an area of siltstone and subordinate shale, sandstone, and tuff of the Amalaf formation of Oligocene age. These rocks have been intruded by porphyry stocks. The alteration zone contains abundant pyrite from which the name Sulphide Valley is taken. This alteration extends northward across the fault where it has affected agglomerate and tuff in the lower part of the Eocene Saindak formation. A local cap of volcanic rocks west of the alteration zone is interpreted as an erosional remnant of a stratovolcano with which the Saindak alteration zone is genetically related. Much of this stratovolcano was removed, probably in Pleistocene time, resulting in the development of a pediment on the Saindak alteration zone. This produced an area of subdued relief, called Sulphide Valley, bordered by prominent ridges of propylitized pyrite-free rock.

The three mineralized zones near Fort Saindak, the North, South, and East copper ore bodies, are associated with three stocks of tonalite porphyry. The three stocks measure 3,000 × 600 ft, 2,500 × 600 ft and 3,000 × 1,200 ft, respectively. The stocks possess well defined oval to elongate forms and near-vertical walls, but their contacts are marked by many dikes and irregular offshoots that have intruded the wall rock. Swarms of near-vertical dikes, as much as 40 ft wide, are seen in these contact zones. The three ore bodies have been hydrothermally altered, having central greyish potassium silicate zones in which are most of the copper values and which are distinct from the surrounding white quartz-sericite zone. The North and South ore bodies have gold and silver values associated with tourmaline veins that cut the tonalite stocks. Also, there is a molybdenum-rich halo around the main copper zone. The ore bodies also contain significant amounts of pyrite and magnetite. The proven reserves in the three ore bodies are:

	Cut-off grade (percent Cu)	*Average grade (percent Cu)*	*Reserves (million tons)*
North	0.25	0.44	28
South	.25	.426	111
East	.25	.334	273
Total			412

Gypsum and Anhydrite

Pakistan possesses large resources of gypsum and anhydrite (table 1); only the few most important deposits may be mentioned here.

One of the largest deposits is in the Dera Ghazi Khan hills (fig. 1), which form a part of the Sulaiman Ranges. The deposit consists of layers of gypsum as much as 25 ft thick and several miles long. The Saidu Wali deposits (fig. 1), though not being exploited at present, are part of a 45–500-ft-thick gypsum-bearing sedimentary sequence. Reserves of high-grade gypsum are estimated to be at least 10 million tons.

Gypsum beds 5–140 ft thick crop out in east trending linear ridges in a belt 20 miles wide south of Kohat (fig. 1). These beds generally overlie massive rock salt and are in turn overlain by red clays of Eocene age. An average of 20 chemical analyses of the gypsum shows the following: 30.0–32.2 percent CaO, 38.0–46.0 percent SO_3, and 17.0–20.0 percent H_2O. Reserves are estimated to be 5 million tons.

The Spin Tangi (fig. 1) gypsum deposits in the Sibi district of Baluchistan consist of gypsum beds as much as 7 ft thick in a sequence of green shales and Nummulitic limestone of Eocene age. The chemical composition is similar to that of the Kohat area, and reserves to a depth of 50 ft are estimated to be 0.4 million tons.

The Chamalang gypsum deposit in the Loralai district is 7 miles southeast of Chamalang village. Thirteen beds of gypsum as much as 50 ft thick, separated by interbedded shale and limestone, have been mapped. Reserves to a depth of 100 ft are estimated at 7 million tons.

White and grey gypsum associated with bituminous oil shale as much as 200 ft thick and red marl and rock salt beds as much as 800 ft thick occur in the Punjab saline series. The lower part of this series is as much as 750 ft thick and consists of anhydrite, dolomite, and red variegated gypsiferous clay. Reserves of gypsum in the Punjab have been estimated at more than 28 million tons.

Detailed geological investigations, including drilling, in the Daudkhel area have proved gypsum and anhydrite reserves of over 55 million tons.

Limestone and Dolomite

Pakistan has practically inexhaustible, widely distributed resources of limestone and dolomite. Estimated reserves in exposed deposits are at least 45,000 million tons.

Magnesite

The best known, though not the largest, magnesite deposits are those at Nasai (fig. 1) about 20 mi east of Muslimbagh in the Zhob district. Cryptocrystalline, milky-white magnesite veins associated with serpentinized dunite occur in a dike about 1,500 ft long and as much as 40 ft wide. Many similar though smaller deposits occur in the nearby area. Analysis of typical magnesite gives 45.38 percent MgO, 0.38 percent SiO_2, 1.72 percent CaO, 1.4 percent Fe_2O_3, and loss on ignition 51.15 percent. The magnesite formed by alteration of ultramafic rocks as indicated by fragments of these rocks. Reserves for the area are estimated to be 60,000 tons.

Another magnesite deposit near the village of Sakhakot consists of irregular veins and lenses of magnesite in grey dolomitic limestone of the Abbotabad Formation. Steeply dipping veins of magnesite are supposed to have been formed by hydrothermal replacement of dolomite or dolomitic limestone. The MgO content ranges from 44.9 to 46.7 percent. Probable and possible reserves of this grade have been estimated at 1.5 and more than 11.0 million tons, respectively.

Marble

Pakistan possesses very large resources of marble, which have been classified into three types: (a) crystalline calcitic or dolomitic rock, (b) partially crystallized compact limestone, the principal commercial marble, and (c) travertine deposits (Ahmed, 1969, p. 117). Only the most important deposits are mentioned here.

Deposits of white, pink, grey, and banded marble are being worked in the Mullagori area of Khyber Agency (fig. 1). Two deposits worked are near the Shahidmina and Kambela Khawai villages. They are 100–2,000 ft thick and the outcrops extend over a strike length of about 2 mi. The marble, though jointed, can be extracted in large blocks. Reserves are estimated to be in excess of 200 million cubic feet.

High-quality white marble is being worked at Ghundai Tarako (latitude 34°13′ N.; longitude 72°25′ E.), in Swabi Tehsil. Reserves are estimated to be more than 100 million cubic feet.

Pink marble with criss-crossing veins of white calcite and brownish streaks of ferruginous material is being worked at Nowshera village (fig. 1) on the banks of the Kabul River. Large blocks can be extracted and reserves are estimated at several million cubic feet.

White marble of good quality is found in hills of Bala Kot near Naran (34°54′ N., 73°39′ E.). The marble is not being worked due to high cost of transport but reserves are several thousand million cubic feet.

High-quality light to dark green travertine onyx is being mined extensively in the Chagai district (fig. 1) and marketed under the trade names of aragonite and travertine. The best known localities are Zard Kan, Patkok, Juhlli, Butak, Tozghi, Zeh, and Mushkichah (Ahmed, 1969, p. 120). Most deposits occur in terrace-like spring deposits forming small hills. Typical deposits are at Juhlli where three terraces 900×100×15 ft, 1,400×40×12 ft, and 30×100×10 ft are being worked. The travertine is generally interbedded with volcanic ash. Light and dark green onyx, cut by veins of brown or yellow ferruginous material, is common. Pale green onyx without veins and which is translucent in slabs as much as one-half inch thick, is found sparingly. The total reserves in the Chagai district have not been estimated, although studies indicate reserves of several hundred million cubic feet.

Rock Salt

Rock salt is one of the most important mineral commodities of Pakistan, and the quantity of salt available in near surface deposits is probably the world's largest. Production of salt during 1971–1978 has been between 336,000 and 610,000 tons per year (table 2).

The salt deposits of Pakistan are too numerous to be considered in their entirety and, therefore, only the most important deposits will be briefly described.

The best known salt deposits are those in the Khewra area (fig. l) of the Salt Range, which have been the subject of study for almost 100 years; and yet details of age, mode of formation, and reserves are far from settled. These deposits are in the 2,000-ft-thick Lower Saline Marl Member of the Punjab Saline series. The salt is in an irregular dome that has been faulted at a number of places. A major north trending fault marks the western limit of the salt mines. Seven salt bands or seams are present, three in an upper group and four in a lower group. The two groups are separated by a 100-ft-thick zone of interbedded thin salt layers and marl. The upper group of salt seams, called the Buggy complex, consists of the following, from top to bottom:

1. North Buggy salt seam, 25–600 ft thick
2. Buggy seam, 150–600 ft thick
3. Sujjawal seam, 60–70 ft thick

At the western end of the present workings the Buggy and Sujjawal seams join to form a single seam 270 ft thick. The lower group, called the Pharwala complex, consists of the following seams from top to bottom:

1. Upper Pharwala seam, 35–50 ft thick
2. Middle Pharwala seam, 60 ft thick
3. South Pharwala seam, 45 ft thick
4. Low level tunnel seam, 60 ft thick

The estimated reserves are in excess of 600 million tons.

The other important salt producing area of the Salt Range is Warcha (fig. 1) near a village of that name in Sargodah division. Five seams having an aggregate thickness of 93–154 ft are present. The seams are separated by beds of marl ranging in thickness from 6 in. to 30 ft. Reserves are estimated to be over 2 million tons.

The Kalabagh deposits (fig. 1), also part of the Punjab Saline Series, are the third most important salt deposits that have been developed in Pakistan. Individual seams as much as 40 ft thick are located on the Lun Wahan, a tributary of the Indus river. The seams are thinner than in Khewra, are contorted and lenticular, and dip at steep angles. Reserves are in excess of one millon tons.

Salt deposits at Jatta-Bahadur Khel and Karak, in the Kohat district, extend over an area of more than 2,000 sq. mi. The salt is confined to the Salt Marl Series of early Eocene age, which is overlain by a sequence of gypsum and bituminous shale. At Bahadur Khel the exposed salt bed is 350 ft thick whereas at Jatta and Karak it is 100 ft or more thick. No estimates of reserves have been made, but at least several hundred million tons of salt are present.

Vermiculite

The largest vermiculite deposit is that of the Doki River area in Chagai district (fig. 1). The vermiculite here is considered to have formed by contact metamorphism of basaltic lavas near the Garrok-Sargahr-Osaphi stock and related diorite and aplite dikes. The vermiculite formed as an alteration product of biotite (Bakr, 1962). Exfoliation tests by the Overseas Geological Survey, London, gave the following results:

Temperature of test: 775° C.
Original thickness, inches: 0.06–0.08.
Final thickness, inches: 0.6–0.7.

Reserves of coarse grained (in books 3/4×1-1/2 in) vermiculite are estimated at 11 million tons to a depth of 100 ft.

MINERAL POTENTIAL OF PAKISTAN

Mineral exploration in Pakistan has been viewed in the past on a non-genetic model and, as such, the exploration efforts were conducted not according to metallogenic environments but according to the distribution of intrusive bodies and volcanic rocks. Only recently was it realised that a systematic approach to exploration through study of known mineral deposits and search for similar deposits in well-defined metallogenic provinces or belts might prove more fruitful. Shcheglov (1969) first attempted to delineate metallogenic provinces of Pakistan on the basis of geological environments. In his model he tried to explain the chromite, mercury, antimony, copper, molybdenum, and gold mineralisation on the basis of the then prevalent geosynclinal theory. He recognised the following three ore provinces:

1. Chromite belt of the Baluchistan geosyncline.
2. Mercury-antimony belt in the Pishin-Makran geosynclinal trough.
3. Copper-molybdenum belt associated with the median massif of the Chagai district.

Unfortunately, the porphyry copper deposits at Saindak, the manto-type copper deposit at Talaruk, and the zinc-silver Kuroko-type deposit at Makki cannot be adequately explained by Shcheglov's model.

Sillitoe (1978, 1979) presented a preliminary plate tectonic model and recognised metallogenic environments in Pakistan, excluding the Himalayan region. These environments are characteristic of specific areas, as shown in figure 2, which may be considered as target areas for exploration of distinct types of mineral deposits. Subsequently, I suggested that the island arc subduction zone environment be subdivided and that six metallogenic environments be recognized (fig. 2), as follows:

1. Ophiolite:
   a. Ultramafic rocks with chromite are found in subduction and collision zones in the Muslimbagh-Fort Sandeman-Waziristan and Ras Koh areas. The bulk of the ultramafic rocks are tectonically deformed and show a high degree of alteration. At their base is a garnet amphibolite zone that probably formed during emplacement.
   b. Ultramafic rocks also are associated with an island arc zone in the Bela-Khuzdar area. As compared to the subduction and collision zones mentioned above, the ultramafic rocks here are less altered and chromite ore bodies generally contain less olivine and serpentine. Chemically, the chromites of both zones are similar.

   Ore deposits associated with the ophiolitic environment include podiform chromite deposits (fig. 1), volcanogenic massive sulphide deposits (fig. 3), and stratiform manganese deposits. All of Pakistan's chromite deposits of economic importance occur in this environment, and it is believed that the potential for discovery of significant massive sulphide deposits is good.

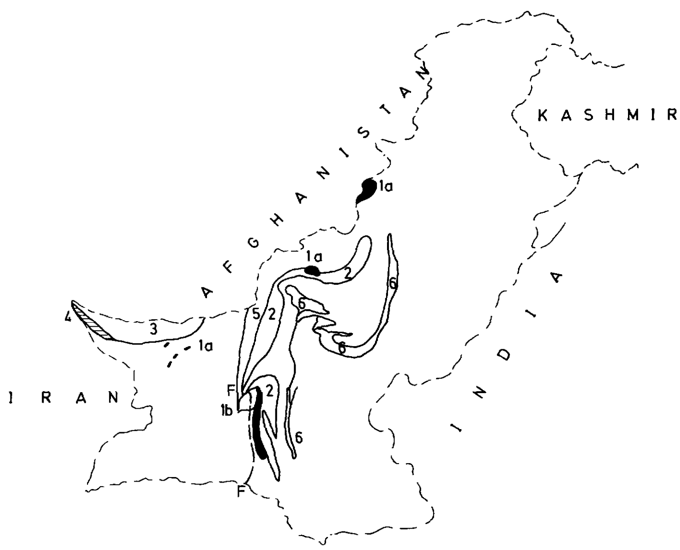

Figure 2 Geological map of Pakistan showing areas occupied by environments of (1) ophiolite (1a, ultramafic rocks in subduction and collision zones; 1b, ultramafic rocks associated with island-arc zones), (2) continental shelf, (3) calcalkaline magmatic arc, (4) Island arc, (5) area of Chaman intracontinental transform fault (F), and (6) Late Cenozoic molasse basin.

2. Continental shelf:
   During Jurassic time a sequence of rocks was deposited on the continental shelf of old Gondwanaland. This sequence, now exposed in the area delineated in figure 2, contains barite and fluorite deposits (fig. 1). Furthermore, it is believed that these shelf carbonates may contain additional barite and fluorite deposits as well as Mississippi Valley type lead and zinc deposits.
3. Calcalkaline magmatic arc:
   Andean-type calcalkaline rocks were emplaced by northward subduction and continental collision in westernmost Pakistan (fig. 2). Several porphyry copper deposits have been found in this region as shown in figure 3. Iron deposits of contact metasomatic or volcanogenic origin also occur in this region.
4. Island arc:
   The island arc environment (fig. 2) is characterized by an assemblage of predominantly dacitic or rarely andesitic volcaniclastic rocks deposited under shallow marine conditions. Associated with these rocks are massive sulphide deposits of the Kuroko type which contain lead, zinc, copper (fig. 3), as well as manto and vein-type copper deposits

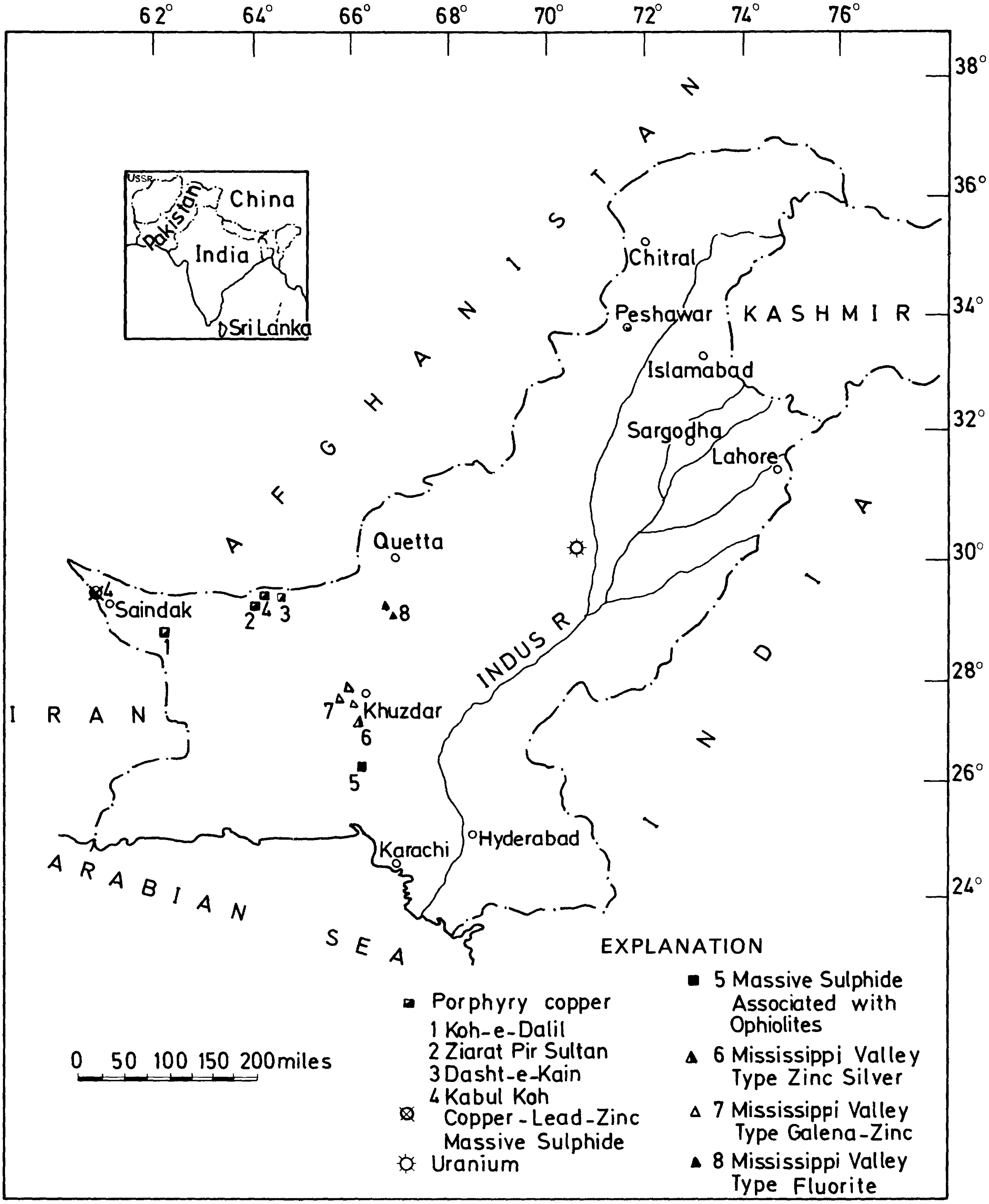

Figure 3 Index map of Pakistan showing mineral deposits of probable economic significance.

and porphyry copper deposits such as those near Saindak (fig. 1). Bauxite and nickeliferous laterites, derived from weathering of the volcanic rocks, also are present.

5. Chaman intercontinental transform fault:
   Vein-type antimony deposits (fig. 1), associated with the Chaman transform fault, evidently formed during mid-to-late Cenozoic dynamothermal metamorphism.
6. Late Cenozoic molasse basin:
   Sandstone-type uranium deposits occur in a late Cenozoic molasse basin that developed during the Himalayan uplift. Uranium has been found at only one locality (fig. 1), in Dera Ghazi Khan, but it is believed that the potential for discovery of exploitable uranium deposits elsewhere in the molasse basin is good.

The above metallogenic model is largely the same as presented by Sillitoe (1978) and gives an idea of the mineral potential of Pakistan. A number of alteration zones, which are favourable sites for porphyry copper deposits, have been identified by Schmidt (1974) and Sillitoe (1978). Investigations by the Resource Development Corporation and Geological Survey of Pakistan indicate that Dasht-e-Kain and Koh-e-Delil might prove to be porphyry copper deposits of economic importance. Similarly, prospects for discovery of Mississippi Valley type lead-zinc and silver deposits near Khuzdar (fig. 3) and fluorite and barite deposits in the shelf carbonate area (fig. 2) are fairly good.

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Discussion

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It is my honor to be here to celebrate the Centennial Anniversary of the U.S. Geological Survey and I am happy to be given a chance to talk here at its symposium.

Listening to many discussions from the first day and to papers today, I felt that hardrock geologists can feel a little easier about the long-term availability of metal and non-metal resources than can softrock geologists who are mostly concerned with non-renewable fuel resources.

I shall comment a little on more naive geological matters rather than on complex and difficult discussions of geopolitics and economics. After all this is the thing I can do best.

Carlos Ruiz emphasized the importance of a National Geological Survey in the assessment of mineral resources. Considering the mineral resources of Chile, he estimated 450 million tons of copper to exist there in known and yet-to-be-discovered deposits. I accept this estimate as a general round figure—a quantity that could supply world needs of virgin copper at the present rate of consumption for about fifty years if our recycled copper can be increased to 30 percent or more of total consumption. Probably this figure will be refined and revised slightly in the future. There are sections of abundance and paucity in the porphyry-copper belt of Chile. Ingr. Ruiz pointed out that about 40 percent of the belt is covered by post-mineral younger volcanic rocks and unconsolidated sediments. Tectonic control of these irregularly rich and poor zones is a very interesting and challenging subject for investigation. I also hope that search for other mineral commodities will be emphasized in order to get rid of a largely mono-mineral Chilean economy. I wonder if there are many signs of mineral resources in the southern part of Chile?

Dr. Bilgrami's paper emphasizes the optimistic outlook for the discovery of significant new mineral deposits in Pakistan, as a result of reinterpretation of its geotectonic history in the light of the plate tectonic theory. For example, in the early stage of mineral exploration now being carried out, it is apparent that deposits of many types and of many mineral commodities are juxtaposed in the Chagai magmatic belt of the Lut-Helnand-Makram microcontinent and also on the eastern side of the Chaman intracontinental transform fault. In the Chagai belt, where we have porphyry copper deposits and Kuroko-type massive sulphide deposits, I wonder if there is any international geologic cooperation among Pakistan, Iran, and Afghanistan. The area along the Chaman fault includes podiform chromites, massive sulphides, and Mississippi Valley type lead-zinc deposits. The explanation for their genesis and zoned proximity is fascinating. The occurrence of auriferous antimony in a quartz vein is also interesting and seems to warrant more study because of the gold. It could be a small but a rich mine.

The area between the State of Peshawar and the Karakoram Mountains should have an abundance of early Tertiary felsic to intermediate igneous intrusions. It would be very exciting to know what kind of metallogenesis has taken place at this most typical collision of plates, involving underthrusting of the Gondwanic subcontinent against Eurasia. I feel especially the importance of this area because of knowing the metallogenesis of the Chagai zone as a part of a microcontinent that collided against the Eurasian continent.

Indeed, it can be said that Pakistan holds one of the keys for solving many of the geotectonic problems pertaining to metallogenesis and resources development in the next century.

As Ingr. Ruiz pointed out, one of the delicate problems is the role of a National Geological Survey in mineral exploration. Without positive results such as discoveries of mineral deposits early in the exploration program, government authorities tend to lose interest in the organization with a resultant loss in financing. In Pakistan, the Resources Development Corporation was created to alleviate problems of this type. Such a corporation, which may depend entirely on government financing or joint government and industry financing, can utilize geological information furnished by the National Geological Survey to guide exploration programs that are beyond the financial capability of the Geological Survey.

Finally, as Ingr. Ruiz pointed out, one of the most important factors determining the success of a national program of mineral exploration is the training of the people who will carry it out. Such training must at a minimum include a college undergraduate education on top of the broad base of elementary to middle school education as well as on-the-job professional training and self-education. Additional graduate-school education is necessary, in addition to special practical training. Style and method of education have to be fitted to the country's social and economic style and condition. I have been managing a unique school in Japan to provide higher-level specialized training to people who are concerned with mineral exploration and development. I am interested in learning about other training programs of this kind.

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Discussion

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Ingr. Ruiz gave an excellent description of the mineral wealth of Chile, terminating by citing the obstacles that he foresees in his own country: he stressed government obstacles. This is something that is not known to any of us but is critically important to all of us.

Dr. Bilgrami, although not actually going into that line of thought, did the same. He gave us an excellent description of the small deposits of Pakistan as we know them now, of chromite, antimony, and the rather large, and what could become important, coal deposits of that country. Earlier the country was purely an industrial-mineral producer. Now they are beginning to take advantage of the changes that they are beginning to see. This includes government obstacles.

We also should consider the problems and challenges of the minerals economist and his role in the geological and marketing field; the challenges to the producer and exporter of a given mineral commodity, the importers of the commodities, and finally the policy makers themselves. We have seen many changes, and will see many more. Ten years ago we would look at a mineral deposit and it would not be ore. It is ore today. These are now resources because of changes. Marketability of ores has changed dramatically in the last ten years, but this is something we must consider in every bit of work to do. Cost increases go into the determination of whether a resource is a resource, or whether it can be marketed.

Geologists and mineral specialists have played a secondary role in government planning until recent years, but now this has changed. It has changed very dramatically in certain countries, but probably the change is one that has disturbed almost all of you, because I think all of you at one time or another have been involved in this change. That is where you can take in your mind a resource, convert it into an exploitation, and then find that the economic/commercial considerations are subordinated to political considerations—a dangerous, dangerous thing. It means that the geologist, the mineral economist, the planner who has mining and minerals background and experience, need to play a far more important role in their government than they have been given the opportunity to do in the past.

Policy makers are now beginning to see the vast importance of the minerals industry and are turning more and more to the geologist to say, "please help me, guide me, advise me." I would like to hope that you yourselves could take this aggressive, reactionary role and be of help. We need to keep in mind that all countries' needs and demands are different. What we need, therefore, would be a balanced policy of maintaining the resources, conserving the resources, but exploiting those resources to the limit that is possible for your own country. Don't cannibalize or over-exploit a given resource or mine, but certainly don't overlook it either. Don't put it into a reserve that no one can see an early return on. In other words, your own government would consider whether you wanted that resource for domestic use, or whether you want it for export only, or both. This is very important.

A drive is always at hand to develop self-sufficiency in mineral commodities. I submit that this is not necessary. I feel very strongly that some countries have gone too strongly toward the self-sufficiency desire. What I do feel is that minerals trade is important, where you sell a commodity you have and buy in return, not with the effort specifically of developing a mineral self-sufficiency in one commodity, whether it be chromite or manganese, or copper or salt.

Dr. Bilgrami made an interesting point. The mineral industry of Pakistan today contributes about six-tenths of 1 percent to the gross national product, a low percentage but not altogether unusual. The unusual might be the other way, somewhere in the range of 15–20 percent. Such an example would be South America's mineral industry that contributes this amount to its gross national product. In many countries, mineral industry contributes in the range of 8–10–12 percent of their gross national product.

There is a vast gap that exists here that can be filled up to varying degrees by the developing countries in reassessments of your resources and in your efforts to move into a world market. The world market is a very unsympathetic, a very impersonal, a very erratic, and certainly a very complex form. It is a dangerous area; it exists, however.

It is not sufficient to develop only the resources of a country; they have to be marketed in this unrelenting, vicious thing we call the world market. On an individual basis, country by country, mine by mine, resource by resource, minerals can be used as a tool in the creation of a balanced long-range trade policy suitable to each individual country and to the extent to which it can contribute to the world market. In this area the challenges are very great, and I think exciting.

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Preliminary Study of Mineral Resources of Latin America

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INTRODUCTION

The purpose of this work is to analyze the position of Latin America's mineral industry, not only to learn of its contribution to international mineral markets, but also as a contribution to world markets in the future. A common concern of Latin American countries is the necessity of increasing exploration and development programs in order to best utilize natural resources, especially minerals, to aid in industrialization and raising the standard of living of the people.

The past two decades have witnessed an explosion of geological information in Latin America and the development of sophisticated mineral exploration programs that have led to discoveries of major new mineral deposits in many countries. During this time many of the countries have prepared national geologic maps, and most countries having a significant mineral industry also have metallogenic maps. New geologic maps of South America and the Caribbean have been published. Metallogenic maps for South America and North America (including Central America and the Caribbean Islands) are in final stages of completion, and will be published in the next year or two. Information provided by all these maps has proven to be of invaluable assistance to mineral exploration programs and will continue to assist exploration during the remainder of this century.

MINERAL RESOURCES AND PRODUCTION IN LATIN AMERICA

There is no integral up-to-date source of information regarding mineral resources in Latin America. As a consequence, the information about production (tables 1 and 2) and reserves (tables 3 and 4) has been compiled from several sources as shown on the tables. The information in the tables is that which is available for 27 nations in Latin America. Other small nations in the Caribbean are not included because they either do not have recorded mineral production or production figures were not available.

Of the 27 Latin American countries reported, only Mexico with a production of 33 mineral commodities and Brazil with 37 show an adequate base of metallic and nonmetallic minerals required for economic and industrial development. Other countries such as Argentina, Bolivia, Chile, and Peru have the resources for a more diversified mineral industry but for various reasons now import some of the mineral commodities that could be produced locally.

Among metallic minerals, 16 countries produce gold; 12 countries produce silver, and Mexico and Peru, both with annual production of more than 1,500 tons of fine silver are the major producers, Chile, which produced 226 tons of silver in 1976, is third and Bolivia which produced 183 tons in 1977, is fourth (table 1); copper is produced by 7 countries of which Chile, Peru, and Mexico are the major producers. The largest quantities of iron ore are produced by Brazil, Venezuela, and Chile, but Mexico and Peru also have significant production. Chile is the major producer of molybdenum, recovered as a by-product of porphyry copper mines, but Mexico and Peru, which are expanding copper production also are increasing recovery of by-product molybdenum from operating copper deposits and from new deposits.

Of the nonmetallic minerals listed in table 2, salt, gypsum, and sulfur are produced by the largest number of countries. Brazil and Mexico produce the widest variety of nonmetallic minerals. Actually, Mexico produces 29 nonmetallic minerals rather than 17 as reported by the U.S. Bureau of Mines in its Commodity Profiles for 1978–79 (U.S. Bureau of Mines, 1980).

As can be seen in tables 3 and 4, information about reserves of minerals in Latin America is scanty, and in some cases the reserve figures indicate an order of magnitude of reserves rather than measured or estimated reserves. Although many of the reserve figures cited in these tables are not as accurate as one would wish, they are of value because they indicate the distribution of some of the major mineral commodities. Reserves of some metallic mineral commodities are as follows:

1. **Iron**—Reserves of iron ore in Brazil are estimated at 16.3 billion metric tons, and in Venezuela 1.3 billion metric tons. Both countries are net exporters. Mexico, with approximately 159 million metric tons of iron metal content, is self-sufficient, but intensive exploration underway should lead to new discoveries that will increase reserves.

2. **Lead**—The principal resources of lead in Latin America are in Mexico, Peru, Brazil, Bolivia, and Argentina. Brazil has reserves of 2.3 million metric tons of lead whereas those of Mexico are estimated to be 5 million metric tons and those of Peru are 4 million metric tons of lead.
3. **Manganese**—Reserves of manganese in Brazil have been estimated to be 39.64 million tons whereas Mexico has only 0.6 million metric tons and Chile 0.4 million metric tons.
4. **Mercury**—Mexico is the only Latin American country now producing mercury. In 1978, mercury reserves in Mexico were estimated to be 261 million flasks of 76 pounds each.
5. **Tin**—Bolivia has an estimated reserve of tin of 980,000 metric tons, Brazil 600,000 metric tons, Argentina 5,000 metric tons, and Mexico 2,000 metric tons. It is expected that significant new tin deposits will be found in Brazil, and Mexico is launching an all-out exploration campaign for tin.
6. **Silver**—Many countries produce silver, but reserve estimates are available only for Mexico and Peru, which are 950,000 and 609,996 troy ounces of silver, respectively.

Distribution and reserves of some of the nonmetallic minerals are as follows:

1. **Asbestos**—No reserves of asbestos are listed in table 3, but Mexico has recently blocked out six million tons of 12 percent cross-fiber chrysotile, and more than 100,000,000 tons of slip fiber. Recently, Colombia has reported large resources of chrysotile, and will soon start production of refined chrysotile in a 20,000-ton-per-year capacity plant.

Table 1 Production of metallic minerals[1] in Latin America for 1976, 1977 or 1978
[Quantities are given in thousand metric tons, except as noted.]

	ARGENTINA	BOLIVIA	BRAZIL	CHILE	COLOMBIA	COSTA RICA	CUBA	DOMINICAN REPUBLIC	ECUADOR
Antimony	—	14[a]	—	—	—	—	—	—	—
Arsenic	—	—	—	—	—	—	—	—	—
Beryl ore (tons)	3[a]	—	368[a]	—	—	—	—	—	—
Bismuth (tons)	—	638[a]	—	—	—	—	—	—	—
Cadmium	—	—	—	—	—	—	—	—	—
Chromite	—	—	305[b]	—	—	—	31[c]	—	—
Cobalt	—	—	—	—	—	—	1[c]	—	—
Columbium	(2)	4[b]	8[a]	—	—	—	—	—	—
Copper	—	—	2[c]	1,061[a]	—	—	3[c]	—	—
Gold (kg)	373[c]	896[c]	5,700[c]	4,017[c]	9,264[c]	298[c]	—	12,870[c]	361[c]
Ilmenite	—	—	5[c]	—	—	—	—	—	—
Iron	160[c]	—	89,412[a]	7,649[b]	237[c]	—	—	—	—
Lead	40[c]	23[c]	48[b]	2[c]	—	—	—	—	—
Lithium (tons)	—	—	54[a]	—	—	—	—	—	—
Manganese	31[c]	12[c]	1,088[a]	24[c]	—	—	—	—	—
Mercury (tons)	—	—	—	—	—	—	—	—	—
Molybdenum (tons)	—	—	—	11,853[a]	—	—	—	—	—
Nickel	—	—	6[b]	—	—	—	36[a]	24[c]	—
Platinum (kg)	—	—	—	—	777[a]	—	—	—	—
Rare earths	—	—	1[a]	—	—	—	—	—	—
Rhenium (kg)	373[c]	—	—	—	200[c]	—	—	—	—
Rutile	—	—	—	105[c]	—	—	—	—	—
Selenium (tons)	—	—	—	16[a]	—	—	—	—	—
Silver (tons)	54[c]	183[b]	7[c]	226[c]	3[c]	—	—	28[c]	1[c]
Tantalum (tons)	(3)	—	68[a]	—	—	—	—	—	—
Tellurium (tons)	—	—	—	—	—	—	—	—	—
Thorium	—	—	1[c]	—	—	—	—	—	—
Tin (tons)	600[c]	30,000[a]	7,000[a]	—	—	—	—	—	—
Tungsten (tons)	82[c]	2,993[a]	1,134[a]	—	—	—	—	—	—
Uranium (tons)	40[c]	—	—	—	—	—	—	—	—
Vanadium (tons)	—	—	—	861[a]	—	—	—	—	—
Yttrium (tons)	—	—	23[a]	—	—	—	—	—	—
Zinc	40[c]	60[b]	47[b]	5[c]	—	—	—	—	—

[1] Metal content. Ilmenite in concentrates: manganese in ore for Argentina, Bolivia, Chile, and Peru.
[2] Less than 1,000 tons.
[3] Less than 1 ton.

[a] 1978
[b] 1977
[c] 1976

2. **Barite**—The largest known deposits of barite are in Brazil, Mexico, and Peru. Brazil has reserves of 3,629,000 tons. Reserves of barite in Mexico, including recently discovered deposits that have not yet been fully explored, are estimated at more than 40 million metric tons. Significant barite deposits also occur in Argentina and Chile, but reserve data for these countries are not available.
3. **Bauxite**—Brazil has an estimated reserve of 2.5 billion metric tons of bauxite whereas Guyana has 1 billion, Jamaica 2 billion, and Surinam 480 million metric tons. Haiti also has sizeable reserves. Haiti and Jamaica are not listed in the mineral commodity profiles for 1978–79 (U.S. Bureau of Mines, 1980). Recent discoveries in Venezuela suggest that this country may also have large bauxite reserves.
4. **Bentonite**—Argentina, Brazil, Mexico, and Peru have produced bentonite, largely for internal use. Estimated reserves of bentonite in Mexico are 1,270,000 metric tons; reserves of bentonite in the other countries are not known. Other countries in Central and South America probably have exploitable bentonite deposits and total resources of bentonite in Latin America are probably large.
5. **Coal**—Brazil, Chile, Peru, Venezuela, and Colombia produce relatively small quantities of coal at present, and reserve data for these countries is incomplete and at best can be considered as rough estimates only. Reserves are as follows: Brazil, more than 20 million tons; Chile, more than 11 million tons; Colombia, more than 300 million tons; Mexico, 1.6 billion tons; Peru, 1 million tons; and Venezuela, 200 million tons.

EL SALVADOR	GUATEMALA	GUYANA	HONDURAS	MEXICO	NICARAGUA	PERU	SURINAM	VENEZUELA
------	1[c]	------	------	2[a]	------	(2)	------	------
------	------	------	------	5[a]	------	1[c]	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	978[a]	------	544[c]	------	------
------	------	------	------	------	------	(2)	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	2[a]	------	------	------	------
------	------	------	------	------	------	------	------	------
------	3[c]	------	------	87[a]	(2)	336[a]	------	------
93[c]	------	487[c]	71[c]	6,283[a]	2,359[c]	2,511[c]	1[c]	451[c]
------	------	------	------	------	------	------	------	------
------	------	------	------	3,556[a]	------	4,021[b]	------	11,288[c]
------	------	------	18[c]	170[a]	1[c]	190[a]	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	188[a]	------	2[c]	------	------
------	------	------	------	6[a]	------	------	------	------
------	------	------	------	76[a]	------	455[a]	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	80[a]	------	18[a]	------	------
5[c]	------	------	92[c]	1,579[a]	6[c]	1,555[a]	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	------	------	12[c]	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	73[a]	------	273[c]	------	------
------	------	------	------	234[a]	------	------	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	------	------	------	------	------
------	------	------	------	------	------	------	------	------
------	1[c]	------	25[c]	245[a]	14[c]	570[a]	------	------

Sources: UNO/ECLA, Economic Study for Latin America, 1977.
U.S. Bureau of Mines, Minerals Yearbook, 1976; Mineral Commodity Summaries, 1979.
Ministerio das Minas e Energia do Brasil, Balanco Mineral e Brasileiro, 1978.
CRM, Anuario Estadístico de la Minería Mexicana, Mexico, 1978.

Table 2 Production of nonmetallic minerals[1] in Latin America for 1976, 1977 or 1978
[Quantities are given in thousand metric tons, except as noted.]

	ARGENTINA	BOLIVIA	BRAZIL	CHILE	COLOMBIA	COSTA RICA	CUBA	DOMINICAN REPUBLIC	ECUADOR	EL SALVADOR	GUATEMALA
Asbestos	1[c]	------	92[b]	------	------	------	------	------	------	------	------
Barite	40[c]	------	54[c]	17[c]	3[c]	------	------	------	------	------	------
Bauxite (dry)	------	------	1,000[a]	------	------	------	------	516[c]	------	------	------
Bentonite	115[c]	------	119[c]	------	1[c]	------	------	------	------	------	------
Boron	100[a]	------	------	27[a]	------	------	------	------	------	------	------
Coal (bituminous)	615[c]	------	2,902[c]	1,165[c]	3,266[c]	------	------	------	------	------	------
Diamond (kg)	------	------	11[c]	------	------	------	------	------	------	------	------
Diatomite	15[c]	------	------	------	------	1[c]	------	------	------	------	------
Feldspar	60[c]	------	109[c]	------	30[c]	------	------	------	------	------	30[c]
Fluorspar	40[c]	------	64[c]	------	------	------	------	------	------	------	------
Fuller's earth	------	------	------	------	------	------	------	------	------	------	------
Graphite	------	------	7[c]	------	------	------	------	------	------	------	------
Gypsum	554[c]	1[c]	384[c]	120[c]	199[c]	------	85[c]	127[c]	1[c]	6[c]	13[c]
Lime	------	------	5,442[a]	725[a]	------	------	------	------	------	------	------
Magnesite	------	------	141[b]	------	2[c]	------	------	------	------	------	------
Mica (tons)	3,443[c]	------	2,000[a]	------	41[c]	------	------	------	------	------	------
Phosphate rock (P_2O_5)	1[c]	------	199[b]	------	15[c]	------	------	16[c]	------	------	------
Potash	------	------	------	15[c]	------	------	------	------	------	------	------
Quartz	------	------	181[a]	------	------	------	------	------	------	------	------
Salt	1,200[c]	------	2,199[c]	428[c]	893[c]	20[c]	------	40[c]	------	------	11[c]
Saltpeter	------	------	------	565[b]	------	------	------	------	------	------	------
Sodium sulfate	36[a]	------	------	13[a]	------	------	------	------	------	------	------
Strontium	1[c]	------	------	13[a]	------	------	------	------	------	------	------
Sulfur	46[c]	15[c]	25[c]	47[c]	33[c]	------	28[c]	------	6[c]	------	------

[1] Includes silicon and silicon materials.
[2] Coal run of the mine.

[a] 1978
[b] 1977
[c] 1976

6. **Fluorspar, feldspar, and diatomite**—Mexico, the world's major producer of fluorspar, has reserves of at least 35.3 million tons. Mexico also produces feldspar and diatomite, and estimated reserves of these substances are 3.02 million tons and 1.18 million tons, respectively. These mineral commodities exist in other Latin American countries but reserve data are not available.
7. **Magnesite**—Reserves of magnesite in Brazil are estimated at 136 million tons. Mexico is beginning to produce magnesite from deposits in an ophiolitic sequence that have estimated reserves of 185,000 tons.
8. **Phosphate rock**—Only small amounts of phosphate rock are produced in Latin America. Brazil has estimated reserves of 199,000 metric tons whereas Mexico has proven reserves of 800 million tons and potential resources of several billion tons, chiefly in the recently discovered phosphatic beach sands on the Pacific coast of the Baja California Peninsula and phosphoric rocks of mid-Miocene age on the Baja California Gulf coast north of La Paz City.
9. **Quartz**—Brazil has a potential reserve of 1.8 million tons of high-purity crystalline quartz suitable for the manufacture of optical glass, whereas Mexico has reserves of more than 4.26 million tons of high-purity quartz sands suitable for the manufacture of glass and chemicals. Many other countries have quartzite, sandstone, and quartz sands suitable for window and bottle glass, and some of them undoubtedly have high-purity materials suitable for special glasses.
10. **Salt**—Large resources of rock salt exist in Colombia, Chile, Bolivia, Argentina, and Mexico. In addition, large quantities of salt occur in brines of salt pans in Argentina, Bolivia, Chile, and Peru. Salt is recovered from seawater in Mexico, which is the world's largest producer of such salt, and in Ecuador, Peru, and other countries in Latin America. Reserve data for salt resources of these countries are not available, but supplies are virtually inexhaustable.
11. **Sodium sulfate**—Large resources of sodium sulfate exist in brines in salt pans in Argentina, Bolivia, Chile, and Mexico. In addition, Argentina, Bolivia, and Chile have recoverable sodium sulfate in the saline crusts of salt pans. The Chilean nitrate deposits contain an estimated 200 million tons of recoverable sodium sulfate (written commun., George E. Ericksen, 1980).
12. **Strontium**—Mexico is the world's largest producer of strontium which is mined as the mineral

GUYANA	HAITI	HONDURAS	JAMAICA	MEXICO	NICARAGUA	PANAMA	PARAGUAY	PERU	SURINAM	URUGUAY	VENEZUELA
------	------	------	------	------	------	------	------	------	------	------	------
------	------	------	------	23[a]	------	------	------	290[a]	------	------	------
3,000[a]	660[c]	------	11,400[a]	------	------	------	------	------	5,000[a]	------	------
------	------	------	------	34[a]	------	------	------	39[c]	------	------	------
------	------	------	------	------	------	------	------	27[a]	------	------	------
------	------	------	------	6,755[a] [2]	------	------	------	89[c]	------	------	------
------	------	------	------	------	------	------	------	------	------	------	35[c]
------	------	------	------	22[a]	------	------	------	17[c]	------	------	------
------	------	------	------	127[a]	------	------	------	4[c]	------	1[c]	------
------	------	------	------	960[a]	------	------	------	------	------	------	------
------	------	------	------	39[a]	------	------	------	------	------	------	------
------	------	------	------	52[a]	------	------	------	------	------	------	------
------	------	1[c]	289[c]	1,757[a]	15[c]	------	16[c]	350[c]	------	------	171[c]
------	------	------	------	------	------	------	------	------	------	------	------
------	------	------	------	76[a]	------	------	------	------	------	------	------
------	------	------	------	401[a]	------	------	------	4[c]	------	------	------
------	------	------	------	322[a]	------	------	------	------	------	------	80[c]
------	------	------	------	------	------	------	------	------	------	------	------
------	------	------	------	532[a] [1]	------	------	------	------	------	------	------
------	------	31[c]	------	5,635[a]	14[c]	13[c]	------	304[c]	------	------	300[c]
------	------	------	------	------	------	------	------	------	------	------	------
------	------	------	------	240[a]	------	------	------	------	------	------	------
------	------	------	------	33[a]	------	------	------	------	------	------	------
------	------	------	------	1,817[a]	------	------	------	16[c]	------	2[c]	90[c]

celestite, for which reserves are estimated at about 1 million metric tons.

13. **Sulfur**—Large deposits of sulfur associated with salt domes exist in Mexico, which is one of the largest producers of sulfur in the world. Estimated reserves in these deposits are 90 million tons. Smaller deposits of native sulfur associated with modern volcanoes in Mexico, Central America, and the Andean countries, including Argentina, of South America. Reserve data for these deposits are not available.

PROGRESS OF THE LATIN AMERICAN MINING INDUSTRY AND ITS IMPORTANCE IN WORLD PRODUCTION

Prior to 1975, the value of Latin American metallic mineral production was equivalent to approximately 25 percent of total world production. In later years, Latin America's share has decreased because of two principal factors: (1) Canada, Australia, South Africa, and other countries of the African continent have opened large new mines for iron, copper, nickel, and other metals, and (2) political and economic problems in some countries have inhibited development of new mines. Currently, conditions have improved, and it is expected that the early 1980's will see a large increase in mineral production in Latin America. For example, production of large volume commodities such as bauxite is expected to begin in Brazil and Venezuela, and production in Guyana should increase. Colombia and Venezuela plan major increases in coal production. Mexico has recently increased iron and steel production to 7 million tons per year, with accompanying increase of production of iron ore and coal. Opening the La Caridad copper deposit will probably increase copper production in Mexico from 75,000 metric tons per year to 150,000 tons per year in the early 1980's.

Nonmetallic minerals and coal will show marked increases in the 1980's. New cement plants are being constructed in Latin American countries, and large increases in production of limestone and gypsum may be expected in the 1980's. Phosphate production of Mexico, utilizing the recently discovered Baja California deposits, will certainly be increased by several hundred thousand tons per year. Production of phosphate rock should also begin in Colombia, Peru, and Argentina in the 1980's. Mexico will begin to produce potash at the rate of about 100,000 tons per year in 1982. Argentina can be expected to increase coal production from approximately 1.5 million tons in 1978 to 3.5 million tons in 1981. It is likely that Colombia will become one of the major coal exporters in the 1980's. Mexico will increase barite production from approximately 150,000 tons per year to 850,000 tons by 1981. Production of the strontium ore, celestite, will probably increase in the

Table 3 Metallic mineral reserves (metal content) in Latin America for 1978
[Quantities are given in thousand metric tons, except as noted.]

	ARGENTINA	BOLIVIA	BRAZIL	CHILE	COLOMBIA	CUBA	DOMINICAN REPUBLIC	MEXICO[1]	PERU	VENEZUELA
Antimony	—	367	—	—	—	—	—	218	63	—
Bismuth	—	14	—	—	—	—	—	5	5	—
Cadmium	—	—	—	—	—	—	—	14	—	—
Chromite	—	—	1,190	—	—	—	—	—	—	—
Columbium (Nb_2O_5)	—	—	8,165	—	—	—	—	—	—	—
Copper	—	—	625	97,069	—	—	—	25,000	31,751	—
Iron ore	—	—	16,329,000	—	—	—	—	159,000	—	1,270,000
Lead	—	—	2,359	—	—	—	—	5,000	4,000	—
Lithium	—	—	—	1,270	—	—	—	—	—	—
Manganese	—	—	39,643	408	—	—	—	600	—	—
Mercury (76-lb flasks)	—	—	—	—	—	—	—	261,074	—	—
Molybdenum	—	—	—	2,449	—	—	—	90	227	—
Nickel	—	—	417	—	816	3,084	998	—	—	—
Platinum (thousand t. oz)	—	—	—	—	1,000	—	—	—	—	—
Rare earths	—	—	318	—	—	—	—	—	—	—
Rhenium	—	—	—	1,179	—	—	—	—	181	—
Rutile (TiO_2)	—	—	55,000	—	—	—	—	100	—	—
Selenium	—	—	—	39	—	—	—	5	13	—
Silver (thousand t. oz)	—	—	—	—	—	—	—	950,000	609,996	—
Tantalum	—	—	3	—	—	—	—	—	—	—
Tellurium	—	—	—	—	—	—	—	—	3	—
Thorium	—	—	54	—	—	—	—	—	—	—
Tin	5	980	600	—	—	—	—	2	—	—
Tungsten	—	39	18	—	—	—	—	20	—	—
Uranium	—	—	—	—	—	—	—	225	—	—
Vanadium	—	—	—	136	—	—	—	—	—	—
Yttrium	—	—	2	—	—	—	—	—	—	—
Zinc	—	—	4,536	—	—	—	—	4,000	7,000	—
Zirconium and hafnium	—	—	—	—	—	—	—	2	—	—

[1] Estimated by Consejo de Recursos Minerales, Mexico.

Table 4 Nonmetallic mineral reserves in Latin America for 1978
[Quantities are given in thousand metric tons, except as noted.]

	ARGENTINA	BOLIVIA	BRAZIL	CHILE	GUYANA	JAMAICA	MEXICO[1]	PERU	SURINAM
Barite	—	—	3,629	—	—	—	14,000	3,629	—
Bauxite	—	—	2,500	—	1,000	2,000	—	—	490
Bentonite	—	—	—	—	—	—	1,270	—	—
Boron[2]	9,072	9,072	—	9,072	—	—	10,000	9,072	—
Coal (bituminous)	—	—	—	—	—	—	1,000,000	—	—
Diatomite	—	—	—	—	—	—	1,180	—	—
Feldspar	—	—	—	—	—	—	3,020	—	—
Fluorspar	726	—	816	—	—	—	35,380	—	—
Fuller's earth	—	—	—	—	—	—	320	—	—
Graphite	—	—	—	—	—	—	1,418	—	—
Gypsum	—	—	—	—	—	—	114,062	—	—
Iodine	—	—	—	363	—	—	—	—	—
Magnesite	—	—	136,078	—	—	—	185	—	—
Phosphate rock (P_2O_5)	—	—	—	—	—	—	800,000	—	—
Potash (K_2O)	—	—	—	9,072	—	—	—	—	—
Quartz	—	—	—	—	—	—	4,258	—	—
Salt	—	—	—	—	—	—	141,056	—	—
Strontium	—	—	—	—	—	—	365	—	—
Sulfur	—	—	—	—	—	—	90,000	—	—

[1] Estimated by Consejo de Recursos Minerales, Mexico.
[2] 20% boron (potential).

early 1980's from 35,000 tons per year to more than 60,000 tons per year. The demand for bentonite for drilling muds in Mexico is expected to increase greatly due to requirements of the Mexican oil industry, and it is expected that production of bentonite in Mexico will increase to 2 million tons per year or more during the early 1980's.

The advantage of an increase in mineral production in semi-industrialized countries, such as Argentina, Brazil, and Mexico, is that on the one hand export of minerals gains foreign exchange and on the other utilization of minerals by local industry creates new jobs and investment opportunities. Requirements for electrical power will grow and new hydroelectric, thermoelectric, and nuclear power plants will have to be built in the 1980's.

When speaking of growth in the mineral industry of Latin America, one must consider the variations in the international mineral market. The rule of supply-and-demand is certain to continue. Thus, an effort must be made in Latin America to increase internal consumption by industries that utilize the minerals in the manufacturing of products for local consumption and for export. Such is the case of Mexico where rapid industrialization during the past 2 or 3 decades has changed the situation from one in which nearly all mineral commodities (except construction materials) were exported to the present when 65 percent of the total mineral production is consumed by local industry. Diversification of local industry requires the search for new minerals that can be produced locally and reduce imports. For instance, Mexico is a consumer of nickel, chrome, titanium, tin, asbestos, ceramic talc, potassium, bauxite, and alumina, all of which must now be imported. It would be of great economic benefit if at least part of these minerals could be supplied from local sources.

TECHNOLOGIC DEVELOPMENT OF THE MINING INDUSTRY IN LATIN AMERICA

The mining industry may be divided into three categories: large, medium and small scale operations. However, parameters for classification vary radically. A small mine in Canada might be a large one in Latin America, a large gold mine might be one producing a few hundred tons of ore per day wherein a large copper mine is generally considered to be one producing tens of thousands of tons of ore per day. Nevertheless, a scale is needed as a means of comparing sizes of mining operations. The Mining Magazine (January, 1978, p. 52), shows a table wherein mines in Central and South America are placed in five categories according to annual productions as follows: 150,000–300,000, 300,000–500,000, 500,000–1 million, 1–3 million, and greater than 3 million tons per year. In most Latin American countries, a medium-size operation probably would be one having a production of 60,000–450,000 tons of ore per year, a small operation would produce less than 60,000 tons of ore per year, and a large operation would produce more than 450,000 tons of ore per year.

Table 5 lists numbers of medium- to large-scale mining operations in Latin America. A minimum size for a medium-scale operation was taken at 150,000 tons of ore per year because reliable data about production from smaller mines is lacking. As can be seen, Brazil has 35 medium to large open pit operations, Chile 12, Mexico 9 and Jamaica and Peru, 7 each. Other countries have less than 7, and some, like Nicaragua, do not have any. Brazil has the greatest number of large open-pit mines, 10 of which have capacities greater than 3 million tons of ore per year and 11 others have capacities of 1–3 million tons per year. Table 5 also shows that Bolivia, Mexico, and Peru have the largest number of medium-size underground mines, most of which produce 150,000–300,000 tons per year. Mexico and Peru have 5 and 9 operations, respectively, producing 300,000–500,000 tons per year. The largest underground mines are in Chile, where 3 mines have capacities greater than 3 million tons of ore per year. No published statistics are available for the large number of small-scale mining operations having capacities of less than 60,000 tons per year. Mines of this size are popular and widespread in Latin America. They are labor intensive operations that promote local economic development by furnishing work to local inhabitants. The Small Scale Mining UNITAR Meeting, held in Mexico in November 1978, revealed that there are more than 12,000 small mines in the world. In Mexico, for example, small mines account for more than 20 percent of the total mineral productions of the country.

A large part of the large mines of the world were discovered by a prospector who started small-scale mining; in some cases progressive increases in production led to large-scale production, in others, large companies purchased the properties and financed large-scale operations. Thus, Latin American countries should foster and stimulate small scale mining, with the expectation that some small mines will reveal large ore bodies that can be exploited on a large scale.

From a financial point of view, small mines require small capital, and the cost of labor per capita is much less than it is for larger mining operations. Financing is much easier to obtain than it is when hundreds of millions of dollars are needed to open a large mine. Furthermore, because small mines may be spread widely throughout a country, some in nearly uninhabited areas, they stimulate economic and social development.

Table 5 Mines in Latin America producing more than 150,000 tons of ore per year

	TOTAL	150,000 TO 300,000 TON/YEAR	300,000 TO 500,000 TON/YEAR	500,000 TO 1 MILLION TON/YEAR	1 MILLION TO 3 MILLION TON/YEAR	GREATER THAN 3 MILLION TON/YEAR
				OPEN PIT		
Argentina	--	--	--	--	--	--
*Bolivia	--	--	--	--	--	--
*Brazil	35	7	4	3	11	10
Chile	12	1	--	1	7	3
Colombia	1	--	--	1	--	--
Cuba	4	--	2	--	--	2
Dominican Republic	3	--	--	--	2	1
Guatemala	1	--	--	--	1	--
Guyana	2	--	--	--	1	1
Haiti	1	--	--	1	--	--
Honduras	--	--	--	--	--	--
Jamaica	7	--	--	2	2	3
*Mexico	9	1	1	--	6	1
Nicaragua	--	--	--	--	--	--
*Peru	7	1	1	--	1	4
Surinam	3	--	--	--	2	1
Venezuela	4	--	--	--	2	2
Total	89	10	8	8	35	28
				UNDERGROUND		
Argentina	3	1	1	--	1	--
*Bolivia	16	3	11	1	1	--
*Brazil	4	2	1	1	--	--
Chile	7	1	1	--	2	3
Colombia	--	--	--	--	--	--
Cuba	--	--	--	--	--	--
Dominican Republic	--	--	--	--	--	--
Guatemala	--	--	--	--	--	--
Guyana	--	--	--	--	--	--
Haiti	1	1	--	--	--	--
Honduras	1	--	1	--	--	--
Jamaica	--	--	--	--	--	
*Mexico	17	6	5	6	--	--
Nicaragua	2	2	--	--	--	--
*Peru	18	4	9	4	1	--
Surinam	--	--	--	--	--	--
Venezuela	--	--	--	--	--	--
Total	69	20	29	12	5	3

*An estimated 16,000 mines in the world produce less than 150,000 tons per year. Countries marked with an asterisk (*) are those where small mines represent an important part of the mining industry.

Source: Mining Magazine, January 1978.

THE FUTURE OF THE MINING INDUSTRY IN LATIN AMERICA

Based on parameters set forth above and because of intensive on-going exploration in many of the countries, the future of mining in Latin America looks bright. The Mining Magazine (1978, p. 65–68) mentions the planned development of 99 major new mines and expansion of existing mines in Latin America. Among these are 3 major projects in Argentina, 14 in Bolivia, 37 in Brazil, 2 in Colombia, 2 in Costa Rica, 1 in Cuba, 8 in Chile, 1 in the Dominican Republic, 1 in Ecuador, 1 in Guatemala, 1 in Guyana, 1 in Honduras, 1 in Jamaica, 14 in Mexico, 3 in Panama, 1 in Paraguay, 14 in Peru, 1 in Surinam, and 6 in Venezuela. Although most of these projects involve capital investment of less than 100 million dollars, at least 37 involve investments of 500 million dollars or more. Of the total new mines, 32 will be open pit and the remainder will be underground operations.

The potential for discovery of new mineral deposits in Latin America is excellent. For example, only about 5 percent of Mexico has been adequately prospected, and it is estimated that 1.5 million km^2 requires reconnaissance exploration and that about half this area will be found to have a significant mineral potential. Because of tropical forest cover and inaccessibility, the mineral potential of a large percentage of Central America is unknown. Much of Central America has a geological environment similar to that of the Sierra Madre Occidental of Mexico, and like the Sierra Madre Occidental should have many exploitable mineral deposits. The Andes Mountains of South America contain many and varied mineral deposits, and represent one of the world's richest mineral provinces. The potential for discovery of new mineral deposits in the Andes is excellent and it is likely that such new deposits and known but as yet undeveloped deposits contain many times the quantities of metal and other mineral commodities as do developed deposits. The eastern and southeastern part of Venezuela, the north and northwestern parts of Brazil, and Surinam have enormous potentials for discovery of new mineral deposits. However, inaccessibility, jungle cover, and deep weathering make exploration of these regions difficult and costly. Paraguay's eastern territory, where coal and copper deposits are known, has a good potential for mineral discovery. Argentina has undertaken extensive mineral exploration programs during the past two decades and many new deposits, most notably large porphyry copper deposits, have been found. Continued exploration should prove to be fruitful and it is expected that by the end of this century Argentina will join the select group of major mining countries.

CONCLUSIONS

The future of the mining industry in Latin America is bright, and it may be concluded that an increasing percentage of the mineral commodities produced will be utilized by local industry. However, because the potential mineral resources of Latin America are so vast, this region will continue to furnish a significant part of the world's needs for mineral raw materials for many future generations. It may be expected that costs of the mineral raw materials will rise and that in the future mineral prices will more nearly reflect their abundance and long-term availability than they do today. Although Latin America has a great variety of mineral commodities, those which show best potential for long-term production (excluding construction materials and industrial minerals that primarily will be utilized locally) include the following: copper, molybdenum, lead, zinc, tin, tungsten, gold, silver, antimony, arsenic, bismuth, nickel, iron ore, manganese, rare-earth metals, cadmium, lithium, bauxite, boron, asbestos, diamonds, phosphate rock, and sulfur. In addition, Mexico, Argentina, and perhaps Peru have huge oil and gas potentials that have only recently been recognized. Colombia has huge resources of bituminous coal.

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Exploring and Evaluating Seabed Resources: The Experience of the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP)

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INTRODUCTION

This paper deals with exploration and evaluation of seabed resources as well as with the unique experience of the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP) in its cooperation with both developed and developing countries of East Asia and with United Nations bodies and other international scientific and professional organizations in the assessment of the offshore minerals of the region. Under the aegis of the United Nations Economic Commission for Asia and the Pacific (ESCAP, formerly called ECAFE or Economic Commission for Asia and the Far East) there has been a strong geological and mining program, giving impetus to regional cooperation in the field of mineral-resource exploration and development. It is within this context that a proposal was made in 1964 to establish a co-ordinating committee for offshore prospecting in East Asia, an idea fostered by the realization that although East Asia was an important mineral producer on land, its offshore mineral wealth was little known. Offshore exploration for petroleum was meager except for that in well-established offshore fields of East Malaysia and Japan (table 1). In the meantime, offshore oil had been discovered in other parts of the world, pointing up the growing potential of offshore oil and gas. It was obvious that East Asia, with its vast shelf areas, needed more attention. It also was evident that offshore exploration is an expensive venture, which would be a burden for individual countries of East Asia. By pooling resources and cooperating in exploration of offshore areas between two or more countries, exploration would be much cheaper and more efficient. Starting with four countries, Japan, Republic of Korea, Republic of China (Taiwan) and the Philippines, CCOP was established in 1966. Since then its membership has grown to 12 countries, including the People's Republic of China which joined CCOP in 1979. The area of interest now covers all of East Asia and its bordering seas, that is to say the countries of Indonesia, China, Japan, Kampuchea, Republic of Korea, Malaysia, Papua New Guinea, the Philippines, Singapore, Thailand, Trust Territory of the Pacific Islands, and the Socialist Republic of Viet Nam. This region has a unique tectonic setting and a high potential for mineral resources discovery and development. As a result of the success of the CCOP cooperative projects in East Asia a second CCOP cooperation project in the South Pacific was established in 1972. Most of the countries in the South Pacific have become members of this project.

MODE OF OPERATION OF CCOP

The CCOP sponsors an annual meeting held in a different member country each year. Although each member country is represented by one permanent representative on the CCOP Committee, attendance at Committee meetings includes representatives of all national agencies participating in the CCOP program. These representatives usually are chiefly from national geological surveys, bureaus of mines, universities, and other geological research institutions, and from national oil, tin, and other mining enterprises. As a consequence, the participants of the meetings represent a cross section of the geological community of participating countries.

In its operations, CCOP is assisted by a Technical Advisory Group consisting of experts mostly from developed countries but also from the United Nations, and from other international scientific and professional organizations. Developed countries supporting the CCOP at the present time are Australia, France, Japan, the Netherlands, the United Kingdom, U.S.A., Federal Republic of Germany, Norway, Switzerland, and USSR. These countries are the cooperating countries of CCOP. Therefore, these countries and the member countries make up a cooperative group of 22 nations. As in the case of the member countries, the cooperating countries have multi-agency involvement with participation of national geological surveys and other geological institutions.

Table 1 Offshore hydrocarbon exploration in East Asia before 1965

	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
Indonesia:										
Drilling operations	–	–	–	–	–	–	–	–	–	–
Geophysics (km)	–	–	–	–	–	–	–	–	400	–
Contract area	–	–	–	–	–	–	–	–	–	–
Companies	–	–	–	–	–	–	–	–	–	–
Japan:										
Drilling operations	–	–	–	3	1	–	–	–	–	–
Companies	1	2	2	2	2	2	2	2	2	2
Malaysia-Brunei:										
Drilling operations	–	–	1	–	5	6	8	3	4	–
Discoveries	–	–	–	–	–	–	–	1 gas	–	–
Metres drilled	–	–	2,133	–	10,972	14,152	20,073	7,953	9,458	–
Companies	3	3	3	3	3	3	3	3	3	4
The Philippines:										
Drilling operations	–	–	–	–	–	–	–	–	–	–
Seismic (km)	–	–	–	–	–	–	4,264	785	–	2,871
Magnetic (km)	–	–	–	–	–	–	–	6,720	–	23
Gravity (km)	–	–	–	–	–	–	300	–	–	–
Cambodia	–	–	–	–	–	–	–	–	–	–
Korea	–	–	–	–	–	–	–	–	–	–
Viet Nam	–	–	–	–	–	–	–	–	–	–
Thailand	–	–	–	–	–	–	–	–	–	–

Among the international scientific and professional organizations involved in the programmes of CCOP are: the Intergovernmental Oceanographic Commission (IOC), the Circum-Pacific Council on Energy and Mineral Resources, the East-West Center (Honolulu), the International Union of Geological Sciences (IUGS), with its programs and committees such as the International Geological Correlation Programme (IGCP), Committee on Storage, Automatic Processing, and Retrieval of Geologic Data (COGEODATA), Commission of the Geological Map of the World (CGMW), Commission for Marine Geology (CMG), United Nations Educational, Scientific, and Cultural Organization (UNESCO), United Nations Environment Program (UNEP), International Programme of Ocean Drilling (IPOD), International Decade for Ocean Exploration (IDOE), Inter-Union Commission on Geodynamics (ICG), United Nations Co-operative Coastal Zones Studies, and the three other regional bodies of ESCAP concerned with mineral resources, CCOP cooperative project in the South Pacific (CCOP/SOPAC), Regional Mineral Resources Development Centre (RMRDC), and the Southeast Asia Tin and Development (SEATRAD) Centre.

From its inception in 1966 until 1972, the ESCAP Mineral Resources Section served as secretariat to CCOP and organized its meetings. Since 1972, UNDP has supported CCOP through its project of Regional Offshore Prospecting in East Asia and now serves as the technical bureau that carries out the program of CCOP. The UNDP support for the period 1978–1981 is currently equivalent to US $3,000,000, of which $2,000,000 is from OPEC Special Funds. This support enables CCOP to maintain a permanent project office staffed by a Project Manager and professional experts such as a senior marine geologist, a senior marine geophysicist, and a petroleum geologist as well as support personnel such as an editor and an administrative officer who serves CCOP in the execution of its programs. Other professional staff members are provided by the developed cooperating countries on a non-reimbursable basis. At present, these include a principal marine geologist from U.S.A., a geophysicist from Japan, a specialist on pre-Tertiary geology from France and hopefully in 1980, a Quaternary geologist from the Netherlands. In the future, we hope that specialists from the member countries of CCOP will serve at the Project Office within the framework of Technical Cooperation Among Developing Countries–United Nations (TCDC).

In short, it can be said that within CCOP there is interaction between professionals in government, university, and industry in the member countries with professionals in the scientific community of the developed countries and international organizations resulting in formulating of practical programmes within the framework of CCOP.

CCOP's SURVEYS 1966–1972

The period of 1966–1972 can be considered as the pioneering period of CCOP. Prior to 1966 CCOP was little concerned with offshore exploration except for isolated projects such as one in Japan (magnetitic sand, coal, and petroleum and natural gas), small areas of east-central Sumatra (petroleum and natural gas), and tin mining in Indonesia and southern Thailand. The most important CCOP programs during this period were several successive geological and geophysical surveys. CCOP's first undertaking in 1966 was a continuous marine seismic profiling survey with magnetic recording along the southeastern coast of the Republic of Korea. While the results of that survey were not encouraging, the interest of the Government of Korea was stimulated to search for hydrocarbons in offshore areas (table 2). A subsequent geological survey in the East China Sea and the Yellow Sea by the RV *F. V. Hunt* was carried out by the U.S. Naval Oceanographic Office and Woods Hole Oceanographic Institution, with support from the Japan Petroleum Development Corporation and the Geological Survey of Korea. This was followed by over 40,000 line-km aeromagnetic surveys of an area of over 200,000 square km in the Yellow Sea, East China Sea, and the Korea Strait by the U.S. Oceanographic Office, Bundensanstalt für Bodenforschung (FRG), and the Geological Survey of Korea. These surveys enhanced our knowledge of these marine areas, and subsequently private industry has undertaken exploration programs in these areas. In 1969, another survey was carried out by the U.S. Oceanographic Office and Woods Hole Oceanographic Institution in the South China Sea and the Gulf of Thailand. In 1971, the Woods Hole Oceanographic Institution, with the participation of the U.K. Institute of Geological Sciences, carried out about 7,400 line-km of geophysical traverses, including 6,000 line-km of seismic profiles and magnetic and gravity surveys in the Japan Sea and the adjacent continental shelf. In the Philippines, the oil industry was active until the early 1960's when major foreign companies closed their operations and local companies exhausted their working capital. Interest in oil exploration was renewed after an aeromagnetic survey, consisting of 25,000 line-km of aeromagnetic traverse over a 136,000-square-km offshore area in the Palawan-Sulu Sea Region, was carried out by the U.S. Naval Oceanographic Office, the Bundesanstalt für Bodenforschung, and the Philippines Bureau of Mines. Renewed exploration by the oil companies led to the discovery of the Nido offshore field of Palawan and subsequently to the first oil production in the Philippines. Other surveys included: (1) shipborne magnetometer and sonic profiling for heavy detrital minerals off the west coast of Korea by the Federal Republic of Germany and the Geological Survey of Korea; (2) 1,600 line-km of magnetic profiling and collection of 18 bottom samples over the Sunda Shelf between Kalimantan and peninsular Malaysia by the Tokyo University of Fisheries and UNESCO; (3) a geologic,

Table 2 Offshore hydrocarbon exploration 1966 to 1975, Republic of Korea

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Drilling:										
Exploration total	-----	-----	-----	-----	-----	-----	0	4	0	1
Discoveries	-----	-----	-----	-----	-----	-----	0	0	0	1
Geophysics:										
Seismic (km)	-----	-----	6,000	-----	-----	-----	5,290	5,650	588	0
Magnetic (km)	-----	-----	6,000	40,000	1,300	-----	-----	5,299	-----	0
Gravity (km)	-----	-----	-----	-----	1,300	-----	-----	4,574	-----	0
Concessions:										
Area, sq. km × 1,000	-----	-----	-----	81.7	341.6	341.6	341.6	341.6	299.7	229.7
Number	-----	-----	-----	2	7	7	7	7	7	7
Operators	-----	-----	-----	1	4	4	4	4	4	4

Table 3 Offshore hydrocarbon exploration 1966 to 1975, Indonesia

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Drilling:										
Exploration wells	-----	-----	8	24	58	85	67	82	102	27
Declared discovery	-----	-----	-----	3	5	5	8	11	15	0
Metres drilled	-----	-----	15,209	33,556	11,520	157,025	131,575	163,547	207,314	44,193
Geophysics:										
Seismic (km)	-----	-----	51,799	97,237	62,492	63,592	35,687	45,213	38,999	12,242*
Magnetic (km)	96,643	-----	2,500	150	10,131	27,050	1,170	10,611	2,536	-----
Gravity (km)	-----	-----	-----	-----	10,169	20,200	-----	1,791	715	-----
Sharing Contracts	-----	7	18	25	32	35	36	34	31	35
Area, sq. km × 10^6	-----	.39	1.68	2.04	2.08	2.86	2.23	1.74	1.23	1.22
Total operators	-----	5	-----	13	18	20	20	20	21	22

* To May 1975.

sparker and seismic refraction survey in the area east of peninsular Malaysia and near Natuna Island by the Imperial College of London, the Indonesia Hydrographic Office, the University of Malaya, and UNESCO.

Although the amount of work during this period was not as much as that after 1972 within the IDOE/SEATAR (International Decade of Ocean Exploration/Studies of East Asia Tectonics and Resources) program, these surveys were important because of their pioneering nature and the impetus that they gave to offshore exploration, as shown by tables 2 through 9. Increased knowledge of these marine areas attracted industry's interest, and increased activities led to discoveries of new oil fields. Offshore oil is important throughout Malaysia, but Indonesia has emerged as a major offshore producer.

Recently discovered oil and gas are being developed in Thailand and the Philippines. A gas field in the Gulf of Thailand is now under development; gas from that field may become available in 1981. Production of oil from the field near Palawan Island, the Philippines began in 1979.

Table 4 Offshore hydrocarbon exploration 1966 to 1975, Japan

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Drilling:										
Exploration wells	4	5	3	na	-----	7	10	8	5	3
Discoveries	2 gas	-----	-----	-----	-----	1 oil	1 oil 1 gas	1 oil	1 gas	-----
Geophysics:										
Seismic (km)	6.2*	1.7*	-----	9,879	6,554	6,140	10,247	8,282	35.5*	6+*
Magnetic (km)	1.7*	-----	-----	-----	19,738	400	550	11,585	6.6*	-----
Gravity (km)	1.8*	-----	-----	-----	7,760	3,070	550	5,856	7*	-----
Permits:										
Area, sq. km × 1,000	na	61	73	213	261	309	600	943	943	943
Companies	2	3	4	6	8	10	9	12	14	14

* Field party months.

Table 5 Offshore hydrocarbon exploration 1966 to 1975, Kampuchea

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Drilling:										
Wildcats	----	----	----	----	----	----	1	----	2	0
Geophysics:										
Seismic (km)	----	----	----	----	2,880	----	----	2,159	1,794	0
CCOP combine (km)	----	----	----	2,000	----	----	----	----	----	0
Concessions:										
Area, sq. km × 1,000	----	----	----	40	40	40	20	37	37	37
Total leases	----	----	----	1	1	1	1	2	2	2
Operators	----	----	----	1	1	1	1	2	2	2

Table 6 Offshore hydrocarbon exploration 1966 to 1975, Malaysia

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Drilling:										
Exploration totals	9	12	17	24	47	23	+Shell 20	+Shell 25	32	7*
Discoveries	3 oil	1 oil	na	na	-----	3 oil 1 gas	3	3 oil	2	-----
Metres drilled	27,566	31,308	na	76,513	+Shell 24,433	+Shell 29,390	+Shell 40,403	+Shell 28,249	+Brunei 78,777	-----
Geophysics:										
Seismic (km)	----- 6*	644 11.9*	1,600 5*	4,680 39*	4,996 -----	9,975 -----	12,798 -----	9,968 +Shell	14,685 -----	----- -----
Magnetic (km)	-----	-----	1,300	4,500	-----	3,300	0	12,872	0	-----
Gravity (km)	-----	-----	-----	1*	-----	0	0	0	0	-----
Concessions:										
Area, sq. km × 1,000	190.1	197.9	347.2	347.2	340.0	258.0	258.0	204.7	202.8	202.8
Operators	5	5	7	7	7	8	8	8	8	8

* Field party months.

Table 7 Offshore hydrocarbon exploration 1966 to 1975, Thailand

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Drilling:										
Exploration total	—	—	—	—	—	1	3	5	12	4
Discoveries	—	—	—	—	—	0	1	—	4	1
Metres drilled	—	—	—	—	—	5,392	5,355	15,688	35,596	—
Geophysics:										
Seismic (km)	—	—	11,686	11,552	6,310	1,670	11,473	12,615	25,472	—
Magnetic (km)	—	—	—	2,413	59,533	—	4,124	1,228	—	—
Gravity (km)	—	—	—	—	—	—	4,124	1,228	—	—
Concessions:										
Area, sq. km × 1,000	—	—	—	Awaiting	—	265.3	218.2	218.2	308.2	308.2
Number	—	—	—	legislation	—	12	11	11	14	14
Operators	—	—	—	—	—	9	9	9	11	11

Table 8 Offshore hydrocarbon exploration 1966 to 1975, The Philippines

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Drilling:										
Exploration	—	—	—	—	—	2	—	3	3	4+
Metres drilled	—	—	—	—	—	4,395	—	7,129	9,992	—
Geophysics:										
Seismic (km)	960	—	—	1,500	786	11,803	5,000	6*	2,100+	—
Magnetic (km)	—	—	—	22,500	4,200	10,000	—	—	—	—
Gravity (km)	—	—	—	—	—	—	—	—	—	—
Concessions:										
Area, sq km × 1,000	—	—	—	—	—	—	12,962	49,403	62,598	63,788
Number	—	—	—	—	—	—	1	7	10	11
Operators	—	—	—	—	—	—	1	7	9	9

* Field party months.

Table 9 Offshore hydrocarbon exploration 1966 to 1975, Viet-Nam

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Drilling:										
Exploration total	—	—	—	—	—	—	—	—	2	4
Discoveries	—	—	—	—	—	—	—	—	1	1
Metres drilled	—	—	—	—	—	—	—	—	5,689	4,000
Geophysics:										
Seismic (km)	—	—	657	4,000	8,406	—	—	4,800	22,032	na
Magnetic (km)	—	140	—	4,000	—	—	—	—	—	—
Gravity (km)	—	—	—	—	—	—	—	—	—	—
Concessions:										
Area, sq. km × 1,000	—	—	—	—	—	—	—	58.3	84.2	84.2
Number	—	—	—	—	—	—	—	8	13	13
Operators	—	—	—	—	—	—	—	4	8	8

THE JOINT CCOP-IOC PROGRAM FOR STUDIES OF EAST ASIA TECTONICS AND RESOURCES

As previously mentioned, the period prior to 1972 was the pioneering period of CCOP and when oil exploration by industry began to grow, CCOP's pioneering role diminished, and it became necessary to search for other viable activities. One proposal was for CCOP to become involved in studies related to the program of the International Decade of Ocean Exploration (IDOE). This project was originally proposed by President Lyndon Johnson of the U.S.A. in 1968 and later endorsed by various entities in the United Nations. Its basic objective was to encourage international cooperation in research, of mutual benefit to all countries, into resources in and under the sea. As a consequence, during the 1972 session of CCOP, held in Bandung, Indonesia, a group of scientists formulated the research proposal entitled "Tectonic Development of East and South East Asia and its relation to Metalliferous Ore and Hydrocarbon Genesis." This project paper was submitted to the IDOE office and copies were sent to the International Oceanographic Commission (IOC) and the Scientific Committee on Ocean Research (SCOR), where it received an enthusiastic response. A workshop on "Metallogenesis and Tectonic Patterns in East and South East Asia" was held in Bangkok in September 1973 to discuss research proposals. Some ninety scientists attended, 50 percent of whom were from government organizations, equally divided between developed and developing countries, 30 percent from universities and research institutes, and 20 percent from industry. Twelve countries and 3 U.N. organizations participated. A major feature of the workshop was the international character and diversity of project proposals and of the discussions. The workshop dealt with five major topics: tectonics, geophysics, sedimentary processes, metallogenesis, and petrogenesis. In addition, heat flow and maturation of hydrocarbons were discussed from the viewpoint of current knowledge and investigations. Project proposals in these fields were discussed in this context.

It was agreed that investigations in metallogenesis and tectonics should be carried out along specific transects, as follows:

1. Burma–northern Thailand transect.
2. Andaman Sea–southern Thailand transect.
3. Sumatra–Malay Peninsula–Sunda Shelf transect.
4. Timor–Banda Sea transect.
5. Northern Philippines transect.
6. Southwest Japan–Korean Peninsula transect.

These transects are in areas of major plate interaction and each cuts across an arc-trench system and adjacent basins and continental areas. The results from study of individual transects could be coordinated to give a comprehensive multidisciplinary picture of this fascinating portion of the Earth's crust.

The IDOE/SEATAR program is one of the most successful programs in which CCOP has been involved. The results of the workshop, which were published in a book entitled "Metallogenesis, Hydrocarbons and Tectonic Patterns in Eastern Asia," have become the basis for the planning of scientific programs aimed at solving specific problems. Member countries are carrying out geological and geophysical studies on land, using their own funds and facilities, and they are cooperating with developed countries in the offshore investigations. Geoscientists from the member countries of CCOP have had the opportunity to join cruises of research ships owned and operated by institutions of the developed countries. Some of these surveys involved 2 or 3 ships as was the case with that in the Banda Sea, which was made by the MV *Thomas Washington*, the MV *Atlantis II* of the U.S.A., and the Indonesian ship MV *Kelapa*.

The U.S.A. has been the principal contributor to the program through the IDOE Program of the National Science Foundation, carried out by the Scripps Institute of Oceanography (SIO), Woods Hole Oceanographic Institution (WHOI), and the Lamont-Doherty Geological Observatory (LDGO). In addition to the U.S.A., the Federal Republic of Germany (Bundesanstalt für Geowissenschaften und Rohstoffe), Japan, the United Kingdom, and Australia have participated in the program.

OFFSHORE EXPLORATION FOR TIN AND OTHER DETRITAL MINERALS, AND STUDIES OF QUATERNARY GEOLOGY

CCOP's interests in mineral exploration have not been confined to petroleum and natural gas, although the work in these fields has attracted the greatest public attention. Exploration for offshore detrital minerals also has been an important phase of CCOP work. Three of the CCOP member countries are among the largest tin producers of the world. Their combined production is more than 60 percent of total world production. Offshore tin mining was important in Thailand and Indonesia before 1966, and the tin potential of the offshore areas of Thailand, Malaysia and Indonesia is known to be great. Cooperation among the countries in the assessment of the tin resources is essential. During annual sessions of CCOP, progress in exploration and application of new techniques used in exploration of offshore tin have been discussed. Two surveys were notable: A survey of tin along the west and east coasts of peninsular Malaysia in 1974, carried out under the Dutch assistance program, and a survey of tin in the offshore areas between Malaysia and Indonesia in 1976, carried out with the assistance of the Federal Republic of Germany. In 1979, a follow-up survey of the 1976 survey of an area west of Port Dickson, west of peninsular Malaysia was begun. This survey involves detailed geophysical studies followed by drilling. Since 1978, the Project Office of CCOP has acquired shallow marine geophysical equipment consisting of a seismic reflection profiling system, a side-scan sonar system, a marine magnetometer, a recording base-station magnetometer-gradiometer, a dual frequency pinger system, a marine geophysical refraction system, and a navigation system. This equipment can be used in the exploration for offshore tin and other detrital heavy minerals, for building materials, and for studies of Quaternary geology and engineering geology. It can be used in national surveys where a given country provides a ship and its crew and most of the professional and technical staff, while CCOP provides the equipment and services of one or two professional geophysicists.

The first survey in this program was carried out by the Thai Department of Mineral Resources in April 1979. A preliminary interpretation of the results indicated the existence of at least one potentially commercial tin bearing area, and other areas that warrant drilling. It was recommended that 129 holes be drilled in the area covered by the survey. This drilling will be carried out by Thailand with the support of UNDP funds for Thailand making it an example of linkage of a UNDP regional project with a UNDP country project.

In addition to tin, other detrital heavy minerals, such as ilmenite, monazite, zircon, rutile, and tantalite-columbite are known to occur in East and Southeast Asia, and have been recovered in Malaysia and Thailand as a byproduct of tin mining. Beach deposits of titaniferous magnetite have been exploited in Japan and the Philippines. Alluvial gold has long been produced in the Republic of Korea, where also exploration for and recovery of small amounts of ilmenite, zircon, and monazite have been made. CCOP's program for exploration of offshore detrital heavy minerals has been undertaken with the assistance of experts provided by Australia.

It is generally recognized that knowledge of Quaternary geology is important to the understanding of the distribution of detrital tin and other heavy detrital minerals, to determination of ground-water supplies, to evaluation of construction materials, and to problems in engineering geology. CCOP studies in Quaternary geology, planned to start in 1980, will be carried out with the assistances of a geologist provided by the Government of the Netherlands.

TRAINING IN SCIENCE AND TECHNOLOGY

The rapid expansion of national programs for exploration and development of offshore resources by CCOP member countries has required training of many new scientists and engineers in these countries. Whereas basic geologic training is generally available throughout the region, facilities for specialized training in such fields as geophysics, mathematical geology, geochemistry, and data manipulation were found to be inadequate. CCOP has sought to provide training by organization of special seminars and workshops, which resulted from recommendations at the annual meetings. For example, a seminar on petroleum data collection, storage, and retrieval was held at Bandung, Indonesia in April 1976. This seminar was intended to be a preparatory phase in the establishment of national petroleum data storage/retrieval centers and sample repositories. Another seminar/workshop on interpretation of satellite imagery for the East-Asia IDOE transect was held in Bangkok in 1976. The meeting was organized by the CCOP project office and conducted by an expert from the U.S. Geological Survey with the assistance of the Thai Department of Mineral Resources. Geochemical processes are important to the understanding of hydrocarbon genesis, particularly the variable complex geochemical processes that characterize distinct marine and nonmarine basins. To gain an understanding of these processes, a seminar sponsored by CCOP and the ASEAN (Association of South East Nations) Council on Petroleum (ASCOPE) on the generation and maturation of hydrocarbons in sedimentary basins was held in Manila in 1977. The Federal Republic of Germany, France, and the United Kingdom provided experts to participate in this seminar. The member governments of CCOP have long recognized that reliable assessment of their undiscovered national petroleum resources, as well as production capacities and life spans of the proven reserves, were critical factors in determining long-term national economic and development plans and setting yearly budgetary allocations and development targets. Based on this, a workshop on the methodology for assessment of undiscovered hydrocarbon resources was held at Kuala Lumpur, Malaysia, in March 1980.

The workshops sponsored by CCOP have shown that the success of a seminar or workshop depends upon factors such as interdisciplinary mixes, types of institutions and countries participating, relevancy to economic development of the region, and nature of the technical and scientific topics. A major objective has been the organization of workshops sufficiently advanced to attract participation of experts from the developed countries.

In the field of training, the Japanese Government has contributed by providing an annual course in offshore prospecting during 12 consecutive years. A field training course in methods and techniques for drilling of nearshore unconsolidated formations and placer deposits was given by the Netherlands. Participants from Indonesia, Malaysia, the Philippines, and Thailand attended this course. On-board training has also been given to participants of CCOP member countries on offshore survey cruises.

Within the CCOP programs, substantial amounts of new geological data on continental shelves of East Asia have been obtained and the results published by the technical documentation program. Four types of publications are issued: CCOP Technical Bulletins (vol. 1–12), Reports of CCOP sessions (once a year), CCOP Newsletters, and CCOP Special Publications.

PRESENT AND FUTURE PROGRAMS OF CCOP

Based on the recommendation of the second CCOP-IOC (Intergovernmental Oceanographic Commission) workshop on IDOE/SEATAR, this program will continue into the 1980's. It will also become part of the regional program of IOC in the Western Pacific (WESTPAC) which in addition to geologic and geophysical studies also carries out studies in physical oceanography and marine biology.

Future hydrocarbon resource programs of CCOP will include the following: (1) acquisition, storage, and retrieval of petroleum data; (2) stratigraphic correlation and regional basin studies; (3) heat-flow measurements and geothermal gradient studies as related to generation and maturation of hydrocarbons; and (4) study of pre-Tertiary petroleum potentials in East Asia. During its annual sessions since 1973, CCOP has repeatedly stressed the importance of establishing national centers for acquisition and interpretation of proprietary petroleum data and of well cuttings and cores. It was recognized that enormous amounts of valuable data about exploration and development had been collected by the petroleum industry in the CCOP member countries during the past decade. The total cost for petroleum exploration and development in the CCOP region has been more than US $1,000 million, and additional data is being collected at an accelerated rate as the pace of petroleum exploration has accelerated in response to discoveries during the past decade. The Committee on Storage and Automatic Processing of Geologic Data (COGEODATA) of the International Union of Geological Sciences (IUGS) assisted CCOP in assessing the needs of the member countries in the field of petroleum-data acquisition, storage, and retrieval, and recommendations were made for establishing systems similar to those now in use in North America and Europe. In the future CCOP will endeavor to strengthen national petroleum-data facilities and to establish regional data-acquisition programs.

Based on available information about occurrences of hydrocarbons in East Asia, it is felt that there is a need to assemble, evaluate, and publish about the character and distribution of oil and gas fields in that area. It has been decided that information about oil and gas in the CCOP area will be assembled in a series of basin study reports, which will include stratigraphic correlation charts and cross sections. These reports will emphasize the occurrence and distribution of oil and gas, as well as the geometry, structure, and stratigraphy of the basins. Eventually, the regional information will be published in an atlas of geology and hydrocarbon resources of the CCOP region.

With the assistance of the United States and Japan, a continuing program of heat-flow measurements and studies of thermal conductivity has been carried out in several member countries of CCOP. A seminar on hydrocarbon generation and maturation was held in September 1977. A follow-up seminar on heat-flow and geothermal gradient studies as related to generation and maturation of hydrocarbons has been proposed. The presence of hydrocarbons in pre-Tertiary sedimentary sequences in the CCOP member countries now appears unlikely, but there is a need to make additional studies of these older rocks before they can be eliminated as potential reservoirs of oil and gas. It was therefore decided to continue and intensify the CCOP program for study of pre-Tertiary sequences, probably with the assistance of an expert provided by the Government of France.

Future investigations of offshore tin and other detrital heavy minerals and construction materials, as well as studies related to coastal engineering and Quaternary geology, should include the following: (1) exploration for offshore deposits of tin and other detrital heavy minerals; (2) the search for offshore construction materials; (3) near-shore and offshore engineering and route surveys; and (4) regional geological studies of unconsolidated Quaternary sediments in relation to the above investigations and to investigations of ground-water supplies. As previously noted these studies will utilize CCOP's recently acquired geophysical equipment. The investigations will consist of successive surveys in individual member countries. In addition, a fact-finding mission will be organized to plan a regional Quaternary geology center to be attached to an existing organization in one of the CCOP member countries.

Other investigations and research relevant to CCOP activities will include participation in Project Magnet, the use of specific techniques such as remote sensing, radiometric dating, and others.

Preparation of geologic maps of the sea-floor and continental margin of Eastern Asia will become a new program of CCOP. At the request of the Commission of the Geological Map of the World (CGMW), CCOP has agreed to be responsible for the compilation of these maps at the scale of 1 to 5 million. Work will be conducted in cooperation with, complementary to, and as an extension of several related studies: International Decade of Ocean Exploration (IDOE), study of Quaternary geology of broad shelf areas and the Circum-Pacific Map Project. In the field of marine environment, a project will be initiated in cooperation with United Nations Environment Program (UNEP).

Consulting services, training of technical personnel, publication of a Technical Bulletin, Proceedings of Annual Sessions, and a Newsletter will continue as part of the CCOP effort. An East Asian offshore training center is planned. It will have the following main objectives: (1) training of drillers in techniques of operation of offshore drilling rigs, (2) training of deep-sea divers, (3) upgrading of personnel through specialized courses on drilling and production, and (4) training of local instructors.

ASSESSMENT OF CCOP ACHIEVEMENTS

CCOP is one of the most successful regional programs of the Economic Commission for Asia and the Pacific (ESCAP) and the United Nations Development Program.

Success of CCOP programs may be attributed to the following:

1. Offshore investigations are more susceptible to regional or international cooperation than are onshore country-by-country investigations.
2. Offshore investigations are expensive and require sophisticated equipment. By sharing resources as under CCOP programs, the member countries acquire data at a fraction of the cost for a single-country program.
3. Although limited in area, which is an advantage in management, the region is one of great geological interest, and has potentially large offshore hydrocarbon and detrital mineral resources.

4. Projects have been planned to yield information that will be of direct aid in exploration and development of mineral resources.
5. The involvement of competent and dedicated personnel from member and cooperating countries of CCOP, from the United Nations and other international scientific and professional organizations.

In conclusion I would like to say that the establishment of manageable practical programs geared to national, regional, and international needs has awakened the interest of many people and has attracted international attention and contribution to the program. I am hopeful that CCOP will continue to be a success, and to make contributions to international understanding for the benefit of all mankind.

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Discussion

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The main theme for this centennial celebration is a thought provoking symposium entitled "Resources for the 21st Century." In my short discussion I hope to tie the papers we have heard about present-day problems with the resources for the future.

First of all, an underlying theme of many of the papers is the interdependence of all countries on resources which exist in other countries. We have also heard that much of the mineral resources in developed countries have already been found, mined, and exhausted, and that a significant amount of resources could exist in developing countries where exploration has been lagging behind because of lack of expertise and capital.

The paper by G. P. Salas is a call for systematic geologic mapping in all countries and the need for mineral exploration in order to improve the balance of payments situation and employment opportunities in each country. A useful call is for promotion of small scale mining as a stepping stone to the establishment of much larger mines which can be so common in the area. It is important to note that if private enterprise will not come in to explore, developing countries can now apply for the United Nations revolving fund or World Bank funds to carry out their own exploration programs, and to pay for infrastructure costs if necessary. Such funding is becoming more easily available and may soon herald a new era of more direct state participation in mineral exploration efforts. It is also interesting to note that vast areas of South America are grossly unexplored, and the South American metallogenic maps show that the area has great potential for the development of many more metallic and nonmetallic mines, which could result in South America becoming an important industrial giant.

The paper by Dr. Johannas shows us an excellent example of a successful international cooperative program over a wide area of land and sea and involving many countries. One of the strengths of this program is that it emphasizes interdependence and similarity in geology to improve the exploration potential of the whole region. The program pools together the resources, expertise and facilities in the region so that exploration can be efficiently carried out on a regional basis without duplicating expensive facilities and equipment. This is the type of successful model which is worth emulating if our various developing regional groups hope to find and develop their resources quickly.

As Dr. Johannas has already pointed out, the developing island states of the South Pacific have now also formed their own offshore prospecting body called Committee for Co-ordination of Joint Prospecting in South Pacific Offshore Areas, with CCOP/SOPAC as its acronym. CCOP/SOPAC is also looking for resources for the present as well as the future—with the emphasis on petroleum potential, detrital minerals such as tin, and construction materials.

To those of you who raise your eyebrows at the mention of petroleum possibilities in the South Pacific it may be interesting to learn that CCOP/SOPAC has just concluded a very successful symposium entitled "Petroleum Potential in Island Arcs, Small Ocean Basins, Submerged Margins, and Related Areas." One of the lessons that came out of this symposium is that explorationists need to look at the basic requirements of source rocks, heat, and maturation, reservoir rocks such as reefs, migration, and traps in light of plate tectonics concepts—and they may be surprised to learn that many areas they had previously written off as non-prospective may actually have enormous potential for petroleum.

Much of the emphasis of the CCOP/SOPAC programs is on deep sea resources such as manganese nodules and phosphorites. And the discussions in this symposium make it increasingly obvious that during the 21st Century it will become necessary to exploit the mineral resources of the sea bed.

We have heard repeatedly during the symposium that resources are finite, and also in discussion that the major consumption of resources is in the developed countries. One has to wonder how much of the resources are being consumed today for essentials of life rather than in simply indulging in excessive luxuries of life. Is mankind really capable of making sensible decisions on rational use of natural resources to maximize their utility for public benefit—an example here could be the preferential use of petroleum for petrochemicals rather than motor fuel, and power supply.

The experience of the U.S. Geological Survey in its first 100 years and the tools it has perfected such as interpretation of ERTS imagery augurs well for the future. We hope that rational decisions by mankind on the use of resources during this century will not leave too many problems for Mother Earth when it comes of age in the 21st Century.

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Discussion

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The Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP), despite its title of coordinating committee, is not a clearinghouse or place to exchange information. It is an operational organization that defines its own problems, seeks solutions, and turns to the more developed countries for advice and assistance when necessary. Scientists from the CCOP member countries meet on an annual basis with their counterparts from the advisor countries to devise plans for uncovering and exploiting the resource potential of offshore areas in East Asia.

This spirit of cooperation served as a basis for a large-scale, coordinated research project—Studies in East Asia Tectonics and Resources (SEATAR). East Asia, from Japan to Korea, south and west through the Banda Arc, the Indonesian Archipelago and Andaman Sea to the Bengal Fan, has long served geologists as a testing ground for theories of island arc evolution and mountain building processes. The area has not been investigated, however, since the development of plate tectonics theory and with modern geophysical/geochemical research tools.

A full understanding of the processes along active converging margins, a subject of primary interest to academic scientists, plus the need for countries in East Asia to fully develop their resource potentials, were both answered by this coordinated program of research. The association of mineral deposits and hydrocarbon accumulations with the plate margins was quickly recognized when the plate tectonics theory first emerged. Efforts to understand the processes, however, have proved elusive. SEATAR is a major effort to come to grips with this problem. Approximately sixteen scientists from seven United States academic institutions did extensive field work, both offshore and onshore from 1975–1980. Final field work will be completed in 1981. The results will be evaluated in a series of workshops during 1981–82. Publication of interim results by SEATAR principal investigators has already been substantial. The exact nature of the plate tectonic processes that are responsible for mineral deposits and hydrocarbon accumulation must still be demonstrated. In another project along the East Pacific Rise at 21° N., however, a dramatic breakthrough was achieved in 1978. Here, scientists in manned deep-diving submersibles observed massive sulfides forming along the flanks of an active spreading center. These sulfides, rich in copper, nickel, and even silver are believed to be the first step in the formation of this major ore forming deposit.

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World Nonfuel Mineral Supply: The Outlook as We Approach the Twenty-first Century

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Agriculture and mineral production are the basic sources of new wealth. They are interdependent in that each helps the other to grow and similar in that adequate supplies of water are essential to both. Thoughtful people have always speculated about future adequacy of food and water supplies and often have taken prudent steps to improve them. Millennia ago, Joseph interpreted the Pharaoh's dream as foretelling that seven years of famine would follow seven years of great plenty. Forewarned, Egypt promptly implemented a grain stockpiling program.

People have also long been conscious of the important role of mineral materials. After initially using naturally shaped stones, man later perfected the art of pounding and flaking them for improved performance in various uses. Sunbaked clay products were followed by those baked in fire. Lime from limestone, plaster from gypsum, mortar from both, and natural mineral colors were all used in construction long ago. Asphalt was used as a cementing and water-proofing material.

Trading of minerals has been important from the earliest times. Salt and amber followed definite trade routes. The tin of Cornwall in England was important to the Phoenician bronze-makers of the eastern Mediterranean. Ancient Chinese bronzes display sophisticated alloying and casting techniques. Zambesi gold led the early Egyptians to circumnavigate the African continent, and Aztec and Inca gold and silver funded the Spanish empire. World production and use of materials have increased sharply in recent decades, as illustrated for four major commodities in figure 1. Except for a few large-bulk, low-value minerals such as sand and gravel, most minerals are now produced not just to meet local or even national uses, but also to participate as appropriate in international trade. Only a few cents per pound can move mineral commodities physically in the major markets of the world, while ownership can often be changed by mail, telephone, or telex for even less. Currently about two-fifths of the world's iron ore, bauxite, alumina, and copper and about one-fifth of the world's steel and aluminum move in world trade. Table 1 shows how these materials move from area to area at various stages from mine to user. Many other mineral materials from diverse geographic sources are used in more or less direct proportion to these major mineral materials; for example, the ferroalloys used in steel, including manganese, chromium, nickel, molybdenum,

Table 1 World production of iron, steel, aluminum, and copper in 1978

[Quantities are given in millions of metric tons; those marked by an asterisk (*) are estimates.]

IRON AND STEEL	PRODUCTION OF IRON IN ORES	CONSUMPTION OF SCRAP	PRODUCTION RAW STEEL	ESTIMATED CONSUMPTION OF RAW STEEL EQUIVALENT
United States	51	75*	124	149
Canada	27	8	15	13
Latin America	75	10	24	30
Western Europe	34	70	160	139
USSR	142	60	151	149
Other Comecon	4	32	64	65
China, People's Republic of	32	8	31*	37
Japan	---	39	102	66
Other Asia	30	7	24	40
Australia, New Zealand	56	3	8	6
Africa	33	4	9	13
Total	484	316	712	707

ALUMINUM CONTENT	PRODUCTION IN BAUXITE (ESTIMATE)	PRODUCTION IN ALUMINA (ESTIMATE)	PRODUCTION OF PRIMARY METAL	CONSUMPTION OF PRIMARY METAL (ESTIMATE)
United States	0.4	3.2	4.4	4.9
Canada	0	.6	1.0	.4
Latin America	4.9	2.1	.4	.6
Western Europe	1.1	2.1	3.4	3.6
USSR	.8	1.4	1.7	1.6
Other Comecon	1.3	1.0	.6	.7
China, People's Republic of	.3	.3	.3	.3
Japan	0	.9	1.1	1.6
Other Asia	.7	.3	.5	.6
Australia, New Zealand	4.9	3.5	.4	.2
Africa	3.1	.3	.3	.1
Total	17.5	15.7	14.1	14.6

COPPER CONTENT	MINE PRODUCTION	SMELTER PRODUCTION	REFINERY PRODUCTION	CONSUMPTION
United States	1.4	1.3	1.9	2.2
Canada	.6	.5	.5	.3
Latin America	1.5	1.3	1.0	.4
Western Europe	.2	.6	1.3	2.6
USSR	.8	.8	1.2	1.2
Other Comecon	.5	.5	.6	.7
China, People's Republic of	.1	.1	.2	.2
Japan	.1	.9	1.0	1.2
Other Asia	.4	.1	.1	.2
Australia, New Zealand, Papua New Guinea	.4	.2	.2	.1
Africa	1.4	1.3	.9	.1
Total	7.4	7.6	8.9	9.2

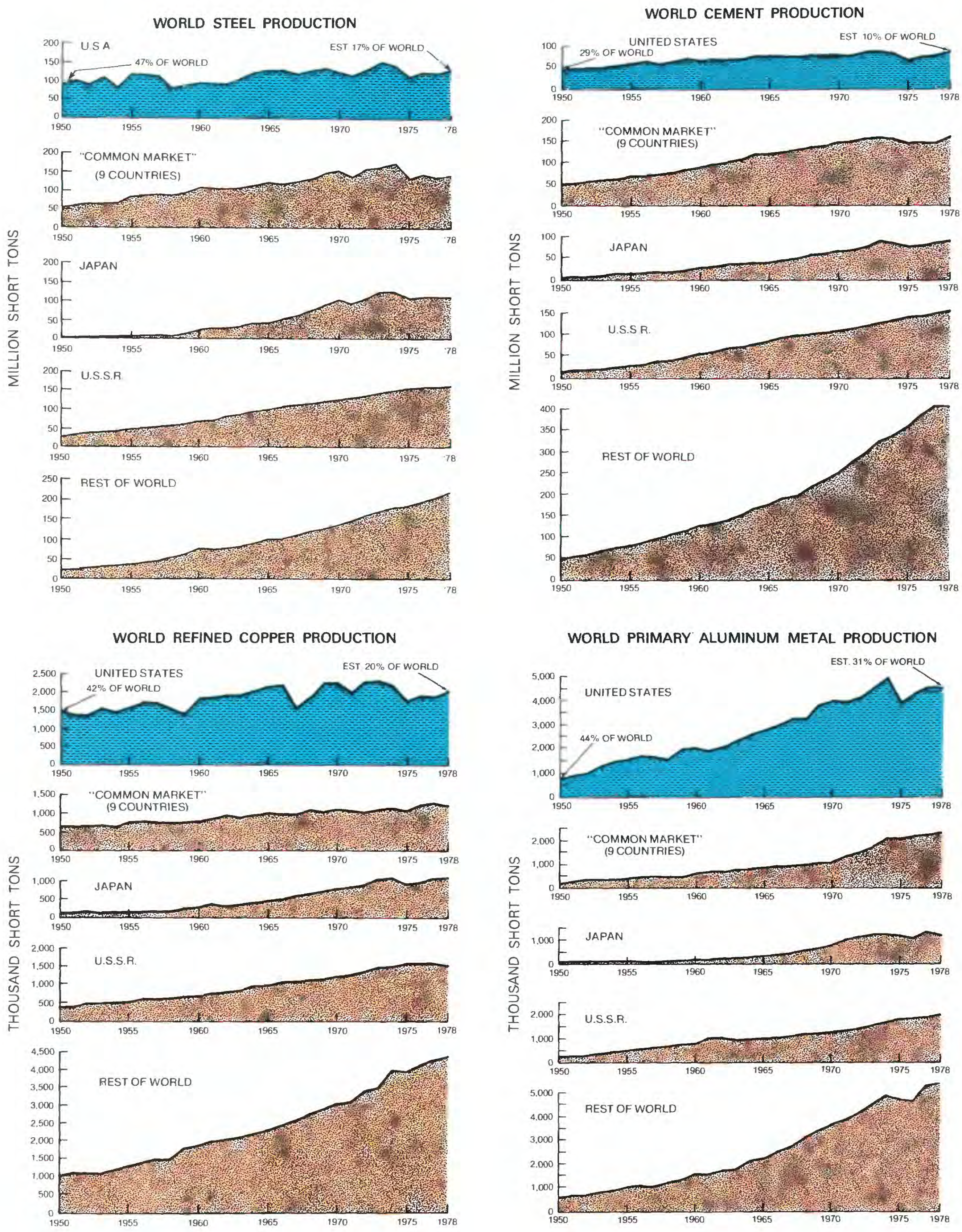

Figure 1 World production figures for 4 major commodities, 1950 to 1978.

tungsten, and vanadium. Table 2 provides additional details of world consumption and production for twelve major mineral materials.

Table 2 Twelve major nonfuel minerals

NET IMPORT RELIANCE, AS PERCENTAGE OF CONSUMPTION IN 1977

	U.S.A.	EEC	JAPAN	COMECON
Asbestos	85	90	98	1
Bauxite	91	97	100	28
Chromium	91	100	98	2
Cobalt	97	100	100	68
Copper	13	100	97	4
Iron ore	48	82	100	5
Lead	13	76	78	3
Manganese	98	100	99	3
Nickel	70	100	100	13
Phosphate	0	99	100	23
Silver	36	93	71	10
Zinc	57	91	74	9

MAJOR MINERAL CONSUMERS, AS PERCENTAGE OF WORLD CONSUMPTION IN 1977

	U.S.A.	USSR	JAPAN	F.R. GERMANY	OTHERS
Asbestos	11	34	6	7	42
Aluminum	33	12	10	6	39
Chromium	16	17	7	7	53
Cobalt	28	16	18	8	30
Copper	22	14	13	8	43
Iron ore	18	28	18	8	28
Lead	22	14	6	6	52
Manganese	13	29	12	8	38
Nickel	22	19	15	8	36
Phosphate	19	18	3	3	59
Silver	32	12	13	9	34
Zinc	17	16	12	6	49

MAJOR MINERAL PRODUCERS, AS PERCENTAGE OF WORLD PRODUCTION IN 1977

Asbestos	USSR, 46; Canada, 29; South Africa, 7; U.S.A., 2; Others, 16
Bauxite	Australia, 31; Guinea, 15; Jamaica, 14; U.S.A., 2; Others, 38
Chromium	South Africa, 34; USSR, 26; Albania, 9; Southern Rhodesia, 7; U.S.A., 0; Others, 24
Cobalt	Zaire, 36; New Caledonia, 14; Australia, 12; Zambia, 8; U.S.A., 0; Others, 30
Copper	U.S.A., 18; Chile, 14; USSR, 12; Canada, 10; Others, 46
Iron ore	USSR, 28; Australia, 11; Brazil, 10; Canada, 7; U.S.A., 7; Others, 37
Lead	U.S.A., 16; USSR, 15; Australia, 13; Canada, 8; Others, 48
Manganese	USSR, 35; South Africa, 24; Gabon, 11; Australia, 8; U.S.A., 0; Others, 2
Nickel	Canada, 30; USSR, 21; New Caledonia, 14; U.S.A., 2; Others, 33
Phosphate	U.S.A., 41; USSR, 21; Morocco, 15; Others, 23
Silver	Mexico, 14; USSR, 14; Canada, 13; U.S.A., 12; Others, 47
Zinc	Canada, 21; USSR, 12; Australia, 8; U.S.A., 7; Others, 52

DEMAND CONSIDERATIONS

We cannot foretell the future by mere extrapolation of historical trends. Instead, estimates of future demand must be based upon known and foreseeable specific end-use applications, taking into account commodity interrelationships, including feasible substitutes and alternates. Many key mineral commodities are used in more or less direct proportion to steel production. Accordingly, the growth of world steel production is an important key to the future. Bureau of Mines' forecasts point to a world raw steel production in the year 2000 of some 1,200 million metric tons, of which the United States is projected to produce about 180 million metric tons.

As an illustration of possible changes in use, consider the U.S. automotive industry which now consumes about 26 percent of iron and steel, 16 percent of aluminum, 12 percent of copper, 69 percent of lead (15 percent in gasoline and 54 percent in other uses), 34 percent of zinc, and 40 percent of platinum-group metals. In recent years automobile weights have been reduced by as much as 1,000 pounds to improve fuel efficiency, and further reductions are in prospect. A leading automotive manufacturer predicted that by 1985 net weights could be in the area of 2,700 to 2,800 pounds—a reduction of about 15 percent from 1978 weights. Aluminum, magnesium, plastics, and fiber glass are being given increasing attention as substitutes for the traditional 2,500 pounds of steel in an automobile. Special steel products such as coated and high-strength, low-alloy (HSLA) steels also are expected to be used increasingly in motor vehicles in the next few years. The United States, with a population of 220 million, now has over 140 million motor vehicles in service—the equivalent of over 2 years of total U.S. steel production.

Escalating growth in the use of plastics illustrates how a new mineral-based material can limit use of more traditional ones. Plastics are largely mineral-based materials in that about 2 pounds of petroleum yield 1 pound of plastics. In 1978, 17 million short tons of plastics were used in the United States, up from only 1 million short tons three decades ago. Current annual consumption of plastics is approaching twice the combined tonnages of aluminum, copper, lead, and zinc. With a specific gravity in the vicinity of 1, the annual volume of new plastics consumed is approaching the volume of steel. No wonder that major metal firms are diversifying not only into other metals but also into plastics.

Programs to improve energy supplies and utilization can be expected to have major impacts upon such materials as chromium, cobalt, columbium, molybdenum, nickel, platinum, tantalum, and titanium. Resistance to high temperatures, corrosion, and erosion is of particular importance in energy-related applications (table 3). The efficiency of thermodynamic processes is enhanced by increased temperature differentials, and the number of elements with high melting points is very limited (fig. 2). Coal gasification, coal liquefaction, magnetohydrodynamics, nuclear fission, and fusion can be expected to make unprecedented demands upon special-property mineral materials. Even electric power generation in conventional steam power plants will make unprecedented demands upon special-property materials if air quality regulations are to be realized. At present in the United States nearly 500 million tons of coal are being burned annually by electric utilities, and about 43 percent of our electricity is derived from coal. At least 15 tons of air are required to burn a ton of coal. If vigorous stack gas cleanup is to become a reality, 8 billion tons of hot corrosive gases will have to be handled in the process.

Table 3 1978 U.S. consumption of metals whose corrosion resistance is a major factor in their selection by industry
[H.T., high temperature; st, short ton; mt, metric ton; *W* indicates data withheld to maintain a company's proprietary information.]

Metal	Total consumption		Use type where corrosion resistance is major factor	Quantity	Percent of total
Nickel	232,000	st	alloying 37 percent, H.T. ox. res. 32 percent, plating 16 percent	197,000	85
Zirconium, metal and alloy	4,000	st	alloying, chemical resistance	3,400	85
Titanium, metal	20,000	st	metal products 65 percent, alloying 10 percent	16,000	80
Titanium, nonmetal	509,000	st	coatings	260,000	51
Chromium	590,000	st	alloying 58 percent, coatings and plating 4 percent	366,000	62
Cadmium	4,500	mt	plating 40 percent, coatings 13 percent	2,400	53
Zinc	1,140,500	mt	galvanizing 40 percent, coatings and sacrificial 2 percent	480,000	42
Tin	61,500	mt	plating, tinning	22,500	37
Gold	4,738,000	t oz	plating, alloying, coating, cladding	1,660,000	35
Columbium	7,099,000	lb	alloying, H.T. oxidation resistance	2,400,000	34
Platinum group	2,259,558	t oz	alloying, chemical and H.T. resistance	678,000	30
Rare earths (REO)	18,500	st	alloying	5,500	30
Silver	160,210,000	t oz	alloying	41,743,000	26
Copper	2,480,000	st	alloying and plumbing	620,000	25
Cobalt	18,870,000	lb	alloying, H.T. oxidation resistance	4,299,000	23
Iron oxide pigments	226,500	st	coatings (primers and undercoatings)	50,000	22
Molybdenum	67,724,000	lb	alloying, coatings	13,500,000	20
Tantalum	1,772,000	lb	alloying, cladding, H.T. ox. res.	320,000	18
Magnesium	109,000	st	alloying, sacrificial	16,000	15
Hafnium	56,000	lb	alloying	6,000	11
Thorium (ThO_2), nonenergy	35	st	alloying	4	11
Aluminum	6,011,000	st	alloying, coatings, cladding	600,000	10
Indium	*W*		coatings	*W*	10
Lead	1,333,000	mt	coatings and plating 6 percent, cable covering 1 percent	93,000	7
Beryllium	188	st	alloying	9	5
Manganese	1,415,000	st	alloying, cladding	55,000	4

Source: Bureau of Mines, July 23, 1979.

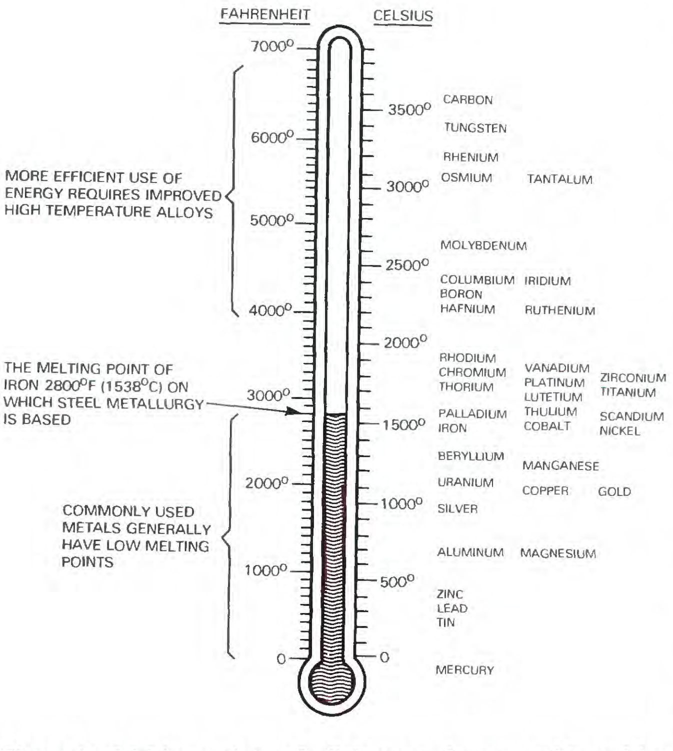

Figure 2 Melting points of all known elements with melting points above iron and major metals that melt at lower temperatures (Source: Bureau of Mines, April 1, 1979).

SUPPLY CONSIDERATIONS

In many parts of the world rugged terrain, hostile physical climates, and often hostile politicoeconomic climates inhibit exploration for and development of mineral resources. Fortunately, some of the most populous regions are also large in area; thus there is the promise that improved standards of living may be possible in Asia with a present population of nearly 2.5 billion people but an area of 44 million square kilometers, in Africa with over 0.4 billion people but an area of 30 million square kilometers, and in Latin America with over 0.3 billion people but an area of 23 million square kilometers. In comparison, the United States has already found extensive mineral deposits in its 9 million square kilometers, but even so, far more needs to be done to investigate our mineral resources on land, on the continental shelves, and in the deep seas.

Once mineral deposits of economic significance are found, there are possibilities of improved technology to permit treating lower grades of ore and to recover accessory minerals. For example, for many years, the U.S. Geological Survey and the U.S. Bureau of Mines have helped to discover and to assess numerous domestic chromium deposits. The Bureau produced acceptable chrome concentrates from domestic deposits as well as acceptable ferrochromium, chromium metal, chromite refractories, and chromium chemicals. Consequently, presently submarginal deposits could become sources of supply at some future time. Current Bureau research includes recovering chromium, nickel, and cobalt from laterite deposits and also from flue dusts, plating wastes, and other residues.

In many regions escalating energy costs will increase the costs of mining, beneficiating, smelting, and refining mineral materials. Nevertheless, while many presently industrialized nations are experiencing energy shocks caused by escalating prices for fuels, they should not overlook that the cost of producing petroleum in Arabia is reportedly only about $0.50 per barrel and that such petroleum production is accompanied by major quantities of natural gas, which are currently being flared. Consequently, in the Middle East there are prospects of greatly increased materials production, including direct reduction of metals, electrodeposition using electricity generated by gas engines, and production of petrochemicals and plastics. Further, there are still many favorable sites in the world for both high-head and low-head hydroelectric development where, if political stability could be ensured, major mineral-material producing complexes could be created.

There are also many possibilities for making use of currently known waste materials. For example, in the United States we are now burning about 500 million tons of utility coal containing about 13 percent ash—which yields over 50 million tons of coal ash annually. Fly ash is typically vesicular, porous, and glassy in nature, with many trace elements. Mineralogically the major crystalline components, upon annealing, are mullite, magnetite, and quartz, with minor amounts of hematite and anhydrite. A typical concentrated fly ash contains about 10 percent iron oxide and 2 percent carbon; the remaining 88 percent is a mullite-quartz-anhydrite mixture. If only half of the 50 million tons per year of ash were beneficiated it would represent over 250,000 tons of iron ore, not to mention large amounts of carbon, mostly flake. Small amounts of fly ash are currently being used in pozzolan cement and in such construction products as bricks and sintered aggregates. But what about a refractory aggregate from a mullite-rich fraction? A castable mix? A raw material for portland cement? Or possibly a source of alumina? Similarly, we now treat about 400 million tons per year of copper concentrates containing 0.5 percent copper. What multiple nonmetallic minerals are present in the 99.5 percent that is now rejected onto tailings piles and into slime pounds, but that could be used in ceramic flowsheets? These concepts deserve thoughtful consideration in mineral supply programs which must also be concerned with energy and the environment. Already significant quantities of several metals are being effectively recycled.

The use of flywheels to deliver power to offset sudden increases in load is accepted practice in machinery design, and the use of surge bins is standard practice in materials handling. Expanding such analogies to national economies points to the desirability of maintaining larger than normal working inventories to deal with unexpected interferences with normal supplies such as may be occasioned by politicoeconomic disruptions or natural disasters such as earthquakes, landslides, hurricanes, and floods. However, escalating costs and higher interest rates in recent years have tended to discourage the private sector from maintaining large inventories. Ever since 1939 the United States has been committed to a policy of stockpiling strategic and critical materials for defense purposes. At present 93 materials are on the U.S. stockpile list (table 4), of which 79 are metals and minerals. The value of the materials in the U.S. stockpile is about $11 billion, the greatest part attributable to metals and minerals. However, by law "the purpose of the stockpile is to serve the interest of national defense only and is not to be used for economic or budgetary purposes." Other countries, including Germany, France, and Japan, either have or are considering stockpiling programs to protect against interruptions of supply. Tax incentives for the maintenance of larger than normal working inventories have been in effect in Sweden for a number of years. In the Swedish system a large proportion of the acquisition costs of raw materials can be written-off in computing taxable income for the year in which materials are acquired, in contrast to current U.S. practice, which limits deduction of raw material costs to the year in which materials are actually used in manufacturing. The wide variety of materials in use (for example, "chromium" can be metallurgical, chemical, or refractory ores from many sources; high-, medium-, or low-carbon ferrochromium; exothermic or electrolytic chromium metal; sodium bichromate; etc.) would seem to commend some such device as the Swedish system, which moreover tends to permit informed judgments by numerous buyers and sellers, rather than direct market intervention by government entities.

ENVIRONMENTAL CONSIDERATIONS

We are now encountering increasing concerns with the role of trace or fugitive elements, compounds, and particulates in possible air, water, and land pollution, and the synergistic effects thereof on the symbiotic relationships that have developed over time. We really know very little of the distribution of the naturally occurring elements and their millions of compounds at parts-per-million or parts-per-billion levels. In fact, it is only in recent years that, for

Table 4 Basic stockpile materials in the United States

1. Alumina
2. Aluminum
3. Aluminum oxide, abrasive grain
4. Aluminum oxide, fused, crude
5. Antimony
6. Asbestos, amosite
7. Asbestos, chrysotile
8. Bauxite, metal grade, Jamaica
9. Bauxite, metal grade, Surinam
10. Bauxite, refractory
11. Beryl ore (11 percent BeO)
12. Beryllium copper master alloy
13. Beryllium metal
14. Bismuth
15. Cadmium
16. Castor oil, sebacic acid
17. Chromite, chemical grade ore
18. Chromite, metallurgical grade ore
19. Chromite, refractory grade ore
20. Chromium, ferro, high carbon
21. Chromium, ferro, low carbon
22. Chromium, ferro, silicon
23. Chromium, metal
24. Cobalt
25. Columbium carbide powder
26. Columbium concentrates
27. Columbium, ferro
28. Columbium, metal
29. Copper
30. Cordage fibers, abaca
31. Cordage fibers, sisal
32. Diamond dies, small
33. Diamond, industrial, crushing bort
34. Diamond, industrial, stones
35. Feathers and down
36. Fluorspar, acid grade
37. Fluorspar, metallurgical grade
38. Graphite, natural—Ceylon, amorphous lump
39. Graphite, natural—Malagasy, crystalline
40. Graphite, natural—other than Ceylon and Malagasy
41. Iodine
42. Jewel bearings
43. Lead
44. Manganese, battery grade, natural ore
45. Manganese, battery grade, synthetic dioxide
46. Manganese ore, chemical grade
47. Manganese ore, metallurgical grade
48. Manganese, ferro, high carbon
49. Manganese, ferro, low carbon
50. Manganese, ferro, medium carbon
51. Manganese, ferro, silicon
52. Manganese, metal, electrolytic
53. Mercury
54. Mica, muscovite block, stained and better
55. Mica, muscovite film, first and second qualities
56. Mica, muscovite splittings
57. Mica, phlogopite block
58. Mica, phlogopite splittings
59. Molybdenum disulphide
60. Molybdenum, ferro
61. Nickel
62. Opium, gum
63. Opium, salt
64. Platinum group metals, iridium
65. Platinum group metals, palladium
66. Platinum group metals, platinum
67. Pyrethrum
68. Quartz crystals
69. Quinidine
70. Quinine
71. Rubber
72. Rutile
73. Sapphire and ruby
74. Shellac
75. Silicon carbide, crude
76. Silver (fine)
77. Talc, steatite block and lump
78. Tantalum carbide powder
79. Tantalum metal
80. Tantalum minerals
81. Thorium nitrate
82. Tin
83. Titanium sponge
84. Tungsten carbide powder
85. Tungsten, ferro
86. Tungsten, metal powder
87. Tungsten ores and concentrates
88. Vanadium, ferro
89. Vanadium pentoxide
90. Vegetable tannin extract, chestnut
91. Vegetable tannin extract, quebracho
92. Vegetable tannin extract, wattle
93. Zinc

Source: "Stockpile report to the Congress, April 1979," from the Federal Preparedness Agency.

most materials, we have been able to make such measurements with these degrees of precision. Very little is known of the ranges of tolerance by plants, animals, and man of individual elements and compounds, to say nothing of their effects in various possible combinations and permutations. We need to know far more about the natural distribution of elements and compounds in the rocks, soils, waters, air, flora, and fauna of the Earth, and we also need to know far more about the precise distribution of elements and compounds in each phase of the mineral processing cycle. If we do not greatly increase our efforts in this direction, we will continuously encounter unanticipated threats to mineral development as new discoveries are made in the effluents of the mineral sector of the economy. "Zero discharge" for most materials at parts-per-million or parts-per-billion levels will be exceedingly difficult if not impossible to obtain. Fortunately, a major increase in research on the distribution of the trace or fugitive elements, compounds, and particulates should have important direct benefits in contributing not only to the search for new mineral deposits but also to a better understanding of the forces that have been, that are, and that will continue to be at work in the evolution of the Earth itself.

SUPPLY/DEMAND OUTLOOK TO YEAR 2000 A.D.

Detailed Bureau of Mines forecasts to the year 2000 (table 5) show that presently known world reserves of most mineral materials should be adequate to meet world demands over the next two decades and that for many minerals the United States itself is in a favorable position. At this time world deficits are foreseen only for asbestos, bismuth, fluorine, germanium, graphite, indium, mercury, sheet mica, silver, sulfur, and zinc. However, in making such assessments as these, the dynamic nature of estimates of demand, reserves, and resources must be kept in mind. Unforeseen uses may stimulate demand, new discoveries may enlarge both reserves and resources, and restrictive actions may move presently proved reserves back into the subeconomic resource category. However, if we continue to encourage research and education covering the processes by which raw rocks are converted to materials and energy to satisfy mankind's needs, and if we also continue to maintain politicoeconomic systems that encourage mineral exploration and development along with conservation and recycling, increased material standards of living should clearly be possible, even as world population increases.

Table 5 Comparison of world cumulative primary mineral demand forecasts, 1976 to 2000, with world identified recoverable mineral reserves.

[Totals may not add due to rounding; *A* indicates reserves adequate; *NA* indicates data not available; *W* indicates data withheld because of company confidentiality.]

UNITS OF MEASURE:

C.F. cubic feet	KG kilogram	L.T. long ton (2,240 pounds)	S.T. short ton (2,000 pounds)
FL flask (76 pounds)	LB pounds (avoirdupois)	M.T. metric ton (2,204.6 pounds)	T. oz. troy ounce (1.09714 avoirdupois ounces)

	PRIMARY MINERAL DEMAND FORECASTS			1976 MINERAL RESERVES			RATIO OF RECOVERABLE RESERVES TO CUMULATIVE DEMAND		
Commodity and quantity	United States	Rest of World	World	United States	Rest of World	World	United States	Rest of World	World
METALS AND MINERAL FORMING ELEMENTS									
Aluminum (million S.T.)	275	682	958	10	5,600	5,610	<.1	8.2	5.8
Antimony (thousand S.T.)	907	1,669	2,576	120	4,620	4,740	.1	2.8	1.8
Arsenic (thousand S.T.)	*W*	720	*W*	400	2,700	3,100	*W*	3.8	*W*
Beryllium (thousand S.T.)	9	6	15	28	391	419	3.1	>10:1	>10:1
Bismuth (million LB)	80	203	283	20	164	184	.3	.8	.7
Boron (million S.T.)	5	11	16	22	67	89	4.4	6.1	5.6
Bromine (million LB)	9,296	9,699	18,995	*A*	*A*	*A*	>10:1	>10:1	>10:1
Cadmium (thousand S.T.)	216	477	693	220	540	760	1.0	1.1	1.1
Cesium (thousand LB)	1,780	1,950	3,730	-----	218,000	218,000	-----	*A*	*A*
Chlorine (million S.T.)	419	722	1,141	*A*	*A*	*A*	*A*	*A*	*A*
Chromium (million S.T.)	18	69	87	<.1	829	829	<.1	>10:1	9.5
Cobalt (million LB)	698	2,030	2,728	-----	3,300	3,300	-----	1.6	1.2
Columbium (million LB)	322	972	1,294	-----	22,000	22,000	-----	22.6	17.0
Copper (million S.T.)	62	256	318	93	410	503	1.5	1.6	1.6
Fluorine (million S.T.)	26	69	95	3	34	37	.1	.5	.4
Gallium (thousand KG)	450	230	680	1,000	*A*	*A*	2.2	>10:1	>10:1
Germanium (thousand LB)	1,517	3,920	5,437	900	3,100	4,000	.6	.8	.7
Gold (million T. oz)	200	954	1,154	110	1,105	1,215	.6	1.2	1.1
Hafnium (S.T.)	1,220	1,090	2,310	*A*	*A*	*A*	>10:1	>10:1	>10:1
Indium (million T. oz)	23	32	56	10	41	51	.4	1.3	.9
Iodine (million LB)	280	660	940	530	5,220	5,750	1.8	7.9	6.0
Iron in ore (billion S.T.)	3	18	20	4	99	103	1.5	5.6	5.1
Lead (million S.T.)	28	99	127	28	108	136	1.0	1.1	1.1
Lithium (thousand S.T.)	153	107	260	410	*NA*	*NA*	2.8	NA	NA
Magnesium (million S.T.)[1]	44	158	202	*A*	*A*	*A*	>10:1	>10:1	>10:1
Manganese (million S.T.)	42	348	390	-----	1,800	1,800	-----	5.2	4.6
Mercury (thousand FL)	1,330	4,740	6,070	410	4,800	5,210	.3	1.0	.9
Molybdenum (billion LB)	3	7	10	8	12	20	2.9	1.8	2.1
Nickel (million S.T.)	7	20	27	<.1	60	60	<.1	2.9	2.2
Nitrogen—fixed (million S.T.)	500	1,540	2,040	*A*	*A*	*A*	>10:1	>10:1	>10:1
Nitrogen—elemental (million S.T.)	608	720	1,328	*A*	*A*	*A*	>10:1	>10:1	>10:1
Palladium (million T. oz)	20	65	85	<.1	194	194	-----	3.0	2.3
Platinum (million T. oz)	22	66	88	<.1	297	297	-----	4.5	3.4
Rare earths and Yttrium (thousand S.T.)[2]	541	425	966	5,050	2,680	7,730	9.3	6.3	8.0
Rhenium (thousand LB)	193	113	306	2,600	4,400	7,000	>10:1	10:1	10:1
Rhodium (million T. oz)	2	3	5	<.1	17	17	-----	5.9	3.3
Rubidium (thousand LB)	61	45	106	-----	2,100	2,100	-----	>10:1	>10:1
Scandium (KG)	258	238	496	*A*	*A*	*A*	>10:1	>10:1	>10:1
Selenium (million LB)	40	67	107	74	298	372	1.9	4.5	3.5
Silicon (thousand S.T.)	21,000	76,000	97,000	*A*	*A*	*A*	>10:1	>10:1	>10:1
Silver (million T. oz)	4,200	7,216	11,416	1,510	4,590	6,100	.4	.6	.5
Strontium (thousand S.T.)	439	239	678	-----	1,155	1,155	-----	4.8	1.7
Sulfur (million L.T.)	400	1,460	1,860	205	1,495	1,700	.5	1.0	.9
Tantalum (million LB)	64	45	109	-----	130	130	-----	2.9	1.2
Tellurium (million LB)	10	6	15	19	82	101	1.9	>10:1	6.6
Thallium (thousand LB)	39	73	112	192	1,008	1,200	4.9	>10:1	>10:1
Thorium (thousand S.T.)	2	3	5	140	640	780	>10:1	>10:1	>10:1
Tin (thousand M.T.)	1,160	5,440	6,600	40	9,960	10,000	.1	1.8	1.5
Titanium (million S.T.)[1]	22	59	81	31	303	334	1.4	5.1	4.1
Tungsten (million LB)	721	2,210	2,931	275	3,925	4,200	.4	1.8	1.4
Vanadium (thousand S.T.)	470	890	1,360	115	10,500	10,600	.2	>10:1	7.8
Zinc (million S.T.)	39	162	201	24	142	166	.6	.9	.8
Zirconium (million S.T.)[1]	3	7	11	6	16	22	2.0	2.0	2.0

[1] Data include metal content in metallic and nonmetallic commodities.

[2] Contains rare-earth oxides (REO).

Table 5 Comparison of world cumulative primary mineral demand forecasts, 1976 to 2000, with world identified recoverable mineral reserves—Continued

[Totals may not add due to rounding; *A* indicates reserves adequate; *NA* indicates data not available; *W* indicates data withheld because of company confidentiality.]

UNITS OF MEASURE:

C.F. cubic feet
FL flask (76 pounds)
KG kilogram
LB pounds (avoirdupois)
L.T. long ton (2,240 pounds)
M.T. metric ton (2,204.6 pounds)
S.T. short ton (2,000 pounds)
T. oz. troy ounce (1.09714 avoirdupois ounces)

Commodity and quantity	PRIMARY MINERAL DEMAND FORECASTS			1976 MINERAL RESERVES			RATIO OR RECOVERABLE RESERVES TO CUMULATIVE DEMAND		
	United States	Rest of World	World	United States	Rest of World	World	United States	Rest of World	World
NONMETALLIC MINERAL									
Asbestos (million S.T.)	17	184	201	4	92	96	0.2	0.5	0.5
Barite (million S.T.)	50	99	149	65	135	200	1.3	1.4	1.3
Clays (billion S.T.)	3	15	18	*A*	*A*	*A*	>10:1	>10:1	>10:1
Corundum (thousand S.T.)	24	361	385	-----	*A*	*A*	-----	>10:1	>10:1
Diatomite (million S.T.)	19	50	70	600	1,400	2,000	>10:1	>10:1	>10:1
Feldspar (million S.T.)	31	103	134	600	400	1,000	19.4	3.9	7.5
Garnet (thousand S.T.)	613	418	1,031	700	1,540	2,240	1.1	3.7	2.2
Graphite (million S.T.)	2	11	13	-----	10	10	-----	.9	.8
Gypsum (million S.T.)	636	1,072	2,338	500	1,780	2,280	.8	1.1	1.0
Kyanite (million S.T.)	*W*	15	*W*	30	70	100	*W*	4.7	*W*
Lime (million S.T.)	646	3,011	3,657	*A*	*A*	*A*	*A*	*A*	*A*
Mica—scrap and flake (thousand S.T.)	4,000	3,500	7,500	*A*	*A*	*A*	>10:1	>10:1	>10:1
Mica—sheet (thousand LB)	70,200	429,000	499,200	<.1	365,000	365,000	-----	.9	.7
Peat (million S.T.)	55	7,300	7,355	10,000	40,000	50,000	>10:1	5.5	6.8
Perlite (million S.T.)	22	51	73	200	810	1,010	9.0	>10:1	>10:1
Phosphate rock (million M.T.)	966	2,971	3,937	3,500	22,232	25,732	3.6	7.5	6.5
Potash (million S.T.)	213	827	1,039	200	13,030	12,230	.9	>10:1	>10:1
Pumice (million S.T.)	169	545	714	1,250	815	2,065	7.4	1.5	2.9
Salt (million S.T.)	1,460	4,170	5,630	*A*	*A*	*A*	*A*	*A*	*A*
Sand and gravel (billion S.T.)	25	*NA*	*NA*	*A*	*A*	*A*	*A*	*A*	*A*
Soda ash (million S.T.)	230	605	835	*A*	*A*	*A*	>10:1	>10:1	>10:1
Stone—crushed (billion S.T.)	29	225	254	*A*	*A*	*A*	>10:1	>10:1	>10:1
Stone—dimension (million S.T.)	27	1,025	1,052	*A*	*A*	*A*	>10:1	>10:1	10:1
Talc (million S.T.)	35	190	225	150	180	330	4.3	1.0	1.5
Vermiculite (million S.T.)	10	9	19	100	90	190	10.0	10.0	10.0
COMMERCIAL GASES									
Argon (million S.T.)	14	10	24	*A*	*A*	*A*	>10:1	>10:1	>10:1
Helium (billion C.F.)	23	*NA*	*NA*	[3]149	*NA*	*NA*	6.5	*NA*	*NA*
Oxygen (million S.T.)	800	1,500	2,300	*A*	*A*	*A*	>10:1	>10:1	10:1

[3] Does not include 38 billion cubic feet in storage.

Source: Bureau of Mines, 1979

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Water and People

Portion of Los Angeles Owens River Aqueduct crossing the desert. Photograph by Department of Water and Power, City of Los Angeles.

Philippine Water Resources Policies: An Appraisal

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In the Philippines, as in many countries, water policies have evolved over a long period of time. When the water supplies are abundant and the needs of the people are few, the policies are just as simple. As the population grows, competition for water resources becomes significant and more policy statements are issued. Some tend to be more sophisticated.

Policy statements are found in the various laws passed by the legislature, in the executive orders of the President, and in the resolutions and regulations of implementing agencies. Some are not even articulated but have been accepted because of common practice, tradition, and common sense.

The Philippines, by nature, is endowed with abundant water resources. Its average annual rainfall is about 2,500 millimeters. Dependable supply from rivers is estimated at about 700 million cubic meters per day. This is more than twice the needs of the whole country for the next twenty years. Groundwater reservoirs are found extensively in the plains where most of the people live.

In spite of these facts, there is an increasing competition in the development of water resources. What was once considered an unlimited natural resource is now becoming a scarce commodity in some areas. The increased pace of development of the country in the early 1970's has made it necessary for government to regulate the water resources sector.

Among the major acts taken are the articulation of basic water policies, the codification of all water laws, and the creation of an independent agency to formulate the guidelines to implement the laws and policies on water resources development and management. All of these actions are based on the fundamental concept that all waters, like all other natural resources, belong to the State. This was first expressed in the 1935 Constitution and again in the 1973 Constitution of the Philippines.

The National Water Resources Council was created in 1974 not only for the various activities on policy issues but mainly for the broader purpose of coordinating and integrating all activities in water resources. The codification of more than 50 pieces of legislation dealing with various aspects of water resources resulted in the promulgation of the Water Code of the Philippines of 1976.

The report concerns the policies on water resources as established and practiced today (1979). It is an appraisal of the institutional framework, the development strategies, as well as the financing aspects. The primary objective is to be able to draw some conclusions which will serve as basic inputs for future policy decisions.

INSTITUTIONAL FRAMEWORK

The authority and responsibility for the control, conservation, protection, development and regulation of the utilization of the water resources of the country belong to the State. This is accomplished by the creation of various government offices which undertake a very large majority of the water resources programs and projects in the country.

Private entities, however, may also engage in water resources activities subject to the rules and regulations prescribed by the State. A very important requirement, applicable to all persons and entities, is the need for a permit from the National Water Resources Council to use the waters of the State.

The government organizations may be generally characterized in three ways. One way is on the particular aspect of water resources for which the agency is responsible. In this manner, there are the offices dealing mainly with each of the sectors of the water supply, irrigation, hydropower, navigation, pollution, watershed management, etc. The exceptions to this are the Councils and Development Authorities whose major role is to coordinate the efforts of the specialized implementing agencies.

A second method is on the source of operational funds of the agency and for this there are two groups. The first group consists of the various Ministries, Bureaus and other offices whose operational expenditures come from general revenues or taxation. The other group is composed of the government-owned corporations which are revenue-generating because of the services that they provide. In the latter group belong the agencies on water supply, irrigation and hydropower.

Another way of classifying the agencies is on their respective geographical areas of responsibility or coverage. Thus, there are national, regional, and local agencies.

For purposes of administrative supervision, all water resources agencies are placed under 12 of the more than 20 executive ministries of the national government. In the case of the government-owned corporations, councils and development authorities, supervision is only exercised at the policy level. This is generally effected by appointing the Head of the Ministry as the Chairman of the Board of Directors of the agency that is being supervised. Needless to say, the Ministries exercise direct line supervision, authority and control over the respective bureaus and other offices under them.

These organizational differences lead to inevitable consequences. There is a natural tendency for each agency to look only after its own targets with little or no consideration to the needs of the other agencies. This makes it absolutely necessary to have an effective coordinating mechanism.

At the national level, the National Economic and Development Authority coordinates the activities of all sectors. The particular sector on water resources is coordinated by the National Water Resources Council. For regional activities, there are the regional development councils and authorities.

Government corporations, in general, have a greater flexibility in their operations as compared to other government agencies. For one thing, they do not have to compete directly with other agencies for a share of the annual budget of the national government for operational expenditures. The expenditures are provided from their revenues as well as from their corporate funds.

In case a corporation decides to increase its level of activities, it has the option to request an increase in capitalization, to issue bonds, or to resort to local or foreign borrowings. While the capitalization is allocated from the national budget, any amount not used during the year is retained as part of the corporate funds. For the other agencies, savings in expenditures over that which is budgeted are reverted to the general funds. This will form a part of the available funds for competition among all agencies in the next annual budgetary cycle.

With regard to personnel, actions and decisions are vested in the Board of Directors or in the Head of the Corporation. All of them are aware of the particular needs of their organization.

In other offices, personnel actions and decisions are subject to the checks and balances of other executive agencies such as the Civil Service Commission, the Ministry of the Budget, and the Commission on Audit. Sometimes the peculiar needs of the water resources sector are not fully appreciated.

One such instance is in the salary scale of corporate organizations which is very much higher than that of other offices. This has existed for many years and it was only recently that a policy has been made to standardize the salary scale of all government agencies. Its implementation, however, has been slow so the tendency of the technical personnel to gravitate to the government corporations as well as to private agencies still exists.

As stated earlier, the bulk of water resources projects are undertaken by the government agencies. For this purpose, planning and programming are done in-house by the agencies. In many instances, detailed engineering and construction are entrusted to private industry. This arrangement of involving the private sector to the largest extent possible is in line with the national strategy.

A critical problem is on operation and maintenance, which government generally undertakes, especially for the small water resources systems. To alleviate the situation, the government has recently encouraged the formation of water consumer associations or cooperatives to be responsible for the operation and maintenance of the systems that are turned over to them after completion.

Thus, Irrigation Service Associations and Rural Waterworks Associations are being formed with the assistance of the government agencies. Assistance is usually provided in the areas of institutional development, engineering, financing, and training.

In spite of the many agencies, there are certain aspects of water resources development which are not being addressed sufficiently. An example is rural water supply; another example is the water data system.

For these, and other similar cases, the approach has been to organize Task Forces to solve the immediate problems at hand. In addition, pilot projects are undertaken with the end in view of arriving at a recommendation for a more permanent solution.

DEVELOPMENT STRATEGY

The current Philippine Development Plan, 1978–1987, outlines the national targets and strategies in attaining an improved quality of life for every Filipino. It indicates a massive effort to provide for the basic needs of the majority of the population and to promote their economic and social well-being.

Among the various development goals of the country, the following are related to the water resources sector:

1. Improvement of the living standards of the poor
2. Attainment of self-sufficiency in food
3. Greater self-reliance in energy
4. Proper management of the environment
5. Increased development of lagging regions

One of the basic thrusts of the government to attain these goals is the improvement of the level and quality of water supply services. At present, less than half of the country's population have reasonable access to public water supply systems. In the rural areas where 70 percent of the population live, only a third are covered by public water services. The rest of the population get their water supply from individual or private sources such as shallow wells, many of which are easily susceptible to contamination or pollution.

The water supply program aims to increase the public water supply coverage to about 85 percent of the population by 1987. In the implementation of the program, three levels of service are developed depending upon technical, economic, organizational, and financial considerations.

The first level is a point source such as a protected well or spring in which the users would have to fetch their water from the source. A second level includes a distribution system with a number of courtyard faucets, each faucet serving about 4 to 6 households. These two levels of services are generally appropriate for the rural areas. The third level consists of individual household connections from the water supply system. This is generally adopted for urban areas.

To attain self-sufficiency in food as well as to promote the economic well-being of the farmers, irrigation is a very important factor. Actually, the efforts to intensify the construction of irrigation projects started several years ago. Rice being the main crop, it requires a large amount of water and accounts for about 80 percent of all water withdrawals in the country.

This year the country has attained self-sufficiency in rice. The irrigation program is a continuing one, however, in order to keep pace with a growing demand as well as to provide a buffer stock in case of crop failures. By 1987, about 70 percent of the arable land of the country will have irrigation facilities.

Hydropower provides about 5 percent of the energy requirements of the country today. It is envisioned that by 1987 the share of hydropower will be about double the present level. Estimates show that only about 20 percent of the total hydropower potential has been developed thus far.

Some of the potential hydropower project sites can avail themselves of the natural gradient of the river to develop the required head. The others require a high dam with a large reservoir. Such projects, however, are so capital intensive with long gestation periods that it will take some time to put them on-stream.

The bulk of flood control activities is concentrated in Metro Manila where the incidence of floods results in extensive damage to property and sometimes loss of lives. Plans were completed a long time ago but these have been implemented only recently.

All of the flood protection measures planned all over the country employ structural devices such as dikes, channel improvements, and detention reservoirs. With the creation of a new Ministry of Human Settlements and the emerging concepts of land reform, it is envisioned that non-structural measures would play a significant role in reducing the damages from floods.

The conservation and protection of water resources and watersheds is also a major concern of the government. In this regard, however, trade-offs with the development needs of a growing population are inevitable.

Many of the regulatory measures, though effective, are relatively new and recent. This makes it difficult to impose them on existing practices and activities without serious social and economic dislocations. It is a major challenge that will require sustained efforts to achieve an acceptable balance in the development and management of the water resources of the country.

In the selection of water resource projects, consideration is given to the depressed and deprived regions which have lagged behind in development compared to other regions. For some, the integrated area development strategy is adopted.

This consists of providing a package of complementary projects such as rural water supply, irrigation, improved farm-to-market roads, health centers and other social services. Since the implementation of individual projects is undertaken by different agencies, the coordination for the delivery of the package of projects is entrusted to the regional development council or authority or to a lead agency chosen from among the various implementing agencies.

The lead agency concept is also employed for multipurpose projects. In fact, it is a requirement that all water resources development projects shall be undertaken on a multi-purpose concept using the river basin, or closely related basin, approach. Single-purpose projects are only implemented if they can be incorporated into the contemplated basin-wide development program.

Although economies of scale favor the prosecution of large multi-purpose projects, time constraints and the pressing needs of the rural areas necessitate the consideration of smaller projects. Many of these projects are undertaken by the citizens themselves with the assistance of the government agencies.

FINANCING ASPECTS OF WATER DEVELOPMENT

The financing of water resources development projects of the government is through general revenues, government bonds, local and foreign borrowings, and corporate funds. For each of the revenue-generating sectors like water supply, irrigation, and hydropower, the levels of expenditures are decided upon by their respective Corporation's Board of Directors. The levels for each corporation depend upon the amount of its capitalization, borrowing ceiling, and revenue generated.

In the case of the other projects, the levels of expenditures are included in the annual national budget which is passed upon by the legislature. These levels are generally governed by the priorities as set forth in the Philippine Development Plan, the general revenues to be expected, and the borrowing capacity of the national government.

Under this arrangement the programs on water supply, irrigation, and hydropower are able to respond more expeditiously to the changing demands of the population. Current levels of expenditures in these programs reflect the high priority given to them as well as to the whole water resources sector in general.

It is a national policy that identifiable beneficiaries of water resources development projects shall bear an equitable share of repayment costs commensurate with the beneficial use derived from the project. The only identifiable beneficiaries are those provided with services on water supply, irrigation, and hydropower.

Urban water supply and hydropower projects are designed for full cost recovery. The tariff rates to consumers of these services are structured so as to include the costs of amortization, operations, maintenance, and a nominal rate of return. As government corporations, the rate of return is limited to about 12 percent.

The beneficiaries of rural water supply and irrigation projects in general have a limited capacity to pay the total cost of services. In view of this, the national government provides some degree of subsidy in the form of grants, lower interest rates, and engineering and technical services. The costs of operation and maintenance, however, are fully accounted for in determining the tariff rates for these services.

There is no uniform policy at the moment on the extent of subsidy for rural water supply. It varies from about 10 percent to full subsidy, depending on the agency that is implementing the project.

The trend, however, is to adopt a maximum of 90 percent as a grant for the first level of rural water supply service. This is in line with the basic-needs commitment of the government. The remaining 10 percent is an equity contribution of the local water-works association to indicate its commitment for the project.

For the second level of service, it is envisioned to require also a 10 percent local equity. The remaining 90 percent is provided as a loan, with an annual interest of not more than 4 percent, repayable in 15 to 20 years. In all cases the level of service that is adopted, as well as the design of the system, is intended to be within the capability of the consumers to pay.

In irrigation projects, 10 percent is provided as a grant, 70 percent is a loan which is repaid without interest, and the remaining 20 percent is a loan that is repaid with an annual interest of 6 percent. The repayment period varies from 10 to 25 years.

The irrigation associations are encouraged to furnish the right of way, labor, and materials that they can supply. As an incentive, the reduction in cost due to the items furnished by the association is applied on that part of the total cost to be repaid with interest at 6 percent per annum.

Flood control, drainage, watershed management, and other water resources projects, in which the beneficiaries are the residents of the community as a whole, are fully funded by the national government. There have been questions on why residents of flood-free regions should subsidize the costs of protecting flood-prone areas. On the other hand, it is pointed out that the major food-producing areas as well as a large number of businesses are located in the low-lying lands. Any reduction in flood losses redounds to the benefit of the whole country. At present, however, there are no plans to impose higher levies in the flood-prone areas.

In the case of data collection, training and research, it is generally agreed that continuing programs for these activities must be maintained since they are indispensable components of water resources development. When there are shortfalls in expected revenues, however, these are the programs which are expendable in comparison with other development projects.

One method that has been adopted to insure a minimum level of activities is the setting up of trust funds in which only the earnings are programmed for expenditures. This provides a significant addition to the annual budgetary allocation of the agencies in charge of data collection, training, and research.

THE OUTLOOK

The preceding discussions provided an overview of the basic water resources policies of the Philippines. These have been mainly centered on the organizational concepts, the priorities in development, and the economic considerations.

The manner of creating government agencies, each with a limited area of responsibility, has resulted in the proliferation of many institutions. Although these agencies have a certain degree of autonomy, the existence of an effective coordinating mechanism makes the system workable.

A corporate structure for government agencies provides operational advantages over the regular bureaus and offices. Efforts are being exerted, however, to achieve a harmonious balance in programs and projects for the whole water resources sector.

In the development of water resources, priorities are expected to be responsive to the changing demands for water which generally occur under developing conditions. With a limited number of project sites available and in the interest of maximizing the benefits, multi-purpose projects on an integrated area development concept are preferred.

While it has been traditional to rely on the government to undertake the myriad activities in water resources development and management, the trend is to involve the community and private industry in many aspects. In some instances public participation is long and tedious but the benefits derived are worthwhile.

In general, the basic water policies are adequate in relation to the development requirements of the country. Gaps, if there are any, are solved in an ad hoc manner until such time that a sufficient study has been made to render a policy decision. There exists a need, however, to pursue more vigorously the implementation of current policies which, after all, is the main reason for their pronouncement.

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The Legal and Administrative Implications of the Hydrological Cycle and Water-related Resources Facing the Twenty-first Century

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THE "QUID" FOR EFFICIENT WATER LAW AND ADMINISTRATION IS THE RECOGNITION OF THE UNITY OF THE HYDROLOGICAL CYCLE

It might seem almost offensive to the scientists and experts gathered at this Centennial Symposium to be reminded that water continually follows a cycle, and that said cycle constitutes a unity, with the only exception—slightly significant from the quantitative point of view—of connate or confined waters. Thus, the fact that waters can be either in the atmosphere, or on the ground surface, or underground is just a mere circumstance, always temporary.

Human acts or deeds interfere with or interrupt this cycle, regardless of any of those states in which water is found, thus affecting the subsequent locations through which water would pass, given normal circumstances. This fact holds particularly true in the case of local hydrological subcycles, which, as a whole, make up the overall hydrological cycle. However, we, both lawmakers and lawyers, have disregarded this law of Nature.

Nature's law of the unity and perpetuity of the hydrological cycle does not distinguish or separate, either, between sea water and fresh water, because the former, when it evaporates and passes to the atmosphere, leaves behind its salts in the sea, retrieving these salts later on when the water returns to the sea, either directly, as rain water, or via runoff over the firm land in rivers.

People, however, have made a clearcut separation, through legal rules, first between sea waters and those which are not such, devoting Maritime Law to sea waters and the so-called Water Law to the others. And, subsequently, they made a further discrimination when they separately legislated on surface and underground waters, giving a different legal treatment to each of them.

The separation between Maritime Law and Water Law took place because the former mainly deals with only one of the uses of water (that is, navigation), rather than with water itself, whereas Water Law, which deals with fresh waters, encompasses many different uses—municipal, domestic, agricultural, industrial, for energy generation, and the like.

Since uses of sea water and of the sea bed have greatly increased (fishing, mineral and oil exploitation of the sea bottom, recreation purposes, tidal energy, and so forth) and since now it is necessary to protect said waters from the resulting pollution, it has become evident that we need to unify and consolidate both branches of legal science (Cano, 1976a). This is particularly necessary and urgent in connection with coastal and estuarine waters where it is difficult to draw a line separating sea waters from continental waters (Sewell, 1976; International Association for Water Law, 1976, Recommendation 27). I believe that in the 21st Century a single Water Law will govern both sea, coastal, and continental waters.

As for the different legal treatment given by human laws to surface and underground waters, this fact is not due, in this case, so much to the great variety of uses—which almost always are the same for both kinds of waters—as to the different techniques for abstraction and utilization of them. However, when giving these waters separate legal treatments, as well as by administering them also separately, we have neglected the unity of the hydrological cycle, as well as the influence that the handling of surface waters exerts over underground ones and vice versa. There are already some modern laws that attempt to remedy such error [Israel Water Law of August 3, 1959; Peru Water Law of July 24, 1969; Colombia, Code on the Renewable Natural Resources and Environment Protection, 1974, Art. 77; International Association for Water Law, 1976, Recommendation 1.16 (b)]. I believe that in the 21st Century an integrated and joint legal and administrative treatment of both kinds of waters will be widespread.

Furthermore, I believe that atmospheric waters should also be dealt with by this combined treatment. Some countries already have legislation on these waters (U.S. Advisory Committee on Weather Control, 1958, 1:23, 2:211; Cano, 1976b, 1:99), and their legal regulation in the international field has also been dealt with (Taubenfeld, 1967; Moses and Corbridge, 1967). But it is advisable to reach the goal of legislating on and administering all of them together, considered as a whole; that is, surface (sea and continental), underground, and atmospheric waters. I have encouraged this approach in the past, discussing the drawbacks that arise when human laws disregard, deviate from, or try to twist Nature's laws [International Association for Water Law, 1976, Recommendation 16 (b), 29 (par. 25-27), 32; Cano, 1979a, p. 67].

FACTORS OF CHANGE IN WATER LAW AS THE 20th CENTURY ENDS

Water Law is as old as civilization: we can find signs of it in the "Laws of Manu" and in the pre-Pharaonic Egypt (Cano, 1943, p. 36-41). Until the 19th Century, Water Law was use-oriented; that is, there were separate laws dealing with municipal use, river navigation, irrigation, and the like (Cano, 1976a, par. 23; 1978, p. 98). This approach remained virtually unchanged until the beginning of the 20th Century.

But in the 20th Century, Water Law underwent deep conceptual changes and it became resource-oriented because it became comprehensive of all uses and problems related to water. It was at that time that Water Codes and General Water Laws appeared (Cano, 1967; International Association for Water Law, 1976, Recommendation 7). Such a change of approach was brought about by several factors, including new technologies, water shortages, environmental problems, energy problems, the need to use international water resources, and various water-related emergencies.

New Technologies

With the building of large reservoirs and the ensuing techniques for water storage, waters began to be distributed not according to the runoff but according to the supply of stored waters, or else through a combination of both. This, in turn, caused a change in the regime of water rights (Spain, Dirección General de Obras Hidráulicas, 1976; Cano, 1979b, art. 340-343).

The introduction of new techniques for the multiple use of a single water source made compulsory the apportionment of priorities among different uses, both for the allocation of said uses and for the pertinent charges to the different users (United Nations, 1970; Cano, 1967, par. 4; International Association for Water Law, 1976, Recommendation 3).

The remarkable increase in the power and degree of intervention of public authorities in the management of waters resulted not only in an increase of governmental control but even in the transfer to public or State ownership of certain categories of waters that had traditionally been considered private property (International Association for Water Law, 1976, Recommendation 14). The need to use technologies or financial resources not available to private citizens was one of the factors contributing to this change.

The need to jointly use and manage water with other resources, either natural or not, as a result of their mutual interdependence led to the implementation of the technique of multiple means for multiple uses (International Association for Water Law, 1976, Recommendations 2, 5, 22; Cano, 1978, p. 194, 237, 248; Cano, 1979a, p. 43; White, 1969, p. 34, 36).

Water Shortages

The population explosion and the considerable progress of agricultural, mining, and industrial technologies, which geometrically increased the demand for water thus making it increasingly scanty on an individual basis, forced the adoption of more stringent legal rules dealing with the allocation of said water and a more efficient use of such water as well. All this also encouraged water recycling (International Association for Water Law, 1976, Recommendation 16).

Environmental Problems

These two same factors—the population explosion and the progress of technologies—also had an influence on the quality of water, polluting it, making it unfit for new uses, and thus diminishing the quality of human life itself, and, consequently, making compulsory the adoption of rules for the prevention and correction of pollution (International Association for Water Law, 1976, Recommendations 41, 42).

Population implosion—that is, the large-scale emigration of country peoples to large cities—caused a change in the pattern of water uses and forced a reapportionment of uses and priorities. It has been said that today such reapportionment of uses is more important than the original allocation of water rights (Radosevich, 1976).

The new occurrences or the worsening of other factors causing environmental degradation and related to the uses of water, such as erosion, siltation, eutrophication, floods or droughts, and the like, were the determinants for the adoption of legal rules aimed at preventing these harmful effects of water use (International Association for Water Law, 1976, Recommendation 43; Cano, 1979b, art. 287-301).

Energy Problems

The energy crisis, which has not yet been perceived world-wide as an actual fact, but whose partial effects have already been foreseen due to the political factors at work, has also led to a greater water use or consumption—hydroelectric power generation, cooling systems in nuclear plants, and the like. Consequently, new legal rules have had to be adopted, thus aiming for a more efficient use of those water resources with energy-generation potential (Cano, 1979a, p. 191).

The Need for International Water Resources

There is an increasingly urgent need to use both the surface and underground waters of international river basins because the waters of the purely national river basins are already fully utilized. This also has led to a considerable increase in the body of international Water Law,[1] although the desirable levels of utilization have not been reached yet.

Emergencies

The increasingly frequent occurrences of water-related emergencies, such as droughts and floods, point to the need to establish legal acknowledgement of said situations and then to adopt ad hoc legislation (Hayton, 1977; United Nations, 1976; Cano, 1979b, art. 101-108).

All the foregoing legislative trends have been dealt with by several international conferences, followed by publication of the pertinent recommendations as follows: International Conferences on Water Law and Administration: First Conference, Mendoza, Argentina, 1968, recorded in Annales Juris Aquarium I (AJA I); Second Conference, Caracas, Venezuela, 1976, International Association for Water Law (AJA II and Asociación Internacional de Derecho de Aguas II [AIDA II, Recommendations 48-52); Second International Conference on Global Water Law Systems, Valencia, Spain, 1975 (report published 1976); and United Nations Water Conference, Mar del Plata, Argentina, 1977 (U.N. Doc. E/70.29).

CHALLENGES POSED BY THE 21st CENTURY

For Water Lawmakers

I am not an expert in "futurology" and I do not have a crystal ball either. But, both water law and water management require extreme caution so as not to fall into the hands of quacks. I do not mean to critize the experts in resource prediction but only those self-styled "futurologists" who lack the essential scientific background.

However, it is not necessary to be a clairvoyant to foretell that the aforementioned world problems, stemming especially from multiple use, severe shortages, population pressures, environmental and energy constraints, and serious emergencies, will be the problems with which water lawmakers and water administrators will be concerned in the 21st Century. And some of these problems deserve a brief comment, which I wish to make here in connection with the general subject of this Centennial Symposium.

New technologies must not be accepted and implemented without prior consideration of their ethical implications, as well as their adaptability to the needs of the particular physical and human environment where they are to be applied. In this sense, Water Law can adopt precautionary safeguards (International Association for Water Law, 1976, Recommendation 29; Cano, 1977, par. 55). This moral concern encompasses our duties towards future generations and the stance of the mass-consumption society as regards said duties. For instance, the act of irreversibly removing water from the hydrological cycle to use it for secondary oil recovery in oilfields can pose a problem of this kind.

Each sector of the population that benefits from a given use of water (even from a single source) must pay for it when multiple uses are involved (International Association for Water Law, 1976, Recommendation 37; Cano, 1967). But in every particular use of a water source there is also the built-in benefit for the population at large, and the latter must pay for it through general taxes. It is necessary to clearly draw the line between such payments on account of indirect benefits, and the subvention with public funds of given sectors of users. Such financial support is not necessarily to be banned; furthermore, it will sometimes be essential. But, in that case, it must be clearly designated as such (Cano, 1979b, art. 67-74).

In the 21st Century it will be fundamental that the use of all waters be either in the public domain or under governmental control (International Association for Water Law, 1976, Recommendations 1, 14, 30; Cano, 1977, par. 61). This is so because no water use, not even a single use by a single individual, fails to have an effect on or to involve the community as a whole—and here I would like to paraphrase John Donne who reminded us that when the bell tolls for one human being, it tolls for the whole of mankind. This control is not opposed to solutions such as placing water rights on the market (Chile, Decree-Law 2603, April 18, 1979) in order to expedite the re-allocation of uses or to remove stored waters from public domain in order to place them on the market (Cano, 1979b, art. 20, 340).

Taking into account their mutual interdependence the simultaneous, integrated, and joint legal treatment of all natural resources, including water resources (Pinchot, 1947), appeared for the first time in the Code on the Renewable Natural Resources and Environment Protection of Colombia (1974, Decree 2811; see also Cano, 1975-1976, and Venezuela, Organic Law of the Environment, 1976). A similar approach is about to be implemented in other countries and I think that, in the 21st Century, this will be a generalized methodology (Cano, 1979b, art. 340-343). This is one of the multiple means that was upheld earlier by Gilbert White (1969) for American water management (see also Cano, 1977, par. 41-42). As for the other natural resources that interact

[1] Those interested in recent developments should consult reports on the rules of the International Law Association, particularly for the conferences on "non-maritime" water at Helsinki (52nd Conference, 1966), at New York (55th Conference, 1972), at New Delhi (56th Conference, 1974), and at Madrid (58th Conference, 1976). Recommendations 48, 50, and 52 by the Second Water Law Conference (1976) of the International Association for Water Law should also be reviewed. Other legal developments are well documented in various reports, particularly in paragraphs 50 and 90-93 of the United Nations Water Conference at Mar del Plata (1977) and by Cano *in* the proceedings of the Fourth World Congress on Water Resources at Mexico City (1979).

with water resources — as I have already mentioned — the soil and the land, the atmosphere, flora and fauna, and ore deposits are the main ones.

Perfecting of techniques for water pricing, not only as a means of distributing charges fairly but also as a tool for the encouragement of an efficient use, will also be a rule in the 21st Century (International Association for Water Law, 1976, Recommendation 35). People must become aware of the fact that the use of water is no longer a gift from Heaven, which, apart from being free-of-charge, also entitles the user to squander it or to debase its quality.

The application of the "polluter pays" principle will become generalized in the 21st Century, not only as an ethical rule that conditions individual behaviour, but also as a political principle that fights imprudent leniency and the lukewarm attitudes of governments and individuals towards preventive actions that forestall environmental pollution (International Association for Water Law, 1976, Recommendation 9; Cano, 1977, par. 66, and 1978, p. 136–146).

It is not possible to be indulgent with or to encourage a commercial competition based on careless practices that further environmental impairment when said competition is backed up by complacent authorities who pretend not to see such environmental impairment so long as either production or export trade is promoted.

The international community, either through worldwide or regional organizations, will need to remove those legal and institutional obstacles that enable some countries to offer resistance to a full development of the water resources shared with other countries, or when said countries attempt to use such water resources for their sole advantage, or, even if shared, through unilateral decisions (International Association for Water Law, 1976, Recommendations 48, 50, 52).[2] Examples and experiences of successful shared or coordinated water utilization must be widely cited and highlighted in order to define courses of action and goals.

Furthermore, a legal and institutional organization that can anticipate emergencies and be ready to deal with them before they arise, will contribute to more efficient, more economical actions when it is necessary to cope with actual emergencies (Hayton, 1977; United Nations, 1976; Cano, 1979b, art. 101–108).

From the legal point of view, the combined use of surface, underground, and atmospheric waters can be based on the fact that water rights grant the right to use a given flow or volume of water, but without referring that flow or volume to a pre-determined source (Israel, Water Law of August 3, 1959). Thus, the authorities in charge of water administration will be empowered to decide that said volume will be taken from a given surface course, or from underground aquifers, or else from already-used and treated waters, or from all these sources at the same time. Said authorities will also be entitled to establish that, in order to determine said water volume, rainfall must also be computed [International Association for Water Law, 1976, Recommendation 5; Peru, Water Law of 1969, Art. 7(f)].

For Water Administrators

In many countries and states the administration of the diversion and distribution of waters has been entrusted to several public agencies or organizations which can differentiate among the waters, according to the way said waters are to be used; that is, for municipal services, or irrigation, or power generation, or the like (Cano, 1976b, p. 156). Generally, the administration of quality control of waters is entrusted to those entities that are also in charge of health matters. Finally, there are countries where surface, underground, and coastal waters are all administered by different agencies. However, there are a few recent exceptions to this uncoordinated scattering of the activities of public agencies (Venezuela, Organic Law of 1976, art. 36; Cano, 1978, p. 287–307). France, for instance, has unified both the quantitative and qualitative administrations, with successful results (Law of 16 December 1974).

The 21st Century must witness the unified administration of all water resources and of all water uses and harmful effects, including administration of quality control. The organization in charge of this will be resource-oriented rather than use-oriented [International Association for Water Law, 1976, Recommendation 13 (c), 33; Cano, 1978, p. 277–285; Cano, 1977, par. 52].

Even more effective would be the concentration by a nation of the administration of all water resources and other related resources in a single organization or agency, as was done in Venezuela's Organic Law of 28 December 1976 (art. 36). This had also been recommended by the Second Conference of the International Association for Water Law at Caracas in 1976, which proposed setting up an environment-oriented administration (International Association for Water Law, 1976, Recommendation 2).

Another trend that seems likely to be further stressed in the 21st Century is operational administration organized by water basins or water regions. This is in keeping with planning made on a national basis (International Association for Water Law, 1976, Recommendations 14, 32, 35; Spain, Dirección General de Obras Hidráulicas, 1976; Cano, 1977, par. 68) coinciding with the strengthening of local governments (Uribe Vargas and Godoy, 1974).

It can also be forecast that there will be a considerable increase in the participation of water users or their consumer organizations, in both the policy making and the direct administration of the final stages of the process of

[2] These considerations are further addressed in the rules that were issued by the International Law Association (1973, 1975, 1977). See also Cano (1977, par. 46–48), United Nations (1977, par. 90–93).

water distribution or related services (International Association for Water Law, 1976, Recommendations 11, 15 (c), 36, 43 (a); Cano, 1977, par. 16–18).

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Droughts and Floods

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It is a great pleasure to have the opportunity of helping to celebrate the 100th anniversary of the U.S. Geological Survey. This organization has for years been a world leader in geology, mapping, and water science. We all owe this agency a great debt. In my comments on droughts and floods, I will concentrate on human responses to these phenomena and public policies. But fundamental to such policies are reliable maps, water measurements, and understanding that only comes through well-founded research efforts. We almost take these for granted now in many parts of the world and this is due in no small measure to the scientific leadership of the U.S. Geological Survey.

Those of us who were trained in the natural sciences tend to think of floods and droughts as phenomena of nature. However, floods are disasters only when man's activities make them so, and droughts fill the headlines only where man is using as much water as is normally available, or more.

The real problems of droughts and floods arise because of man's inadequate adjustments to these natural occurrences. If the climatologists are right, and we can expect some decades of greater extremes of weather, we had better begin thinking through more clearly the possible range of man's adjustments to floods and droughts and put in place the policies and program options most appropriate to the region or country concerned.

To contribute to the consideration of useful options, I will draw largely on our experience in Canada and on some in the U.S.A., and comment on both successes and failures of public policies, or lack of them, in adjusting to droughts and floods.

In terms of precipitation, much of Canada's north is desert—a very cold desert, mind you. But population pressures are light and the Eskimo and other peoples have, over many years, made very intelligent adjustments to the very low water supply—10 inches (25.4 cm) per square mile. The adjustments make the exceptional year of low snowfall or rain not a serious drought problem, unless conditions decimate or drive away migratory caribou or ducks or polar bears or other wildlife on which most native groups still depend. In cases like this, the people themselves sometimes become migratory and follow the game, or join their coastal brethren and use the resources of the sea.

However, in southern Canada, on the Great Plains which we share with north-central U.S.A., periods of low precipitation are a different matter altogether. World-wide and national demand for grain crops has spurred agricultural development and an associated infrastructure of cities and transportation networks in this region. In its driest part, it has a mean annual precipitation of less than 11 inches (28 cm). Here is where droughts are felt most acutely in Canada.

This region, like many other parts of the world, is under real pressure to produce for present and future residents, and for "export" earnings, many products from farm, ground, and factory which require more water than currently available. The increasing demand for water in some of these regions seriously outstrips the supply, and government water policies for these areas are under careful scrutiny.

One type of public policy has, so far, been most effective in the southern Canadian Prairies. That is the undertaking by government or private interests of small water projects—deeper farm and community wells, 180,000 dugouts and farm ponds constructed, improved summer-fallowing practices, planting of shelterbelts of drought resistant trees and so on. The federal government, through the Prairie Farm Rehabilitation Administration, undertook or subsidized much of this work after the disastrous drought of the 1930s. More recently, provincial governments in Alberta, Saskatchewan and Manitoba have also participated actively in this type of program. These kinds of activities have been intensified again during and following the "mini-drought" of 1976 and 1977. They can provide a valuable cushion at least for short dry periods such as this.

A second type of public policy, the construction of large water projects, has been notably less successful or has been of greatest value for reasons other than those of the original plan. For example, the last major water project on the Canadian Prairies, the Gardiner Dam and Lake Diefenbaker reservoir, was completed in 1967 at a cost of 130 million dollars. It provides an interesting and very recent case history. Its main initial justification was the potential irrigation of 500,000 acres of land. Its actual use now is almost exclusively for power production and urban-municipal water supply. Only 31,000 acres are presently being irrigated from this reservoir, with interest growing only slowly among the farming community. Nevertheless, we are extremely lucky to have the reserve capacity of the Lake Diefenbaker reservoir now and in the future, but its use was certainly not according to plan. Large developments of this sort are rare nowadays, since only very small portions of the water resource in this region remain uncommitted to various uses.

The third type of public policy affecting the impact of droughts relates to responses to the problem of pressures for secondary and tertiary developments attracted to or required by increasing agricultural activity through irrigation or other means. In the southern Prairie Provinces of Canada, an expanding food processing industry, coal and hydrocarbon extraction and processing, potash mining and processing, and growing municipalities, all need more water both directly and indirectly, for electric power production by hydropower or thermal-power plants. Indeed, in the 1976–77 drought, the greatest economic impact was not in agricultural crop losses, although these were substantial, but in the loss of energy production due to low river flows. It is estimated that replacement electrical energy cost about $100 million. About $20 million extra was spent on forest fire fighting.

Pressures are therefore growing for supplementing water supplies by diversions from northward flowing river systems in Canada to the more arid southern Prairies. This poses the classic policy dilemma – do you take the water to the people, or try to get the people to move to the water? Recently, as a first step to try to come to grips with assessing the *need* for major water diversions to the southern Prairies, the federal-provincial Prairie Provinces Water Board has launched a comprehensive water demand study which will be completed in 1982 (fig. 1).

An environmental view of the water resource is gaining increasing acceptance and will make future major

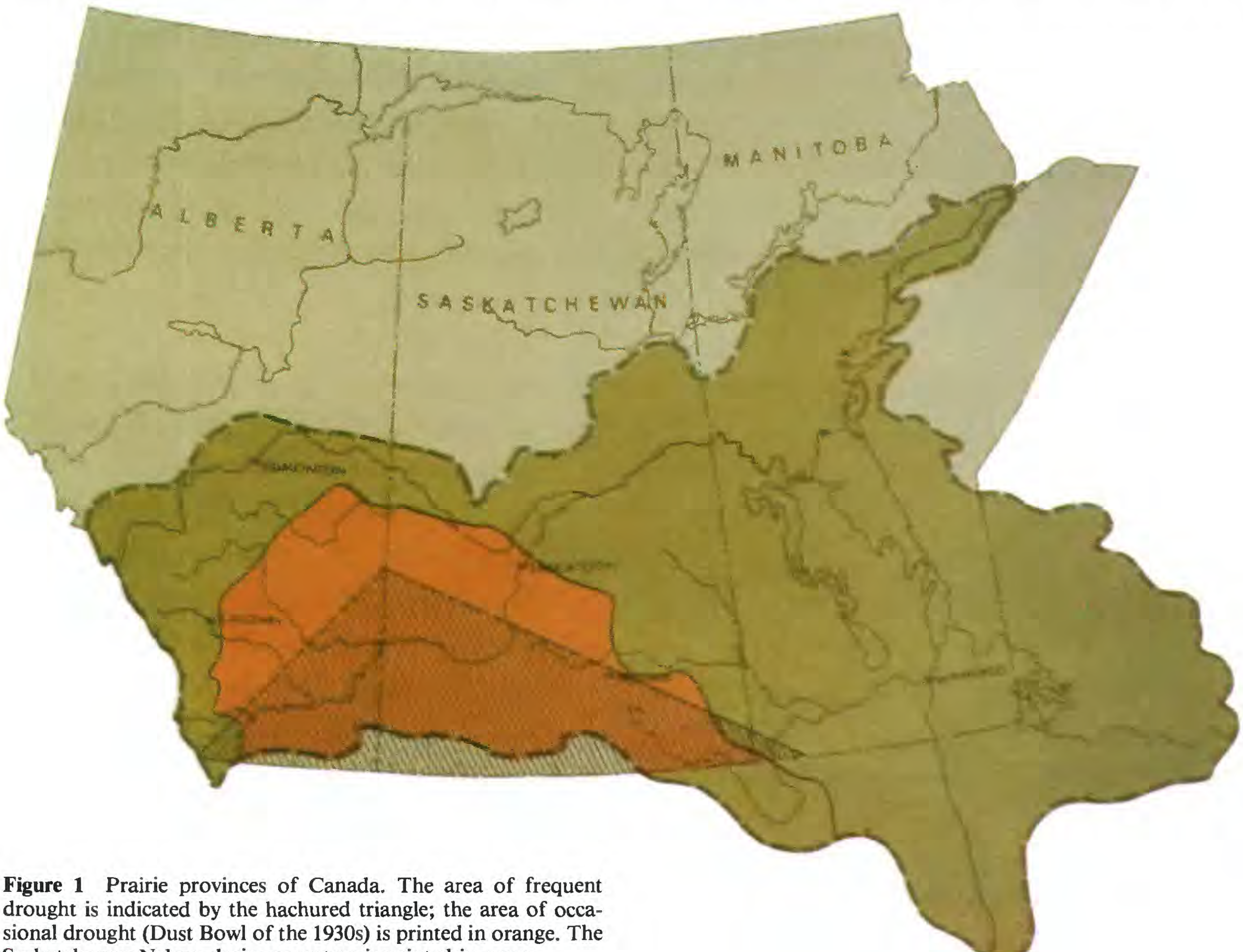


Figure 1 Prairie provinces of Canada. The area of frequent drought is indicated by the hachured triangle; the area of occasional drought (Dust Bowl of the 1930s) is printed in orange. The Saskatchewan-Nelson drainage system is printed in green.

inter-basin water diversions less acceptable, especially to donor regions. The formerly held concept of "wasted" water finds no place in this environmental view. Every river system, even if largely unused by man, supports an ecosystem including fish, wildlife and plants, and forms part of a larger ecosystem. There is a legitimate fear, for example, that diversion of waters from northward flowing streams into the water-short southern provinces will change the salinity and thus the ice conditions of the Arctic sea, by reducing fresh water discharges. This, in turn, it is thought, could trigger a major climatic change.

An example drawn from the U.S.A. may illustrate the policy dilemma more starkly. The rapid and intensive development of irrigation in the Texas-Oklahoma High Plains area in the last two decades is a clear example of the rate at which resource development can occur. The estimated overdraft of ground water resources of 10,400 million imperial gallons per day has already made its impact felt. A major study program is underway to find alternative water supplies.

This development illustrates the short-term attractiveness of irrigation even in the face of the lack of a long-term assured supply. With farm and irrigation investments in place, and many people committed to this land, pressures to find other water sources will be great. However, we must ask if the real social and economic costs of meeting this future water need had been considered, would the irrigation-dependent area have been developed so intensively?

A major factor in making some regions more drought susceptible is artificially low prices for water and for energy to pump it. As the most accessible and easily developed water resources were used up, prices had to rise. This natural process was masked by the way relatively cheap energy in the 1940–1970 period allowed us to overcome the higher basic costs of development and transport. Meanwhile, all of this became anchored in an affluent style of life, wastage, and a set of expectations which is unequalled in history. To name but one example: Canadians have benefited from the low prices and the convenience of fresh farm produce in our winter that past water developments and pricing policies in the United States have made possible. We are every bit as dependent as are U.S. citizens on California's Imperial Valley salad bowl. Even in season, Canadian-grown produce has difficulty competing—in Canada—because of the subsidies involved in these massive water developments to the south and the present relatively low costs of transportation and energy.

However, the era of cheap energy for pumping water and transporting products is rapidly ending in North America, and with it the era of cheap water.

A study of the Oldman River basin in southern Alberta completed in 1978 illustrates a somewhat new perspective on water resources. The Oldman River study dealt mainly with irrigation which now consumes 93 percent of the water in that basin and has great potential for expansion. Instead of relying on the development of new storage facilities alone, considerable attention was paid to increasing the efficiency of use of presently available supplies. A $200 million canal and headworks improvement program by the government of Alberta and similar efforts by the federal government on its irrigation projects in the basin are directed towards this end.

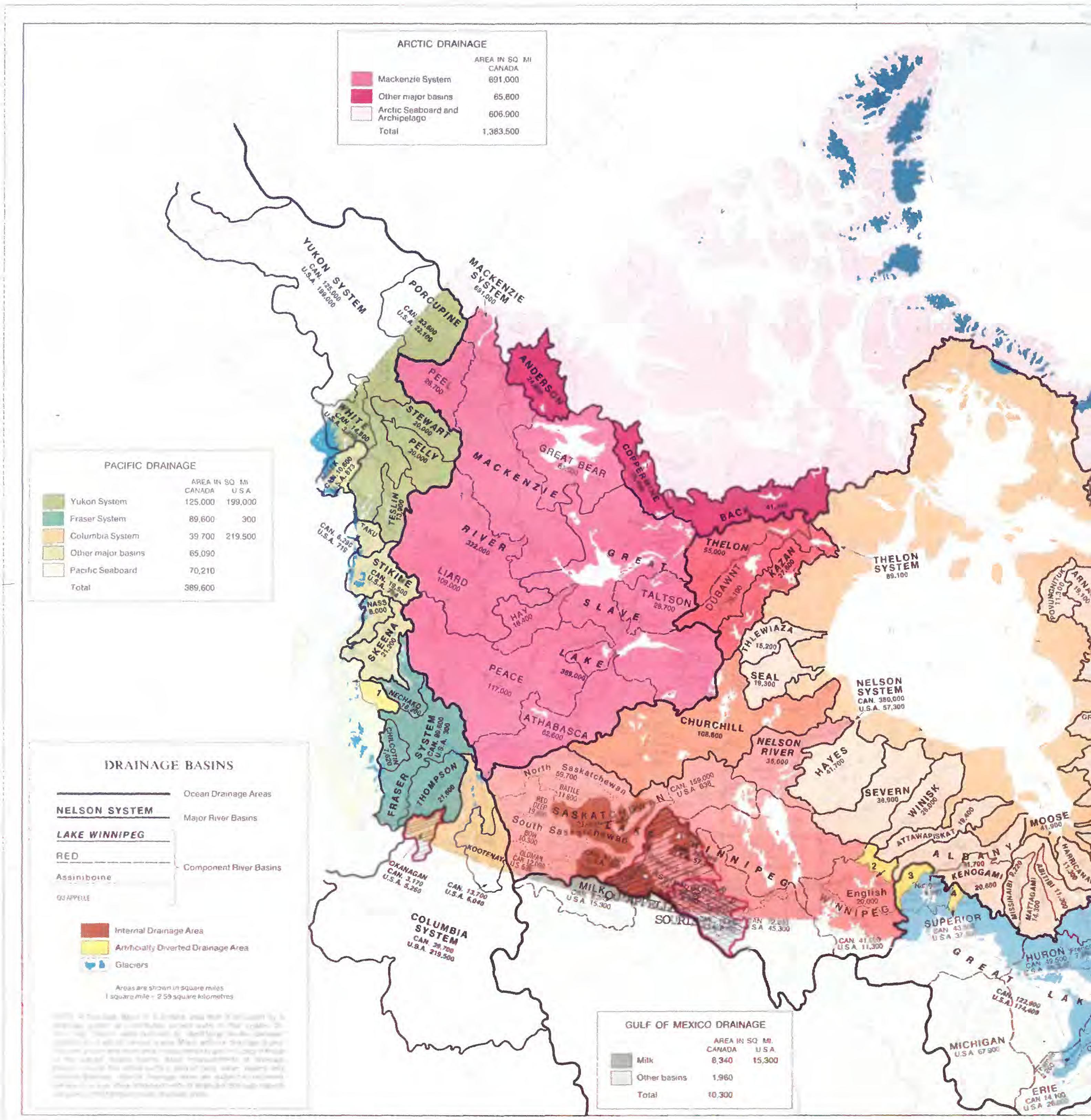
The need to consider carefully the future availability and allocation of water implies the great value of comprehensive water planning on a large basin or regional basis. Some very successful comprehensive river basin plans have been developed under Canada Water Act programs north of the border, for the Souris River Basin, the Qu'Appelle, and the Okanagan within the dry sections of western Canada (fig. 2). These have provided valuable blueprints for drought-proofing through better control of available supplies and balanced allocation and conservation of the resource for a long-term sustained economy. In the Okanagan study, for example, the public participation program led to acceptance of a low to medium economic growth option and made unnecessary a proposed costly diversion of water from a more northerly basin.

There are three policy guidelines concerning major inter-basin diversions which may be inferred from these examples. Firstly, the environmental implications of major diversions, both in the donor region and the region receiving additional waters must be carefully reviewed—in the broadest possible ecosystem context. Secondly, development and water policies for a region must stress *long-term* stability based on sustained supplies and productivity, rather than on maximum short-term production. Thirdly, long-term planning of water and related resources on a large river basin or regional basis is essential to wise decisions on water management.

Droughts, in the sense of periods of low water supplies, will continue to affect man's activities, but judicious selection of policies, and borrowing from experience of others, can improve man's adjustments to these natural phenomena.

Floods present quite a different problem in adaptation. The first thing that must be recognized is that floods are part of the natural balance and are thus often valuable. It is when man and river compete for the use of floodplains that disasters occur.

We all know of the benefits to agriculture that have been conferred by the annual floods of rivers like the Nile. Let me cite a less well known example of the beneficial effects of floods—on the Mackenzie River—the only river in Canada with a recorded flow on one occasion greater than 1 million cubic feet per second.



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THE NATIONAL ATLAS OF CANADA

The Mackenzie drains nearly 700,000 square miles and has a number of major tributaries, most importantly the Peace, the Slave, the Athabasca, and the Liard (fig. 3).

The lower Mackenzie Valley sustains a population of 7,000 Indians, Inuit and whites who, even at 68° North, grow some of their own vegetables, cut trees for fuel and construction, and fish and hunt in the remarkably productive Mackenzie Delta. The way of life is delicately balanced with the natural cycles. The major life-renewing event of the year is the spring breakup and flood.

In the lower Mackenzie, breakup proceeds at a faster rate than in the surrounding countryside, due to silt-laden waters flooding over frozen surfaces which darken in color and absorb more insolation, hastening the melt. The physical action of spring floodwaters in lifting up, breaking and moving to seaward the winter accumulation of ice is instrumental in causing a rapid increase in local air temperatures. This meso-climatic effect advances the start of the spring growing season in the Mackenzie Valley and Delta, in relation to the surrounding area, providing those extra degree days needed for growing essential plants.

The dynamic interaction of flooding and sedimentation shapes the surface of floodplains and deltas and is reflected in the distribution of successional plant communities. The existing species and patterns of vegetation are dependent upon the deposition of sediments resulting from the spring flood. In turn, the migratory waterfowl and other wildlife depend on the equisetum and other protein-rich species which grow because of the spring flood.

The primary cause of early breakup of the lower Mackenzie River and the major source of sediments is the Liard River tributary. Some initial planning has been undertaken for hydro-electric development on the Liard River—to store spring flood waters for power generation.

Some have claimed flood control benefits for the lower Mackenzie from such a project. And it is true that reducing and delaying the spring flood would prevent damage to wharves, some communities, and perhaps the oil and gas drilling rigs that now dot the region. But this would be at the expense of a way of life built on the beneficial microclimatic, sedimentation, and floodwater effects created by the spring floods.

Recognizing both the beneficial effects of spring floods in many river valleys of the country and also recognizing that floods become disasters only when man competes for the floodplain, the Canadian government adopted in 1975 a new Flood Damage Reduction program. Note—not a *flood* reduction program, but a *damage* reduction program.

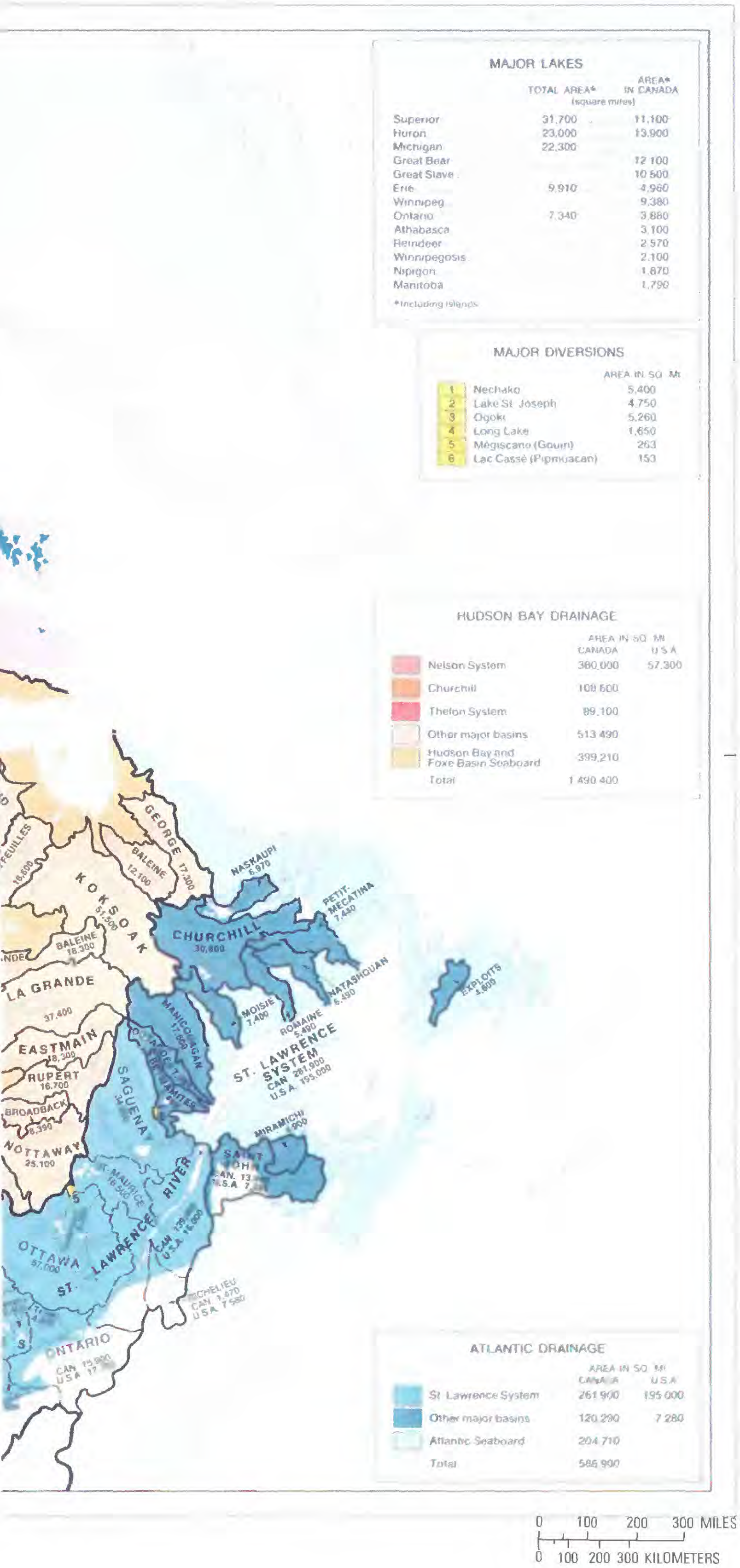

Figure 2 Location of studies of the Souris, Qu'Appelle, and Okanagan River basins.

Figure 3 The Mackenzie River basin.

The strategy is to first get ahead of the problem of ever-increasing development in floodplains and ever-increasing liability for damages by individuals and governments. To this end, the cornerstone of the Flood Damage Reduction program is a series of federal-provincial agreements to map and delineate the floodplains of all significant communities and their suburbs (fig. 4). On the basis of these maps, the two senior governments, federal and provincial, jointly and formally "designate" the floodplains. Once designated, the federal government will not build and will not provide loans or mortgage funds for new buildings which are not adequately floodproofed. Nor will they provide any disaster assistance to those developers who have proceeded to construct in the floodplain after the designation has taken place. The provinces on their part also do not build or support building in the designated area. They also zone or ask their municipalities to zone the floodplains for use for non-flood susceptible activities—such as parks and natural areas. In these ways we are preventing future encroachment on the floodplains.

The 100-year flood was adopted as a national standard for this program but provinces are allowed to adopt a more restrictive criterion if they wish. A two-zone policy is also allowed for when necessary—a central zone where no encroachment will be allowed and a broader area where flood-proofed buildings are permitted.

The Flood Damage Reduction agreements with the provinces also recognize the need to take action where there are existing flood vulnerable areas. In these cases, the governments agree to investigate all options to find the most cost-effective damage reduction solution which can include letting some flooding occur. In some areas this has involved structural solutions such as building dykes or floodways, and in others, flood-proofing and (or) removal of buildings to another site.

On other occasions, when describing this program, I have been told "that may be fine for Canada which has a small population and lots of land, but it would never work in my country." I guess that there is some truth in this—but I would point out that this policy is followed in the regions of metropolitan Toronto and Montreal where 50 × 100 feet house building lots range in price from $20,000 to $100,000 and population density is as high as 550 persons

per acre. In these cities, the value of recreational parks along the river and lake fronts, set aside by floodplain zoning, is just beginning to be realized. In short, it seems to me that there are rather few parts of the world where some adaptation of these policies would not be valuable.

The thread that runs through my remarks today will now be obvious to all of you. In the recent past we tried to tame natural phenomena. In hindsight, we can recognize that over-exploitation of a limited water resource only leads to drought disasters or possible environmental disasters associated with major inter-basin water diversions. We know that flood damages simply increase in magnitude in spite of flood control works if some restraint is not exercised on man's use of floodplains.

So we still face the problems of how best to reduce the human suffering and economic disasters that result from floods and droughts. The examples I have discussed suggest that, by and large, programs based on the idea of "taming" nature have usually failed. Development of intensive agriculture in water-short areas eventually results in

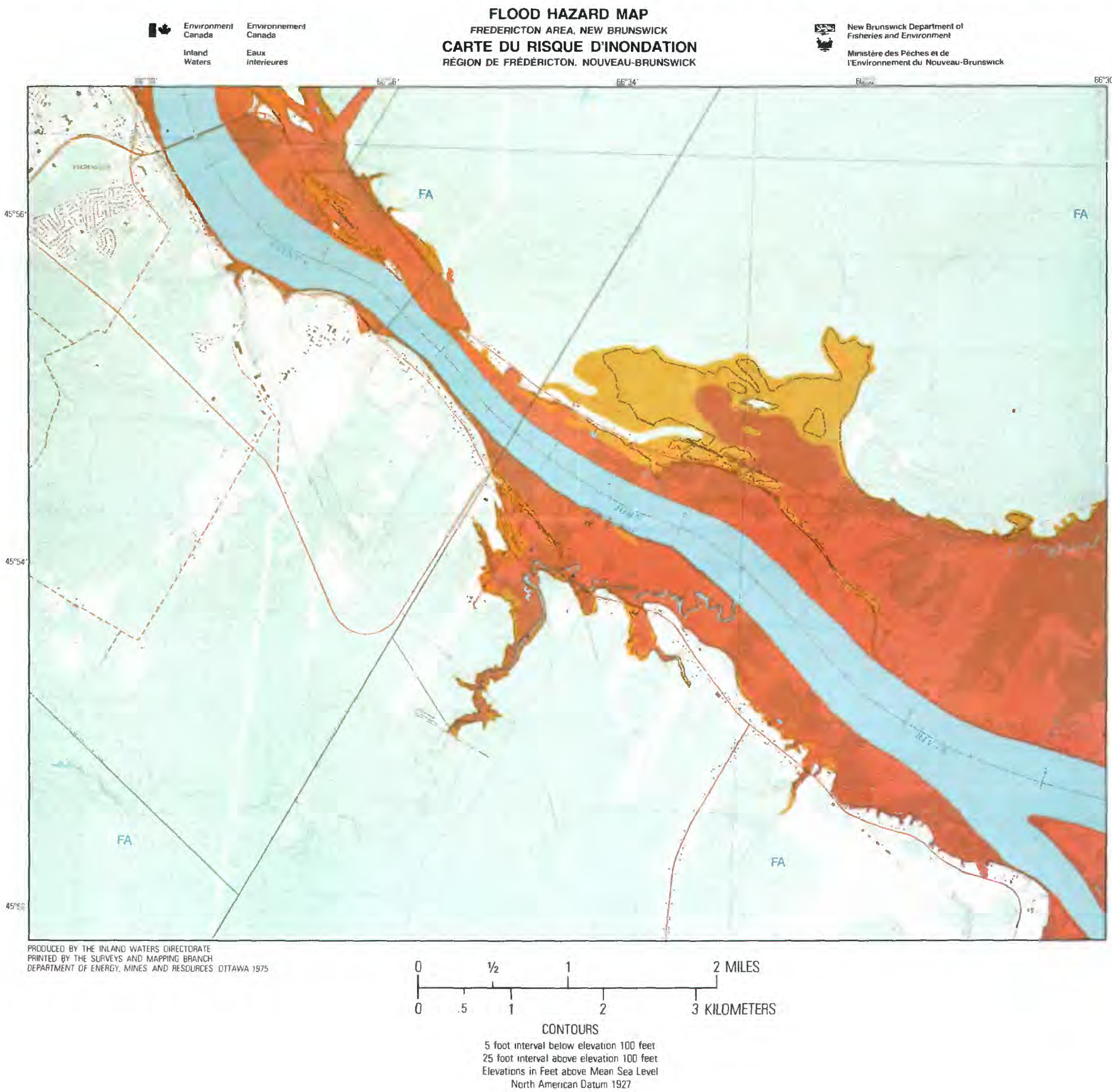

Figure 4 Example of a flood-plain map.

devastating drought damages. Upstream flood control dams have often given a sense of false security to downstream communities, which have then been seriously damaged in floods exceeding the storage capacities of upstream reservoirs.

On the other hand, where agricultural and other water uses are in reasonable balance with long-term supplies, local water and soil conservation practices can buffer drought effects—at least for short droughts. Prevention and removal of flood hazards from the floodplain reduce flood damage and provide for recreational breathing space in cities and suburbs.

There is a clear lesson here. We must turn away from policies which put man against nature—which are based on overcoming the force of natural phenomena like droughts and floods. Rather, we must move consciously to choose those policies and programs based on man's harmonious adaptation to nature.

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Panel Discussion

Joseph Cragwall (USGS): Thank you very much, Mr. Bruce, for that very enlightening overview of Canadian policy and programs that gives emphasis to living and adapting to nature. I take this opportunity, as part of the chairmanship this afternoon, to thank these three speakers for their very excellent presentations.

Philip Cohen (USGS): It is indeed a pleasure to participate in the program. I would like to introduce an additional member of our panel: He is Dr. Dean Freeman Peterson. Dr. Peterson is a prominent educator who spent a long and illustrious career at Colorado State University and Utah State University. He retired in 1976 and joined the United States Agency for International Development. At the present time he is with USAID as chief of the Office of Agriculture. Dr. Peterson is sitting immediately to the right of Joe Cragwall. I think we were indeed fortunate with respect to the three speakers whom we heard this afternoon. Among the three of them, in my view at least, they were able to discuss virtually all ramifications of man and his interaction with the hydrologic cycle. Dr. Alejandrino focused in large part on the institutional relations as manifested by the situation in the Philippines; institutional relations between man and the hydrologic cycle. Dr. Cano gave us a detailed overview of the legal interactions between man and the hydrologic cycle. Mr. Bruce talked about some of the structural and non-structural interactions between man and the hydrologic cycle, especially with regard to hydrologic extremes. It was also interesting to note that, as is not often the case, there was no major emphasis during the presentations on the scientific problems associated with managing water resources of the world. This, I am sure, is not related to the fact that scientific problems do not exist. They do exist and will continue to exist and require solutions. However, in large part our emphasis reflects the social perspectives of water, the emergence of water as a scarce commodity, one which man has chosen to handle in a way which is almost unique with respect to the mineral resources of the world, and that, by and large, developing nations and developed nations have chosen to manage water as a commodity owned by the general public and managed for the good of the general public. The law of supply and demand generally is not applied. By that I mean, water is not treated as a free market commodity, and yet economic constraints and economic opportunities must be brought to bear in terms of managing our water resources. I think the presentations that we heard were provocative. They lend themselves to in-depth analysis, and I hope that you will inquire of our speakers and comment on any of the areas that are of interest to you.

Dean Peterson (USAID): It is a great pleasure to participate in the Centennial of the Geological Survey. It is almost half of a centennial since I had one of my first jobs as a junior engineer for the USGS back in 1937, so it is like home to be here. It is always a great pleasure to see old friends. Jim Bruce I have known for a number of years; I have known and admired Dr. Cano's work for more than a decade. I have followed with interest the water resources development programs in the Philippines. It seems to me that the Philippines has done a very sophisticated job in developing their water resources policy based on the idea of ownership by the public or ownership by the States. In some of the United States' Western States we assert that the water is owned by the public; in others, it is dedicated to the public and held by the State as trustee for its use. The difference between State ownership and trusteeship for the public is something that appears to be very significant to me. Perhaps there are legal connotations about which Dr. Cano will comment. I was interested, too, in the apparent high effectiveness of the "Water Resources Council," or the comparable overview body in the Philippine situation. They seem to have done a better job of coordinating there than we have with our own Water Resources Council, which is the coordinative mechanism here in the United States. I am not sure why that is. There are probably several reasons: (1) the Philippines has a stronger federal system, perhaps, with less responsibility on the provinces in contrast to the States, and (2) in the United States the Geological Survey and the Bureau of Reclamation were well established before the WRC was started; this may have placed the WRC at a disadvantage. The maturity in the Philippines of approaching such things as non-structural measures, conservation of watersheds and so on, is very commendable. The role of financing, the two threads of financing, by making available credit and private financing so that things happen in water resources is a very good development tool which we in USAID like very much to use. In considering financing, there is always the question of what is the social benefit, what kind of subsidy is desirable for society. We try to approach the question through the benefit-cost ratio by including some tangible allowances for some of the real social costs. I would be interested in knowing whether there is a standard procedure for determining benefit-cost ratios in the Philippines comparable to the "Principles and Standards" of the United States. Another thing I would be interested in knowing is about water quality and how water quality is integrated into planning and policy in the Philippines. Again in the United States we have not done very well in getting water quality integrated into overall water policy. For example, water-quality investments are not subject to our Principles and Standards for Evaluation of Water Resources, as are irrigation, navigation, and so on. I was very much interested, too, in the comments about the use of cooperatives in developing irrigation projects. This is also an area of interest to my agency, USAID, because we find that in many developing countries there is a social or an institutional vacuum between the engineers and hydrologists who design the dam and the farmer who is trying to make a living. There just do not seem to be institutions to get the agricultural information to him and the water from the reservoir down where he needs it. I think the Philippines, as I understand it, has done quite well in recognizing and filling this institutional vacuum.

Dr. Cano's talk, I thought, was fascinating—a very comprehensive analysis and a very clear-cut one. Looking to the 21st Century, I certainly agree with the nine points that he made regarding the issues which the lawyers will have to deal with, and again the issues which those who administer water programs would need to worry about in that century. It was very incisive to divide the presentation between the legal universe and the administrative universe. We who have worked in the water field in the United States know that the laws and the administration do not always pull together as teams.

Mr. Bruce's talk on floods and droughts, I thought, was very appropriate and raised some very interesting points. I am still not sure that developing countries in the tropical areas, the drought-prone areas that are monsoon-fed like western India, and the Sahara region in Africa, face quite the same problems, however. In at least the case of southern Asia, the people are in place on the drought-prone lands, and they must use the water resources that they can capture in the good years and somehow bridge the gaps during the drought years. They cannot afford not to use those good-year resources as efficiently as they possibly can, primarily for food production because the resource situation is so tight. Your approach to flood controls, I thought, was a fascinating one. I think it is one of the more mature ideas that I have heard. You did not mention anything about flood insurance. In the United States, you will recall, we got into mandatory flood insurance, as one of the means for flood damage reduction. I do not know if this is a part of your mix or whether your idea of flood-proofing is a substitute for it. One other point I would like to raise is the question of mining ground water. Jim Bruce referred to the high plains of Texas, and maybe if we had had the right kinds of policies and the right kinds of legal tools, we would not have started to mine this water. I guess I can hypothesize an adversary view to that whether I believe it or not. In mining coal or oil we create demands, the resources disappear, and somehow we go ahead; so I wonder what parameters one should try to use; what criteria society ought to try to use in resolving ground-water mining policies. Another issue that I did not hear much discussion on was the use of ground water as a drought relief measure, and what kinds of administrative and legal tools could be developed so that the ground-water supply is not overexploited in the good years to the point where it is not available for use as drought relief in the bad years. I did not study the last drought and how we managed it in detail, but drawing down ground water was a very helpful tool in helping to get through the drought.

Philip Cohen: I would now ask that each of the speakers respond in kind to Dean's comments and questions and ask the members of the audience to please join in and participate.

Angel Alejandrino (The Philippines): Dr. Peterson had, I think, two questions regarding my presentation. I would paraphrase one as: What is the extent of the subsidy that is being given to the rural water-supply sector and the irrigation sector? Actually, I had them in my paper but because of time constraints I did not mention them, since maybe I considered them too detailed. Now since it has been asked I can say that we have no uniform policy on the extent of subsidy for rural water supply. It varies from 10 per cent to full subsidy depending upon the agency that is implementing the project. If you will remember, I mentioned that we have many agencies implementing projects. The plan, however, is to adopt a maximum of 90 percent as a grant for what we call the first level of rural water supply service. This is a point source such as a well or a spring in which the users go to the source to fetch their water. This is in line with the basic-needs commitment of the government. The remaining 10 percent is an equity contribution of the local water well association to indicate its commitment for the project. Of course, operation and maintenance would be mainly shouldered by the Rural Water Works Association.

For the second level of service for rural water supply, we have a distribution system having a number of faucets, each servicing about 4 to 6 houses. We also envision requiring a 10 percent local equity. The remaining 90 percent is provided as a loan, with an annual interest of not more than 4 percent, repayable in 15 to 20 years. The tariff structure of the various consumers is designed to recover all these costs. Of course, the 4 percent interest is highly subsidized.

For some irrigation projects, 10 percent is provided as a grant. It seems that this is a trend. Seventy percent is a loan that is repaid with an annual interest of 6 percent. The repayment period varies from 10 to 25 years. That is the extent of subsidy. Now the irrigation associations are encouraged to furnish the right of way, labor and materials that they can supply. As an incentive, the reduction in cost due to the items furnished by the association is applied to that part of the total cost to be repaid with interest at 6 percent per annum. I hope that answers your questions.

With regard to water quality policy, this is only recent. It is easy enough to impose water quality standards for industries or even for the large state projects. For that matter we also have environmental assessments on parts of our big water resources projects. As far as pollution is concerned, domestic pollution is the greatest problem. In the rural areas, for instance, disposal of wastes and waste water is very hard to control. In the first place, we cannot give them clean water so it is very difficult to control their dirty water.

George Davis (USGS): I have a question for Dr. Alejandrino. You stated that in the Philippines, the water is owned by the State. Dean Peterson commented that in several of our Western States there is a similar doctrine of ownership by the people in the State. It seems to me what really counts is the right to use the water. Now in the Philippines, by using water, does the water user then establish property rights for that use?

Angel Alejandrino: We use the appropriation doctrine. In other words, anybody that wants to use water has to apply to the State for the use of that water, and this is controlled by the State.

George Davis: So then it becomes a property right, does it not?

Angel Alejandrino: No, we have moved away from what we call water right. In other words, the State reserves the right to withdraw the permit to use water for greater beneficial use; of course, with proper compensation, like providing substitute water. Take the case where individual irrigators have drawn water individually from, for example, a stream. If it can be shown that the government's larger project will result in greater beneficial use, the government can provide substitute water for these individual irrigators and withdraw the individual permits.

George Davis: But with compensation?

Angel Alejandrino: Yes, with compensation.

Philip Cohen: Dr. Cano, would you care to respond to Dr. Peterson's comments?

Guillermo Cano (International Water Resources Association): Well, he says he agrees with me; I have no comments. But I would like to comment on the subject of property. This problem can be solved in different ways. One way is used in the eastern United States with the Riparian Rights System. Here the right to use water is a natural right of the landowner. In some cases this pertains only to riparians, and then there is not public ownership of the water. A second way is the "concession system" under which the users receive a concession by grant, i.e., for agriculture, as in my country. There the water rights granted are attached to the land and the men who won these water rights cannot sell the land separate from the water rights. I think this system worked well when dealing with long-term agricultural enterprise, for instance, growing vineyards or fruit orchards or that kind of agriculture which needs heavy long-term investments, not agriculture on a year-long basis. This system worked well to protect the individual's initiative to promote this kind of agriculture. I said during my lecture that the need to reassign water rights has now appeared. For instance, the immigration of rural population to cities has required the people to use water rights for municipal supply that were originally assigned for irrigation (agricultural use). The use of the water is thus changed. I mentioned that the government of Chile passed a law just a few months ago (April 1979). They have had the system where the water right is tied with the land ownership; now they have changed the law to allow the water rights to be put on the market. In the free market the economic system will allow the use to be changed. This means that the landowner who has water rights for irrigation can sell his rights to somebody who wishes to use them, for example, for industry, or to somebody wishing to use the land for human habitation. I do not know what the outcome of the Chilean solution, which is a very new one, will be. I cannot speak about the results because the law dates only from last April, but I do think it is one way to find a solution to the need to reassign the uses of the water. I would also like to comment that this is the first time in my life, as a lawyer, that other people say that they agree with me!

Philip Cohen: Thank you very much. . . . Mr. Bruce.

James Bruce (Canada): Yes, Dean Peterson raised three points that I would like to address. One is the question of whether drought-proofing methods would work in economically developing parts of the world. I really do not have enough experience in such areas to answer that question, but I would say one thing and that is that if major development, depending on a water resource, is allowed to take place in an area and the water supply required exceeds the average annual water supply in that region, then I think you are going to be in deep trouble at some stage. If use does not exceed the average annual supply including recharge to ground water, you can get through the dry periods by the kind of legal and administrative arrangements that Dean was suggesting, by allowing a greater ground-water withdrawal in the dry periods to cover up the water shortage. That is what we have been doing in many parts of Canada. If we allow developments to take place which use more than the average annual water supply, I think we are eventually in for a serious drought problem in that location.

We talk about mining ground water. It seems to me there is a great difference between mining gold or other metals and mining ground water. In mining gold, at least what happens in my country is when they run out of gold, the guys who are doing the mining pack up and leave. But when you have a water development or an agricultural development or a municipal development that takes place based on mining of ground water, those people want to stay and they want to get their water from somewhere else when their ground water runs out. This is the big difference and this is why I think that it is not wise to build an economy based on mined ground water.

Dean also asked about whether Canada used flood insurance as part of the mix in dealing with floods, and the answer is no. We have considered flood insurance as a possibility, and looked very carefully at the experience of the United States. We finally decided that flood insurance could not work without government subsidy, and we thought also that flood insurance provided very little incentive for people in the flood plain to flood-proof their own homes or to get out of the flood plain. In fact it provides a disincentive. There's a benefit to be gained with flood insurance by just staying in the flood plain; a subsidized benefit. So that in fact, we reviewed the experience in the United States with flood insurance and consciously decided not to include it in our mix of policies.

Philip Cohen: Are there any further questions or comments from the audience?

Lauro Sodre-Neto (Brazil): I would like to know if you have some information on salinization of large reservoirs. We have this problem in Brazil.

Philip Cohen: Is there anyone on the panel who would like to respond? The question concerns salinization of surface water reservoirs. Any experience with increased salinity in surface water reservoirs?

James Bruce: Well, certainly we have had similar experiences, some reservoirs showing increased salinity over the years, and of course, also increased sedimentation. One of the reasons why I was not advocating large reservoirs was partly because of that experience. On the other hand, if you have a fairly large annual flow through the reservoir, the problem does not appear to be a very severe one, but if you do not have a large flow through the reservoir it certainly can result in evaporation losses concentrating the salts in the reservoir. But we have very much less experience in this than the United States, and I would suspect that Joe Cragwall or Dean Peterson could explain more fully.

Joseph Cragwall: What troubles me is the increasing salinity in the reservoir. One can rationalize that that can be a problem in our Western States, but those reservoirs were authorized and built to supply irrigation water which leaches the soil, which increases the salinity in the river systems, and that is where our problem has been, not in the reservoirs.

S. Limaye (India): I have a question regarding the enactment of ground-water law. In some of the developing nations at present there is no ground-water law. At present these developing nations really do not have very much knowledge about the ground-water law patterns, geology, etc. Without ground-water law even a poor farmer with a small plot of land, say two acres, will dig a well to irrigate even this small plot. Would you recommend that these countries enact a ground-water law?

Guillermo Cano: The private-property aspect of ground water does not mean that the owner is free to do what he wants. I will use an example, concerning land use. If you buy a piece of land in a city and you wish to build a building, you need a permit. This is a land use of private property and you need a permit and also you must follow some regulations concerning the quality of the building. The same legal solution applies to the use of private underground water. The power of government policy is enough to put conditions on the use of private property. In the same way, you have a speed limit for your car on the highway; it is the same kind of restriction. It is not necessary to have public ownership of the underground water to have administrative conditions or restrictions. Even if the government does not wish to declare the underground water for public ownership, it has the means to control its use through the exercise of police power by limiting the capacity of pumps, or limiting the time of use. There are many countries that do that, in indirect ways. For instance, using a system of differential fares for the electricity used: when the consumption exceeds a certain amount, the fare can be raised. There are many ways, i.e., the protection of the wells through prohibition of other wells within a certain distance. In any case, the permit even for the landowner to build a well or drill, can be subjected to technical conditions or can be subjected to the duty of reporting to the administration about the geological structure, and also about the level of the water table and many other things. For me, the ideal is to achieve public ownership of the underground water, and to use a system of granting concessions to use those waters. Some new legislation does that, excluding from public control only the wells dug solely for domestic use. When they say "domestic use," they mean only for food or house needs, not for any agricultural production. Under this new legislation that kind of use of the aquifer does not need a permit, but in the other cases a permit is mandatory.

Vincent E. McKelvey (USGS): About twenty years ago, in trying to figure out the cost of the total water used in the United States, I hit upon a method for figuring out the cost of water used on rain-fed cropland as well as for silviculture. Rain water is bought and sold except that it is bought and sold with the land and with the product. I will not explain that any further. But a very interesting thing came out of that study, and that is the enormous range in the price of water. Let us say that, when water is sold as a commodity, the price very closely reflects the actual cost of bringing the water to that point for its use. At the time of the study, about 1959, the cost of water for domestic use in the United States averaged about $98 an acre-foot. The cost of water for industrial use was about $8 or $8.50 an acre-foot. For irrigation, it was averaging about $3, as I recall; and for rain-fed cropland, I estimated it was worth an average of about $1 an acre-foot, and about 25 cents an acre-foot in silviculture. So there was an enormous range in the market value of the raw commodity. All of the value-adding steps taken to prepare water for use represent costs involved and reflect the user's willingness to pay for them. At any rate, when I finished that tabulation, the whole history of Owens Valley [Calif.] immediately became clear to me. In a market economy such as we have in the United States it is possible for a particular group of users who are able to pay a lot more for water than another group of users to readily acquire the water rights and make a decision about water use that may have a tremendous effect on a whole range of activities in a given region as, indeed, the people of Los Angeles had with respect to water use in much of California. I'd just like to ask – perhaps this is a question for Ambassador Cano – the extent to which regional planning the world over is taking into account problems of water use in the development of major water-using projects. Planning for the use of water over a major region would seem to involve people with omniscience that it's hard to imagine that they might always have, but I'm curious about the extent to which over the world there are patterns developing, either by legislation or practice, related to planning water use region-wide.

Guillermo Cano: To reply I will use an example. A good example is the system adopted by the French ten years ago, depending upon what we call regional planning. In the matter of water, I think regional planning means river basin planning or planning for a group of river basins. As you may know, the French government divided the country into eight basin regions, principally basins of the main rivers. For each basin, they created two organizations. One is a financial agency and the other is a technical agency. Both have direct participation by the local people involved. When I say local people, I refer to representatives of municipalities and representatives of Chambers of Commerce, and also the national government. The French pay taxes for use of water, the proceeds being used only for water works. They tax not only the consumptive uses but also the use of water to produce hydroelectricity, which is taxed by volume. This taxation has nothing to do with the cost of storage or diversion of the water. This means that this tax is not an element of the cost of use or diversion, or storage: it represents the value of the water. Separately they also tax the use of water courses for return flows of wastewater. This is a different taxation. They use the pollution taxation to induce the people to treat the water before returning it. The proceeds of both these taxes are administered by the financial agency of each basin. The money collected is apportioned through a budget to 3- or 4-year programs. They use the money in different ways. The minor part is for direct construction by the basin agency of treatment works. Another part is used to give loans at low interest. They give loans not only to municipalities but also to private industries. The third part is used to give nonreimbursable subsidies. They manage this financial system mainly through agreements with sectors of industry. Take for example the pulp industry; they make an agreement with the entire pulp industry in France thereby avoiding unfair competition among the members of that industry. In that way, they can speak of regional planning on the different uses of the water. They do cost analyses of the total expenditures to apportion them among the different categories of uses. I think that the French experience has been successful. They, in eight years, have abated pollution by 50 percent, and they are going ahead with that plan. The other tool they use is tax exemption. This means that the industry, or the municipality which does its own treatment, is exempted from taxes. Thus they are promoting private initiative through tax exemption.

Della Laura (USGS): I would like to make a comment on a statement that Dr. Cano made concerning water rights; not just ground-water rights (which is the context in which it was phrased in Dr. Limaye's question) but also surface-water rights. Dr. Cano's recommendation is that if a ground-water right system or ground-water law has not been instituted, a state or a nation would be wise to consider possibly taking all waters and making them the property of the state or nation and then having a system of permits for distribution. I think that this is the conclusion that all of us must logically reach. However, I think one of the things we must keep in mind is the social, political, and economic system in which this kind of law will operate.

I would like to point out a problem, for which I have no simple solution: it is the problem of "baksheesh." That is, what is actually paid to get the right? We know that in some places we may set the price of a permit as low as 25 cents, but it may cost a person two, three, or four hundred dollars in payments, crossing the right palm, to get that 25-cent right. We pay a sophisticated "baksheesh" in our country. For instance, we pay "baksheesh" to the system. Not to bribe an individual, although that may happen too, but to get ourselves a very good lawyer. It is a very different way of paying "baksheesh," so to speak. In the developing countries, as well as in the United States, where we do not have sufficient ground-water and surface-water law, I think whenever we talk about a system of permits, we must be aware of the additional ramifications that the permit itself may introduce. It is similar to "the rich get richer"—"the rich get the water right."

I wanted to point this out as a problem to be aware of in initiating these systems. I do not think there is a simple solution. A lot may be achieved, however, by carefully planning the organization, administration, and enforcement of the system so as to minimize the inequities.

Philip Cohen: I will try to summarize if I may. I think the main thrust of Della's point was, although she does not find fault with the concept of government developing a permitting system for developing and managing surface and ground waters, that, depending upon the social and economic environment, such a system may impose undue hardships in some cultures. She pointed out, for example, that the cost of applying for a permit and going through the process may become inordinately expensive, whereas in other areas it may be fairly simple. She also indicated that in the United States where there are matters to be litigated, there are certain costs associated with who can hire the best attorney. She agrees with the general concept but she is concerned about the methods of implementation depending upon the social, political, and economic environment.

Guillermo Cano: I do not think the cost to apply for a permit needs to be expensive. That depends on the requirements asked of the applicant. But how can the government know how much water has been used if it does not know who uses the water? The United Nations had a program in my province in Argentina under which they made a water balance study of the aquifer in the region. In this region of one million acres of irrigated land, thirty percent of the total water used was ground water. They discovered that there was a deficit of three cubic meters per second between the recharge and the use. The level of the water was going down. The farmers, owners of the wells, objected that every year they needed to deepen the well two or three meters. I am not proposing a complicated system of hiring lawyers and engineers. This can be made simple. I think in water-short areas, there is a need of government control because if not, what would happen is the primacy of a Far West law. The man who has the most powerful pump is the winner (not the gun, the pump). And then somebody must put order on that. If you look at the history of the development of ground water in many countries you will see a first period in which the government promoted more use of ground water. Then they established a system of protected rights for the first drillers. That means that a second driller cannot harm the availability of water to the first in chronological order. This was good when there was more water than people with a need. But now there are more people than water. This system of chronological priorities no longer works because if the government tried to enforce it we would have a revolution; we would have a war, a civil war. When time of shortage of water comes, somebody must put in force the system of rationing. That is my answer. I make it very clear that I, in my country, am a member of a conservative party, not on the other side.

I would like to address this question to Mr. Bruce. I am encouraged by the concept that water belongs to all the people. But in both Canada and the United States there are many instances where private interests win out: pollution, acid rains, the water table dropping, and there are many instances where private corporations right now are holding the upper hand as far as control of our water usage is concerned. Is it your perception, Mr. Bruce, that Canada, through its Federal government, has more control over its water resources than the United States, and secondly, do you feel that both countries should have more Federal control over the use of the water than is now exercised through the Federal governments?

James Bruce: I suspect, though it is hard to document, that the Federal government in the United States has more authority and more power in water matters than the Federal government in Canada. For one thing our provinces are much larger than the U.S. States geographically, and therefore are able to, within their boundaries, manage the water resources reasonably well, if they have a mind to do so. In the Canadian Federal government we try to focus on things of a transboundary nature. That is, to make sure that what a province does, doesn't hopelessly louse up what the next province or the United States could do, or vice versa. The basic responsibility for the local management of water resources in Canada rests with the provinces, and that is the way our constitution is written. I do not think that that is necessarily a bad thing. I think it is important that the Federal governments in both countries establish standards to ensure that one jurisdiction does not hurt another jurisdiction; for example, establishing national standards relating to pollution control problems so that pollution havens do not develop among the States and provinces. In some cases, I think, we have to take a very strong hand in management of toxic chemicals because, in fact, the only way you can reasonably control many of the toxic chemicals that get into our water systems is through control of the products used and either manufactured or imported into a country. So, there are a number of important roles that the Federal agencies have to play. I have a very strong feeling that, within those guidelines and within those roles, the provinces and the States should play an important role, or *the* important role, in local allocation of water and in dealing with the local requirements of municipalities and industries. I certainly think that in many cases our record is not good in both countries in reducing or controlling the pollution from industries. Certainly the acid rain problem is going to be a very severe one before we are through, and having listened, in a previous talk, to the problem of the volume of gases that will have to be dealt with in the stacks, I think it is not going to be an easy problem to solve. I do not know whether that answers your question.

O. Milton Hackett (USGS): I would like to suggest to Jim Bruce that probably Canada is in a substantially better situation, not because of having more control, but because of the antecedent conditions, which, in this country, by the time the problems are recognized by the public, are really quite out of hand at some places. The measures that have to be taken are very unpalatable, and I think you in Canada have had some chance to reflect on what has happened here and have taken advantage of our experience.

James Bruce: I think that is very true. Our population pressures have not developed as early as yours did and I think we have, through good cooperation with organizations like the U.S. Geological Survey, been able to learn from your experiences and tried to take advantage of them. I am not sure how wisely we have done so, but we have tried.

Philip Cohen: Are there any other comments or questions? If not, I would like to take this opportunity to thank our speakers, our discussant, Dean Peterson, our Chairman, Joe Cragwall, and all of you for coming and helping us celebrate our Centennial and for participating in this Symposium.

Geologic Hazards

Mount St. Helens, Washington. May 1980.

Earthquake Hazards, and Requirements for Their Mitigation in the Andean Region

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INTRODUCTION

As requested, I present some comments on the challenges, problems and requirements for assessment of earthquake hazards in developing countries in general and Peru in particular. Although damaging earthquakes occur several times each year throughout the Andean region and many of them have been catastrophes that killed thousands of people, caused great property loss, and delayed social and economic development, there has been a surprising lack of concern on the part of both the populations and governments involved. Public awareness is limited to the acknowledgment that a problem exists but in no way is this awareness translated into preventive action, despite frequent small and not so small tremors that are continuously reminding us that earthquake hazard is an ever-present and not an improbable occurrence.

After each major disaster, urgent priority action is taken to cope with the emergency, and there is nation-wide concern and mobilization to do all that can be done to provide relief for the victims. This is followed by the rehabilitation and reconstruction phases. Such relief activity quickly erases from the minds of the authorities, and of the people themselves, whatever thoughts they may have had as to the causes of the problem and the measures that should be given high priority in order to mitigate effects another time. Even the sequence of fairly strong aftershocks, which is characteristic of most large earthquakes, does little to concentrate attention on the importance of earthquake hazard studies. Perception of the danger from the earthquake itself and from its secondary effects is high in the stricken area immediately after the disaster but this is all forgotten not many months later. For instance, people will usually rebuild on the very same site where a recurring avalanche is bound to cause damage in the not too distant future. Indeed, there is no evidence that perception of earthquake hazards increases in regions near a devastated area—even within the same country.

During the years following a major earthquake, the rehabilitation and reconstruction efforts, which are often carried out with substantial aid from other countries, become projects that are generally implemented without much thought for the earthquake problems of the future. Frequently such reconstruction affords a seldom-found opportunity to build highways, new buildings, and public facilities, in "forgotten" areas of a country, but much of this work is done on the basis of expediency and political considerations rather than by taking into account long-term measures to reduce to a minimum an area's vulnerability to earthquakes.

But the situation is improving. Although not enough is being done to assess earthquake hazards or to implement appropriate programs for hazard reduction, at least most countries in the Andean region are becoming increasingly involved in research projects to evaluate seismic hazard and to reduce risk.

Significant progress has been made in studies of historical seismicity, a very important part of earthquake analysis. Descriptions of earthquake occurrences and shock effects can be found in archives dating back to the beginning of the sixteenth century, with some passing references to events of the late fifteenth century. Investigators from several countries have published impressive catalogues with such data but additional information is still to be located. It is a slow and painstaking process and the descriptive material must be converted so as to approximate contemporary magnitude and intensity measures and epicentral locations. Work is also underway on the re-analysis of old seismograms, the recalculation of parameters, and the compilation of comprehensive seismic catalogues.

PROJECT SISAN

Proposed in 1973, the pilot study of Seismicity in the Andes, known as SISAN, was approved and funded by the Organization of American States. The OAS provided US $65,000 to the Regional Center for Seismology for South America (CERESIS), so that I could carry out Project SISAN in Bolivia, Colombia, Ecuador, and Peru and produce preliminary seismo-tectonic and seismic risk maps. It was necessary to collect and catalogue data pertinent to the seismic history—hypocenters, earthquake magnitudes, and observed intensities, as well as any available information on active faults, particularly of the Quaternary period, and on avalanches, landslides, ground failures, and other geological evidence of earthquake activity. With the project nearing completion, more than thirty thousand seismic events have now been identified and the resulting data processed. Moreover, historical sources from more than five centuries have been examined, and relevant information from the year 1471 through 1977 has been compiled. Thus, on the basis of both reported damage and geological evidence, preliminary maps have already been produced.

Figure 1 shows a hazard map of shock intensity for Peru. Available archives and modern records were used to identify these earthquakes and to determine corresponding intensities according to the Medvedev-Sponheuer-Kornik Scale (MSK). The locations plotted on this preliminary map are points of maximum intensity and not the epicentral coordinates. The intensities were estimated from reports of damage, mainly to similar one-story houses, and from geological evidence, in order to represent, as nearly as possible, comparable average severity of ground shaking for the location most seriously affected by a given earthquake.

The size of the circles on the map indicates MSK intensities according to the scale shown. For intensities VIII or greater, the date of the event is placed within the respective circle; for intensity VII events, the date is next to the circle; and, for events of intensity VI or less, the numbers either inside or next to the circles indicate the number of events, and these events are not dated.

In Ecuador and southern Colombia the earthquake events are associated with volcanic activity; northward the record of intraplate events continues to Mérida in Venezuela. The hypocenters are shallow for this region except for the Bucaramanga area, in which the events occur at depths of about 165 km. The largest events shown for Peru, intensity IX, correspond to the Quiches earthquake of 1946, which had a measurable fault displacement of about 3 meters, and the two Huaytapallana (coordinates: 75.1 W. longitude, 11.9 S. latitude) shocks of 1969 which caused a vertical shift of 60 cm first and then of 1.70 m. The high earthquake intensities associated with active faults in Quiches, Cuzco, Moyobamba, and Huaytapallana are noticeable. The seismicity in Bolivia is relatively low.

Figure 2 is a seismic map of Peru showing known events for the period 1900–1976, showing epicenters, magnitudes, and depth of foci, based on instrumental data recorded since the beginning of the 20th Century. This type of map is also available for the other SISAN countries but it does not portray the earthquake hazard as clearly as do the shock intensity maps.

Most SISAN countries also have seismic zoning maps similar to that shown for Peru in figure 3. Peru has adopted three zones. The formula for the horizontal force H includes a Z factor of 1.0 for zone 1, 0.7 for zone 2, and 0.3 for zone 3. There are relatively few records from strong-motion instruments that can be used for design purposes throughout the Andean countries. In the past thirty years fewer than 20 accelerograms have been obtained in Peru, mostly at one site in Lima. Attenuation curves for maximum acceleration were estimated and compared with similar curves obtained elsewhere. This appears to show that South American shocks excite higher acceleration than did shocks in other areas. Taking into account the source mechanisms, fault dimensions, and other parameters obtained from data for 1900 to 1973, seismogenic areas in Peru have been delimited. Thus, seismic risk is estimated by the attenuation curves and the seismogenic zones that are in part derived from them.

In figure 4, a map made for the Department of Lima, Peru, shows maximum accelerations expected with an 80 percent probability that they will not be exceeded in a 50-year period. Earthquake maps of this type have been produced for many areas throughout the region. Another factor that is being taken into account for urban areas is soil response. Seismic microzonation, by various methods, is progressing at an increasing pace in several large cities.

PROJECT SISRA

A more ambitious project called Seismicity and Seismic Risk in the Andean Region (SISRA) will involve all the CERESIS countries in South America. With objectives somewhat similar to SISAN, Project SISRA was submitted for funding early in 1979 to the Office of Foreign Disaster Assistance of the Agency for International Development of the U.S. State Department. It is our understanding that the project will be adequately supported by OFDA/AID. SISRA is devoted to seismic risk evaluation. This means construction of data banks for seismic, geological and geodetic information, and improved hypocentral parameters; technical education and training; upgrading of existing seismological stations and the installation of new ones; and the implementation of a seismic net with satellite relay on a continental scale, using the GOES satellite. SISRA was scheduled to begin in 1980 and be complete in 1985.

IMMEDIATE AND LONG-RANGE BENEFITS OF SISAN

Project SISAN has been a very worthwhile exercise because its tangible results are of immediate application. It has also been an invaluable experience in bringing out the

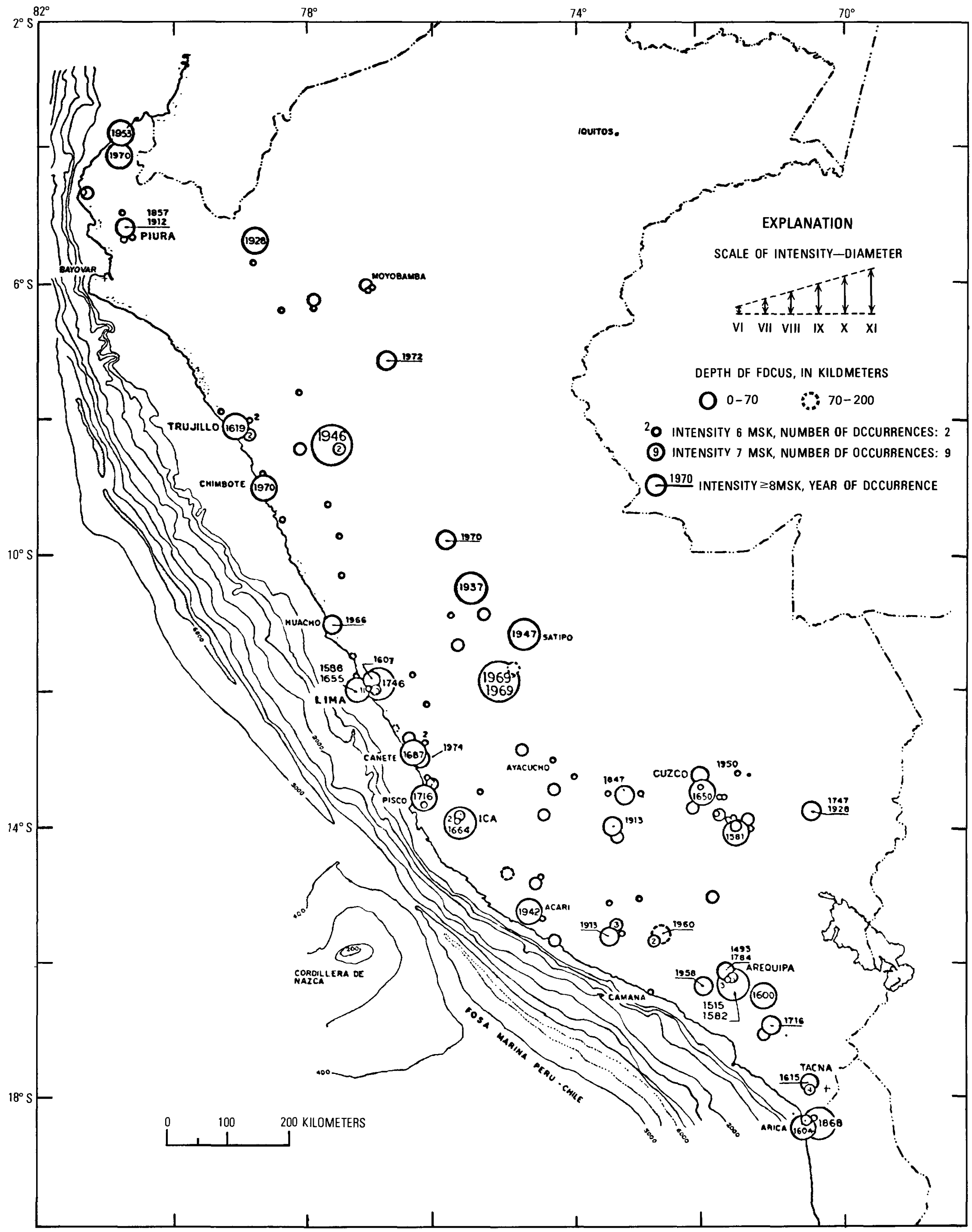

Figure 1 Preliminary map of earthquakes in Peru, plotted according to points of maximum intensity, from 1471 to 1974. [Intensities are estimated on the Medvedev-Sponheuer-Karnik scale (MSK); dates are given for events of intensity VII or greater; sizes of circles are proportionate to intensities. Data source: Project SISAN.]

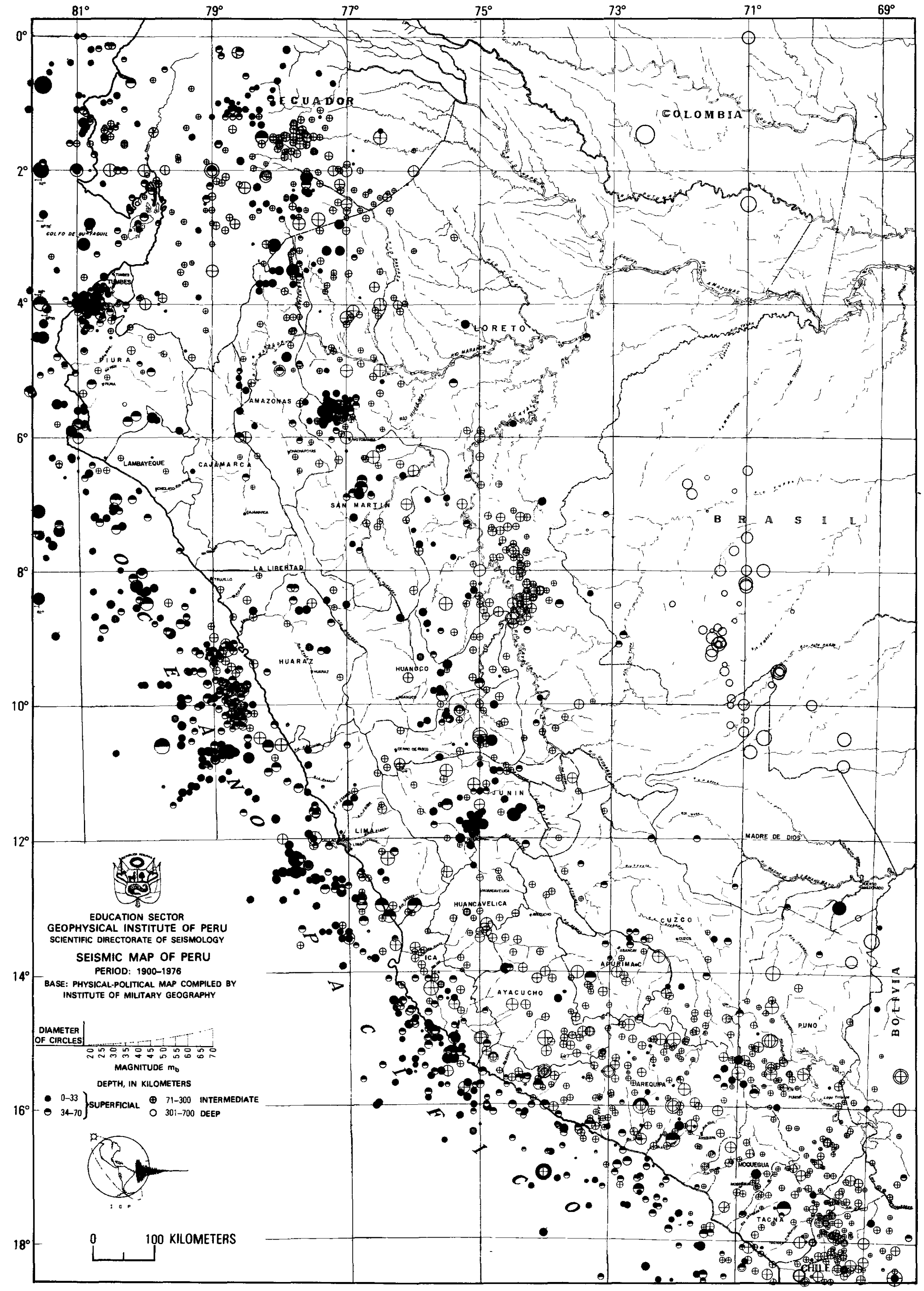

Figure 2 Seismic map of Peru, locating events from 1900 to 1976. (Epicenters, magnitudes, and depths of focus for plotted seismic events are based on instrumental data.)

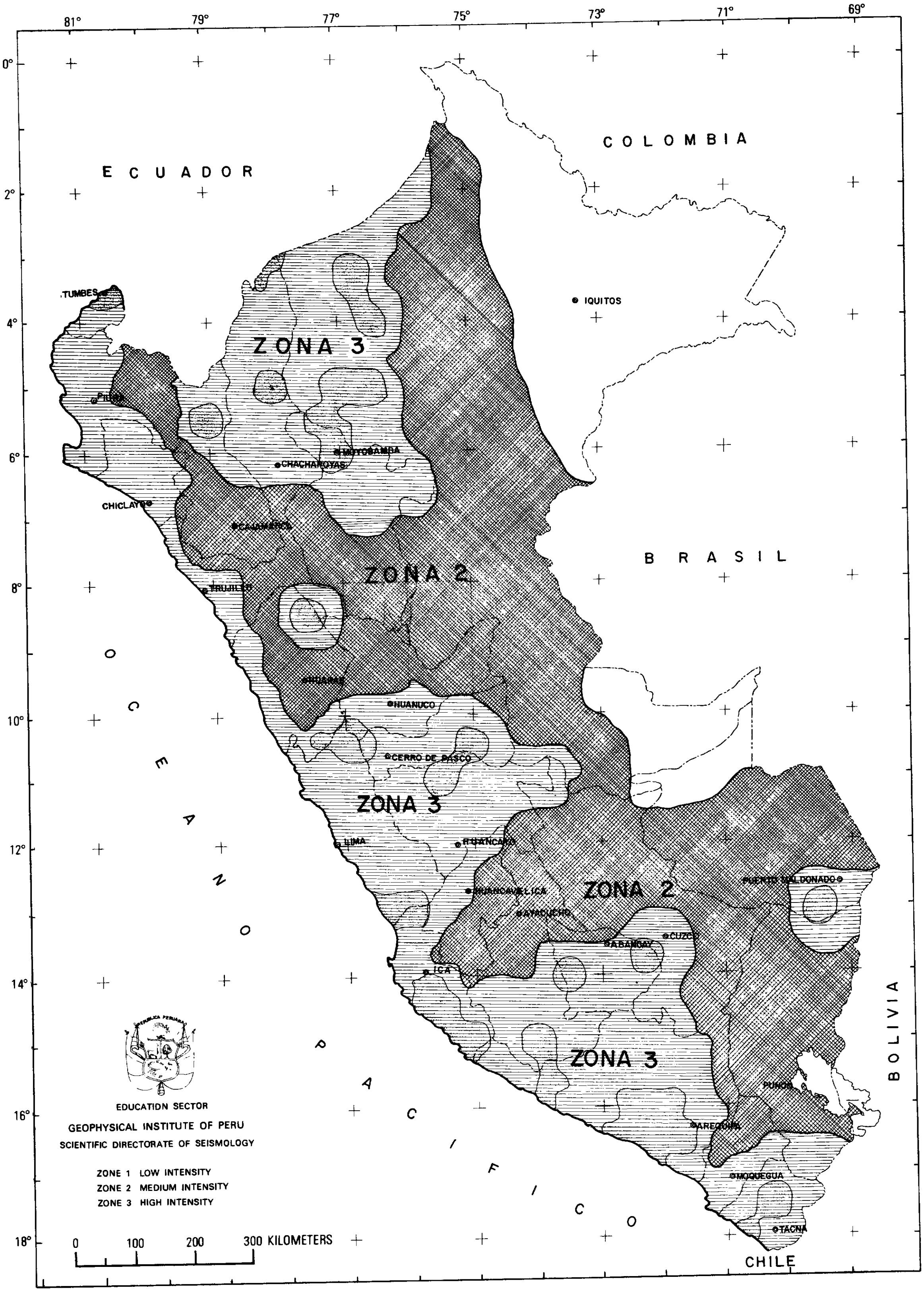

Figure 3 Seismic zoning map of Peru. (The formula for the horizontal force H includes a Z factor of 1.0 for zone 1, of 0.7 for zone 2, and of 0.3 for zone 3.)

difficulties that we must overcome to meet expected earthquake prediction goals, this despite the fact that our institutions are very much understaffed and the principal investigators appointed to SISAN have never had as much time as they should to devote to the project. Moreover, institutions within the same country do not work together easily; counterpart funds are always insufficient and are not always provided on a timely basis; all other urgent matters took precedence over SISAN—these and similar obstacles were and are constraints on this or any project of this nature.

In addition to projects like SISAN and SISRA, which require significant national commitment as well as matching funds from outside, important basic research relevant to the assessment of earthquake hazards is also underway. Most such effort is due to the initiative of foreign investigators under the auspices of their home institutions. Usually there is no significant participation by our local scientists, although locals are involved with aspects of logistic support. Often, in the past, data from such projects has not even been shared with our local institutions. An example is the Nariño Project (1973), which was designed to study crustal structure from seismic refraction data and was carried out in southern Colombia and northern Ecuador. It was carried out by the Instituto Geofísico de los Andes Colombianos, the Instituto Geofísico del Peru, the Carnegie Institution of Washington, the University of Wisconsin, the University of Texas at Dallas, the University of Hawaii, the University of Washington, Seattle, and the Institut für Geophysik of Kiel University. Other projects, similar to Nariño, have also been completed in central Colombia and southern Peru and Bolivia, with shotpoints offshore, or in fairly deep lakes, or by using large mining explosions. These have involved the Universities of Wisconsin, Texas, Oregon, and Washington, the Hawaii Institute of Geophysics, the Carnegie Institution, the Instituto Geofísico del Peru, the Instituto Geofísico Arequipa, and the Instituto Geofísico de Bolivia. Some of the results of these projects have been reported in the literature but a considerable amount of data is still to be processed and interpreted, although years have elapsed since the field work was done. Nevertheless, such research was and indeed is important. Other recent projects are as follows:

1. A collaborative project was begun in 1976 by the Instituto Geofísico del Peru and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. Together, Peruvian and American geoscientists looked for a shallow aseismic region near the coast and studied in detail the form of the Benioff zone in the region between 12 and 16 degrees south latitude and between 72 and 77 degrees west longitude. They are correlating this form with an interface in the region that is determined by the conversion of near-vertical shear waves. The region is also characterized by the existence of an electrical conductivity anomaly. Observations and data analysis are nearing completion.
2. Beginning in June 1980, scientists from the Massachusetts Institute of Technology (in the United States) and the Centre National de la Recherche Scientifique (in France) joined scientists of the Geophysical Institute of Peru (IGP) in a long-range study of both shallow and intermediate-depth earthquakes beneath Peru. One of their goals is to understand the active deformation of the Earth's crust that creates the Andes. They hope it will thus be possible to define the depth, orientation, and type of faulting resulting from the process. A second goal is to determine the configuration of the intermediate-depth seismic zone. As a result, we should gain a better understanding of how the Andean crust deforms, how the Nazca plate is subducted beneath Peru, and how to place constraints on earthquake hazards in Peru. MIT and CNRS plan to work on these problems for several years, and the data obtained by each team of earth scientists will be made available to all the others.
3. Another new joint project relates to neotectonics, especially since the mechanisms responsible for deformation are associated with strong seismic activity. The general objective of this new two-year project is to gain knowledge that will lead to a better understanding of the processes that originate seismic activity. Specialists from Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) of France will work with ours in the Geophysical Institute of Peru.
4. At present we are also discussing participation with the U.S. National Aeronautics and Space Administration in their Geodynamics Program, which seeks to apply space methods and technology to advance our understanding of earth dynamics because a successful earthquake prediction system must be based on a very good comprehension of tectonic processes. It is proposed to locate mobile stations Very Long Baseline Interferometry (VLBI) and Laser Ranging at several sites, arranged in five or six profiles and running from the coast over the Andes to the eastern plains, from Ecuador to Chile.
5. In cooperation with Canadian scientists from the Universities of Alberta and New Brunswick, a small geodetic net has been set up across the Huaytapallana fault, which is visible at the ground surface for 800 meters (fig. 5). The net has

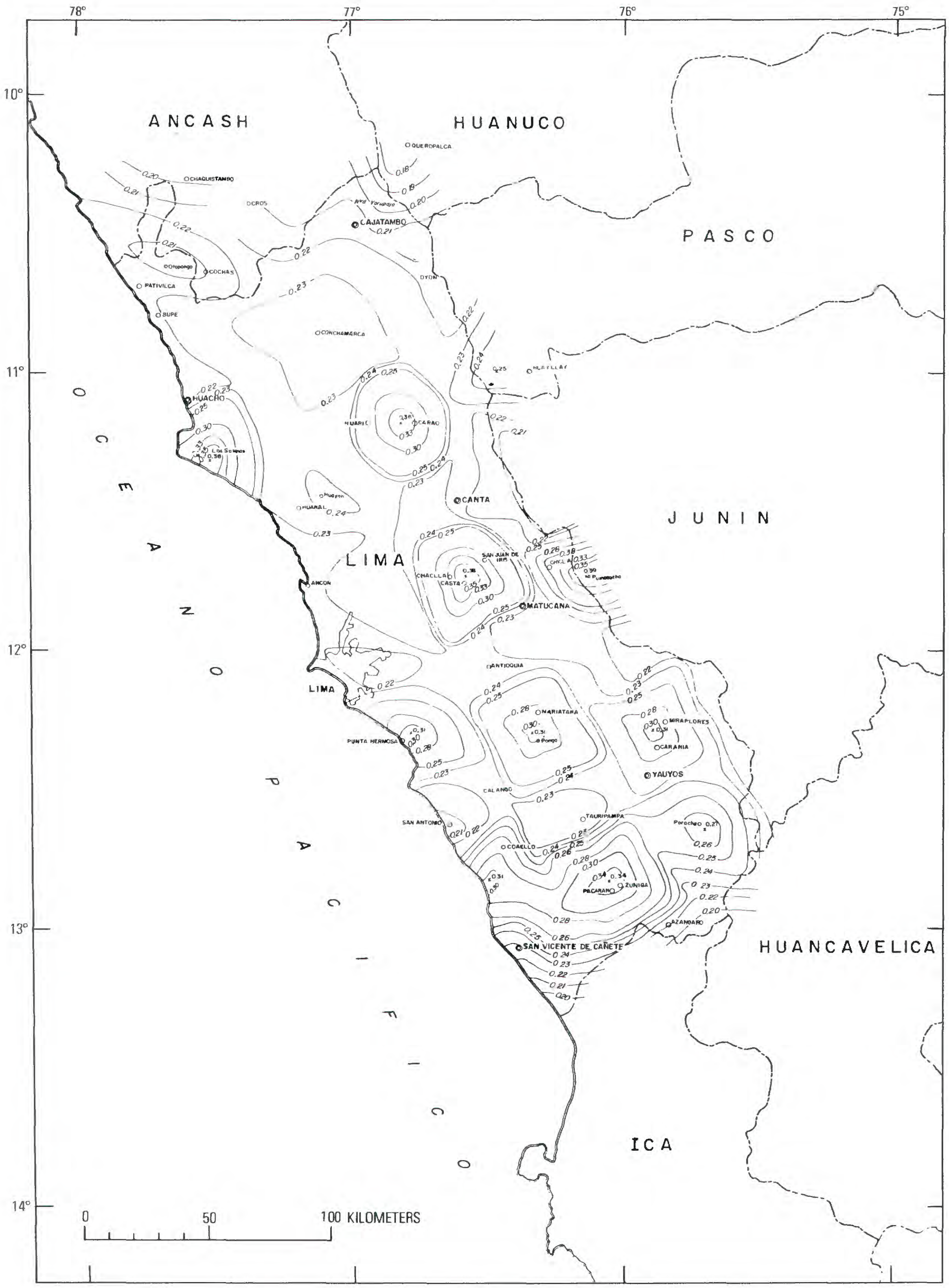

Figure 4 Area seismic risk predictions for the Department of Lima in Peru: Expected maximum accelerations as located, with an 80-percent probability of not being exceeded in a 50-year period.

Figure 5 View of part of the upthrust visible for about 800 meters along the Huaytapallana fault, which runs from the locality of Cosmos (Junin) about 16 km to the SE in Peru.

been remeasured periodically during the past six years, and as yet there is no evidence of movement. In figure 6 it is possible to observe the rock displacement which took place during the 1969 Huaytapallana earthquakes. This would substantiate the propositions that ground acceleration of 1.0 G and greater does occur in the fault-break zones. Similar small nets are being set up in other locations in Peru and other countries.

Research of the sort described in the above examples is to be found in several of our countries. It requires a fairly large budget, good equipment, laboratories, computing facilities, and qualified scientists. So we must encourage our foreign friends to continue such work in our countries, since it will be some years before we ourselves can allocate significant funds for the sole support of such basic science. At the same time we must produce a sufficient number of qualified geophysicists, seismologists, and geologists of our own, who have the same academic preparation and

Figure 6 Rock displacement visible after the 1969 Huaytapallana earthquake in Peru (measured at intensity XI MSK).

know-how as their foreign colleagues and are able to fully understand the objectives of a research project. Then they can participate actively and benefit from what they learn and relate it to the earthquake hazard and prediction capability needed in our countries.

Projects with regional objectives, such as SISAN and SISRA, are of more immediate relevance to hazard evaluation than is basic research. On a national scale, high priority should be given to projects such as the estimation of seismic risk in relation to huge dams and nuclear power plants, earthquake triggered landslides, expansive soils, liquefaction, tsunamis, and other secondary effects that are often difficult or even impossible to foresee and evaluate. Proper land-use planning from a seismic hazard point of view is recognized as an important way to reduce the hazard level, but there is really no general implementation of rational policies to this effect.

Civil Defense National Committees have been established in most South American countries for many years. These institutions are doing a very important and necessary job with regard to several kinds of hazards. In Peru, the National Civil Defense Committee appointed a scientific advisory group drawn from other government agencies. Without a budget, this group depends on the voluntary contributions of people employed elsewhere. Despite such a constraint the group has done some interesting work, for example, on the evaluation of the "physical factor" with regard to the hazard potential. This project includes investigations in the fields of external geodynamics, such as landslides, mudflows, subsidence, rock fall, liquefaction, inundation, tsunamis, and sand migration, and of internal geodynamics, such as earthquakes and volcanism. Effects of rainfall, electrical storms, freezes, ocean currents, droughts, pollution and other man-made hazards are also included. This is, of course, a very ambitious project and one that will take many years to complete but, at least, it is an effort that makes a few people aware of the general problem.

Defensa Civil has also sponsored a project to determine the impact on the city of Lima of a destructive earthquake of intensity IX, estimating the probable damages, as a percentage of the value of the property, to different building types and to public utilities: water supply, sewage, power, transportation, and communications. Secondary effects such as tsunamis and fire have also been estimated. The study concludes that a seismic event slightly stronger than the events of 1940 and 1974 would have catastrophic consequences. Much has still to be done, but this effort and the other hazard-assessment activities that I have described illustrate the fact that, in countries like Peru, people are becoming more knowledgeable and more aware of what should be done to reduce the damage potential. But there is still much to be done to adopt and to enforce official policy that will translate earthquake-hazard assessment into appropriate action for the protection of people's lives and the reduction of property damage.

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An Earthquake Research Programme in Turkey

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INTRODUCTION

Turkey is one of the seismically most active continental regions in the world. The rate of recurrence for destructive earthquakes in Turkey is about 1.1 per year. In addition to contemporary data, we have historical records going back 2,000 years. For example, at least 14 destructive earthquakes have occurred in Niksar, a town on the North Anatolian Fault, during its long history. Again, Erzincan has been completely destroyed five times by the worst of the 23 destructive earthquakes that have occurred in that region of east central Turkey where 150,000 people have lost their lives. Millions of people in Turkey live with a significant risk to their lives and property from earthquakes; that is to say, 22 percent of the population live in first-degree earthquake regions, 29 percent in second-degree earthquake regions, and 25 percent in third-degree earthquake regions. Thus, only a very small percentage of the Turkish people can ignore the earthquake hazard. Most people occupy buildings that were not designed to be earthquake resistant, and most of these buildings could collapse in an earthquake with major losses of life. According to official figures, 65,000 deaths were due to earthquakes between 1900 and 1977. Today, 25 percent of our industrial centers are located in the first-degree earthquake regions, and 49 percent in the second-degree earthquake regions. Figure 1 shows earthquake damage after the November 24, 1976, Çaldiran ($M_s = 7.3$, 4,000 deaths) and August 16, 1966, Varto ($M_s = 6.9$, 2,500 deaths) earthquakes. The toll of an earthquake in Turkey or in any developing country is much higher than in a developed country, and, as a result, earthquake prediction studies are a much more important undertaking in developing countries than in the developed countries.

Earthquake prediction is still in a research and experimental stage. However, theory and experience are advanced enough to justify confidence that an expanded prediction capability can be achieved. The need for more data on responses to earthquake prediction should already be obvious, and much can be learned from carefully planned monitoring of responses to actual predictions of earthquake.

Turkey, with a well-known active plate boundary and very high seismic activity produced by different kinds of source mechanisms, is an ideal place to test the monitoring of the known physical precursory phenomena. Because of its higher seismic activity and correspondingly higher hazards to life and property, the starting point for earthquake prediction in Turkey is the North Anatolian fault zone, along which the European and Anatolian plates move transcurrently. The area offers many opportunities to monitor such parameters as the aseismic creep along the well-exposed fault trace, the high microearthquake activity (averaging 5 events per day), and water level changes in established observational water wells, as well as the opportunity to make geodetic measurements at the preestablished net. Another particularly important reason for selecting this area to test precursory phenomena is the seismic gaps that exist in several parts of the fault zone (Toksöz and others, 1979).

Current and planned earthquake prediction programs in Turkey are sponsored mainly by the Mineral Research and Exploration Institute of Turkey (M.T.A.), a sister organization of the U.S. Geological Survey.

SEISMICITY OF TURKEY

The seismicity of Turkey demonstrates several aspects of the plate tectonics theory exceptionally well in certain parts of the country. In the north, seismic activity is associated with the slip of the North Anatolian transform fault, which is quite similar to the San Andreas Fault, having also a well exposed fault trace, creep, and predominantly righthanded motion. The East Anatolian transform fault connects the North Anatolian Fault and the Dead Sea rift to form a triple junction at Karliova in east central Turkey. The East Anatolian Fault shows sinistral motion while the Anatolian Plate moves westwards. In the southeast there is a major thrust zone. In western Turkey, however, seismic activity is associated primarily with normal faulting. Figure 2 shows the earthquake epicenters in Turkey.

The North Anatolian Fault seems to have episodes of seismic unrest, separated in time by quiescent periods of about 150 years (Ambraseys, 1970). Now, during this most recent cycle the style of seismicity of this fault zone is similar to the behavior of the San Andreas Fault in California. The unstationary character of earthquake occurrences along the fault zone still exists in this last cycle, with relatively high activity between 1850 and 1900, a quiet period from 1910 until 1939, and an active period from 1940 to the present (Toksöz and others, 1979).

Using the data from 1900 to 1971, Alptekin (1973) has studied frequency-magnitude relations in Turkey. He first considered Turkey and the surrounding areas as a single region, then subdivided the area into thirteen subregions. His division was based on the space distribution of earthquakes and on the major tectonic lines.

A comparison of the frequency-magnitude relations indicates higher b-values for the eastern and the western parts of the North Anatolian Fault Zone. Seismic risk estimates based on these frequency-magnitude relations indicate higher seismic risk due to larger earthquakes in the central part of the North Anatolian Fault Zone than in the relatively more active eastern and western sections. Two possible earthquake gaps on the North Anatolian Fault (between longitudes 29°–30° E. and 42°–43° E.) have been indicated by Toksöz and others (1979).

The earthquake epicenters on the northeast side of the eastern segment of the North Anatolian Fault are quite scattered (fig. 2). Aerial photographs and surface mapping show that the general trend of the faulting in this area is parallel to the North Anatolian Fault, and there exist some visible foldings indicating a NE. to SW. compression (Saroglu of M.T.A., personal commun.; Şengör, 1979; Şengör and Çanitez, 1979; Şengör and Kidd, 1979).

An earthquake with magnitude $M_s = 7.3$ hit the Çaldiran area on November 24, 1976, and caused more than 4,000 deaths. The surface faulting accompanying this event was parallel to the North Anatolian Fault with a strike direction of about N. 70° W. at the western part, and N. 135° E. at the eastern part of the fault (Arpat and

Figure 1 Earthquake damage in eastern Turkey. *A*, School building collapsed after August 16, 1966 earthquake. *B*, A collapsed building at Karliova, near the junction of the North Anatolian and East Anatolian faults. The building was located right on the fault. *C*, A view of November 24, 1976 Çaldiran earthquake. *D*, 3-m right-handed offset after Çaldiran earthquake. Photographs by Ihsan Ketin.

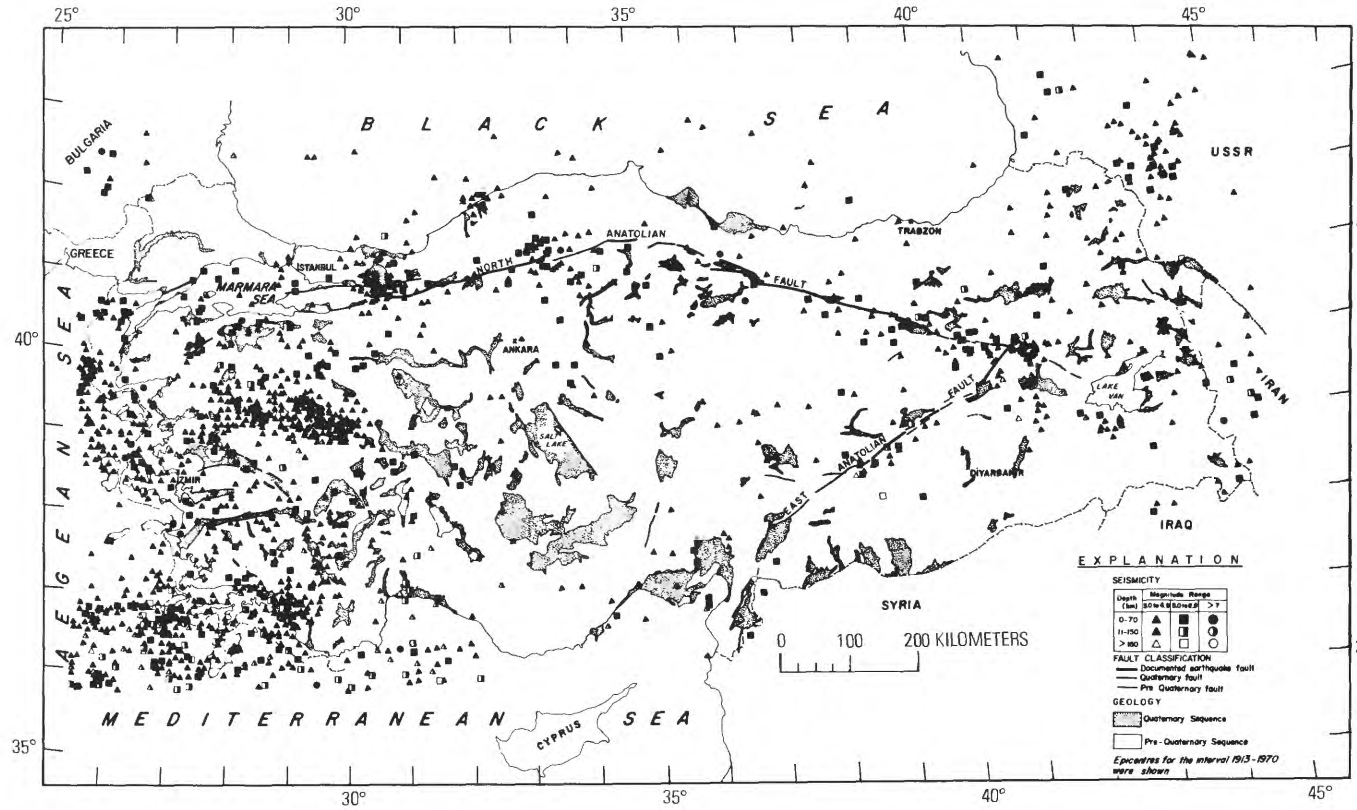

Figure 2 Locations of earthquake epicenters in Turkey (map compiled by Aydogan Boray of the M.T.A. Institute of Turkey).

others, 1977; Toksöz and others, 1977). Figure 1*D* shows the 3-m right-handed offset of the fault. The stress drop calculated from the static parameters of the fault is higher than that of some other strike-slip faults (Toksöz and others, 1977; Toksöz and others, 1979).

A microearthquake study undertaken by the M.T.A. Institute in this area indicates that the three other en echelon faults (Tutak, Hasantimur Gölü, and Balik Gölü faults) are also very active (Aktimur and others, 1979). This active faulting and high stress accumulation support the idea that this part of Turkey might be a potential area for another strong earthquake. Taking into account the length of the seismic gap, Toksöz and others (1979) expect a magnitude 7 earthquake, with a rather speculative assessment because of the limited knowledge of geology, tectonics, and seismic history of the area.

The strike-slip faults north of Lake Van in southeast Turkey in general are regarded as the elements of the convergent regime of the Turkish-Iranian plateau and not as the continuation of the North Anatolian Fault (Şengör and Kidd, 1979; Şengör and Çanitez, 1979) though some interpretations exist favoring the idea that they are the translation of the North Anatolian Fault to the northeast (Toksöz and others, 1979).

Another important seismic region in Turkey is the East Anatolian Fault. This fault starts from the village of Karliova in the north, forms a triple junction with the North Anatolian Fault, and continues in a southwesterly direction up to the Hatay rift valley in the south, which is a roughly NNE.-striking narrow graben located at the northern end of the Dead Sea rift. The East Anatolian Fault is located within the Tauride tectonic unit and cuts the unit with a low angle. In the southern part, it is almost parallel to the border folds and the southern Taurus boundary thrust.

Very little is known about the age and offset of the fault. Presently available data indicate that the fault started moving during medial Miocene (probably Burdigalian) time, perhaps at the same time that the North Anatolian Fault was developed (Dewey, 1977; Şengör, 1979).

Distribution of earthquake epicenters (fig. 2) and displacements in the Quaternary sequences observed in the field and from aerial photographs (Arpat and Şaroglu, 1972, 1975) reflect the recent movements of the East Anatolian Fault. Present-day seismic activity of the fault is not as high as that of the North Anatolian Fault. However, historical and archeological data indicate that the East Anatolian Fault and the fault zone south of it were very active in the past (Ambraseys, 1970, 1971; Arpat and Şaroglu, 1972).

A microearthquake study was undertaken by the Technical University of Istanbul with collaboration of the M.T.A. Institute at a dam site on the Firat River at

Karakaya, near the East Anatolian Fault. Since a part of the dammed-up lake will be on the fault, it was decided to monitor microearthquake activity before the impounding of the dam. The study showed that the microearthquake activity was as high as 5 events a day (Ercan, 1979).

The source mechanisms of earthquakes are consistent with the observed left-handed displacement of the East Anatolian Fault (McKenzie, 1978; Büyükaşikoglu, 1979). In southern Turkey, near the Adana Basin and around the junction of the fault with the Hatay Rift, the source mechanisms of earthquakes are predominantly tensile in character as is to be expected from the geometry of the faults and plate tectonics of the area (Alptekin and Ezen, 1978; Büyükaşikoglu, 1979).

South of the East Anatolian Fault there is another seismic area partly covering the Bitlis Suture zone. The earthquake activity in this region is mainly associated with the Southern Taurus Boundary Thrust. A destructive earthquake in this area occurred at Lice on September 6, 1975 ($M_s = 6.7$, 2,400 deaths). The source mechanism of this earthquake was thrust faulting with left-handed strike component, which is quite similar to the San Fernando earthquake (Nabelek and Toksöz, 1978).

Earthquake activity in western Turkey is quite high. Generally speaking, the seismic activity in this area is mainly controlled by the extensional regime in the Aegean area. However, the complicated geometry of the faulting in this area and the interaction between adjoining microplates create a complicated strain pattern, and, as a result, we observe strike-slip faulting at the two western strands of the North Anatolian Fault, normal faulting at the Marmara and Menderes graben systems, and thrust faulting in southwestern Turkey (McKenzie, 1972, 1978; Çanitez and Ücer, 1967; Dewey and Şengör, 1979; Alptekin, 1973).

For a better understanding of the present-day tectonics of Turkey and surrounding areas, closer attention has to be given to the North Anatolian Fault Zone. It is likely that we can thus collect more beneficial data to understand the nature of deformation of the plates in the Eastern Mediterranean area. A brief summary of the evolution and morphology of this fault therefore follows.

Evolution and Morphology of the North Anatolian Fault

A tectonic boundary coincident with the present North Anatolian Fault was recognized early in the 20th century (Nowack, 1928; Salomon-Calvi, 1936, 1940), but it was interpreted as an integral part of the orogenic structure in Turkey. Based on his previous experience in the Central Alps and Corsica, Salomon-Calvi viewed it as the suture zone along which the converging Eurasian and Gondwanan continental elements had been apposed during the Alpine orogeny.

Ketin (1948) was the first one to recognize the strike-slip nature of the entire structure. He synthesized the results of the field work carried out on earthquakes that had occurred on the fault between 1939 and 1948. He remarked that the entire Anatolian block south of the fault was rifting westwards with respect to the regions north of it.

Since the beginning of the 1960s, numerous studies, both geological and geophysical, have been undertaken to understand the present structure, the behavior, and the geological evolution of the North Anatolian Fault.

The North Anatolian Fault is a long and narrow, dextral strike-slip fault zone that extends from the Gulf of Saros in the west to the vicinity of the village of Karliova in the east. Thus defined, it has a length of about 1,300 kilometers.

Morphologically, the North Anatolian Fault is extremely well-defined for the largest part of its course as a narrow "rift." The fault zone exhibits numerous cut-off, offset and dammed stream valleys, sag ponds, island-like hills within major stream valleys following the rift zone of the fault, and springs with associated travertine deposits. In the rift zone, the country rock is extremely crushed and mixed (Ketin, 1957, 1969; Allen, 1969; Wallace, 1968; Şengör, 1979; Seymen, 1975; Ambraseys, 1970). The photographs in figure 3 show the morphological character of the fault zone.

Until the 1970s, the scarcity of field data on the general geology of the North Anatolian Fault Zone was the primary cause of the wide disagreement among various workers as to the age and cumulative offset of the fault. Blumenthal (1945) viewed the structure as "Cratogenic," which implies a post-orogenic time of origin. In 1948, Ketin emphasized that the North Anatolian Fault had nothing to do with the orogenic structure of Turkey, but instead, was a young, post-orogenic element ruptured during the Neogene. Pavoni (1961) argued that the fault must have originated during the early Tertiary and probably has an offset on the order of 350 to 400 kilometers. However, the succeeding field work not only fully confirmed Ketin's original estimate with respect to the age of the structure, but also showed that Pavoni's offset estimate was too large. Ketin (1976) indicates that before the medial Miocene, at least the morphological expression of the fault did not exist. The geological data presently available bracket the age of initiation of the fault between the Burdigalian and the Pliocene (Abdüsselamoglu, 1959; Dewey and others, 1973; Erinç, 1973; Seymen, 1975; Tatar, 1975; Bergougnan, 1976; Ketin, 1976).

Although a Neogene age, bracketed between the Burdigalian and the Pliocene, seems well-established for the entire structure, we still lack the very detailed observations needed to see whether different segments of the fault are of the same age or whether they began their activity at different times.

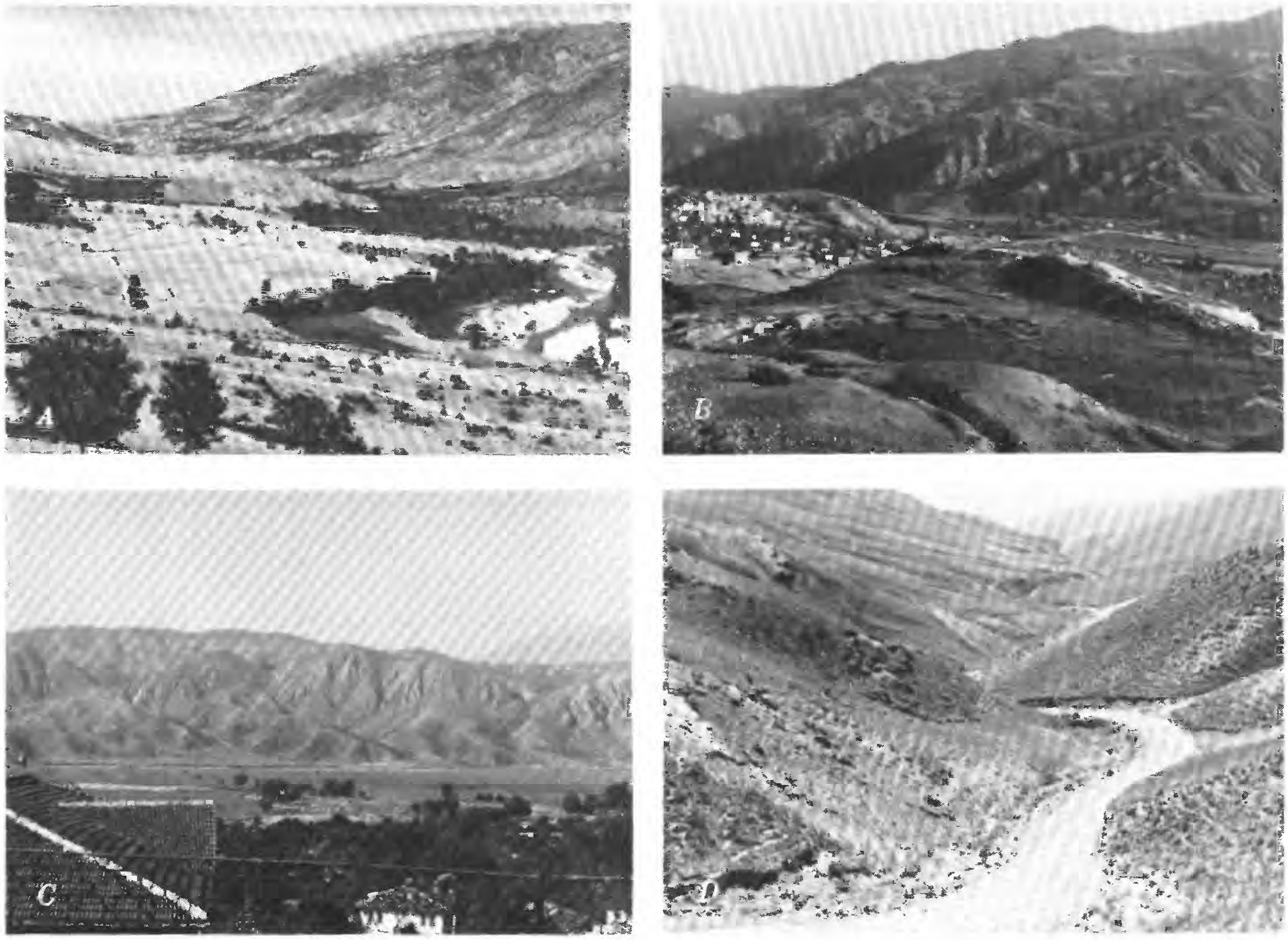

Figure 3 Morphology of the North Anatolian and Caldiran faults. *A*, Typical fault morphology at the Melen Creek Valley along the North Anatolian Fault Zone. *B*, North Anatolian Fault near Resadiye. Rift morphology accompanying the hot water springs and travertine deposits which are seen in many parts of the fault. *C*, Rift morphology within metamorphic series in Kizilirmak Valley, south of Kargi. *D*, Central part of the Çaldiran fault reactivated in 1976 earthquake. Photographs by Ihsan Ketin.

The North Anatolian Fault is one of a large number of big strike-slip faults that strike at low angles to the segments of the orogenic system in which they are located. Such faults seem to have originated late with respect to the compressional deformation that largely shaped the orogen. The genesis of these structures is viewed as an integral part of the process of continental collision (McKenzie, 1972; Molnar and Tapponnier, 1975; Şengör, 1976; Dewey, 1977). For the specific case of the North and East Anatolian Faults, McKenzie (1972) and Dewey and Şengör (1979) suggested that the medial Miocene collision of Arabia with Eurasia caused crustal thickening, as a result of north-south shortening, in eastern Anatolia. The Anatolian plate was thus squeezed out along the two newly-generated plate boundaries, the North and East Anatolian Faults, so as to consume the subductable oceanic lithosphere of the eastern Mediterranean along the Hellenic Trench.

In conclusion, we can say that the North Anatolian Fault is one element in the complicated "incomplete" collision system of the eastern Mediterranean and that its evolution has progressed in time in harmony with the related structures that surround it.

RESEARCH PROGRAM ON EARTHQUAKE PREDICTION IN TURKEY

The human and economic losses due to earthquakes are particularly serious in the developing countries. The increase in population and the tendency towards urban concentration may increase the toll of future earthquakes.

The population growth in the developing countries has caused a very rapid expansion of towns and a considerable proliferation of large urban areas, the growth of which is neither planned nor controlled. This phenomenon is causing and perhaps will continue to cause increasingly severe human and economic losses.

First Phase

The widespread concern aroused by such destructive earthquakes as those in Lice in 1975 ($M_s = 6.7$, 2,400 deaths) and in Van Province in 1976 ($M_s = 7.3$, 4,000 deaths) led to the mobilization of Turkish institutions for earthquake prediction studies. Organizational meetings were sponsored by the Scientific and Technical Research Council of Turkey (TUBITAK), and were attended by representatives of universities, ministries, observatories, and the Mineral Research and Exploration Institute (M.T.A.). The M.T.A. was chosen as the lead agency for earthquake prediction and given the primary responsibility for all field operations.

The program was organized to include:

1. Detailed geological mapping of active fault zones;
2. Monitoring of microearthquakes;
3. Ground deformation measurements; and
4. Collection of earthquake statistics to prepare a data base for risk analysis and to locate seismic gaps along major fault lines.

An extensive program for the mapping of the active fault zones has already been started by the Department of Basic Research of the M.T.A. Institute. Studies involving fieldwork, space images, air-photos, and microearthquake studies have led to the discovery of active faults that had not been recognized before. One such example is the right-lateral, strike-slip fault named the "Tutak Fault." It was found to be similar to the Çaldiran earthquake fault on the basis of such features as sense of motion, direction, and length. The Tutak and Çaldiran Faults constitute an en echelon system whose third member is the Balik Gölü Fault located at the north of the Çaldiran Fault, 50 kilometers away.

The most complicated and important part of eastern Turkey has already been mapped with Landsat imagery and fieldwork. This mapping covers mainly the junction of the North and the East Anatolian Faults and the area extending up to the Iranian border and will be published soon (F. Şaroglu of the M.T.A., personal communication).

The M.T.A. Institute has sponsored fieldwork by universities in monitoring microearthquakes along the North and the East Anatolian Faults. Monitoring of seismicity using a small portable array between 1975 and 1977 indicated that, on the average, there were about 5 local earthquakes per day along the North and the East Anatolian Faults.

Ground deformation along major fault zones and anomalous tilts prior to some earthquakes have been observed (Johnston and Mortensen, 1974; Johnston and others, 1975; Rikitake, 1974, 1976; Thatcher, 1976; Savage and others, 1973; Castle and others, 1976). With the collaboration of the M.T.A. Institute and the Technical University of Istanbul, two bore-hole type tiltmeters have been installed on the Menderes graben in western Turkey. Well-documented creep has been observed along the North Anatolian Fault at Ismetpaşa (lat 40.8° N., long 32.7° E.) (Geotimes, 1972). There is also some evidence of creep further west, near 32° E.

In order to make reliable estimates of the time, place, and magnitude of future earthquakes, an ultimate prediction system has to be based on well-understood physical principles. Particularly a basic understanding of the tectonic process is required to achieve a practical earthquake prediction capability. This requires detailed observations regarding the nature of the contemporary movements of the plates, the nature of their deformation, and the changes of strain field with time near a given plate boundary by repeated surveys of a network established for these purposes. Some seismic markers were placed by the M.T.A. Institute around the North and East Anatolian Faults, and in western Anatolia as well, to initiate conventional geodetic surveying. This effort starts this year (1979).

Repeated surveying of small networks using conventional techniques gives us detailed and quite accurate information about the near-field deformation of the Earth's crust. However, for information about global-scale deformation, long base line measurements are necessary. Conventional geodetic techniques are not accurate enough for this purpose. The North Anatolian Fault is a logical candidate, along with the San Andreas Fault of California and the Alpine Fault of New Zealand, for large scale investigations of the lateral motions of plates across the faults. Space technology is the most suitable means to achieve this goal. It is both the most economical and practical means, since it does not require extensive road networks and active continuous measurements. For example, passive ground networks of reflectors can be integrated with satellite-borne lasers. To that end, the European Space Agency is presently formulating a program for the application of space technology to measurements of the North Anatolian Fault (ESA, 1979).

One important point in geodetic measurements is the continuity of the program, and in general, developing countries have experienced difficulties in sustaining continuous measurements. However, the use of mobile stations within an international program could be most helpful in overcoming these difficulties.

Second Phase

The second phase of prediction studies in Turkey was started this year 1979 within the framework of a research project sponsored by the U.S. Geological Survey, and under the leadership of Dr. Mehmet Nafi Toksöz of the Massachusetts Institute of Technology. The program is carried out as a cooperative project by M.I.T. with the M.T.A. Institute and two Turkish universities (Istanbul

Technical University and Karadeniz Technical University). The instruments are provided by the U.S. Geological Survey. The M.T.A. Institute provides the sites, local logistical and labor support for installation, and assumes the responsibility for routine operation and maintenance. The project will include the following work:

1. Installation of short and long period seismic stations in eastern and southern Turkey;
2. Installation of a relatively dense network for a detailed study of seismicity and possible earthquake precursors at the western segment of the North Anatolian Fault;
3. Ground tilt measurements in western Anatolia;
4. Creep measurements along the North Anatolian fault zone; and
5. Monitoring water level changes in water wells.

An eight-station network of portable instruments has been in operation along the western segment of the North Anatolian Fault since July 1979. There are 20 short period seismic stations operating in the Marmara region, including those of Kandilli Observatory (fig. 4). One seismic station, with both short and long period instruments, has already been installed at Trabzon, in northeastern Turkey. The second station of this type will be located at Adana, near the junction of the East Anatolian Fault with the Dead Sea Rift. The site preparation of this station is finished and the instruments are scheduled for installation this autumn (November 1979).

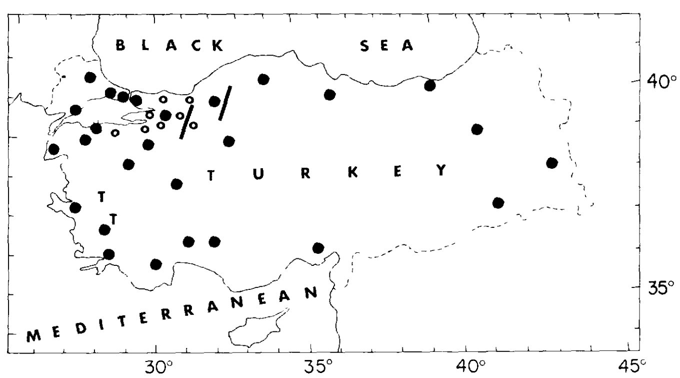

Figure 4 Location map of seismic instrumentation in Turkey. Dark circles designate permanent seismic stations; small open circles, portable seismographs; T, tiltmeter sites; bars, creep meter sites.

Because the developing countries are hampered by both inexperience and severe economic problems, international and (or) bilateral cooperation are necessary if they are to begin useful earthquake prediction studies. Thus the cooperative program between the U.S. Geological Survey and the M.T.A. Institute of Turkey, which was started this year, will not only initiate prediction studies in our country, but it will also supply more input to world knowledge of earthquake prediction. We are sure also that this program will encourage additional physical measurements by the Turkish scientific groups.

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Volcano Hazards—Lessons Learned in the Eastern Caribbean

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INTRODUCTION

Active volcanoes and earthquakes threaten the lives and property of people in many parts of the world. Scientists in numerous countries have intensified efforts to understand and predict these phenomena, but much additional work needs to be done. Two aspects of the volcano hazard, those relating to the adequacy of baseline geophysical data and the interactions among scientists and members of the press corps, can be brought into somewhat sharper focus by considering, very briefly, two recent eruptions in the eastern Caribbean—on Guadeloupe in 1976 and on St. Vincent in 1979. The lessons learned as a result of these experiences are pertinent not only to volcanologists but to earthquake specialists as well.

The habitat of active volcanoes around the world is very much the same as that of destructive earthquakes. If plotted on a world map, most volcanoes and epicenters of earthquakes occur in rather narrow zones or bands that coincide with the boundaries between the giant plates or slabs of lithosphere that, according to the theory of plate tectonics, are slowly moving over the Earth's surface. Specifically, most earthquakes and volcanoes are clustered in places where these plates are being created and moving away from each other (such as along the mid-ocean ridges) and in places where these plates collide and override (such as along the "circle of fire" that rims the Pacific Ocean). Significantly, places where lithospheric plates slide laterally past each other, such as along the San Andreas fault in California, are places where large earthquakes can be expected, but where there is little or no volcanic activity.

Focusing more closely on the eastern Caribbean, volcanoes that have erupted within the past few hundred years, or within the recent geologic past, form a gently curving necklace-like array extending from Saba in the north to Grenada in the south. At depth, the lithospheric plate underlying the central Atlantic Ocean is slowly descending beneath the Caribbean plate, and this process, called subduction, results in partial melting of rock at depth. This melt rises buoyantly to the surface, producing the volcanic activity that is so characteristic of island arcs, such as the one lying along the eastern margin of the Caribbean Sea.

Looking at the same map of the eastern Caribbean in a somewhat different way, it is possible to appreciate one important difference between the hazards posed by volcanoes and earthquakes. Volcanoes occur as discrete entities, virtual dots on a map, and the location of the hazard is considerably constrained. Land use planning and strategies for evacuation can therefore be developed in the context of the specific areas that might at some time be exposed to danger. Hazardous earthquakes, on the other hand, can originate anywhere beneath a wide band extending along the Lesser Antilles, and therefore the hazard posed by earthquakes in this area, and in similar areas around the world, is much more pervasive. In a sense, therefore, volcano hazards can be dealt with more straightforwardly, because we already know where future hazards are likely to occur.

What is the nature of the volcanic hazard in the Lesser Antilles? In brief, volcanoes such as Soufrière, on St. Vincent, and Mont Pelée, on Martinique, are amongst the most dangerous in the world. The lavas that they emit are fairly viscous and contain significant amounts of water vapor and other dissolved gases. These characteristics tend to cause extraordinary build-ups of pressure within the volcanoes' underground plumbing systems, leading to explosive eruptions at the surface.

The most infamous eruption in the Lesser Antilles in historic time took place in May 1902 on the French island of Martinique. Mont Pelée, which rises just to the northeast of the city of St. Pierre, erupted violently and sent avalanches of searing hot gases and debris pouring down the slopes of the volcano. The edge of one of these avalanches swept across St. Pierre, killing all but one of the town's 29,000 inhabitants in a matter of seconds. The two volcano crises of the 1970s, which are the chief focus of this brief report, can better be appreciated by keeping in mind that the memory of the St. Pierre catastrophe has not been forgotten by the people of the Lesser Antilles.

CRISIS ON GUADELOUPE, 1976

The first volcanic crisis of the 1970s took place at La Soufrière volcano on the French island of Guadeloupe.

Abnormal counts of local earthquakes began to be recorded in mid- and late 1975, and by the spring of 1976 the volcano had been the site of many hundreds of small earthquakes. In early July, steam and ash burst from the summit of the volcano accompanied by numerous felt earthquakes, and even the most sanguine of the local inhabitants knew that they were dealing with a highly unstable volcano. By mid-August 1976, steam and ash were erupting almost continuously from the summit of the volcano and hundreds, or even thousands, of local earthquakes were recorded each day (fig. 1). Fearing the worst and, of course, remembering the fate of St. Pierre on another French island in 1902, and having inadequate baseline data upon which to make accurate predictions, civil authorities ordered the evacuation of all 72,000 people living on the slopes of the volcano—including all of those inhabiting the capital city of Basse Terre (fig. 2).

Figure 1 Oblique aerial view of the summit of La Soufrière, Guadeloupe, August 1976. Plume of vapor and ash boils from the summit of the volcano; the villages and towns that can be seen in the background were totally evacuated during the crisis.

Figure 2 Street scene of the totally evacuated capital city of Basse Terre, Guadeloupe, August 1976. The smoldering summit of La Soufrière rises just to the east of the city.

The evacuation, once implemented, rapidly became a nightmare. The much feared eruption never did occur, and the tens of thousands of evacuees became more and more restless as the weeks and months dragged on. After three and a half months of costly disruption to the people and economy of the island, the French government assembled an ad hoc *Comité Scientifique Internationale sur la Soufrière*, to help decide whether or not the volcano continued to pose a hazard. Because there was such controversy amongst the French scientific community as to whether the volcano was ever really dangerous, and whether the evacuation was justified in the first place, the government of France invited six non-French scientists to serve on this Comité—two from Italy, two from the United States (then Massachusetts Institute of Technology professor Frank Press and myself), and one each from Iceland and Japan. The Comité determined in mid-November 1976 that the volcano appeared not to pose as great a hazard as it did a few months earlier, and that with increased monitoring possible future outbursts could be anticipated. Once this determination was received by the French government an end to the evacuation was ordered, and life gradually returned to normal on Guadeloupe.

To my way of thinking, the crucial issue at La Soufrière in 1976 was that there was an inadequate data base of scientific information upon which to assess the ongoing activity. In mid-1976 the volcano was obviously in a restless state, with steam and ash pouring from its summit and thousands of local earthquakes originating within several kilometers of the surface. But the network of seismometers was not sufficient to document any upward migration of earthquake foci that might have taken place. Furthermore, prior to the climax of the crisis, there had been no baseline measurements, which would be necessary to detect changes in shape of the volcano (deformation studies of the type developed at the U.S. Geological Survey's Hawaiian Volcano Observatory) or the configuration of the local magnetic field. Thus, there was considerable uncertainty as to what the volcano was going to do, and, in this air of uncertainty and apprehension, the most conservative course of action was followed—total evacuation.

CRISIS ON ST. VINCENT, 1979

Few people would have dreamed that a second volcano crisis would arise in the Lesser Antilles in the 1970s. Another volcano, also named Soufrière, thundered to life on April 12, 1979, on the island of St. Vincent, about 300 kilometers south of Guadeloupe. Despite the similarities in the names of these volcanoes, there were important differences between the crises on Guadeloupe and St. Vincent. At St. Vincent, a fairly good set of baseline geophysical data was in hand before the eruption began. The temperature of the water in the crater lake at the summit of the volcano had been monitored at regular intervals, and telltale increases of several degrees during the summer and fall of 1978 suggested that something abnormal was developing. Two stations designed to detect possible deformation of the volcano (utilizing the "dry tilt" technique first developed by U.S. Geological Survey scientists) were established two years before the eruption, and repeat measurements at these stations indeed indicated that the volcano was swelling, possibly as a prelude to a future eruption. Finally, and undoubtedly most important, seismometers were in continuous operation on and near the volcano, and the signals from these instruments were telemetered to Trinidad so that they could be observed and interpreted in real time by scientists of the Seismic Research Unit of the University of the West Indies.

Not only was there better understanding of geophysical changes that were taking place at Soufrière, St. Vincent, but there was no doubt that the volcano had entered a dangerous phase by the early morning hours of April 12, 1979 (fig. 3). Powerful vertical explosions sent clouds of ash and vapor to altitudes of more than 18 kilometers, and avalanches of debris, much smaller than

Figure 3 Vertical eruption cloud rises into the early morning sky from the summit of Soufrière volcano, St. Vincent, April 22, 1979. The profile of the volcano, as seen in the left center of the photograph, rises to an altitude of about 1 kilometer above sea level. The eruption cloud, therefore, is at this point about 6 kilometers in altitude; the cloud eventually rose to an altitude of 15 kilometers.

those that destroyed parts of Martinique in 1902, swept down valleys on the east and west slopes of the volcano. At the outset of the crisis, there was no time for an official evacuation order from civil authorities—the volcano itself provided an alarm, and most of the 22,000 people living in exposed areas evacuated themselves within a few hours. The government of St. Vincent enforced this evacuation for several weeks, permitting people to enter the hazardous areas only during daylight hours to tend or retrieve livestock and to remove other valuable possessions (fig. 4).

Figure 4 River valley on west slope of Soufrière, St. Vincent, that was devastated by the repeated passage of hot avalanches and mud flows. The scouring action of the mud flows deepened the floor of the valley about 30 meters. Photo taken in June 1979.

The hazardous phase of the St. Vincent eruption lasted for about two and a half weeks, during which a series of powerful vertical explosions punctuated periods of volcanic "restlessness," characterized by thousands of local earthquakes and many hundreds of small explosions. During this period, the one scientific team, made up chiefly of researchers from the University of the West Indies (located in St. Augustine, Trinidad) provided the local government with daily reports, both orally and in written form, on the status of the volcano. This team constituted the only source of scientific information, and therefore it became the single focal point for detailed knowledge of the ongoing event. Members of the press corps were prohibited from travelling into the evacuated zone (where a temporary volcano observatory had been established), and therefore there was very limited contact between scientists and the press. The press received daily briefings from government officials, which consisted essentially of information digested from the daily reports provided by the scientific team. Only one reporter insisted strongly that he be permitted to interview scientists on the scene within the evacuated area so that he could get his own story. The government, however, insisted that there should be only one channel of information flowing from scientists to government to press, and, therefore, this particularly aggressive reporter, not wanting to adhere to this policy, was summarily deported from the island.

After the series of large explosions ceased, the lava began to extrude quietly to the floor of the summit crater, the government gradually relaxed the evacuation restrictions, and by early June life had essentially returned to normal on St. Vincent. During the summer, the government and the scientific team kept in close contact in the event that the situation were to suddenly worsen. It never did, and the rate at which the lava was quietly erupted gradually diminished and ceased altogether by October 1979.

SOME COMPARISONS

It is interesting and instructive to compare aspects of these two eruptions—La Soufrière, Guadeloupe, 1976 and Soufrière, St. Vincent, 1979. Despite the fact that both of these volcanoes occur along the same island arc (or, to put it another way, they both are the result of the collision between the Atlantic and Caribbean lithospheric plates), the nature of the activity at these two volcanoes was dramatically different. The 1976 activity at La Soufrière, Guadeloupe, had been classified as phreatic—consisting entirely of the emission of steam and other gases without the eruption of new lava. At times, these gases jetted forth with such violence that fragments of older and altered rock from the interior of the volcano were torn free and swept high into the air, giving rise to the ash that was showered over the surrounding countryside. Large explosions, much feared during the summer of 1976, never occurred. In contrast, the 1979 activity at Soufrière, St. Vincent, was clearly more violent, more dangerous, and resulted in fairly large quantities of new lava being erupted at the surface.

Even though the 1976 activity on Guadeloupe appeared to be more dangerous than it actually was, the paucity of baseline scientific data on Guadeloupe prevented this fact from being appreciated at the time. To further complicate the situation, there were differing scientific opinions being expressed on Guadeloupe during the summer of 1976, again resulting in large part from the inadequacy of the available data base. Finally, members of the press corps were permitted almost unlimited contact with groups of disagreeing scientists and, at times, these disagreements themselves became the "news" rather than what was actually happening at the volcano. In St. Vincent, on the other hand, scientists and the press communicated with each other only via the central government, and from all indications the government did an entirely adequate job of making information available on a timely basis to the media.

In conclusion, earthquakes and volcanoes threaten millions of people, especially those living in regions near the boundaries of lithospheric plates. In the eastern Caribbean in the 1970s two volcano crises took place in the context of limited baseline data. One of these (at La Soufrière, Guadeloupe) appeared to pose a dire threat, but never did erupt as expected; the other (Soufrière, St. Vincent) erupted violently and clearly posed a threat to the nearby population. On Guadeloupe, members of the press corps had unlimited access to the various scientific teams, and the disagreements amongst the scientists were broadcast worldwide. On St. Vincent, the press and the scientific team did not communicate directly, and the single narrative of the eruption provided by the scientists was dispersed by the media in a far more orderly manner.

Scientists concerned with predicting earthquakes might be well advised to familiarize themselves with the lessons learned in the eastern Caribbean during the 1970s, especially those related to the availability of baseline data and the interface between scientists and the media, as they address the much more challenging problems posed by earthquake prediction.

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The International, Multidisciplinary Approach to Earthquake Hazard Reduction

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I have been asked to comment on the preceding talks by Drs. Giesecke and Çanitez. Dr. Giesecke decried the lack of national commitment and of political and administrative action in regard to the earthquake problem. This seems to be a problem that we who are concerned about earthquakes have in common with the mineral specialists, the cartographers and the hydrologists, who each in turn, over the past few days, have voiced their concern about the lack of public attention given to severe natural resources and environmental problems facing the world. On the other hand, I was impressed with the international cooperation reported by Dr. Giesecke. A group of countries in South America have developed a cooperative earthquake hazard reduction program, and Japan and the United States have helped.

Dr. Canitez reported on the development of a technologically advanced earthquake program in Turkey. I have watched with great gratification the growth of a center of excellence at the Mineral Research and Exploration Institute of Turkey (MTA), previously under the direction of Dr. S. Alpan and more recently under Dr. Çanitez. With the help of Turkish studies of the North Anatolian fault in Turkey, we should hasten our understanding of the San Andreas fault in California because the North Anatolian fault, very analogous to the San Andreas fault, has produced far more large earthquakes in recent decades than has the San Andreas.

Dr. Çanitez emphasized the human and economic problems brought on by earthquakes, and the potential importance of earthquake prediction, especially to less developed countries. I will comment more fully on that thesis in one moment.

We continue to be reminded of the hazard of living with earthquakes—a hazard shared by many, many countries. For example, our colleagues in the People's Republic of China estimated that the casualties in the Tangshan earthquake of 1976 reached 240,000. Earthquakes can inflict the most sudden and concentrated disasters of all natural events.

The worldwide nature of the earthquake threat has stimulated an extremely free and rapid exchange of information, technology, and methods, and a true sense of cooperation throughout the world. The fact that the common cause is essentially nonpolitical no doubt enhances this international cooperation.

The methods of earthquake hazard reduction can be categorized into two main approaches: (1) postdisaster response, and (2) preventive measures. I shall comment briefly on preventive methods, as they hold much promise for reducing the hazard in the future.

In the past 50 years, technological advances in earthquake-resistant engineering design and construction practice have become sophisticated and today represent our first line of defense against earthquakes. But other defenses are emerging. Defensive use of land (a form of land-use planning) and earthquake prediction are two that are in their infancy. In only a few places in the world is the adverse behavior of land during earthquakes considered in planning urban areas. As one example, California State law requires that special studies be made when structures for human occupancy are to be built near active earthquake faults. The logic is that to build astride an active fault is ridiculous when by moving a few tens of meters, the hazard of shearing by surface faulting can largely be avoided.

Earthquake prediction has been evolving for about a decade as a topic for credible research. In the People's Republic of China, however, tens of thousands of lives have already been saved by successful earthquake predictions. In the Soviet Union, successful predictions also have been achieved; Japan is making rapid advances in earthquake prediction; and a major research effort is underway in the United States. When earthquake prediction becomes operational, it can be a powerful alternative to engineering and land use in our defense against earthquakes. In the less developed countries neither earthquake-resistant design and construction nor land-use planning may provide full or satisfactory protection. Materials for earthquake-resistant construction may be either unavailable or economically unobtainable in many areas of different countries. Even in the most technologically developed areas, structures built during past decades and centuries are not necessarily safe from earthquakes. In the city of Los Angeles there are approximately ten thousand buildings that likely will collapse in a great earthquake, and all structures built to standards now out of date can be considered unsafe to some degree. No economy can consider retroactive measures on so massive a scale as complete rebuilding; even the most hazardous buildings are difficult to phase out because of economic and social constraints.

Earthquake predictions, that will permit evacuation of hazardous buildings (not evacuation of cities, may I emphasize) for a short period of time, can provide an adequate means of safeguarding lives in many situations. Although highly accurate prediction is still only a dream, I believe it is a realistic hope and, to my mind, an extremely worthy goal.

Another powerful measure, though perhaps to be claimed by the engineers, is one more nearly to be classed as a sociological or communications approach; that is, the improved education of the laborer and craftsman in elementary earthquake-resistant techniques of construction. As an example, the common failure of brick and masonry work around the world during earthquakes causes many casualties. My engineer friends point out that the simple techniques of applying mortar to bricks can vastly affect the strength of a brick wall. If all bricklayers and masons were to use good mortar, if they were to moisten their bricks properly, and if they were to apply mortar to the vertical ends as well as the horizontal flats of bricks rather than chinking the vertical holes later, their walls would be stronger. Perhaps more lives would be saved by improving indigenous masonry work than by all the advanced-technology methods combined. A list of other simple techniques for making structures more earthquake-resistant could be presented. Even in more advanced countries, where codes, standards, and designs are good and materials are available, the system often fails in the execution phase.

During the past decade a real sense of international cooperation has grown in our mutual defense against earthquakes, and close cooperation among extremely diverse disciplines has become a growing practice. Engineers, seismologists, geologists, sociologists, politicians, and financiers are at last learning each other's languages, are communicating freely, and have a sense of joint dedication toward solving the earthquake problem. Those of us who are engaged in earthquake studies still have many technical problems to solve, but I would be gratified if history records our most important contribution as one small demonstration of how international and multidisciplinary cooperation can enhance mankind's problem-solving ability.

Indeed, without far greater international cooperation and without the full application of all the scientific and social understanding we can muster in common service to mankind, mankind may not survive the 21st Century.

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Assessment of Earthquake Prediction in Seismic Hazard Reduction Problems

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It is really a pleasure for me to have participated in this symposium for the Centennial of the U.S. Geological Survey.

Last Tuesday, Dr. Bender compared the resources problem to an interesting comic picture, in which three men on a drifting raft are consuming their raft logs as fuel. Taking this analogy, I would propose to add to his picture a storm approaching the raft to illustrate the relation of geological hazards to the natural resources problem. Once a geological hazard such as an earthquake happens, it will take a vast amount of wealth, prosperity, and even human lives away from us. It is really a catastrophic consumption of stock resources, and, in this respect, hazard reduction provides us with a counter approach to saving of the limited resources of the world. I would like to review, in the following, an approach to assessment of hazard reduction, taking earthquake prediction research as an example.

A prediction seismologist may be compared to a baseball player in a batter's box. He should not swing his bat at any false ball, but he should swing and hit every nice (strike) ball. This analogy suggests that predictions of earthquakes must be scored with respect to two categories, i.e., the hit and alarm rates. The symbols M, m, and F in figure 1 denote number (or frequency) of the earthquakes to be alarmed, to be successfully predicted, and to issue an alarm, respectively. Then, the hit rate p_1 and alarm rate p_2 are defined as

$$p_1 = m/F,\ p_2 = m/M. \qquad (1)$$

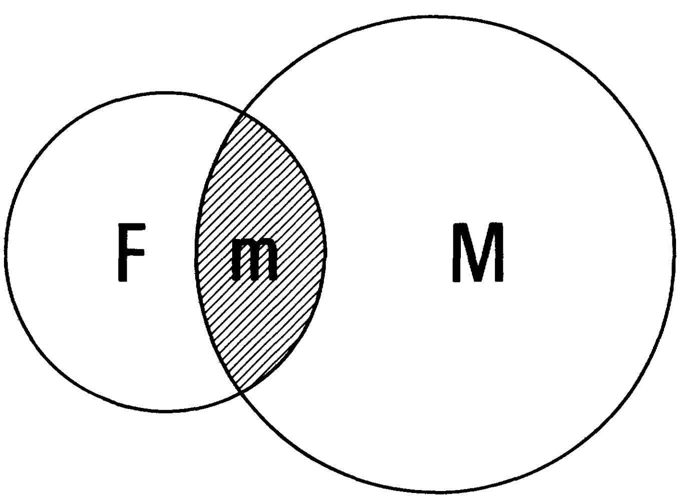

Figure 1 Seismic events and prediction success. M, events to be alarmed; F, alarm issued; and m, successful prediction.

If $p_1 = p_2 = 1$, then our prediction is perfect.

Another quantity to be introduced is the merit factor of earthquake prediction which Utsu (1977) defined as

$$E = \frac{mL - ml - Ff - C}{ML} = p_2\left(1 - \frac{l}{L} - \frac{1}{p_1}\frac{f}{L} - c\right) \qquad (2)$$

where, we take the following notations:

L, seismic hazard without prediction per event;
l, seismic hazard per event, when properly predicted;
f, cost of imminent treatment after prediction per event;
C, total cost of prediction work for a certain period of time; and,
c, C/ML.

For the sake of simplicity, we have assumed a uniform size of events, in the above. The total loss will amount to ML if we have no prediction, and to $Ff + ml + C$, if we succeed in prediction. Briefly, E is the difference of possible losses in these two cases relative to that without prediction. By use of (1), we may obtain the last expression in (2), which permits us to deal with the losses only in a relative manner, i.e., l/L and f/L. If we assume $p_2 = p_1 = 1$ (perfect prediction), then the merit factor in this case E_o is

$$E_o = 1 - (l + f)/\mathrm{L} - c \qquad (3)$$

and the following inequality may be derived from it:

$$-\infty < E < E_o < 1 \qquad (4)$$

Practically, p_1 and p_2 are related to one another. In a cautious (pessimistic) prediction program, we may improve p_1 ($\rightarrow 1$) at the expense of p_2 ($\rightarrow 0$). In an optimistic prediction program, on the other hand, $p_2 \rightarrow 1$, but $p_1 \rightarrow 0$. Qualitatively, therefore, the merit factor E will be lost if we take either of the extreme attitudes for prediction research (Utsu, 1977).

Suppose E is below zero, then our prediction program is useless, or even harmful. Precise evaluation of E is apparently difficult at the moment, but we may develop some more discussion, in reference to the records of hazards in the past and a guess of prediction costs. Figure 2 illustrates the frequency per century of disastrous earthquakes in Japan since 1000 A.D. Statistical homogeneity is generally questionable over such a long duration of time. Yet, the frequency of extremely large earthquakes in the main islands (excluding Hokkaido) suggests fairly uniform seismicity during this period, counting one or two events per century during this period on an average (see the shadowed column in the middle part of figure 2). In other words, the recent increase of frequency of smaller earthquakes (top figure) is principally attributed to urban development. This effect may be noticed in the statistics of loss of lives (bottom figure), which shows an accelerated increase of life loss from earthquake hazards in the recent centuries. Further details of the statistics (not shown in the figure) show us a notable trend: that tsunamis and collapsing of houses were the predominant causes of life loss in early centuries, but death in fire has been the principal cause in the recent two centuries.

Explosive increase of potential disaster in big cities may be a consequence of the heavy concentration of population there. Figure 3 illustrates the population in Tokyo from 1850 to the present time. We have three major seismic hazards during this period, in 1855, 1894 and 1923, respectively, where the last event caused about 145,000 deaths (including missing) out of a population of four million. At present, Tokyo's population is almost twelve million (even more, including those of the adjacent cities), so that a simple calculation suggests that the loss would be tripled, if a similar event recurred now. Our situation is apparently much worse, since the fragility of a modern city must be taken into account. It is easy to imagine that a tremendous amount of damage will occur both in human lives and property in the next catastrophe, unless efficient countermeasures are provided before the potential disaster.

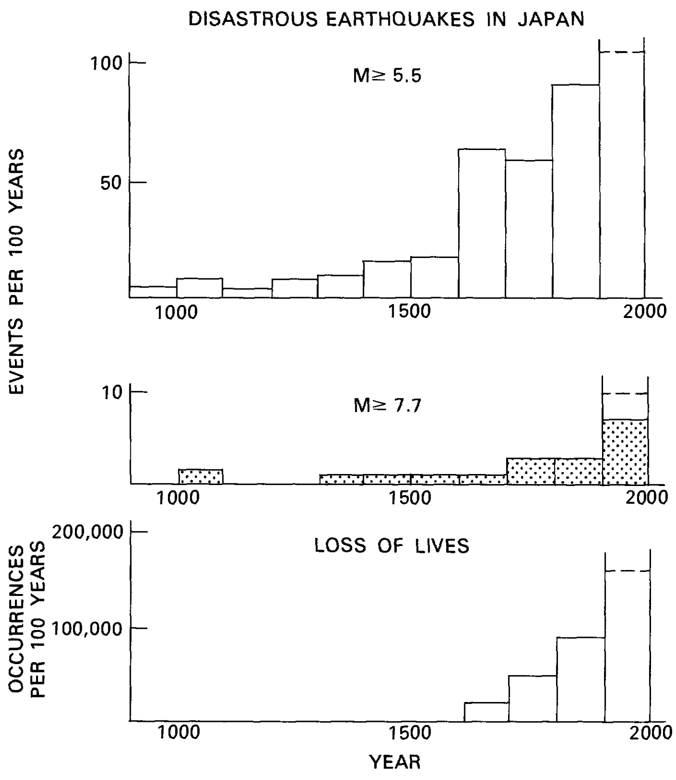

Figure 2 Disastrous earthquakes and loss of lives from earthquake hazards in Japan.

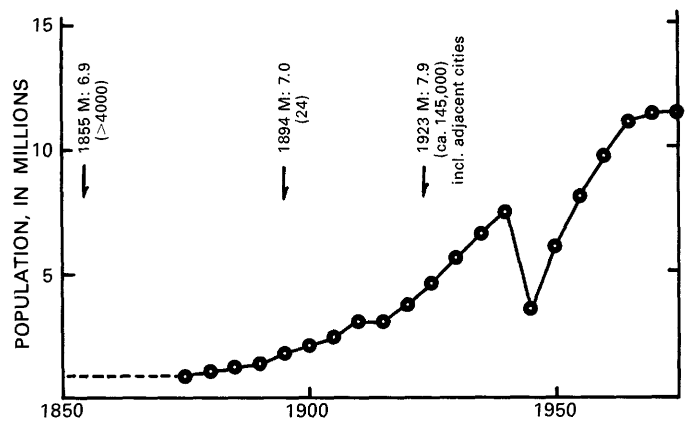

Figure 3 Population in Tokyo, Japan. Major disastrous earthquakes are indicated by arrows, where M is the magnitude and numerals in brackets represent loss of lives in the respective event.

Figure 4 is a summary of annual budget for Japanese prediction research since 1965. After the previous three phases, we entered into the fourth five-year phase, last year, where an annual budget of about 40 million dollars is being proposed. In our strategy, our efforts for making predictional observations are concentrated into several regions, which occupy about 20 percent of the Japanese land area. Precise estimate of the total expenses for prediction is of course difficult, at the moment. If a very rough guess is allowed, then we estimate for the next ten years the total cost of prediction research at about half a billion dollars. The cost would be several billion dollars, if the budget is ten times as high as the said level. Even in the latter case, the cost of prediction research is still only a fraction of a percent of the seismic loss in the 1923 event, after conversion to the present price index.

Let us avoid the difficulty of absolute estimates of seismic losses and prediction costs, and study the assessment in a relative manner. Figure 5 refers to eq. (2) and shows the merit factor in the l/L versus f/L domain with p_1 and p_2 being fixed. The shadowed space showing negative values of E is eliminated from discussion.

Little is known about these four parameters l/L, f/L, p_1, and p_2. Only a slight clue for estimating the hit and

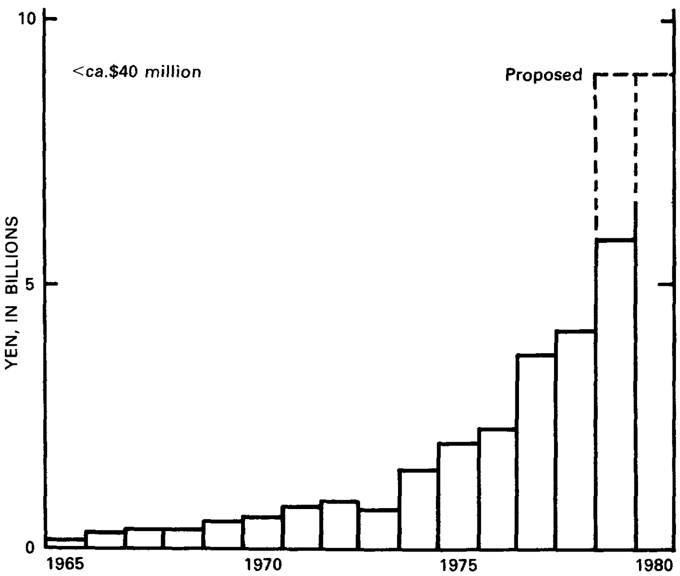

Figure 4 Annual budgets for earthquake prediction work in Japan, 1965-1980.

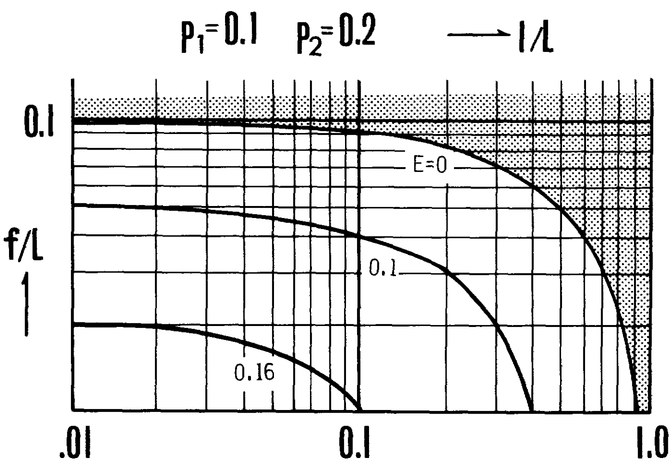

Figure 5 The merit factor E as a function of p_1, p_2, l/L and f/L (c is assumed as 0).

alarm rates is provided in retrospect by evaluating the statistics of anomalous events which preceded appreciable earthquakes in the past (Kasahara, 1980). So far as the Japanese leveling work is concerned, the frequency of meaningful preseismic land uplifts is only a fraction of that of anomalous land uplifts which were detected by leveling. This score suggests that the hit rate p_1 by this single technique may be about 0.1. The ratio of the frequency of seismic events with preseismic land uplift to that of disastrous earthquakes seems similar to the above score. From these considerations, p_1 and p_2 are provisionally taken as 0.1 and 0.2 respectively, although these rates may be improved by operating dense observational networks of various geophysical instruments to define the anomalies and taking cross-correlation of anomalies in various data channels. In the present case, therefore, a likely figure of E is 0.1 or so, if l/L and f/L are 0.1 and 0.04, respectively, where $c = 0$ is assumed.

The above model of prediction assessment is an oversimplification. Yet I shall be pleased if it provides a basis for examining the merit and limitation of earthquake prediction in hazard reduction problems. Some may criticize my above guesses of parameter values as too optimistic, and some, as too pessimistic. I would like to leave the final evaluation to your own judgement.

The prediction of geological hazards is doubtless an old and ever-new target for scientists. I recall a short note by L. H. Adams (1947). He pointed out origins of earthquakes (precisely, deep-focus earthquakes) as one of the unsolved fundamental problems of geophysics. Seismology has made notable progress since that time, and the mechanism of earthquake occurrence is known much better, so far as shallow origins are concerned. Now we can draw a fairly realistic picture of a seismic source, but the prediction of the earthquake occurrence is still far on the horizon in seismology. Several countries started their respective projects of earthquake prediction about ten years ago, indicating an ambitious effort by mankind to reach a new frontier. The way to the horizon is far and uneven, but I expect that our steps will continue and we will be successful someday in the near future.

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Urban Development in Relation to Earthquakes, Landslides, and Unstable Ground

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At the beginning of this century the population of this globe was 1.6 billion. By the end of the century it is estimated that the population will reach 6 to 7 billion. Urban areas are growing especially rapidly. Whereas in 1900 about 10 percent of the people in the world lived in urban areas, by the year 2000 half of these will live in cities. Even now, in many developed countries, urban inhabitants make up about three-quarters of the population.

Coincident with this trend toward urban population growth, we also observe a more rapid development of large cities. This phenomenon occurs in every climatic zone and in countries at different levels of development. From 1960 to 1970, the number of cities in the tropics with populations of more than 1 million grew from 4 to 14. During the same period in the Union of Soviet Socialist Republics, the number of cities with more than 1 million inhabitants grew from 4 to 10, and by 1980 that number will increase to 22.

This includes not only the simple growth of preexisting cities and towns, but also the establishment of completely new urban areas. So, in the Soviet Union every year more than 20 new towns come into being; half of them are in previously uninhabited areas. The same tendency is observed in other countries.

Towns, transport lines, and industrial complexes take away from agriculture enormous areas, amounting to millions of hectares per year. During recent times areas under development of different kinds have been redoubling each 15 years. In many cases this development of new lands occurs spontaneously, often without necessary geological investigations.

Naturally, urban growth is more intensive in areas with the greatest increase in population, generally between 40 degrees North and South latitude. Almost three-quarters of the world's population lives in this region. And in this same area, geological processes are the most active. Thus, geologic hazards such as earthquakes, landslides, and mud flows annually account for serious losses of life and property.

It sounds paradoxical, but recent technical developments are actually capable of increasing geologic hazards if they are not properly applied. In fact, every year man's interference with nature increases. Already, the large-scale production and burning of fuel, the subsequent pollution of the atmosphere, the constant reduction of forest areas, the modification of rivers and lakes as well as subsoil waters, which are in turn connected with the enormous consumption of fresh water for agriculture and industry, and other of man's activities have adversely affected geological processes. The mining industry is developing one and a half times faster than other branches of industry. According to estimates by experts, disturbances caused by opencut mining can affect an area up to ten times larger than the area of quarry operation itself, changing the hydrological regime and natural geochemical processes, depositing erosion products, and otherwise altering the landscape. Dumps and waste heaps are not carefully monitored, they can give rise to landslides that endanger neighbouring settlements. It is sufficient to remember the tragic case of Aberfan in South Wales. Likewise, demands for fresh water and for energy have caused a sharp rise in the number of large dams. Dam heights continue to increase and reservoir volumes continue to grow. Naturally, dams are erected in the places with large reserves of energy, mainly in mountainous regions where geologic hazards are high. Besides natural geologic hazards it is necessary to take into account the possibility of manmade earthquakes, connected with the impounding of the reservoir itself. Unfortunately, destruction has resulted from such earthquakes. The enormous potential danger of the failure of a large dam for downstream towns can scarcely be exaggerated. Moreover, building and development in highland areas can disturb slope stability, thus causing rockfalls and landslides. Often these phenomena are observed not only in highland regions, but also near rivers, lakes and coastal areas.

To reduce the losses due to geologic hazards it is necessary to plan future population expansion in regions chosen for this purpose. First, they should be areas with low geologic hazards, and second, areas of little use for agriculture. It is vital that we provide the legislation necessary to ensure that both the estimation of geologic hazards and the consideration of suitability are included in the development of new lands set aside for civil and industrial construction. In the Soviet Union legislation for protecting lands and the environment has been issued during the past 10 years to pursue just these goals—land recultivation after mining exploitation, control of water pollution, protection against soil erosion, and the development of lands useless for agriculture.

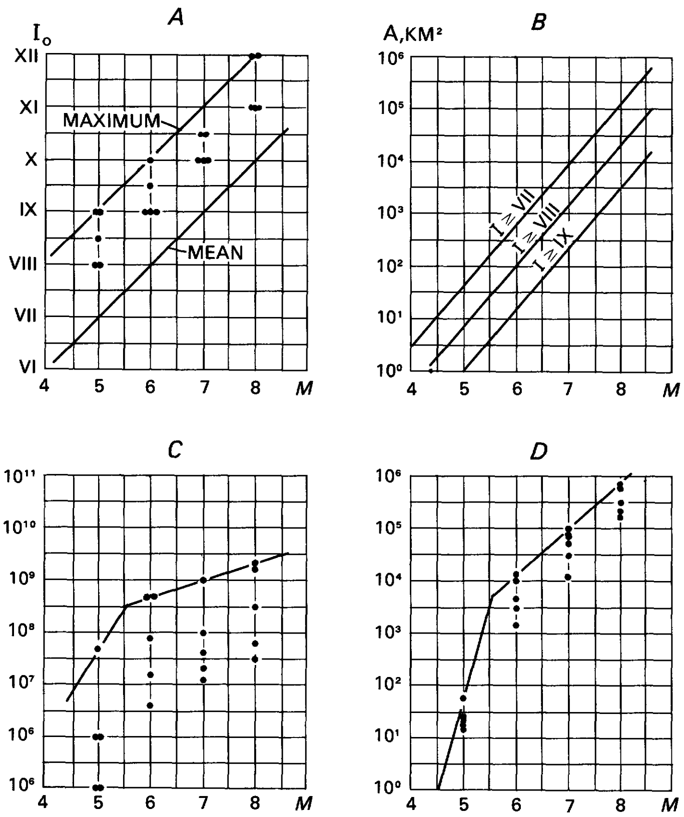

Figure 1 Some earthquake characteristics versus magnitude (*M*): *A*, Maximum and mean intensity (*I*). *B*, Area (in km²) shaken at different levels of intensity (*I*). *C*, Maximum monetary loss, in dollars. *D*, Maximum loss of lives.

Of all geologic hazards, earthquakes can cause the greatest loss of life and the largest property damage. Some numbers can illustrate this. Landslides affecting an area of one square kilometre are considered serious. However, an earthquake with magnitude $M = 7.5$ on the Richter scale (not the largest possible) can destroy an area of as much as one thousand square kilometres—an area large enough to include a city with a population of several million. Thus the rapid spread of population in active earthquake belts has resulted in the presence of more settlements near zones in which destructive earthquakes may occur. Not only are the direct effects of seismic vibration most serious in such built-up areas but so also are the secondary geological phenomena—rockfalls, landslides, soil subsidence and soil liquefaction.

Earthquake hazard is especially great in large urban areas where there is not only a high concentration of structures and goods, but where the disruption of the normal course of the urban economy—water supply, gas lines, electricity, telephone lines, computer systems—can also provoke additional economic problems.

In figure 1 we have plotted some of the summary data on hazards in order to assess the possible strongest effects of earthquakes according to the following factors: (*A*) intensity versus magnitude (mean and maximum values); (*B*) areas shaken at different levels of intensity (mean values), (*C*) monetary losses; and (*D*) loss of lives (maximum values). Maximum estimates correspond to the effects observed during the five most severe earthquakes in each magnitude range. According to these data, the lives lost during the strongest earthquake could reach up to one million. This estimate is based upon the most unfavourable conditions: (1) demographic (high population density); (2) social (low level of economic development resulting in non-antiseismic construction), and (3) geological (unconsolidated substrate, location relative to active faults). For earthquakes greater than magnitude 5.5 an increase of one magnitude unit causes a tenfold increase in the number of fatalities; however, equivalent decreases in fatalities for earthquakes of magnitude less than 4.5 are not observed as a rule. Antiseismic construction could reduce these estimates of lives lost by a factor of ten. In urban areas each fatality is accompanied by about one million dollars loss to the economy. Furthermore, the growing concentration of material values in large cities will in the future increase both the absolute and relative values of monetary losses when geological catastrophes occur. The relatively rare occurrence of the strongest geological catastrophes, especially seismic ones, and the use of mean values in loss estimates, can result in underestimation of geologic hazards.

First and foremost, these examples clearly illustrate the practical necessity for estimates of the seismic hazard for new lands, and for estimates of accompanying geological phenomena before civil and industrial construction. The wide complex of geological and geophysical methods used in seismic zoning indicates the breadth and importance of this technique. Seismic zoning includes estimating the danger not only from vibration but from other geological phenomena as well—creep, landslides, snow slides, flash floods, and soil deformation.

Seismic zoning as a complex geological-geophysical method has been under development in the Soviet Union since 1930 (Seismic Zoning of the USSR, 1978 [trans. 1980]). The earliest seismic zoning maps were made at a scale of 1:2.5 million. This scale is still being used. Every 10 to 15 years these maps are revised on the basis of new experimental data and further development of the zoning method. In addition to seismic intensity estimates, maps that were completed in 1978 include possible strong earthquake zones, probability of different magnitudes, and the mean isoseismal lines for large earthquakes. These maps show the isoseismal areas up to intensity 9 (fig. 2*A*). Higher intensities may occur in source zones and these areas should be excluded from areas for development (fig. 2*B*). As general seismic danger estimates our general seismic zoning maps receive government approval and are the legislative basis for all planning, design and building organizations of the State.

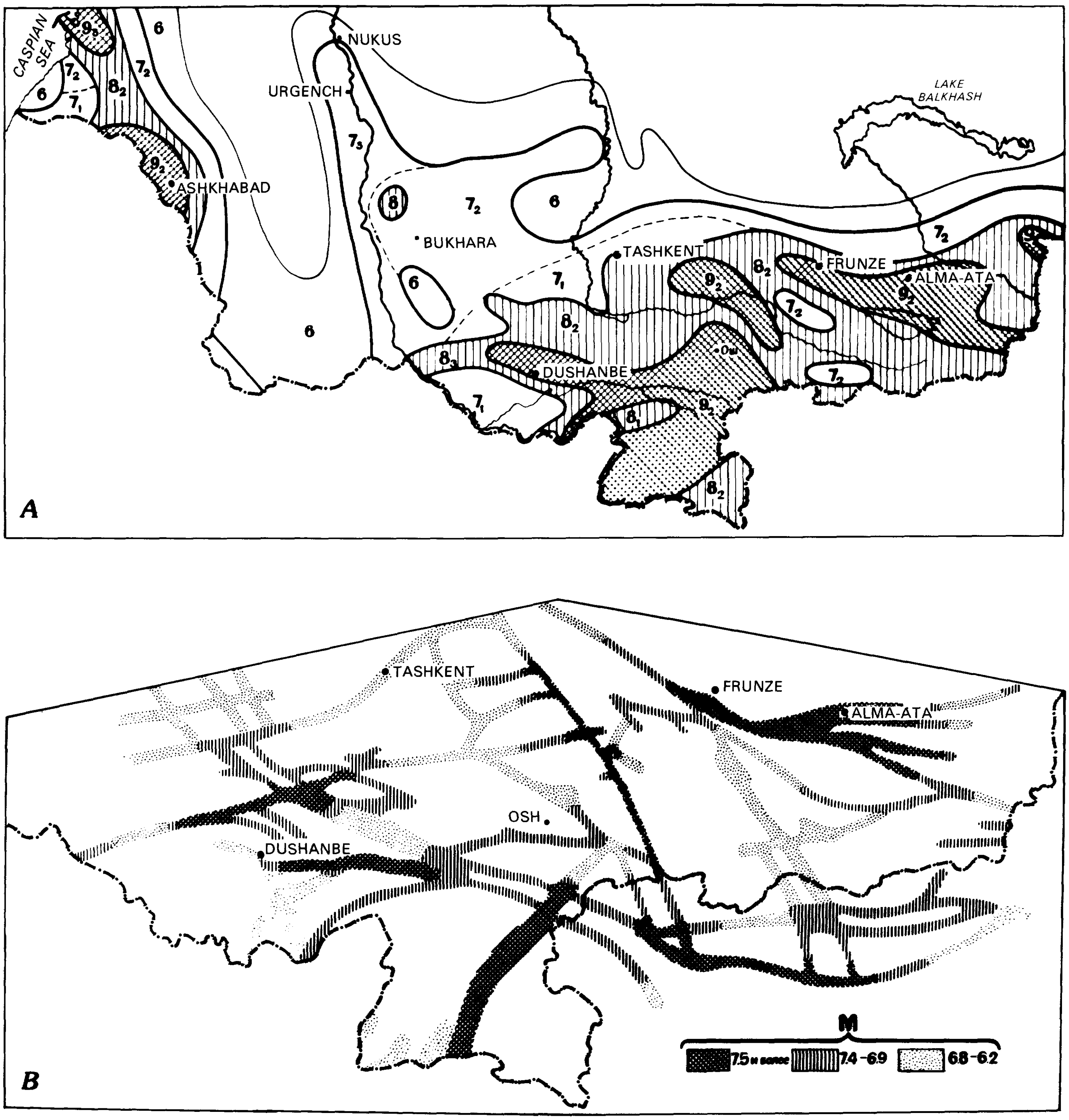

Figure 2 *A*, General seismic zoning map of Central Asia showing intensity zones. *B*, Detailed seismic zoning map of southeast part of Central Asia showing seismogenic faults.

In the Soviet Union, legal codes regulate detailed investigations of local conditions: engineering geology; local tectonics; geodetic estimates of small scale crustal deformation; hydrogeology; soil characteristics and their influence on seismic vibration. Investigations of this kind are called "seismic microzonation."

However, in many cases of civil and industrial development, general zoning cannot answer questions about geologic hazards with the required accuracy, nor can microzonation, which provides information on a small area of only local interest. For these reasons special methods for more detailed estimations of geologic hazards are being developed. This large-scale detailing is necessary for large hydrotechnical projects, nuclear power plants, urban design, and long-term planning of new land developments. This new direction in planning is called "detailed seismic zoning."

Thus, engineering seismology investigations for specific building sites naturally separate into two types—detailed seismic zoning and seismic microzonation. The first is aimed at investigation of seismic events, the second at the influence of local conditions upon seismic effects. While microzonation in the Soviet Union already has a long tradition, detailed seismic zoning work has only begun. Currently a special commission is developing recommendations to implement this technique.

The basic principles of detailed seismic zoning are

1. For seismically active areas detailed seismic zoning is obligatory and is based on data plotted on the general seismic zoning map.
2. Maps of detailed seismic zoning are overlaid on topographic base maps with scales from 1:200,000 up to 1:1,000,000. Engineering geology maps may be more detailed. The mapping scale depends on the level of hazard. The size of the mapped area depends on specific conditions, but as a rule a mapped area will include a radius of 50 to 100 kilometers from the building site.
3. Selection of the building site and estimation of possible seismic forces affecting this site are made on the basis of both detailed seismic zoning and microzonation. Site selection is also based on estimates of geologic hazards of non-vibration character.

Detailed seismic zoning is carried out by using different scientific methods to obtain the needed data. Those data are then examined in an integrated fashion, and on this basis, the final conclusions—including earthquake predictions if possible—are drawn about the geologic hazards of the region.

Seismological methods, both macroseismic and instrumental, are used to determine the distribution of events in time and space, the nature of focal mechanism, the maximum magnitude and intensity, the wave attenuation and estimates of the probable characteristics of seismic motions.

Geological methods are used to estimate the places of possible earthquakes, their magnitude and focal mechanism, and to determine places unfavourable for use because of geological conditions.

Engineering geology is used to identify locations with high geologic hazards, such as landslides and rockfalls, and to estimate the specific effect upon construction of materials beneath the site.

Correlations between seismic activity and geophysical parameters are used to find the places of possible earthquake origin. In addition, geophysical methods are used to investigate geological structures.

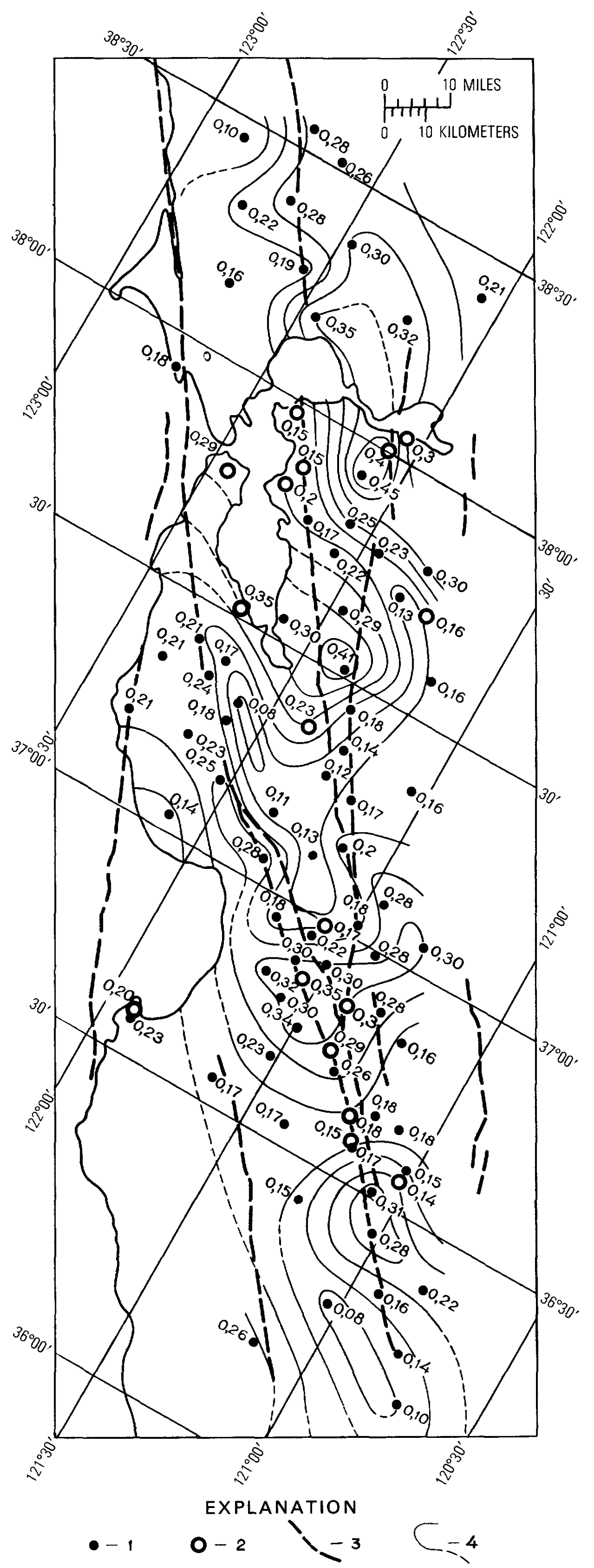

Figure 3 Expected predominant period of acceleration for California earthquakes: 1. Solid circle, high sensitivity station. 2. Open circle, strong motion station. 3. Solid line, isoline of periods. 4. Dashed line, main faults.

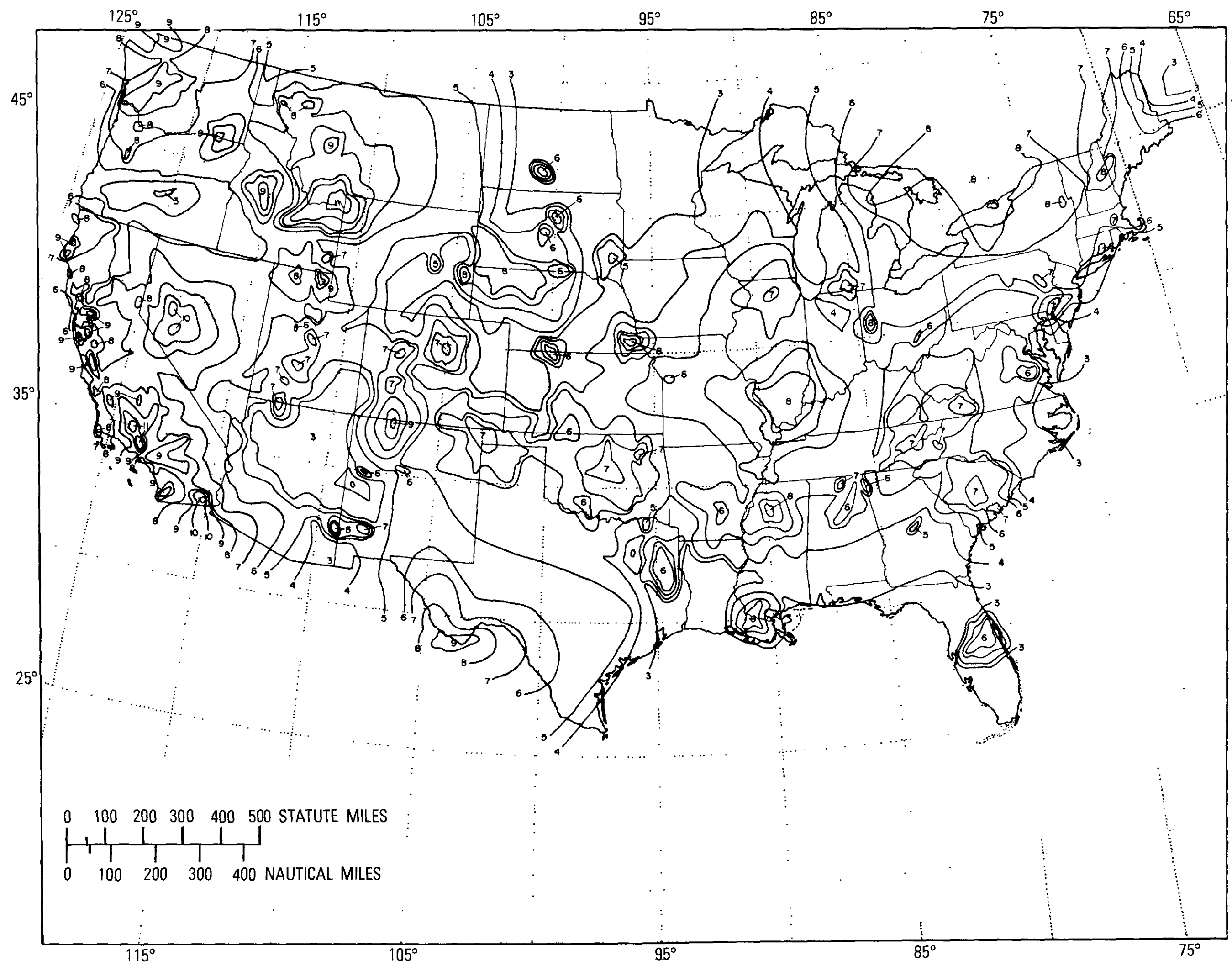

Figure 4 Maximum intensities experienced through the 48 conterminous States of the United States from 1928 through 1973 (from R. J. Brazee, 1976).

Geodetic observations are used to estimate recent crustal movements and the tectonic strain field.

Finally, the basic results of detailed seismic zoning investigations are summarized on four types of maps, which must show the probability ranking of all the mapped values:

1. Tectonic map showing the various seismogenic structures and epicentral areas.
2. Engineering geology map.
3. Map of expected seismic intensity.
4. Map of expected seismic motion characteristics.

In addition to these final maps, working maps compiled during a detailed investigation show different geological and geophysical characteristics of the area such as its geomorphology, epicenters, and isoseismal lines of former earthquakes. Working maps show the basic data used in preparing the final zoning maps.

Within the bounds of joint Soviet-American work on earthquake prediction we have together studied the development of detailed seismic zoning and have investigated methods for quantitative estimation of seismic motion. The essence of this latter approach is its assessment of quantitative characteristics in specific places, using both instrumental records of strong and weak local earthquakes and those of distant shocks (Aptikaev and others, 1976, 1979).

As an example we show some results for California. Figure 3 is a map of predominant periods of acceleration during local earthquakes in California. Any other parameters of strong motion, such as peak amplitude or relative duration, could be mapped in the same manner. By comparing a map of general seismic zoning with a map of quantitative characteristics it is possible to see clearly some difference in motion within the same intensity zones. Such

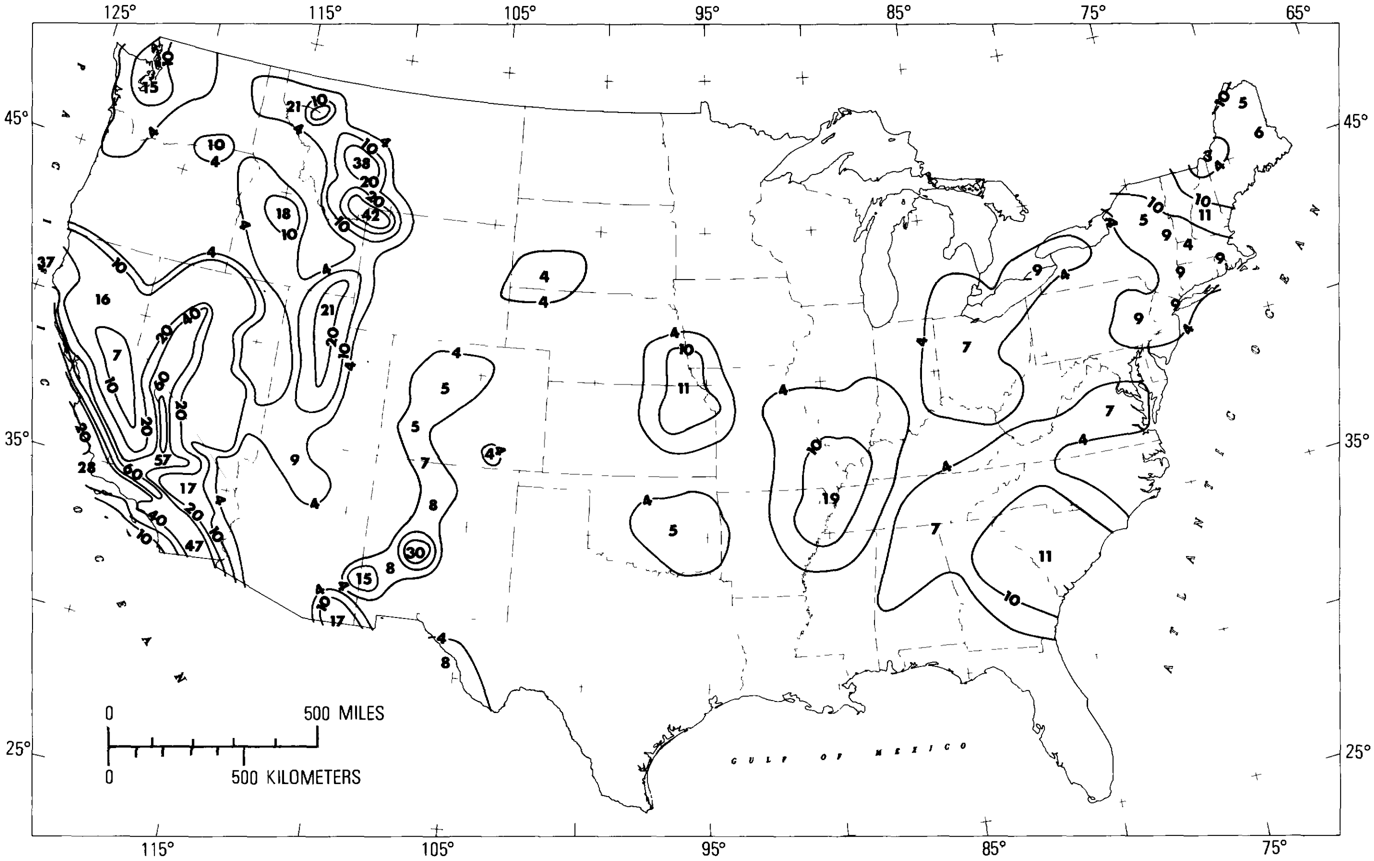

Figure 5 Preliminary map of expected horizontal acceleration (expressed as percent of gravity) in rock with 90 percent probability of not being exceeded in fifty years. Maximum acceleration within the 60 percent contour along the San Andreas and Garlock faults in California is 80 percent of gravity (using the attenuation curves of Schnabel and Seed, 1973). The 48 conterminous States of the United States (from S. T. Algermissen and D. M. Perkins, 1976).

knowledge of seismic motion characteristics allows engineers to take into account local peculiarities of vibration and to choose for designs employing the most earthquake-resistant construction methods. We have so far described in a general way the seismic zoning methods used in the Soviet Union.

The American school of seismology, geology, geophysics and earthquake engineering has made valuable contributions to methods of earthquake-hazard estimation. Most zoning maps in the United States, just as in the Soviet Union, show the expected seismic intensity (fig. 4). These maps are usually based on historic data and on fault tectonics (fig. 5). U.S. microzonation includes mapping of the existing or potential geologic hazards at a given location and of the ground amplification factor. To estimate quantitative characteristics of seismic motion the United States has also developed the world's best strong-motion array.

The U.S. Government initiated and has supported major research in earthquake-hazard estimation and earthquake prediction. At the time of its passage, the enabling Field Act was a great event, and not only for America. By 1978 Congress had also approved the Earthquake Hazard Reduction Program. Generally speaking, this program is similar to the Soviet national program. It further indicates that such programs are the only true way to solve this dangerous problem and thus save thousands of lives.

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Geologic Hazards and Man

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In contrast to the sensationalism and spectacle of a sudden and rare event such as a volcanic eruption or earthquake, the slower type of hazard, such as a ground subsidence, usually results from phenomena that proceed without publicity, especially in the early phases. It occurs very slowly over a long period of time or involves such a small area that few are affected by it. However, increasing development of water, oil, gas and minerals to meet the needs of a progressively more industrialized world has increased the interest in the land subsidence that often results from such development. This interest was reflected in such meetings as the Second International Symposium of Land Subsidence held at Anaheim, California, in 1976. In contrast to the natural event such as the eruption or the quake, subsidence can be related to or caused by man's activities. This distinction—natural or manmade—is used primarily for the purpose of discussion, because the causes (natural or man) are becoming more and more interrelated.

Land subsidence is the sinking of the land surface resulting from such causes as withdrawal of water, oil or gas, dewatering of organic deposits, hydrocompaction, removal of material by mining, and collapse in carbonate rock areas.

Because of the large land areas involved, subsidence resulting from removal of water, oil, and gas is best known. More areas are being affected by development of these supplies, and in addition, through instrumentation, we are being made more aware of the increasing number of areas affected. Some of the more notable areas are San Joaquin Valley and Long Beach in California, U.S.A.; Mexico City, Mexico; Bangkok, Thailand; and Venice, Italy.

Caving that occurs in mined areas is in response to removal of rock or minerals without subsequent replacement. The subsidence may occur as a planned event as mining progresses, or it may occur haphazardly as collapse following mining, when the overburden support fails due either to natural causes or to man's activities. Although karst conditions (solution openings) in carbonate rocks may be common in an area, and some caving may occur naturally, many of man's activities such as construction and agriculture can trigger collapse. Considerable progress is being made in detecting and avoiding these hazardous features using geophysical, remote sensing, and other techniques.

Although subsidence causes considerable property damage and loss, it can be put to beneficial use by development of intentional, controlled subsidence. For example, surface reservoirs can thus be constructed for storage of water for municipal, industrial, and recreational purposes. Underground cavities may serve as subsurface storage facilities.

Techniques are being developed for determining accurately the amount of subsidence and for predicting subsidence under varying conditions. These techniques provide options for avoiding, reducing, or otherwise controlling the effects. Similarly, progress in the development of prediction techniques for natural hazards is encouraging. Hopefully, through these various kinds of techniques, we will continue to move forward not only in developing a warning system for evacuation but also in actually controlling to some extent the magnitude of these events by methods such as recharge or discharge of fluid.

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Panel Discussion

R. Wesson (USGS): Dr. Fiske suggested that in the case of St. Vincent, the situation was handled in a more orderly fashion because a smaller group of scientists was involved. The extent to which information can be controlled depends not only on having just a small group, but certainly on political and societal conditions in various countries.

In the case of Southern California there is no way to control the number of scientists viewing an earthquake. I pose the question to the panel, how should information be handled in this era where we are moving toward earthquake prediction, but we don't have the routine capability to predict an earthquake? How open should we be with the public in saying what we do know and don't know?

R. Fiske (Smithsonian Institution): It is far easier to control information on small tropical islands than in Southern California. The scientists on St. Vincent transmitted information only to the government, not to the media. By having good communications with only one focal point, I think that the situation was handled very well. Haven't they set up an orderly reporting process in California?

R. Wallace (USGS): Yes and no. The system is intricate. We are told by our sociologist friends that if there is not a constant flow of information from reliable sources, the vacuum will tend to be filled by rumors. How to release complex information and to express the inadequate state of our knowledge is of continuing concern. The media tend to select only certain parts of the full story, commonly the sensational or controversial parts. Earth scientists are delighted that sociologists have entered the earthquake field to study the response of people to news. These studies should help guide us so that we can serve society better.

K. Kasahara (Japan): The role of journalism in this matter is doubtless important; therefore our scientists have continued their effort to gain the journalists' confidence and to insure a moderate response to critical seismic information. In this respect, the Coordinating Committee for Earthquake Prediction is used to release the necessary data promptly to the press, so that they may understand and report correctly the points of the Committee's announcement. Thus the three essential groups—scientists, governmental staffs, and journalists—are developing a basis for successful cooperation in this field.

A. Giesecke (Peru): There are problems that arise in the prediction of tsunamis. You can tell what is going to happen from something that is known. If you have an earthquake causing the tsunami then you can predict the time. It is much more certain. The Civic Alert Warning System [in Peru] has been in existence for many years and is being used continually. Seismologists turn information over to the navy to get ships offshore, etc. Unless you carefully control information going out to the public, you can start a needless evacuation. It happened to them in the port of Callao. They do not have absolutely free press, but there is no censorship in the area of earthquakes. They give more credibility to psychic interpretation than scientific.

I. L. Nersesov (USSR): The possibility of prediction is not too advanced. There is little experience in this complicated problem.

R. Wesson: It is relatively easy to arouse people concerning earthquakes and volcanic eruptions because they are sudden and rare events. There are many geologic hazards that over the long run may cause quite significant economic losses. Examples of this would be landslides, ground subsidence, expansive soils.

Because of the sensationalism associated with these rare but very publicity-prone events, are we placing enough emphasis on some of the slower-type hazards?

Geologic Factors and the Environment

Cooper Creek, Queensland, Australia: Landsat image during wet season showing creek in flood. Used for classification of terrain types on basis of vegetation and topography.

Environmental Problems and Geoscientific International Cooperation

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DEFINITION

Environment can be defined as the equilibrium of natural conditions surrounding and including man. Anything that affects this balance is regarded as an environmental problem.

Environmental problems can be man-made, such as the effects of large-scale mining and industrialization, but they can also be of natural origin, such as geohazards or certain types of changes in climate or sea-level.

It is interesting to note that the awareness of environmental problems is much more pronounced in industrialized regions of the world than in the developing countries. In a sense, the consciousness of the environment is at least partly typical of societies living in a state of luxury and achievement. This, however, is quite understandable, since there is little room for concern about environmental problems in societies where the three basic needs of mankind are missing: food, shelter, and clothing. These thoughts could lead us to the conclusion that at least for the moment environmental considerations can be put aside when the development of the Third World is concerned—and frequently, they are.

All the same, scientists and politicians alike share a responsibility for the future of mankind, and, therefore, wherever a development is initiated it should be analyzed not only with regard to its immediate economic effect but also with regard to its long-term environmental implications. If we really want developed societies in the world, and this inevitably means industrialized, technically developed societies, then we must foresee their course of development and try to avoid mistakes which have been made and are apparent in today's world. This, in my view, is the reason why we should and must consider the environmental aspects in geoscientific international cooperation.

REGIONAL AND SCIENTIFIC ASPECTS

The set of environmental problems which we encounter in the world depends to a large degree on the type of climate and on the surface configuration. We only need to follow the geographers' well-known systematic division. In this context, only brief examples of environmental problems typical for individual climate zones can be given:

The jungle areas of the *humid tropics* are particularly sensitive to deforestation. Only one year is needed to completely leach out the soil of a deforested tropic region and remove all organic particles from it. It takes years to recuperate. The extraordinary speed of the leaching process in the tropics is a fact of which economic geologists must be intensely aware when planning new mining sites in such regions. The geographic factors to which most of us have become used in the temperate regions cannot be transferred to the tropics. The special dynamics and the speed of natural processes in the humid tropics cannot be overemphasised. Unfortunately our professional training pays little attention to this problem as yet.

The *semi-arid regions* are affected much more than the rest of the world by even the slightest variations in rainfall. They are, indeed, marginal habitats of man. Everything which can influence the amount of rainfall is of vital importance in these regions, and any dynamic environmental system in which rainfall is one of the components has a basic environmental impact. Excessive use of firewood, changes in the agricultural system, large-scale mining operations, especially those producing dust and thereby changing the reflection index of the surroundings, all are potential triggers influencing the amount and the distribution of rainfall. Once set into motion, the system can move for a long time and take in very large areas before it becomes stable again by reaching a new balance. Impressive examples of this are known from the Sahel Zone.

Environmental problems in *temperate regions*, where most of the industrialized countries are located, are well-known to all of us. Probably the most serious problems here are not the localized ones, threatening for instance the recreational value of a particular landscape or a specific animal species, but the global ones resulting from the large-scale use of fossil fuels. The effects of even the slightest change in the composition of the atmosphere, especially its CO_2 and O_2 contents, will be felt worldwide and they are bound to have very severe impacts if the scientific forecasts are correct.

Some very important regions have one thing in common: they are not inhabited by man. These are the *oceans*, the *arctic regions*, the *deserts* and very *high-altitude mountain ranges*. They deserve special attention since their role in the environmental dynamics is essentially one of stabilization, filtration and purification.

These examples may suffice for emphasising the particular importance of the climatic and regional background to the environment.

There is another type of environmental concern, which – so to speak – comes from within the environment: the wide range of geohazards. Geohazards have had a greater destructive impact on man than all the other types of environmental dangers together. I must emphasise the tense "have had." The various types of geohazards are well known: earthquakes, volcanic eruptions, landslides, flooding. Of these, earthquakes and volcanic eruptions cannot be prevented or controlled to a significant degree. Great efforts are being made, however, in unravelling and understanding their genesis and thereby helping to accurately forecast these disasters. Accurate forecasting is the best way to minimize their consequences. Great progress has been made in this direction and major efforts are still underway. The investigations along the San Andreas Fault employing drilling programs and structural and geophysical studies are an impressive example. The success of Chinese geologists in accurately forecasting a major earthquake, in at least one instance, has proved that there are valid tools and methods available. They are far from perfection and completeness as yet, as we all know. But even the limited progress is a challenge to the geoscientific community, a challenge with good prospects for success.

INTERNATIONAL COOPERATION

International geoscientific projects are being initiated worldwide at an increasing rate. The great majority of them are concerned with the application of geoscientific tools to development. Accordingly, the majority of these projects are in countries of the Third World. Prospecting and exploring for minerals, fossil fuels, and water in hitherto unknown and developing regions is the aim of most of these projects. To a lesser extent, projects aimed at geotechnical safety are also being undertaken, such as geoscientific studies in connection with foundation work for large structures, road, railway and harbour construction. Environmental studies are few and far apart. The increasing number, size, and complexity of international geoscientific projects make it desirable – or even imperative – to pay more attention to these problems.

Probably one of the best-known examples of an international geoscientific effort aimed at preserving evidence of cultural heritage was the Abu Simbel project. Few people of that time spoke of the environment, but the project clearly served an environmental goal. The driving force behind it was the common responsibility of man towards culture and history. The success of the project also paid tribute to the men who initiated and executed it.

The great majority of projects, however, serve more practical goals of immediate economic interest. It is only too often that these immediate economic interests override the more cautious and considerate approach. Environmental consequences are being overlooked or neglected. Mostly, this is by no means due to willful neglect. It is just the consequence of a rather narrow-minded approach. Broader and long-term aspects are underrepresented and all of us have a lot to learn about how to include them in our planning. There are many published examples of unexpected environmental damage due to human activity, and the more we learn about them, the better for our own work. To give you a recent example from Germany: for many years, some cement works in Germany have added wastes from the Meggen zinc mine to their raw-materials feed because they had found that it improved the reactions in their rotary kilns. Nobody suspected any harm until by chance it was found that in the vicinity of these cement works an unusually and even dangerously high concentration of thallium had developed. The culprit was finally discovered by a painstaking search for the source of this dangerous element: the ores from Meggen contain about 300 ppm thallium as opposed to a normal background of 1 to 2 ppm. In the reactions in the rotary kiln the thallium was set free in gaseous form and constituted 3 percent of the gases emitted from the kilns. This thallium was then precipitated in the area around the cement works. After the damage had been discovered, large quantities of vegetables and other agricultural products had to be destroyed. The exact processes and reactions of the thallium in this case are still not completely known. This is a good example of how environmental problems can develop, and it is by learning that we can prevent them in the future – learning beyond the immediate goals and aspects of a project. Case histories are the best teachers.

It is important to develop an understanding of environmental problems in all scientists. Environmental considerations must become an integral part of project planning and execution. At this point, however, I should inject a note of warning: sometimes, environmental concern leads its promoters to overreaction. The real skill consists in balancing the various interests contained in a given project.

I feel that there is a difference between the environmental threat of a municipal waste-dump and the possible impact connected with the final storage of radioactive wastes. The treatment and management of the latter can clearly be considered as one of the major challenges to all scientists. It is interesting to note that the degree of public concern about the final storage of radioactive wastes varies considerably from one country to the next, and the differences are apparent not only between industrialized and developing countries but also among the industrialized countries themselves. This may have several reasons, but one aspect of the picture is certainly the way in which these matters are handled by the politicians. It appears that in a climate of patiently consistent and open information policy and free discussion there are much better chances for achieving a balance of views than where there is suspicion of secrecy, or of only partial release of information. We as geoscientists should accept this challenge by openly stating what is known to us already and where further research is needed before the question of safety can finally be answered. And, again, I am convinced that international cooperation in geoscientific research not only helps in speeding up the solution of scientific problems but also and at the same time with no extra cost serves the goals of technology transfer, mutual motivation and education.

Finally, I want to make a plea for intensified geoscientific research on an international basis aimed at understanding the above-mentioned geohazards. Here concerted efforts of the international geoscientific community are a necessity in order to answer the challenge. There are few research areas where scientific progress can be of more benefit to the lives of so many people. I am convinced that by the year 2000 the processes governing geohazards will be largely understood and that ways and means can be found to better forecast these events. There is a need for more international geoscientific programs dealing with environmental problems on a multilateral and bilateral basis than are in operation at present.

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Construction Materials and Ground Water: Important Subjects for Applied Geological Research in Developing Countries

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A major part of the development potential of a country, and this applies particularly to the developing countries, is the optimal use of natural resources. Traditionally, this means useful minerals and (or) raw materials for energy (coal, gas, oil). These resources determine to a great extent a certain but not necessarily a permanent level of prosperity.

Another type of natural resources may, however, contribute to a more balanced minimum level of existence. These resources include raw materials for housing, ground water for domestic, agricultural, and industrial purposes, and also areas and locations that can be earmarked for specific agricultural or industrial purposes.

In view of the nature of the deposits in question, mainly the "soft rocks," attention must be primarily focused on delta, river, estuarine, and coastal areas. As a rule, such areas are the centers of development and prosperity as a result of their favorable connections with the sea and with the hinterland, their fertility, the presence of ground water, and a level topography, which make them potentially suitable for connecting roads and cause them to become prime areas of settlement. This means also a rapidly developing economic infrastructure with a high population density, increasing density of industrial plants and other structures, and thus a large demand on the ground water potential and a heavy demand for surface materials such as sand, gravel and clay for construction. Because of the resulting ground-water draw-down, excavation, and construction, the soft-rock complex, with its water circulation partly fed from the surface, is extremely vulnerable to pollution.

During initial development, sufficient material will be available and areas for building can be easily indicated. This may produce, however, a trend which can be corrected or rectified only at great expense and with advanced techniques. The problems could have been avoided by planning based on geological patterns. As an example, delta areas generally have a poor carrying capacity as foundation for structures. A geological study may reveal a number of covered former riverbeds, filled with sand (figs. 1 and 2). These sandy tracts are ideally suited for roads, with low cost for construction and maintenance. The same sandy tracts may widen towards the coast, thus offering much better possibilities for building than the interjacent clayey or peaty areas (fig. 1).

On the other hand, such sandy tracts, when intersecting the coastline, may cause sliding down of sea defenses by scouring, unless the danger is recognized in time and adequate measures can be taken. This shows the

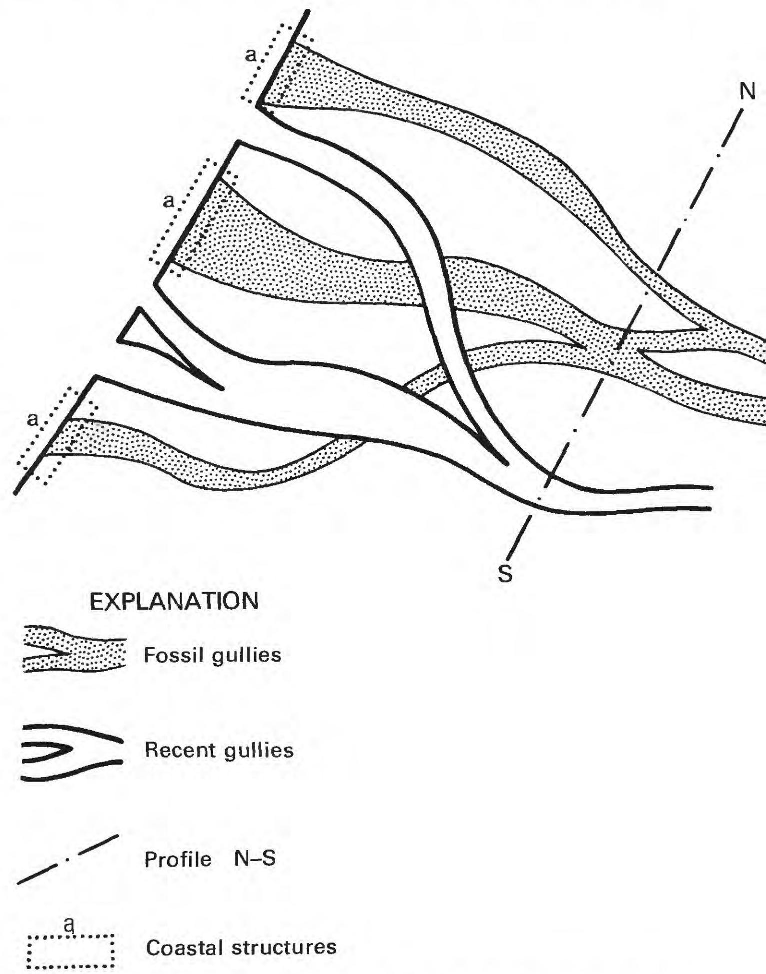

Figure 1 A simplified example of a geological pattern in a coastal plain.

close relation between geological and soil mechanics aspects (fig. 1, sectors a).

Because of low stands of the sea during the preceding glacials—10,000 years ago the sea level was about 60 meters lower than today—the erosion base was lower and subsequently in many cases coarse material was accumulated in lower river courses and coastal plains. Therefore in many sedimentary coastal plains, these coarse deposits with high bearing capacity are to be found at depths from 5 to 25 meters below the present surface. In such coastal plains this layer mostly forms the base for pilings for buildings and other structures. However, the surface of this layer is irregular either by origin or by later marine erosion, sometimes with differences in elevation of ten meters or more over short distances (fig. 2). This again makes a great difference in suitability of locations from the point of view of construction difficulties, of the amount of concrete to be used, and of total costs—all related to physical characteristics as shown by geological patterns—a form of natural resources.

By an efficient and justified use of natural patterns, risks can be avoided, the repair of which requires expert knowledge that may not be available for many, many years.

The rapidly growing demand for building materials should preferably be met by local supplies. Because of the specific requirements for sand for mortar, concrete, or other industrial purposes, sand deposits meeting these requirements are likely to be scarce. These must be located and evaluated, and they should be kept accessible, in order to prevent their becoming unavailable by being covered by buildings, roads, canals, or other structures, and to avoid their being used for other lower-priority purposes, such as land fill and grade improvements at construction sites.

The same considerations can be applied to gravel and clay.

For ground water, it is important for hydrologists and geologists to determine the distribution pattern and amount of available water in order to exercise resource management directed toward continuity without adversely affecting the availability of water to those who need it. It is a fairy tale that lowering a pipe into the ground solves the problems of water supply, even if in some low "soft rock" areas water might be produced by this method.

Drawing water as a rule causes a forced movement of water in the subsoil to replenish the withdrawn quantities. This movement may be either vertical or lateral. A vertical movement may cause a lowering of ground-water level and subsequently a drying-up. Lateral movement may attract water of poor quality, e.g., sea water or badly polluted water from distant intake areas. Finally, salt water from greater depths may be attracted by vertical and (or) lateral movement.

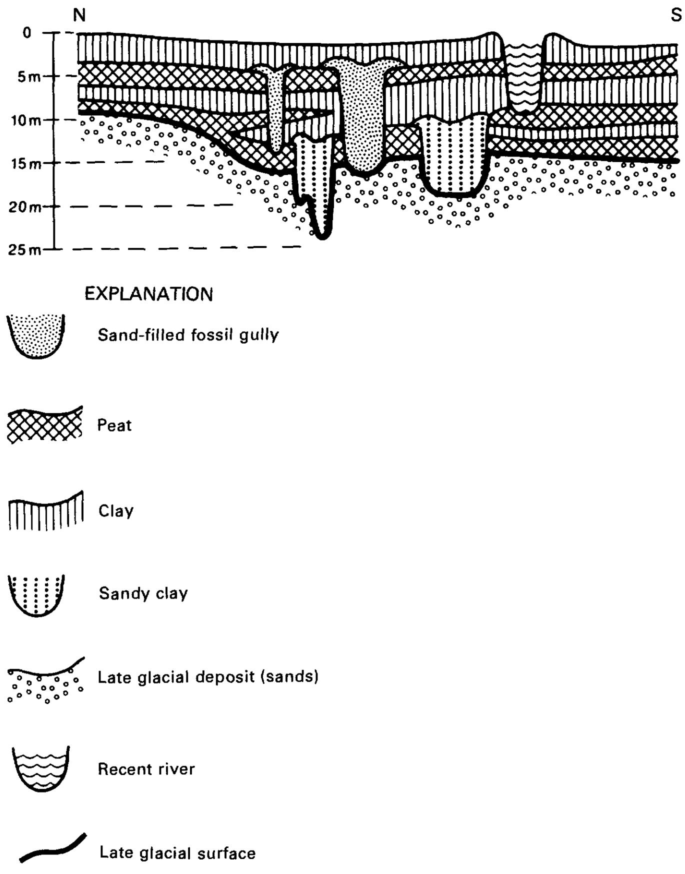

Figure 2 A schematic profile in the same area.

It should be realized that a subterranean basin, once polluted, remains practically unusable forever. For this reason it is imperative to handle water reservoirs with expert geological knowledge.

To make the best use of available water supplies, particularly when these are scarce, the better water should be primarily used for consumption, whereas water of poorer quality may satisfy the demand for industrial and other purposes.

In order to protect the ground water against pollution by human activities, the pattern of ground-water movement should be known and the intake areas should be protected against defilement.

It is self-evident that agricultural techniques should be adapted to an efficient management of ground-water supplies. Withdrawal of water, coincident with agricultural development, causes a lowering of the ground-water level that may have serious consequences for agricultural activities. For this reason, a well-considered development of agricultural techniques must be integrated in the total management of available water supplies.

In summary, it can be stated that delta areas, lower coastal areas and lower courses of rivers, all of which are mostly "soft rock" areas, contain a considerable supply of natural resources, consisting of raw materials (sand, gravel, clay) and the vitally important ground water.

In addition, the above-mentioned areas should have clearly defined optimum localities for certain settlements, for roadways, harbors, and dikes, thus enabling man to build simpler, cheaper, and longer lasting structures. Proper geological knowledge provides the essential information for efficient construction and for avoiding possible calamities. Neglecting the possibilities offered by nature means the loss of prosperity. Neglecting the above information is to choose to be increasingly dependent on highly specialized, alien techniques, and an ever-threatening loss of human lives.

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Application of Earth Sciences to Land-use Problems in the United States with Emphasis on the Role of the U.S. Geological Survey

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"There is one final problem that is in itself not primarily of a scientific character, but is as difficult and important as the others—namely, the problem of communicating the results of our work to the public in a way that they can be understood and used.

"Taking a hard look at the work of the Geological Survey several months ago, I suddenly realized that the maps and reports of which we have been so proud—and justly I think—have been released in a form in which they are understandable only by other earth scientists.

"Little wonder that insufficient use has been made of our results by land users and land-use planners, and little wonder that the general public lack understanding of fundamental resource and environmental problems." (McKelvey, 1972)

INTRODUCTION

In setting the theme for her history of the U.S. Geological Survey (USGS), *Minerals, Lands, and Geology for the Common Defence and General Welfare: Volume 1, Before 1879,* Mary C. Rabbitt noted that

> more than 2,000 years ago, a wise man, foretelling in one sense Lyell's thesis that geological processes of the past were the same as those now in operation, said: "Generations come and generations go, while the Earth endures forever. The sun rises and the sun goes down; back it returns to its place and rises there again. The wind blows south, the wind blows north, round and round it goes and returns full circle. All streams run into the sea, yet the sea never overflows; back to the place from which the streams ran they return to run again. * * * What has happened will happen again, and what has been done will be done again, and there is nothing new under the sun."

She goes on to say that "It has been said many times that history repeats itself. It only seems to repeat because there is a kind of uniformitarianism in human nature. Today we know more than the men of old, and we have new problems and new ways of solving problems, but human reactions to problems have not changed" (Rabbitt, 1979, p. 5 and 6).

I hope to show that while this theme is probably pertinent, at least for the applications of the earth sciences prior to 1879, it is less pertinent to the last 100 years and is far less so today. Although I will allude to a number of possible reasons for what I regard as a real change in human reactions to problems—severe depletion of energy resources, population growth and accompanying overuse of land, and a greater need for awareness of and concern for the constraints of our environment—I make no pretense of knowing which one, or ones, are the true cause. Nor do I mean to suggest that this change was abrupt, has been completed, or may not reverse itself in part. However, I do feel that humans are gradually evolving to a greater use of the earth sciences to reduce their suffering and to try to achieve a better balance with their environment. And I think we can attribute some real degree of that change to a greater knowledge of the Earth and to the efforts of earth scientists to interact more with people and to seek direct applications of their science to human problems.

A HISTORICAL PERSPECTIVE ON EARTH SCIENCE APPLICATIONS

In reading Mrs. Rabbitt's history of the role of the earth sciences, the major application of geology to human problems in the United States prior to 1879 was largely limited to the identification and development of mineral and energy resources. There were a few exceptions, however, such as the concern of Michael Tuomey in the mid-1840's over the wasteful methods of developing mineral resources.

Tuomey apparently was also concerned about the need to preserve forests in mining districts. But it remained to George P. Marsh in 1864, as the "fountainhead of the conservation movement," to point out "that man was fast making the Earth uninhabitable by wanton destruction, waste, and neglect; he expressed the hope that geologic, hydrographic, and topographic surveys would supply the facts from which the interaction between man and nature might profitably be determined" (Rabbitt, 1979, p. 5). Marsh was joined by a number of earth scientists, notably Arnold Hague, J. D. Whitney, W. A. Ashburner, and F. V. Hayden, in providing the scientific rationale and fighting for designation of the Yellowstone area as a National Park. It was this effort that resulted in legislation which Gifford Pinchot much later claimed was "the beginning and basis of our whole National Forest system" (Manning, 1967, p. 164).

But perhaps it was John Wesley Powell who set the stage for modern applications for land use by claiming that "The aim of science in the West should be to prepare the way for settlements by classifying the land according to environmental possibilities, and the land laws should make this possible" (Dupree, 1957, p. 202). Although Powell was sharply rebuffed by the Congress in his attempt to have science determine the suitability of lands for irrigation as a basis for decisions on the development of the West, his efforts stimulated the later concept of Federal responsibility for such development and the formation of the Reclamation Survey in the USGS and subsequently as a separate Bureau. It was Powell who, as second Director, expanded the area of USGS responsibility to include the entire United States and initiated the first cooperative arrangement with States—to share the cost with Massachusetts of a map to follow the style of the National Survey (Dupree, 1957, p. 213).

EARLY APPLICATIONS IN USGS

After Powell's resignation in 1894, the USGS returned to a greater emphasis on basic research and particularly on economic geology and water resources. Nevertheless, the research was "largely practical" as demonstrated by Alfred H. Brooks, who constructed charts to show that in 1890 less than 1 percent of USGS publications involved applied geology; in 1910, 98 percent of the publications were in this field (Manning, 1967, p. 225). For example, it was during C. D. Walcott's directorship that the first of a series of geologic and hydrologic folios of urban areas was published (e.g., Darton and Keith, 1901). The early folio series, published between 1894 and 1940, covered many of the largest metropolitan areas, including Washington, D.C., Chicago, and New York. Most of them, however, concentrated largely on basic geologic mapping, generally at a scale of 1:250,000; they provided little interpretation of data directed to the solution of land-use or environmental problems.

World War I brought a new and, until then, a unique application of geology in the United States—military geology. "In 1917, with the entry of the United States into the war, a geologic section of the American Expeditionary Force was formed under the command of Colonel A. H. Brooks of the U.S. Geological Survey" (Whitmore, 1954, p. 212). It was a small section attached to field armies for direct consulting services, largely involving recommendations of procedures to be followed in mining and countermining and the resolution of drainage problems attendant to trench warfare. The Survey's geologists were also heavily involved in assessing the availability of "war materials" and its topographers were assigned to support a mapping program drawn up by the Army's General Staff (U.S. Geological Survey, 1974, p. 18). The first major organizational commitment to applications other than resource development took place in World War II, when as many as 180 geologists of the USGS were assigned directly to a Branch of Military Geology or indirectly in support of military operations, largely to intelligence work (Whitmore, 1954, p. 213). Such support, which continued beyond the Korean War, emphasized the prediction of geologic conditions in inaccessible areas and their effect on possible military operations—an analysis of the effect of slope and surface materials on trafficability, location of construction materials, foundation conditions, water supply, construction of roads and airfields, and underground installations.

THE BASIS FOR PRESENT DAY APPLICATIONS

Urban Growth

With the return to peace, the energies of the United States were turned to construction of large developments, particularly in urban areas where many people had moved during the war and where many of the members of the armed services relocated. The development of large earth-moving equipment during the war provided the means for rapidly remolding the land surface for housing, shopping centers, and construction of the largest highway network in the world. Such development, occurring so rapidly, however, resulted in a myriad of problems, many of which remain today. First was the need to locate sand, gravel, cement materials, crushed rock, and other construction materials to meet the heavy demand. Second was the construction of buildings and roads in geologically sensitive areas without regard for the geologic constraints or with the misapprehension that the existing technology could engineer for the problems. Third was the impact of increased demand on limited water supplies in many areas and the effects of development on the quality of surface and subsurface water. Fourth was the rapid exhaustion or preemption of readily available sources of construction materials. And last was the impact such heavy and rapid growth had on limited energy and mineral resources. The earth-science community responded to this rapid growth largely by a rapid expansion in the fields of petroleum geology and engineering geology.

The second major organizational commitment of the USGS to applications came when the U.S. Geological Survey established its Engineering Geology Branch in 1948, concentrating at first on river basin studies and then on the location of sand and gravel deposits. A forerunner of these and subsequent applications was the publication in 1953 of the Hollidaysburg quadrangle, Pennsylvania (U.S. Geological Survey, Engineering and Ground Water Branches). This pioneering work clearly demonstrated how interpretation of general purpose geologic maps could be applied to determining foundation and excavation conditions, water supply, the location of construction materials, and site selection for engineering works. This set the pattern for a series of projects in urban areas throughout the United States—Boston, Massachusetts; Washington, D.C.; Great Falls, Montana; Rapid City, South Dakota; Omaha-Council Bluffs, Nebraska-Iowa; Salt Lake City, Utah; Denver and Pueblo, Colorado; Seattle, Washington; San Francisco-Oakland, San Mateo-Palo Alto, and Los Angeles, California; Anchorage, Alaska; Knoxville, Tennessee; and Portland, Oregon. Although these projects were designed to provide large-scale maps (1:62,500 or larger) interpreted for engineers, each was concerned with other urban land-use problems. The products were intended to provide general background for more detailed site investigations and to encourage, by example, the greater use of engineering geology in urban areas (McGill, 1964, p. 4).

In the mid '60s, a number of factors led to a change in emphasis of the work in the USGS and greatly stimulated related work in other parts of the earth-sciences community.

Geologic Hazards

A series of geologic events in the 1950's and early 1960's emphasized the need to identify areas subject to geologic hazards and to increase our ability to deal with them either through refined engineering practices or through wiser land-use planning and management. The explosive population growth in Los Angeles after World War II involved greatly increased residential development in hillside areas, which comprise about 60 percent of the city; at least two-thirds of that development occurred in the 1950's (McGill, 1964, p. 2). A sequence of heavy rains in 1952, 1958, and 1962 resulted in severe erosion, settlement, and landsliding in many parts of the city, and losses were heavy (Yelverton, 1971, p. 76–77). These events triggered the adoption by the Los Angeles City Council of increasingly stringent grading codes in 1952 and again in 1962 and the termination of landslide insurance on hillside lots by the insurance industry in 1958.

The 1964 Alaska earthquake, followed by the 1971 San Fernando earthquake, brought home to the present generation the tremendous forces of the Earth and the vulnerability of man and his structures to these forces. It also brought home to many geologists that the responsibility for the utility of their science is not discharged with the publication of a map or report. This became appallingly apparent following the Alaskan earthquake, which destroyed and severely damaged many structures located in areas delineated in a 1959 USGS Bulletin as landslides, slumps, or flows and prone to future failure (Miller and Dobrovolny, 1959). It also resulted in many geologists becoming involved with the reconstruction planning teams that recommended significant land-use changes, including relocation of the town of Valdez. The San Fernando earthquake also caused much damage in areas that had, or could have, been delineated as subject to ground failure. Although not mapped as such, "previous subsurface investigations revealed a ground water anomaly along the trend of the * * * San Fernando fault that could reasonably have been interpreted as a very young fault" (U.S. Geological Survey, 1971).

Even though much of the impetus to lessen hazard losses began before the earthquake, the San Fernando earthquake resulted in the introduction, with the involvement of many geologists, and passage of numerous bills in the California Legislature that have greatly increased the application of geology to engineering and land-use decisions. These included the seismic safety element, strong motion instrumentation, school siting, building records, hospital safety, dam safety, and Alquist-Priolo geologic hazards (Special Studies Zone) bills (Nichols, 1974b).

The Environmental Movement

Much of the stimulus for a great surge in the application of earth-science information was the environmental movement in the United States during the mid to late 1960's that culminated in the passage of the National Environmental Policy Act by Congress in 1969 (Nichols, 1975, p. 11, 12). This act directs all agencies of the Federal

Government to "identify and develop methods and procedures which will ensure that presently unquantified environmental amenities and values are given appropriate consideration in decisionmaking along with economic and technical considerations." The most widely distributed publication by the USGS—"A procedure for evaluating environmental impacts"—was prepared to help guide the preparation of environmental impact statements (Leopold and others, 1971). But the National Environmental Policy Act was not alone. A 1973 study by the Library of Congress showed that 23 Federal departments and agencies were administering programs which impact on land-use policy and (or) planning, including at least 112 Federal land-oriented programs (General Accounting Office, 1977, p. 10). Although many related to economic and commercial development, air quality, and social benefits, more than half of these programs and the enabling environmental legislation required earth-science information, especially hydrologic data, for effective implementation. As one consequence of the environmental movement, the water-resources activities in the USGS have grown substantially and are closely geared to State and local government programs.

At the same time, State governments were passing a similar array of legislation requiring contributions from the earth-science community for implementation—environmental protection, coastal zone management, powerplant siting, defining areas of critical concern, resource management, mined land reclamation, water quality control, and seismic safety are but a few examples.

In addition to this impressive array of legislation, individuals in many other disciplines had become aware of the contributions geology and hydrology could make to a better life style in America. A particularly effective advocate was Ian McHarg in his now classic book, "Design With Nature," which showed how environmental planning must involve earth-science information along with data more traditionally used by planners as a basis for comprehensive physical planning (McHarg, 1969). At the same time, professional groups such as the American Society of Civil Engineers, the Soil Science Society of America and the American Society of Agronomy (Bartelli, 1966), the Department of Agriculture (U.S. Department of Agriculture and U.S. Department of Housing and Urban Development, 1968) and others were urging parallel efforts.

I do not mean to imply from this discussion that the earth-science community sat back until forced to respond to legislative pressures and leadership from other disciplines. The geologic profession has had its own effective groups and spokesmen in Peter Flawn (1970), John Frye (1967), Bob Legget (1973), John McGill (1964), and the Association of Engineering Geologists (U.S. Department of Housing and Urban Development and the Department of the Interior, 1971).

RESPONSE BY THE EARTH-SCIENCE COMMUNITY

State Geological Surveys

Many State geological surveys were early advocates of applying earth sciences to land-use problems and were active in the design of innovative maps and reports. For example, the Illinois Geological Survey initiated an "Environmental Geology Notes" publication series in 1965 in which a wide range of both urban and rural land-use problems are addressed. Two of the early reports in that series—"An application of geologic information to land use in the Chicago metropolitan region" (Hackett, 1966) and "Geology for planning in McHenry County" (Hackett and McComas, 1969)—are especially noteworthy.

In 1968, the Kansas State Geological Survey began publication of abstracts and notes of interest in its "Environmental Geology Digest" series as a means of fostering communication between geologists and other earth scientists concerned with man's use of the physical environment. They also developed a method for incorporating environmental information in the planning process in any region by using a prototype area for data gathering and mapping (Hilpman and Stewart, 1968). A few selected examples from other States include

- Alabama—Environmental geology as an aid to growth and development in Lauderdale, Colbert and Franklin Counties, Alabama (Moser and Hyde, 1974).
- California—Urban geology; Master plan for California (Alfors and others, 1973).
- Colorado—The Governor's conference on environmental geology (Colorado Geological Survey, 1970).
- Connecticut—Use of natural resource data in land and water planning (Hill and Thomas, 1972).
- Iowa—Resource development, land- and water-use management, eleven-county region, south-central Iowa (Iowa Geological Survey, 1973).
- Missouri—Environmental geology in town and country (Hayes and Vineyard, 1969).
- North Dakota—Environmental geology and North Dakota (Arndt, 1972).
- Oregon—Land-use geology of western Curry County, Oregon (Beaulieu and Hughes, 1976).
- Tennessee—Environmental geology summary of the Kingston Springs quadrangle, Tennessee (Miller, 1973).
- Texas—Approaches to environmental geology (Wermund, ed., 1974).

Local Government

Local government also played a role, albeit a more limited one. In an analysis of geology and the conduct of local government in the United States, Jim Pendleton (1978, p. 7) notes that "Unfortunately, very few local governments have incorporated geological data in their land-use planning without Federal or State participation." This conclusion appears to be based largely on his survey of State and local geological agencies, which found only 25 local governmental geological programs in the United States — 18 of these being in California and 3 in Colorado. In only 6 States was it determined that local governments had geological staffs (Pendleton, 1978, p. 22). Although a number of individuals with training or degrees in geology work for local government, and undoubtedly were not counted in Pendleton's survey, it is unlikely that many of them function primarily as geologists. His survey also does not recognize the quite extensive use in some communities of geologic consultants both for capital improvement projects and for planning and plan implementation. In a few jurisdictions, notably in California, towns and cities received geologic assistance from higher government levels. For example, geologists with the county of Los Angeles were "contracted" by a number of jurisdictions in the county to assist in the preparation of safety and seismic safety elements of their general plans. In a talk to a group of planners several years ago, I noted the seeming inconsistency of some public opposition to the hiring of even one geologist on the staff of local government where they commonly employ as many as 40 planners and, in some jurisdictions, even more (Nichols, 1974a, p. 83).

Assuming that each community with a population of 25,000 people or more could or should employ one or more geologists, Pendleton projected a potential market for between 972 and 1,894 qualified geological practitioners (1978, p. 203). He urges the geological profession to encourage the use of geology in the daily conduct of local government — a policy the USGS has long advocated. In fact, in cooperation with the Washington Division of Geology and Earth Resources, the USGS in 1979 began sponsorship of a geologist "circuit rider" program in which a geologist from the State makes scheduled trips to three counties in Washington to advise and assist county governments on geologic problems.

U.S. Geological Survey

As indicated earlier, the USGS has played a major role in applying earth sciences to land-use problems. In 1967, the then Director, William T. Pecora, initiated an analysis of USGS urban programs to evaluate how they might be redesigned to better support the needs for earth-science information in urban and urbanizing areas. As a result, two new programs were initiated in 1967 — one dealing with urban hydrology and one with land resource analysis. These were later largely incorporated into an Urban Area Studies (UAS) program proposed to Congress in 1970. The pilot study for this effort was begun January 1, 1970, in the nine-county San Francisco Bay area in cooperation with the U.S. Department of Housing and Urban Development (U.S. Department of the Interior and U.S. Department of Housing and Urban Development, 1971). Other urban areas in which studies were undertaken included the Connecticut Valley, the Greater Pittsburgh region, the Baltimore-Washington corridor, Fairfax County, Virginia, the Colorado Front Range urban corridor, the Tucson-Phoenix area, and the Puget Sound region.

One of the purposes of the urban-area studies was to prepare as many earth-science related products as possible that might be of significance to urban and regional development and planning and to evaluate the effectiveness of each. These studies have resulted in more than 600 maps and reports that deal with a wide range of land development problems associated with both geologic and hydrologic hazards, resource development, and engineering constraints. Although many of these are technical reports that serve as a basis for other more refined interpretations intended for planners and public officials, most are presented in formats and language that can be understood by the intelligent layman.

The reports range from relatively simple basic-data maps, such as geologic maps, maps showing active faults, margins of marshlands, or boundaries of water and sewer service areas, to more sophisticated interpretive reports dealing with topics such as regional slope stability and water-quality management. Other products include maps showing flood-prone areas, archeological sites, and landslides; maps identifying erosional and depositional provinces; reports on topics such as criteria for hydrologic design of storm-drainage facilities, benthic faunal surveys, climatography, and pollution potential of land-based waste disposal.

Two reports illustrate the scope and intent of the urban area studies. One is a study titled "Quantitative land-capability analysis" (Laird and others, 1979) which was prepared under contract with the Association of Bay Area Governments (ABAG), a regional planning agency, as a part of the San Francisco Bay region study. It describes a method of evaluating land-use proposals by estimating the costs that are related to overcoming geologic and hydrologic constraints. Although the method is still being tested, it appears flexible enough to be adapted to other regions where geologic and hydrologic problems are important to land-use decisions.

The other report is titled, "Nature To Be Commanded . . ." (Robinson and Spieker, 1978), which is the first half of a quotation attributed to Sir Francis Bacon — "Nature to be commanded must be obeyed." By now, I hope, you may have had a chance to see this report which uses six examples across the United States to demonstrate some of the ways that earth-science information can be applied effectively to urban planning and decisionmaking.

An evaluation of the San Francisco Bay Region Environment and Resource Planning Study (SFBRS) (Arthur D. Little, Inc., 1975, p. 5-3, 5-4), conducted on contract for the Department of Housing and Urban Development (HUD), found that the program has

- "Raised the level of consciousness about natural hazards in the user community.
- Begun to bridge the communication gap and improve information transfer among scientists, planners, and decisionmakers.
- Developed new, more detailed earth-science data for a complex geological area larger than Connecticut.
- Expanded the focus and content of earth-science studies in other urban areas of the nation.
- Strongly influenced the organizational structure of USGS, making it more responsive to data application needs of others.
- Strengthened the environmental requirements of and responses to HUD programs in the Bay Area.
- Improved the capability of ABAG in environmental assessment, regional planning, and decisionmaking.
- Improved the capability of county and local planning agencies to perform environmental assessments and land use planning, and to prepare codes and ordinances.
- Experimented with new methods of data presentation and begun the development of a common language among scientists, planners, and users of resources."

The report provided a number of recommendations for maps and reports remaining to be completed and for future studies, such as

- "certain cartographic design improvements,
- reference direct applications to land-use ordinances and legislation,
- reports and maps should include a "how-to-use-it" section,
- increase publicity upon the release of reports,
- prepare an illustrated manual about the project informing the reader about earth sciences as a subject, about the implications of hazards and risks, and about the availability of alternative course of action [Author's note: Such a "manual" is now in press],
- explore preparation of model land-use ordinances based on the earth-science problems experienced in the Bay Area,
- transfer similar programs to other regions" (p. 5-9 to 5-11).

A much more in-depth study on the use of the earth-science products of SFBRS by W. J. Kockelman is now underway. Kockelman, in interviews with 99 cities (1975), 8 counties (1976), and 7 selected regional agencies in the Bay area (1979), found that

- "Three-fourths of the cities, all 8 counties, and all 7 regional agencies had planning staffs who were familiar with or had made use of SFBRS products.
- More than half of the cities, all 8 counties, and all 7 regional agencies had planning documents that referenced SFBRS products.
- Eighty to ninety percent of the almost 100 SFBRS products were used at least once and one was used 67 times for various city, county, and regional planning activities.
- The most widely used map products were small-scale, covered a wide area, and dealt with hazards.
- To ensure more effective use of earth-science information, future studies should include: (1) monitoring and analyzing new State and Federal laws or regulations and emerging critical issues so as to anticipate and respond to regional earth-science information needs; (2) creating a users' advisory committee to help identify critical issues and needs; (3) providing engineering interpretations and land- and water-use capability ratings to make earth-science information more readily usable; (4) giving priority to areas impacted by development; (5) providing earth-science information at the larger scale and greater detail commonly used and needed by regional agencies; (6) releasing earth-science information faster and according to a formal distribution pattern; and (7) providing educational, advisory, and review services in connection with any earth-science information product designed for planners and decisionmakers" (Kockelman, 1979, p. 3).

The study by Arthur D. Little, Inc., (1975, p. 93) concluded that

- "We firmly believe that the works accomplished thus far by SFBRS should be continued and that the momentum generated should not be abandoned. Much remains to be done to strengthen the fledgling impact of earth sciences in land use and environmental planning decisions. We do not wish to sound like Cassandras, but the consequences of not following through can be more costly—in terms of dollars, lives, and resources wasted—than the costs of fulfilling the potential of this concept. However, for the full potential to be realized, whether in the San Francisco region or elsewhere, the concept needs more institutional commitment * * *."

That need had already been recognized by the USGS when then Director Vincent E. McKelvey formed the Office of Land Information and Analysis (LIA) in 1975. LIA was created to

> "provide the information needed to evaluate alternative uses of the land and provide a sound basis for decisions on land use. LIA's function is to link the core

disciplines of the Survey's separate divisions to produce reports and maps designed especially to be readily understandable and usable by planners and decision-makers having little or no training in the earth sciences. It marks the Survey's recognition of the peculiar needs of land-use planners and resource managers, and it serves as a model for the broader, less compartmented kind of organization the Survey must expect to become" (Menard, 1979, p. 2).

The five programs in LIA include the Earth Sciences Applications (ESA) Program, the Earth Resources Observation Systems (EROS) Program, the Geography Program, the Resources and Land Investigations (RALI) Program and the Environmental Impact Analysis (EIA) Program.

The ESA Program, incorporating urban area studies and land resource analysis, was established to direct and coordinate multidisciplinary Survey projects specially concerned with disseminating earth-sciences information to land-resource decisionmakers in readily usable forms. The program's objectives are threefold: (1) to interpret, demonstrate, and encourage the use of earth-science information for land-resource decisionmaking through specially designed projects and interaction with, and technical assistance to, users; (2) to stimulate development of multidisciplinary studies in the Survey through coordination and integration of activities; (3) to serve as the focal point within the Survey for multidisciplinary studies in support of the work of other Federal, State, and local agencies.

The EROS Program, a Department of the Interior program administered by the Geological Survey, was created in 1966 to apply remote-sensing techniques to the inventory, monitoring, and management of resources. To meet its primary objective, the EROS Program conducts research and training in the interpretation and application of remotely sensed data and provides remotely sensed data for purchase by scientists, resource planners and managers, and the public.

Although the USGS had a Division of Geography as early as 1881 (Manning, 1967, p. 94), the position of Chief Geographer was unfilled for many years and it was not until 1968 that what is now called the Geography Program was defined. Currently one of that Program's principal objectives is to provide land-use and land-cover maps of the entire United States at a scale of 1:250,000. Such maps, updated periodically and supported by geographic research and by evolving technologies for digitization of spatially related data and for information retrieval and analysis, are intended to assist planners and managers by determining changes in land-use patterns and their environmental effects.

The RALI Program, established in 1972 by Secretarial Order 2743 as a Department of the Interior program administered by the Geological Survey, is designed to provide a mechanism to improve technical communications between the collectors of natural-resource information and the users of such information for planning. RALI coordinates, conducts, and (or) funds studies and provides services to resource planners in those instances where both a multidisciplinary perspective and an extensive multibureau interaction are indicated. These studies and services include: (1) the development and case study applications of planning methods and technologies in areas such as coal development, mine reclamation, and onshore impacts of OCS development; (2) the dissemination of information in forms usable by planners and decision makers; (3) the conduct of workshops and other educational activities; and (4) the provision of technical assistance to State and local planning agencies by the Department of the Interior Programs.

In response to the National Environmental Policy Act of 1969, the U.S. Geological Survey has been responsible for preparing statements on the environmental impacts of decisions regarding the exploration, development, and production of mineral and energy resources from public lands. The USGS also provides technical information for and reviews of environmental impact statements prepared by other agencies. This activity was formalized organizationally under the Environmental Impact Analysis (EIA) Program in 1975 when an effort was also initiated to support research on the problems involved in collecting and presenting environmental data.

The experiences gained in attempting to achieve the objectives of these programs have recently been summarized by T. F. Bates (1979, p. 28 and 29). Bates concludes that

> "If earth-science information is to be applied nationwide to the solution of land resource problems, the entire earth-science community must mobilize to achieve what LIA has attempted to do with its projects:
>
> - Create nationwide awareness of earth-science information needs and uses.
> - Provide specialized, technical information in a form and language understandable to the intelligent citizen.
> - Engage in the educational, advisory, and review services necessary to assist the public and its representatives in making effective use of that information.
>
> In striving toward these objectives, many approaches are needed; some will succeed better than others. However, all will require establishing intimate working relations by every possible means of communication and interaction between the two "communities" involved—the earth scientists and the land resource planners and decisionmakers throughout the Nation" (p. 28, 29).

APPLICATIONS IN THE FUTURE

The consequences of environmental and related legislation over the past decade are to require increasing numbers of geologic site studies in support of development projects, thus placing much of the burden for earth-science applications on developers, both private and public. Nevertheless, there remains a major need for independently derived, readily understandable earth-science information for decisionmakers in order to assess the merits of proposed developments. In the past, such information, where provided, was through packaged interpretive maps and reports or from poorly trained interpreters of basic earth-science data. I would expect in the future that there will be a much greater direct participation by geologists and by planners with better training and understanding of the significance and application of earth-science information in the decisionmaking process at all levels of government. In both cases, I would expect an increased demand for basic geologic mapping and sophisticated interpretive information—a demand that would far exceed the very limited use today of earth sciences in land-use decisions in the United States.

The continuing population growth and the impacts such growth has on the environment point to the need for basic research on man's effect on the environment. An outstanding example is the need to locate suitable repositories for human by-products, including septic tank effluents, other household wastes, toxic industrial wastes, and radioactive substances, and to isolate these wastes so as not to impact fragile geologic and hydrologic environments.

And finally, the world energy crisis requires that earth scientists play a major role not only in the location of new energy resources but in devising innovative ways of developing them so as to minimize environmental impacts. The USGS now has such programs dealing with the environmental impacts of offshore oil development, surface mining of coal, mined-land reclamation, geothermal development, siting of nuclear power plants, disposal of radioactive wastes, and hydrologic and geologic consequences of synthetic fuels development. Such programs make their greatest contribution when they are conducted in advance of the need for information and do not serve to hinder or prolong the development process.

But energy resources are not the only nonrenewable resources being depleted. As a Nation, we can expect other serious shortages in the not-too-distant future. In a state-of-the-art review of the application of earth-science information in urban land-use planning, Spangle and others (1976, p. 13) point to the need for broad, national policies to guide State and local jurisdictions which make the principal land-use decisions related to resource development on private lands. They rightly point out that "Planning and regulatory authority are dispersed; costs and benefits—both environmental and economic—fall unevenly on different jurisdictions and communities; and mechanisms for resolving basic conflicts over whether or not to develop a particular resource are lacking." It remains to the earth scientist to take Vince McKelvey's words to heart and to articulate these and other concerns, not to fellow scientists, but to those who make decisions.

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Environmental Mapping in India

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"Earth provides for enough to satisfy every man's need, not every man's greed."

MAHATMA GANDHI

INTRODUCTION

The emergence of Man as a geological agent has come into focus during the last few decades, leading to a direct responsibility on the part of earth scientists to evaluate this sphere of environmental change and to suggest remedial measures that are conformable with the intrinsic natural characteristics of the various geological formations and geomorphological units constituting the significant environmental domain. The rapidly proliferating population and the demand for utilisation of our finite natural resources, including soil and water, have made such studies crucial.

In the Indian context, the Geological Survey of India initiated environmental geological studies in 1970, with the launching of two major projects, involving the flood-infested Brahmaputra Basin in Assam and the rapidly growing urban complex of the twin cities of Hyderabad-Secunderabad in Andhra Pradesh (fig. 1).

ENVIRONMENTAL GEOLOGY OF THE GANGA-BRAHMAPUTRA BASIN

The high priority, multi-disciplinary project in the Lower Brahmaputra Basin was completed in 1972, followed by a symposium and a report (Balasundaram, 1977). The studies included geomorphological mapping of the fluvial regions of some of the Himalayan tributaries of the Brahmaputra after they debouch into the plains, and hydrogeological and geotechnical investigations of these tributaries as well as some geotechnical investigations in their upper reaches. The studies were carried out over large tracts of the basin using aerial photographs and topographic maps on the one-inch scale. The studies, representing the first attempt of its kind by the Geological Survey of India, led to delineation of three different surfaces at successively different levels. The oldest—also the highest—surface is the most oxidised and pedogenised; it developed during late Quaternary and Holocene time. The hydrogeological studies significantly revealed the increments to surface flow from ground-water sources. The second phase of these studies, undertaken during 1977–79, saw the completion of such studies in Lower Assam and parts of northern West Bengal, encompassing the Brahmaputra and its south bank fluvial features. During the second phase, ERTS imagery (bands 5 and 7) was used to identify lineaments, geomorphic features and changes in river courses. The most important aspect of the work has been the use of sequential aerial photographs and topographic map sheets to understand the changes which have taken place in the fluvial system in response to earthquakes, including the major earthquakes of 1897, 1934 and 1950.

The studies, along with the maps generated, have led to some major conclusions on the geological and geomorphological evolution of the basin and also in regard to certain significant trends in the fluvial regime focussing on environmental geology. The geomorphological maps showing the different surfaces, with unique soil characteristics, can also be converted into maps depicting land use, with inputs of some additional pedological information. These studies are now being extended to Upper Assam.

Some studies on Quaternary geology and its effect on land use have been carried out in West Bengal, in the tracts where the Hooghly, a distributary of the Ganges, has been active. Since fluvial processes and geomorphological features in the basins of the Ganges and Brahmaputra have many features in common, it is expected that a unified programme encompassing the entire Ganga-Brahmaputra basin will evolve in the near future, utilising the methodology already worked out both in Assam and in parts of Western Uttar Pradesh. Such a programme will lead to the generation of valuable information and land-use maps that will provide data on crucial areas that need to be tackled for ultimate flood protection and catchment conservation by means of afforestation, river training, identification of spill basins and other means of water conservation. Studies on various fluvial tracts are also being carried out by the Geological Survey of India in other parts of the country.

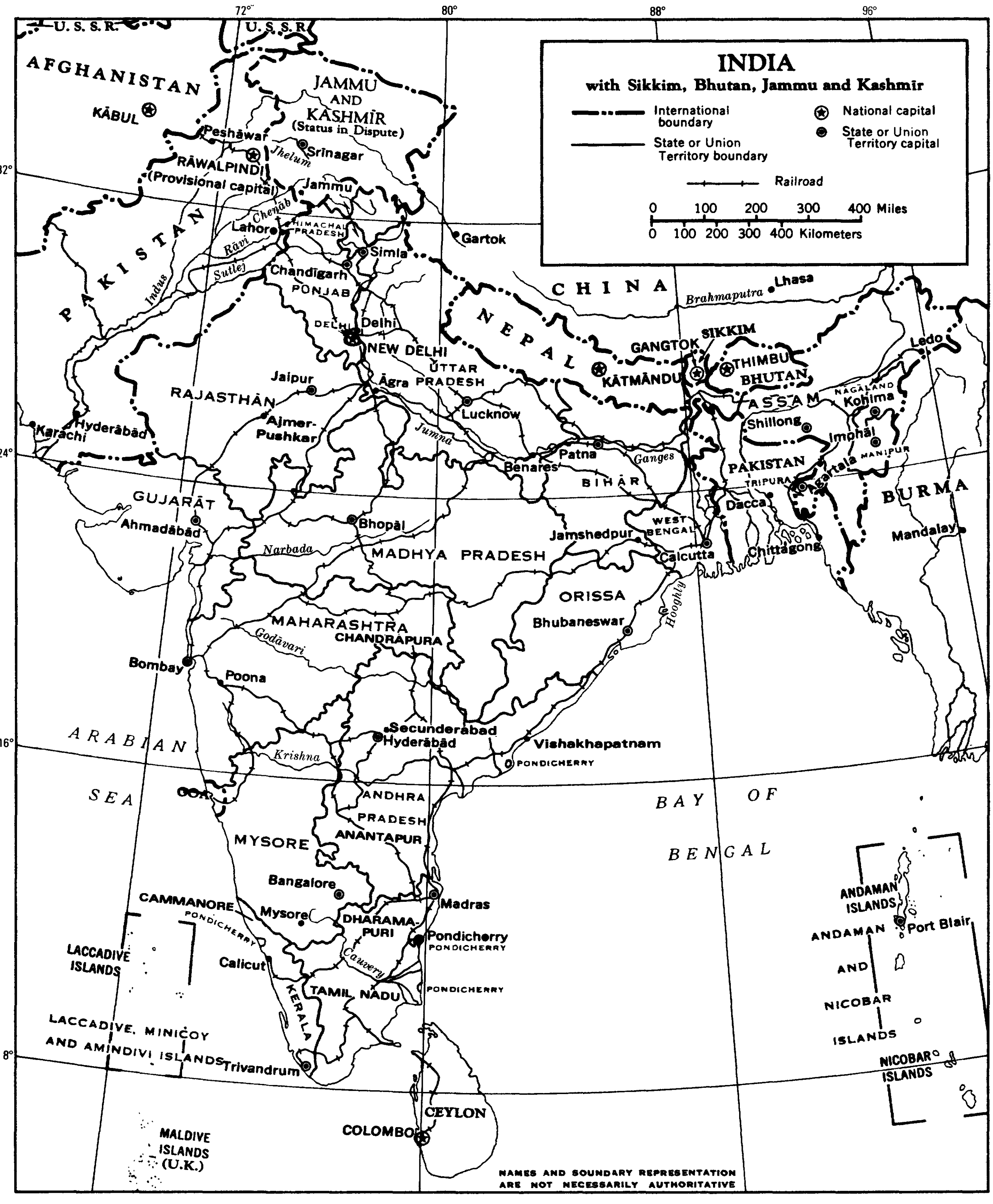

Figure 1 Map of India, including Sikkim, Bhutan, Jammu, and Kashmir.

ENVIRONMENTAL GEOLOGY OF THE INDIAN COAST

In the important sphere of coastal problems, the India Institute of Technology, Kharagpur, has carried out studies on the coastal erosion of the West Bengal beach areas, while the Geological Survey of India has been investigating various coastal areas where such problems have been posed by the port authorities. Significant contributions have also been made by the Andhra University in the field of coastal studies in the Eastern seaboard in the Krishna and Godavari deltaic areas.

ENVIRONMENTAL GEOLOGY OF CITIES AND TOWNS

The project for environmental appraisal of the twin cities of Hyderabad-Secunderabad in 1970 marked the Geological Survey of India's entry into the vital sector of evaluation of urban-growth problems and of providing the basic terrain information for rational planning. Large-scale maps, depicting geological, geomorphological, geotechnical, pedological and hydrogeological features of the cities and their environs were prepared, in collaboration with the Central Groundwater Board and the concerned State Government agencies. This exercise helped the State Government in the planning process. In fact after the first phase was completed in 1975, the Urban Development Authority got interested after an inter-disciplinary workshop discussed the results.

As the project area is located in the Peninsular Shield of India, in granitic terrain, hammer seismic traverses have helped in the delineation of the soil cover. This programme is now being targeted for completion in 1982. Based on the approach adopted in this investigation, the Geological Survey of India initiated similar studies for the Delhi capital region, the important port complex of Vishakapatnam, the increasingly important urban-cum-industrial centres of Bangalore (capital of Karnataka) and Jaipur (capital of Rajasthan) and the pilgrimage centre of Ajmer-Pushkar in Rajasthan. However, the work in many of these areas was not as comprehensive as that in the Hyderabad-Secunderabad complex.

In the case of Vishakapatnam, aerial photos have been used for geomorphological mapping by the Andhra University and geological mapping by the Geological Survey of India, in addition to topographic maps, satellite imagery and field checks. Interesting neotectonic activity could be discerned. A workshop organised this year (1979), "On Integrated Resource Evaluation for Vishakapatnam Urban Growth Centre," based on these studies, focused attention on various problems of development and also indicated the help that such maps can render in rational growth planning for this vital urban region.

As in the case of Hyderabad-Secunderabad, Bangalore is also located in the crystalline rocky terrain of the Indian Shield, with a rolling topography and thin soil cover. The investigations included geotechnical and hydrogeological evaluation aided by hammer seismic traverses to depict the depths to bedrock.

The investigation for Jaipur City and its agglomeration limits was carried out during 1977–79. Located in the fringe of the Indian arid zone, the tract shows the presence of the Precambrian metamorphites with erosion surfaces forming inselbergs and hill ranges, the urban areas being located on dominantly aeolian sand dunes and restricted fluvial deposits. As in Assam, these alluvial/aeolian surfaces form geomorphological units of stratigraphic significance, with varying degrees of oxidation and consolidation and slope, vital in evaluating the desirable land use for each unit. The investigations included hammer-seismic and resistivity surveys, hydrogeological evaluation and a total environmental appraisal that included suggestions for conservation, alterations of land use, and selection of possible new growth centres in the rural hinterland. The map also depicted areas where afforestation, soil conservation, dune stabilisation and change of quarrying sites are called for. The Ajmer-Pushkar area, an important pilgrimage centre for both Hindus and Muslims, about 120 kilometers from Jaipur, was also studied. The data and maps enabled the suggestion of alternative sites for urban growth and of measures for flood control and relief of drainage congestion. In both these cases, dialogues with the State Government are leading to a gradual acceptance of the suggestions made and their incorporation in the regional plans.

ENVIRONMENTAL GEOLOGY OF MINING PROJECTS

Some pilot studies have been undertaken by the Geological Survey of India in selected mining belts (both polymetallic copper-lead-zinc deposits and rock phosphate) of Rajasthan, where the dispersal of toxic pollutants in the soil-water system, disposal of tailings and mine waste, and other effects of mining are being studied through geological and geomorphological evaluation, including geochemical analysis. The mines development agencies belonging to Public Sector Undertaking are showing interest in such programmes.

REGIONAL ENVIRONMENTAL GEOLOGICAL STUDIES

The concept approach and experience gained during the urban appraisal of Hyderabad-Secunderabad led to the initiation of a regional multi-disciplinary project "OPERATION ANANTAPUR" for the district of Anantapur in Andhra Pradesh in 1975. The district was chosen because it had already been covered by the Indian Agricultural Research Institute's soil survey, had complete aerial photo coverage, and was one of the Indian districts selected for development through World Bank financing. It also had a fair geological data base. The first phase of the studies, with collaboration between the Geological Survey of India and several other State and Central Government agencies, was completed in 1977; further work is in progress. The maps have been prepared on the basis of the administrative units of the State Government, the district and *tehsil*, although, scientifically, the basin concept was kept in view. To ensure the completion of the necessary maps for at least one such unit, the Anantapur *tehsil* was selected. The work was completed and all relevant maps printed in the Geological Survey of India Map Printing Press; these maps, released for the first time at this Symposium, together with a Bulletin (Raju and others, 1979), form a landmark in environmental geology in India.

The following maps are included: geological, geomorphological, hydrogeological (arranged by sub-basin), pedological, geotechnical and mineral resources. The Bulletin accompanying the maps gives considerable detail and many more derivative maps with additional information. The studies were based on interpretation of aerial photographs, with the various terrain features transferred to topographic maps and then field checked. Geophysical work was carried out in limited areas. ERTS imagery was invaluable in identifying lineaments that were tested for their water potential.

The Anantapur district is located in the Precambrian crystalline shield of South India which consists mainly of gneisses. The area also has schists (meta-sediments and meta-volcanics) and granulites and is riddled with numerous dolerite dykes. The northwestern part of the area is a part of the mid-Proterozoic Cuddapah Basin with quartzites, dolomitic limestones and shales. Most of the area has a very thin unconsolidated cover of a few metres; the exciting discovery of a lineament, about 110 km long, with a relatively thicker veneer of unconsolidated material (more than 30 metres) led to the yield of potable water sources after drilling by the State Government on the basis of the Geological Survey of India's recommendations. This was a turning point for this drought-affected area. This also confirms the possible use of lineaments as indicators of deep fracture zones with good water potential. Many other suggestions that evolved from these studies are leading to the development of pastures and forests.

In the wake of the Anantapur programme, similar studies have been taken up in the Dharamapuri district in Tamil Nadu (half of this area has been completed), one of the declared drought-prone areas of the country. Similarly, geomorphological mapping by the Geological Survey of India has been completed for the Cannanore district of Kerala, the Union Territory of Goa and some other areas of the country. These are being followed up by the preparation of other thematic and derivative maps. The Geological Survey of India has also been participating in the environmental studies for the backward district of Chandrapura in Maharashtra, a project initiated by the India Institute of Technology of Powai (Bombay), where several types of maps are being prepared. In the Indian arid zone of Rajasthan, considerable geomorphological mapping has resulted in identification of areas prone to salinisation and waterlogging, zones susceptible to sand movement, and the impact of adverse land use on the fragile desert land-water system. Regional maps are being prepared that depict not only the lithology and landforms but also a suggested land-use pattern for proper environmental management.

ORGANISATION OF ENVIRONMENTAL GEOLOGY STUDIES IN THE GEOLOGICAL SURVEY OF INDIA

Thus the decade commencing with 1970 has been the stage of inception of systematic environmental geology in the Geological Survey of India with a multidisciplinary approach and with emphasis on the preparation of various types of thematic maps. With the basic organisational setup in the Geological Survey of India and its logistic support, it was possible for the Survey to break new ground in this field, as a lead agency as a part of its chartered responsibilities. Besides the Engineering Geology Divisions already existing since 1945, the Geological Survey of India set up Quaternary Geology Cells in its various regional offices in 1973. In 1974, full-fledged Quaternary Geology Divisions were formed in five regions, besides a Desert Geology Division at Jaipur. The gradual realisation of the essentiality of geomorphological mapping for both Quaternary studies and environmental appraisal led to the reconstitution of all these Divisions, as Quaternary Geology, Geomorphology and Environmental Geology Divisions, for the six regions of the Geological Survey of India, covering the entire country, in 1976. With the realisation that environmental problems and their solution will need different types of work, with a multidisciplined team approach, a further step was taken in 1979 to set up special Divisions for Environmental Geology in three of the regions. At present, there is a small nucleus of geologists (a few dozen) who have gathered experience in various aspects of environmental geology in the diverse terrains of the country. Environmental maps of the types prepared for Anantapur and those that are being attempted for other terrains are bringing the Geological Survey of India's work into focus with the various developmental agencies of the different State administrations and the relevant Central agencies. It would be correct to record that the 1970–79 decade has been a phase of experimentation with different terrains, various ideas and approaches by the Geological Survey of India. It is indeed satisfying that these have evolved as we went along, problems tackled as they were faced, with noticeable impact on the various developmental agencies that are in charge of implementation.

THE GEOLOGICAL SURVEY OF INDIA AND ENVIRONMENTAL GEOLOGY, 1970-79

From the experience gathered in the Geological Survey of India, so far the following points emerge:

1. The major problems of India at its present state of development are
   a. to introduce better land use, based on a more intimate understanding of the soil, geomorphological and geological characteristics of various units of a terrain, that also reflect the climatic situation;
   b. to arrest the process of extensive soil erosion that is fast depleting this invaluable and well-nigh irreplaceable resource, which is linked up with
   c. proliferation of floods and acceleration of desertification as a result of wrong use of land and soil;
   d. to rationalise and check the rapid growth of urban sprawls, beyond the carrying and cleansing capacity of the terrain, with related problems of hinterland resources development and equitable rural development, to reverse the rapid migration of people from rural to urban centres.

      It is hoped that simultaneous mapping of urban areas and the surrounding rural regions for planned development will eventually help the Government to stimulate a balanced and complementary growth between the two sectors.
   e. to ensure that environmental mapping and appraisal is a built-in part of all mining and engineering activities affecting natural resources and the terrain.
2. Undoubtedly, such maps as have been attempted in some of the areas discussed will be based primarily on a geological and geomorphological evaluation of the terrain. This naturally will cause the Geological Survey of India to play a major role in making this successful and also in ensuring that the problem will be viewed in its totality.
3. Experience gathered shows that maps of various types have to be prepared with the cooperation and involvement of diverse agencies having the requisite specialisation and capability. Collection of various types of terrain information will have to be geared up to remove the vital information gaps of the present day, such as information on the trace elements of various soil types in most areas.
4. The increasing utilisation of information from aerial photographs and satellite imagery (with its enlargement and enhancement technique), besides the modern topographic maps. This will mean increasing involvement of the Survey of India and National Remote Sensing Agency.
5. In order to make the published documents readable and usable, there is need for continued dialogue with the State Government agencies and other user agencies, not only after the maps are ready, but during the field work stage, so that the investigators are able to appreciate the problems from the user's viewpoint. In a culture which is primarily statistics-oriented, it is essential to make the users aware of the problems, their cause and the value of cartographic depiction. This dialogue must be extended to other levels of planning and administration to make the policy and funding agencies take cognisance of the value of such programmes. In the words of Brown and Fisher (1975, p. 27, 28), "the environmental map is a common language and vehicle which can bring together the many divergent specialists and allow their collective contribution to be simultaneously focussed on a problem. * * * The derivative map is a means of translating basic geology into a form that can be utilized by a wide variety of persons interested in the environment and its proper exploitation and conservation."
6. The Indian scientific community, especially those connected with the earth sciences, has a crucial role to play in the preparation and proper evaluation of maps and data, to make rational suggestions to the State Governments, which are at present largely deprived of this valuable data bank to draw on for their policy decisions in the field of regional planning. This alone can ensure a developmental strategy that will not initiate or aggravate environmental hazards.

FUTURE STRATEGY FOR ENVIRONMENTAL GEOLOGY IN INDIA

The work so far done in India, and particularly by the Geological Survey of India, has brought into focus the magnitude of environmental problems, their diversity, and also the positive role that earth scientists can play in providing the fundamental map as an information base to resolve these issues and rationalise overall development of the country. The various pilot studies have also helped in evolving a strategy and approach towards the investigations. Once the value of such maps and information is realised by the administration in the States, the Geological Survey of India will be faced with requests for such programmes on a massive scale. In fact, the publication and distribution of the Anantapur series will probably be the triggering factor for such a situation. Even at this stage, various State Governments have started favourably reacting to such activities by the Geological Survey of India.

In order to tackle expeditiously the anticipated work load and the magnitude of the problems, a two-pronged strategy will be called for:

1. Carry out detailed studies along the lines already discussed in critical and priority terrains indicated by the State Governments, by strengthening the Geological Survey of India setup for such studies.
2. Initiate an immediate programme for broad geomorphic mapping of the entire country, with extensive use of satellite imagery from the ERTS and other projects. Together with the available regional maps, such geomorphic maps will make possible the classification of the entire terrain into broad units that will form the basis of land use, and will allow changes in pattern to be made as necessary. These maps will be an invaluable tool, not only for rational planning but also for selecting critical zones for environmental management and monitoring.

   Utilisation of satellite imagery will include visual interpretation of multispectral, black and white Landsat imagery, the RBV pictures from Landsat 3, enhanced by the use of positive-negative film, sandwiches and colour renditions through additive colour viewers. Photographic enlargements to a 1:250,000 scale will also be very valuable in demarcating the regionally significant geological and geomorphic units. In the second stage, panchromatic air photographs and digital enhancement of satellite multi-spectral imagery will allow refinements to be made in interpretation and mapping. Obviously, the use of repetitive imagery interpretation and aerial photography will also be most useful for monitoring morphological changes of significance in both arid and fluvial regimes, consequent to floods and aeolian activity.

   The Earth station to receive Landsat pictures is already set up in India, which will help in this sphere of activities. Furthermore, there is a strong ground-truth organisational base available in the country to back up such remote-sensing exercises, by way of verification and follow-up. With improvement in remote-sensing technology, it is expected that such a large scale environmental mapping programme will receive adequate support.

The strategy for the Twenty-first Century in India, insofar as rational utilisation of the fast dwindling resources, especially soil and water, is concerned, will largely depend on the availability of such thematic and regional maps before the turn of the century. Not only is it a question of preparing the maps but also of publishing them in the language of the user, if necessary in many regional languages, to enable the permeation of this knowledge of the environment down to the grassroots level of the people.

Obviously, the task is vast and the Geological Survey of India alone cannot tackle it, especially in view of the other strategic responsibilities that it is vested with. Nevertheless, it is mandatory that the Geological Survey of India retain its leadership in this vital field of the present and future by performing as the lead agency and also by keeping the overall environmental perspective in its purview, assisting other agencies, especially those in the States, to carry out many of the detailed studies.

Environmental problems, as commonly understood, lay emphasis on pollution of water and air. The more subtle, but equally vital, pollution, using this term to mean "degradation," will not be obvious except through the preparation of various types of environmental maps as outlined in this paper. The manifestation of proliferating floods, soil erosion, and desertification, often a consequence of injudicious land exploitation and degradation, is already overtaking India's economic development. Therefore it is no overstatement to stress the immediate necessity of providing the country with environmental maps to enable proper planning so that a prosperous, self-sufficient, self-reliant India will emerge in the Twenty-first Century. The task is great, but not impossible. The task is urgent; it is later than we think!

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The Australian Approach to Environmental Mapping

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INTRODUCTION

Because of Australia's size and wide range of natural resources, its environmental mapping encompasses a great variety of activities. In this paper I will discuss two kinds of environmental mapping in Australia: the mapping of some of the more significant individual components of the natural resource base and the mapping of resource environments as entities.

The major individual resource components relevant to the theme of this centennial conference are climate, geology and minerals, water, soil, and vegetation. Each can be represented in qualitative or quantitative terms or by some interpretative or use function and can thus be presented in a series of thematic maps. These maps will be discussed only insofar as they indicate a particular Australian requirement or method.

Mapping the resource environment involves the subdivision of the Earth's surface into areas that are either sufficiently similar to be treated alike or sufficiently dissimilar to require separate attention at the scale that has been selected as appropriate.

One approach is the ecological mapping of vegetation which is taken to express a response to, and therefore a reflection of, the environment as a whole. This is the ecosystem approach as developed by Costin (1954). However, this and the many subsequent vegetation studies have not yet been generally applied to Australian environmental mapping and assessment, so vegetation mapping as such will only be mentioned under thematic mapping.

The resource environment can also be expressed in terms of land areas having distinctive physical and ecological characteristics. We will later examine a method of land resource mapping developed in Australia for this. It has been applied widely in Australia and other countries. Associated land-assessment methods will not be discussed.

The Australian continent is about the same size (7,686,810 sq. km) as the 48 contiguous States of the United States, but has only about 7 percent of their population (13,100,000 in 1970). The number of trained personnel available to map resources is correspondingly smaller. Further, because of the distribution of rain fall, water resources, and the more productive soils, the population is concentrated mainly in the southern, eastern, and southwestern margins of the continent. About 80 percent of the continent is arid, semiarid, or dry hot tropical country. Its natural biological productivity is low; its mineral wealth is generally unknown. This large, sparsely populated section has always been a challenge to Australian initiative to know, understand, utilize and manage (fig. 1). It is not surprising therefore that Australian approaches often tend towards broadscale assessment. Such a tendency is reflected, for instance, in the many early attempts to assess continental land use potentials by developing generalized climatic indices that subdivided the continent into a number of distinctive zones (Davidson, 1934; Prescott, 1934, 1949). There has always been the need to seek useful, if imperfect, conclusions from limited data, by using limited numbers of personnel as efficiently as possible.

While staff limitations persist, our increasing need for more definitive information about environment management in the developing areas has led to the modification or evolution of methods designed to produce more quantitative and explicit geographical data.

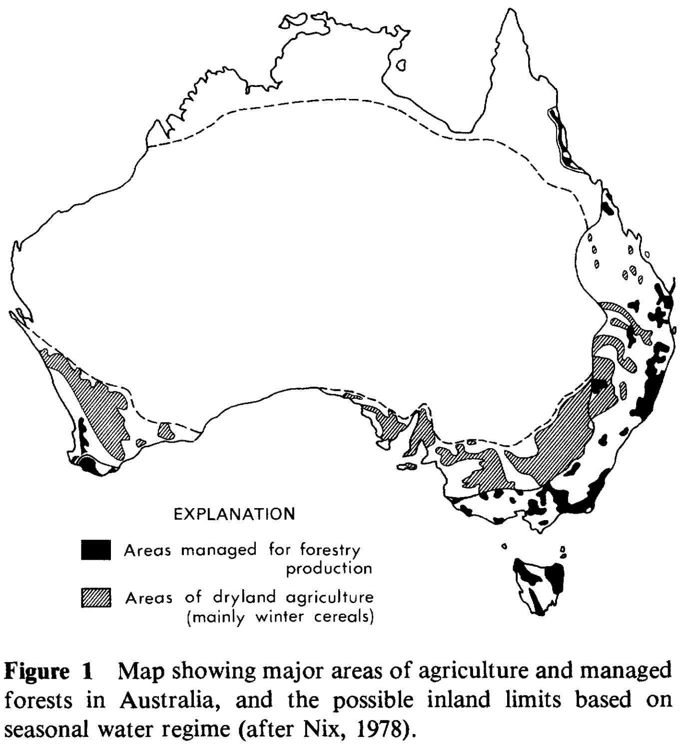


Figure 1 Map showing major areas of agriculture and managed forests in Australia, and the possible inland limits based on seasonal water regime (after Nix, 1978).

Australia is mainly a flat country with limited areas of higher relief in the south and east and a small part of the centre. Geological ages range from Archaean to the Quaternary, and climate from the hot dry tropics in the north where rainfall is restricted to a few summer months, to the cool temperate south where rainfall is mostly confined to the winter. These factors, plus the near concentric distribution of rainfall and water resources, and the random distribution of minerals, have resulted in a wide range of natural biophysical resource environments, and in varying degrees of resource utilization. Utilization ranges downward from the highly developed rural areas in the better rainfall zones to completely undeveloped areas in the interior and northwest.

Constitutionally, the responsibilities for terrestrial natural resources in Australia lie with the individual States, except for those areas within Commonwealth Territories. However, the Federal Government does have specific responsibilities in defence, the marine environment, and meteorology, as well as general responsibilities for national development policy. A wide range of survey and mapping activities at the regional and local level, for administration, project, and operational purposes are performed by numerous State authorities such as those concerned with lands and survey, geology and mines, agriculture and soil conservation, water, forestry, national parks and wildlife, planning, conservation and environmental control, and local government. In addition, numerous disciplinary groups in research, education, museums, and private enterprise organisations contribute to the total mapping effort.

We will restrict our discussion to mapping at the continental scale and to special techniques. Continental scale mapping is mostly done by our Federal agencies in collaboration with the States. State and Federal information are coordinated through a number of National Councils or Committees.

The emphasis on reconstruction and development in the post-1945 period resulted in a substantial acceleration in the study, survey, and mapping of natural economic resources, especially in the less developed parts of the continent. In the last decade or so, other aspects of the environment have been receiving attention. For example, there has been a growing concern about conservation of wilderness and reference areas, the initiation of an ecological survey of Australia, more activity in the survey and study of natural biological resources, such as the International Biological Program (IBP) concerned with plant communities (Specht and others, 1974), and attention to the establishment of environmental statistical indicators. In due course these will all influence the mapping programs.

Currently, at the Federal level, the major bodies concerned with mapping are the Division of National Mapping and the Bureau of Mineral Resources (BMR), Geology and Geophysics, both in the Department of National Development; the Royal Australian Survey Corps; various divisions of the Commonwealth Scientific and Industrial Research Organization (CSIRO); the Bureau of Meteorology; and the Environment Division of the Department of Science. The Bureau of Statistics and the Department of Primary Industry have related specialist roles.

TOPOGRAPHIC MAPPING

For all environmental mapping purposes an accurate base map is essential. Topographic maps are produced by the Division of National Mapping, by the Royal Australian Survey Corps, and by each of the States. Close coordination is achieved through the National Mapping Council, which is composed of representatives of each mapping organization. The Director of National Mapping is Chairman.

In general, the Division of National Mapping undertakes mapping at scales of 1:250,000 and 1:100,000, the Royal Australian Survey Corps at 1:250,000, 1:100,000 and 1:50,000, and the States at 1:50,000 and larger.

A major contribution towards all post-1945 mapping was the organization by the Division of complete coverage of the continent by black and white aerial photography at a scale initially of 1:50,000 and later of 1:84,000. This was completed in 1965. Complete coverage of planimetric maps was then compiled at photo scale. This series, published at 1:250,000, was completed by 1968.

Currently a 1:100,000 map series is being produced for the more densely populated and special interest areas, and orthophoto maps for other areas, both series having 20-metre contours. At the same time the 1:250,000 series is being revised with more detail and 50-metre contours.

Two activities have contributed to the accuracy of the present mapping: geodetic surveys made between 1965 and 1966 that used electronic magnetic distance measuring equipment to cover the continent, and a levelling program completed between 1961 and 1971.

THEMATIC MAPS

The Division of National Mapping publishes an annual Bulletin that records thematic maps produced each year throughout Australia. The Division is also involved in producing thematic maps: information from a variety of sources is compiled in map form by the Division. Maps are produced at a variety of scales, from 1:5,000,000 to larger scales. Of special significance is the Atlas of Australian Resources of which two series have already been published; a third is in progress. Maps produced so far concern the biophysical environment, including climate, geology, geophysics, landforms, land classification, land use, minerals and mining, forestry, fish and fisheries, agriculture, nature conservation, soils, vegetation, water resources and population. All Atlas maps are accompanied by a handbook giving general information about the theme mapped and describing the methodology used. The following paragraphs describe special features of some of these monothematic maps.

Climate

The Bureau of Meteorology is currently producing a Climatic Atlas of Australia at a scale of 1:12,500,000.

General climatic maps are prepared and published by the Division of National Mapping from information supplied by the Bureau. Apart from a wide range of standard climatic presentations, interpretative maps for various other practical uses are required. For instance, current maps significant to both agriculture and engineering illustrate the variation in seasonal water balance for different parts of the continent. Others depict the range of human comfort conditions and the energy requirements for adequate heating or cooling of the indoor environment. Because of the variability of rainfall and other factors in the Australian environment, climatic maps are often based on median and percentile values rather than on means and standard deviations.

Water Resources and Hydrology

Through the efforts of the Australian Water Resources Council, established in 1963, and with financial assistance from the Federal Government, there has been a substantial expansion of recording networks and of research programs. Data from this increased effort are presented in reports and publications of the Council, such as Australia's Water Resources (1975), produced by the Department of National Resources, and in maps prepared by the Division of National Mapping. These include maps showing surface and underground water resources, water quality and water use. The surface-water map depicts zones having different average runoff, expressed in water depth. It also indicates the annual discharges for selected major streams. A related map of special importance in the Australian scene shows the variation in surface runoff in different parts of the continent and in different seasons, using 10 and 90 percentile values.

Considering its large area, the number of instrumented basins in Australia is small compared with many countries. For this reason the Council initiated a study of 100 basins, selected according to principles of landscape analysis and climatic characteristics to represent the range of conditions prevailing on the continent. It was hoped that such a study would permit extrapolation from instrumented to non-instrumented basins on the basis of comparable physical and biological characteristics, thus extending the value of the existing network. A mathematical model developed to relate runoff to rainfall and catchment characteristics is currently being subjected to sensitivity tests.

About 45 percent of Australia is covered by smooth plains that have a very different hydrology from the steeper coastal catchments with more consistent rainfall. So a special study was established to determine appropriate methods of collection and analysis of data for arid and semiarid catchments of low relief. A map depicting an ecological classification of those smooth arid plainlands was prepared for the special study and published by National Mapping at a scale of 1:5,000,000.

Vegetation

A vegetation map: At a scale of 1:6,000,000, this map was compiled for the Atlas of Australian Resources by J. A. Carnahan (1973) from numerous vegetation survey sources. It provides information on the distribution of vegetation types that are based on structural forms differentiated by their taller and lower strata. It indicates the typical genus or family of the upper stratum and, where the top canopy cover is less than 10 percent, that of the lower stratum also. Maps of forestry resources, grazing lands, and pastures have also been produced.

A new floristic map of Australia: Prepared by Professor N. C. W. Beadle of the University of New England, in New South Wales, this new vegetation map is nearing completion and should be published in the near future (personnal commun.).

Australian Biological Resources Study: Sponsored by the Environment Division of the Commonwealth Department of Science and Environment, this study has the goal of recording and collating available information on flora and fauna and relevant environment data. Currently it is encouraging, and in part supporting, preparation of a uniform series of vegetation maps of Australia at a scale of 1:1,000,000. So far a classification system based on structure has been defined. The study is also concerned with mapping the distribution of plant and animal species. Current mapping of fauna in Australia is largely restricted to the recorded distributions of individual species. A book with maps showing the distribution of birds has already been published (Busby and Davies, 1977).

Soils

Both for resettlement and for agricultural development, soils information was widely sought in the post-1945 period of economic reconstruction. Numerous soil surveys were conducted in many parts of the country. Other surveys, such as the broader land resource surveys and ecosystem and vegetation studies, also collected soils information. However, it was difficult to collate this information because of the lack of uniformity of soil classification and description. Northcote (1960) made a major advance in his development of a factual key for the field identification and description of soils. Following a great deal of collating effort and the collaboration of many soil surveyors, as well as additional field and photo interpretation study, an extremely useful soil map of Australia was produced with one uniform classification system.

The map is at a scale of 1:2,000,000 and its ten sheets cover the continent (Northcote, 1960–68). The map depicts different soil landscapes, each area representing an association of soils whose dominant soil is nominated. An accompanying handbook describes all the soils in each map unit and gives information on lithology and topography and the soils associated with different parts of the terrain. To some extent the map represents the type of land system map that is described later in this paper. However, the amount of information about the landscape, other than soils, is limited and there is no biological information on vegetation, for example.

Land Use

A new land use map at the scale of 1:5,000,000 is nearing completion by our National Mapping Division. It depicts type and density of livestock, crops produced at low, medium and high intensity, urban settlements with populations about 2,000, larger mine sites, managed forests, and national parks. Based on 1976 agricultural census data, the map provides information on a Local Government Authority area basis. Visual interpretation of small-scale Landsat imagery is used to delineate the distribution of pastures and crop areas within these areas.

Geology and Mineral Resources

The importance of geological and mineral mapping to Australia is shown by the success in discovering mineral and energy resources in the last 20 years. Minerals now represent 30 percent of the country's total exports, and oil discoveries currently supply 70 percent of the nation's needs. Australia is self-sufficient in major minerals, except petroleum, sulphur, and phosphate. It has over one-fifth of the Western World's low-cost uranium reserves; it is the largest exporter of lead and iron ore, the third largest exporter of coal, bauxite, and rutile, and the sixth largest exporter of unrefined copper.

The recognition of any country's mineral and energy potential is dependent on an awareness of its geological framework and on abundant information for studying and interpreting geological history and structure. Therefore, the starting point in any systematic search for mineral and energy resources is a systematic geological and geophysical map series and comprehensive data bank. Our accurate base map series was prepared, assembled, and interpreted by the Bureau of Mineral Resources and the State Geological Surveys, with input from and application by many companies and institutions.

In a large continent such as Australia one can expect to find a range of geological conditions with differing tectonic and metallogenic domains having characteristics that indicate the presence of mineral and energy resources. Furthermore, with fairly sparse vegetation cover over most of the continent, and modest urban development largely restricted to coastal areas, some types of exploration are straightforward.

But against this, mineral resources exploration also presents some problems. Geological mapping advances depend very much on the number of geologists per unit area. Australia has about 3,000 geologists and less than 500 geophysicists, compared with about ten times this number in the United States.

Other factors inhibiting exploration are the vast areas of superficial sediments and the relatively flat landscape resulting from the lack of major Tertiary tectonics. In general, rock exposures are not as prevalent or as fresh as in some other continents. This means that geological deductions and models need to be applied frequently to find "blind" or non-outcropping ore bodies. Also, because of low rainfall and deep weathering from past climates, large areas have a blanket of saline groundwaters that play havoc with some geophysical techniques.

On the other hand, these generally old land surfaces have produced a diverse and valuable assortment of supergene concentrations as well as conditions unfavourable to electrical geophysics. The detrital beach sands, the deep leads of gold and tin, the superficial concentrations of bauxite and gypsum are of obvious supergene origin. More complex and, in some instances, perhaps more remote supergene events have led to enrichments which form secondary copper bodies, manganese ores, nickel laterites, some uranium deposits, and the widespread and thick iron ore deposits.

The Bureau of Mineral Resources and the State Geological Surveys have completed regional geological maps for 95 percent of the continent at a scale of 1:250,000. Since this phase of field work was made possible by aerial photography after 1946, about 540 such map sheets have been produced for the onshore continent, and a further 245 sheets for the offshore continental margin.

Modern photogeological methods and multidisciplinary approaches are emphasized, along with integrated laboratory and field investigations. Not only is use made of palaeontology, petrology and mineralogy, chemistry and geochemistry (rock, soil and stream), and geochronology, but geophysical techniques are also an integral part of problem solving.

A large part of the BMR geophysical effort has been devoted to completing the systematic gravity and magnetic survey of Australia, including the continental shelf. Complete gravity coverage of at least one station per 130 square kilometres is available, and 70 percent of Australia is covered by aeromagnetic maps. All the oil-prospective land areas and offshore basin extensions have aeromagnetic coverage. Systematic recordings of seismicity and crustal structure measurements are now underway for the whole of Australia.

Prior to 1953, oil exploration of Australia had been sporadic and not very successful, a commonly held opinion being that, in general, the Australian continent was too old to have produced oil. Exploration was spurred by the first significant, although not commercially important, flow of oil in 1953 from an Australian well at Rough Range No. 1 in Western Australia.

A very significant impact on oil exploration resulted from the petroleum subsidy scheme introduced by the Commonwealth Government in 1957. It was very successful in encouraging exploration in the 1960–70 decade during which most of Australia's oil and gas discoveries were made. Its success was due not only to direct financial contributions, but also to additional expenditures by industry and because large amounts of exploration data were made available publicly within a short period.

BMR and CSIRO research findings in airborne geophysical techniques have been widely adopted by mining companies for their nickel and uranium exploration. Results from ground method research have also been applied successfully in metalliferous provinces.

Reconnaissance marine surveys were begun in 1965 with gravity, magnetic, and seismic measurements being made simultaneously at a ship speed of 10 knots and a line spacing of 15 km. The whole continental shelf to a depth of about 2,000 metres has been largely mapped, and most of the continental slope to about 4,000 metres has been covered at 40-km line spacing. The total area covered is 6 million square kilometres.

Continental coverage by black-and-white aerial photography, as a basis for plotting field observations and for compiling base maps, has been essential to the post-1945 systematic geological program. Over the complex geological provinces, colour photography is used at a scale of 1:25,000 for the more detailed metalliferous studies.

To solve the problems of mapping a large area with a relatively small population, Australia seeks to make full use of remote sensing technology. Research is being conducted into the effectiveness of various aircraft and spacecraft remote sensing methods, including Landsat, Skylab and SLAR, for mineral and petroleum exploration in the Australian environment. It has been found that Landsat imagery complements the use of aerial photography in regional studies. It can provide new information about some previously unrecognized structures depicted by lineaments, extension of previously known structures, and the joining of discontinuous lineaments in areas of sparse outcrops. In some areas a broad indication of various rock distributions and structure may be obtained. In turn, this new information can lead to fresh ideas about the whole geological framework. But, so far, Landsat imagery has not proved to be a substitute for conventional aerial photography coupled with careful and extensive field mapping.

LAND RESOURCE SURVEYS

Apart from making Australia largely self supporting in most food and other rural products, the agricultural and pastoral industries have long been Australia's major source of overseas income. Thus interest has always been great in land for development purposes. On top of this there has also been interest in Australia's unique flora and fauna and the land habitats that they occupy.

Land System Surveys

The most distinctively Australian method of land resource survey and mapping is the land system approach, also known as the integrated land resource survey method because it involves the simultaneous study in an integrated program of many land features by a team of investigators—including a geomorphologist, a soil scientist, and a botanist-ecologist, along with other scientists, according to circumstances.

The land system method is described in detail by Christian and Stewart (1953), by Christian (1958), and by Christian and Stewart (1968). Its relationship to other concepts is discussed in the 1968 reference, in Davis (1969), in Gibbons and Haans (1976), and in Ollier (1977).

The systems approach was first developed in 1946 to meet a practical need for mapping and broadly evaluating, for various purposes, large areas (50,000 to 350,000 sq. km) of virtually undeveloped country in Northern Australia in as short a time as possible.

In these studies the word "land" is used to refer to the total complex of all observable and non-observable, physical and biological attributes of a site, including those above and below as well as those at or on the surface (Christian and Stewart, 1953, 1968). Thus land is seen as an entity, not as something determined by one or a few observable features.

While one or another component of this complex may have a dominating influence on land use at certain locations, more often it is the combination of several or many factors that determines the quality of land, the purposes for which it might be used, and the problems or limitations it may present. Not all factors can be identified by visual inspection and the importance of some may not become evident until land has been actually used for a particular purpose. Furthermore, understanding the geographic and topographic disposition of different kinds of land can be of considerable importance, for instance, in respect to drainage, erosion, accessibility, transport, markets, and the like.

The traditional methods of mapping individual components of the environment were not adequate for the purpose, partly because they were too time consuming and partly because the conventional classifications alone were not satisfactory for broad regional assessments. For speed of operation a method was needed which mapped areas of land as entities, describing the many features, but without taking time to map these features individually.

Australia's land system approach therefore subdivides landscape into areas which are inherently similar or inherently dissimilar, thus providing a permanent framework for sampling and applying any kind of information or inquiry relevant to the nature of land. More detailed information from subsequent studies may also be entered handily in this framework.

This land system mapping method is based on the recognition and interpretation of the tonal and stereoscopic patterns revealed in air photos which have been or can be independently verified by field examination of corresponding areas on the land surface. Assumptions concerning similarity of different areas depend partly on comparison of the observable features of each part of the landscape—particularly topography, soils and vegetation—and partly on their occurrence within major geological and geomorphological subdivisions of the landscape. The latter are identified by combined air photo examination and ground observations. The landscape is subdivided into a hierarchical system of units. The more complex ones are mapped; the simpler ones within them are described.

The land system concept: The following quotations explain the reasoning underlying the concept (Christian, 1958):

> "The concept visualises that each part of the land surface is the end product of an evolution governed by parent geological material, geomorphological processes, past and present climates and time. During this period the land surface has been shaped to existing land forms, each developing in the process its own hydrological features, soil mantle, vegetation communities, animal populations, and range of microenvironments. [See figs. 2 and 3.]
>
> "Where such parts of the land surface can be identified as having a similar genesis and can be described similarly in terms of the major inherent features of consequence to land use—namely topography, soils, vegetation and climate—they are regarded as being members of the same land unit. * * * The common genesis of the various occurrences of one land unit also implies that they may be similar in many respects additional to those most easily observed, and this is likely to be expressed in the technical problems associated with land use development."

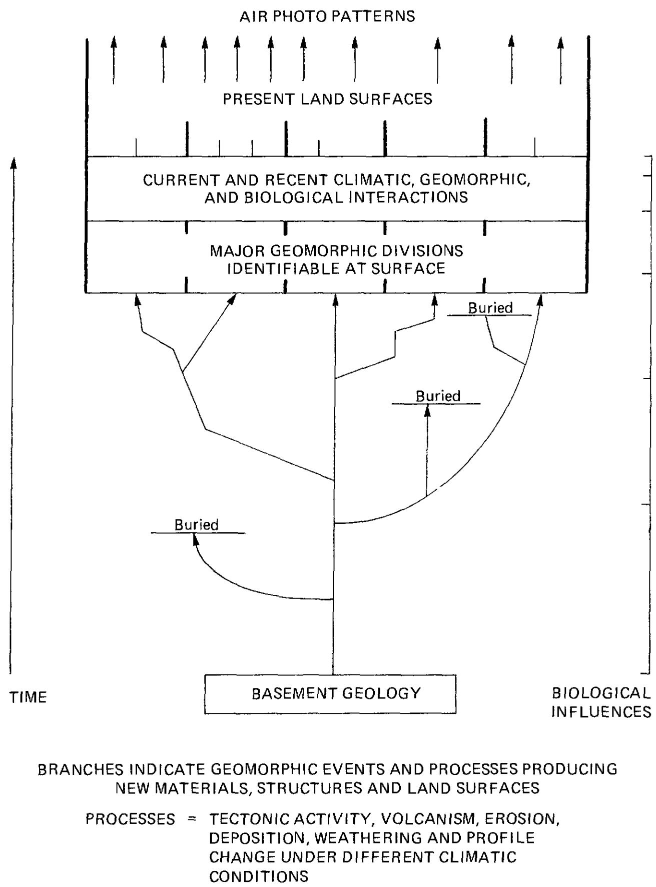


Figure 2 Some land surface evolution sequences (diagrammatic). Branches indicate geomorphic events and processes producing new materials, structures and land surfaces. Processes are tectonic activity, volcanism, erosion, deposition, weathering, and profile change under different climatic conditions.

The land system has been defined as "an area, or group of areas, throughout which there is a recurring pattern of topography, soils and vegetation" (Christian and Stewart, 1953). The land units are the topographic elements constituting the pattern: each topographic unit has a restricted array of soils and vegetation. These units represent the smallest areas requiring specific management or planning decisions at the chosen scale of the survey.

The term "land system" was adopted because it connotes the occurrence of the land units within distinctive landscape patterns. It also had other connotations, particularly that the various factors composing the land surface were in a constant state of interaction, that is in a dynamic, and not a static, state. Thus any induced change, such as clearing for agriculture, could be expected to have repercussions throughout the system. Further, "Land Systems" may be recognized as Simple, Complex or Compound.

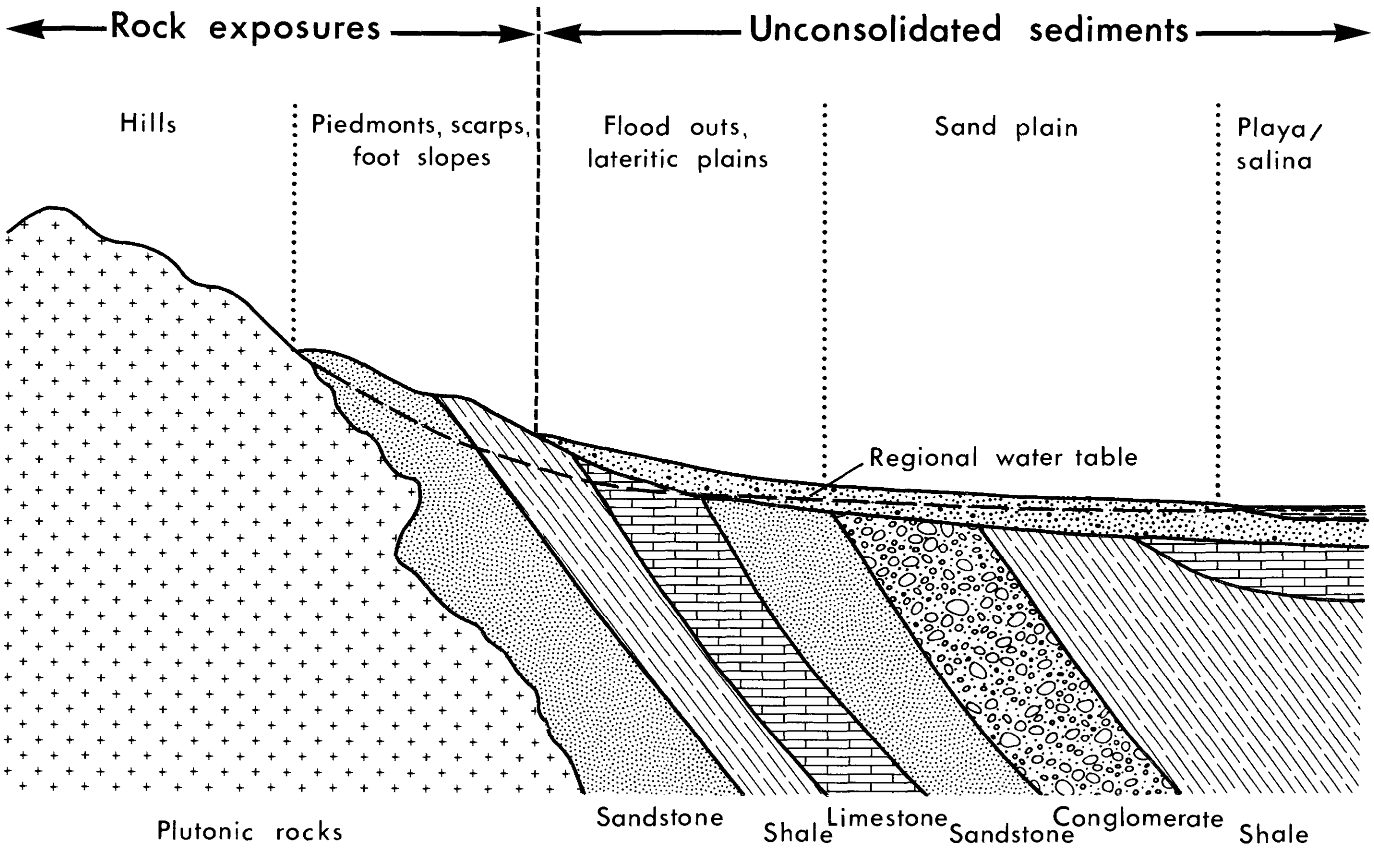


Figure 3 Central Australian landscape (diagrammatic) (After M. F. Fleming, unpublished).

"A Simple Land System is a group of closely related topographic units, usually small in number, that have arisen as the products of a common geomorphological phenomenon. The topographic units thus constitute a geographically associated series and are directly and consequentially related to one another. A Complex Land System is a group of intermixed and related Simple Land Systems. A Compound Land System is a group of land systems enclosed within the one boundary for convenience in mapping.

"A land system can be continuous or discontinuous, providing it does not extend over too wide a climatic range. A boundary may be somewhat arbitrary where there is a broad transition zone. Boundaries frequently, but not always, coincide with geological boundaries. Geomorphic processes are more important than the basic geological material, although the two are obviously related. A land system may comprise several geological groups that have lost their surface identity as the result of a dominating geomorphic influence. On the other hand, several land systems may occur within one geological group as a result of different geomorphic influences.

"If a pattern of a land system is adequately sampled and described, and the boundaries of the system can be defined, then the broad potentialities of the area occupied by any system can be determined without investigating the whole area in detail. An approach of this nature enables the work of survey and appraisal to proceed at a much greater pace than could be done by standard traverses" (Christian and Stewart, 1953).

In many places man himself has been a factor in determining the present nature of land, in some instances to such an extent that these man-made effects may be regarded as a persistent feature of the land unit. Where the effects are of only a partial nature it may be necessary to seek remnants of undisturbed areas to describe the land unit, or to make a further subdivision into used and unused areas.

Other factors may alter the appearance of the landscape either erratically or seasonally, and can complicate the interpretation of the photo image, as for example, fire, seasonal rainfall, and floods. A low order of correlation between environmental components may reduce the precision of extrapolation from a limited number of sample sites. Bleeker and Speight (1978) report on variable soils in a high-rainfall, hilly area in New Guinea. Austin (1978) found it necessary to describe vegetation in terms of toposequences in a survey of that part of temperate coastal New South Wales where altitude and aspect have a marked influence on floristics. Dense climatic climax vegetation may also make photointerpretation of geomorphic features difficult.

In addition to providing a basis for the delineation of areas that warrant priority attention for further study, whether for development or nondevelopment purposes, the land unit-land system concept also can contribute to the understanding of the geography of soils, of the ecology of plants and animals (Christian, 1969), and of vegetation classification. Ollier (1977) claims that a soil survey of Uganda, which took 12 man-years to produce before air photos were available, could have been done better in less time had a subsequently published land system map been available. Myers and Parker (1975) found that the increase in rabbit populations after rain, their decrease in dry seasons and the location of dry season refuges varied in different land systems. Coaldrake (1961) discusses and uses the concept of integrated land environment in vegetation studies.

Methodology: Details of the methodology of land system surveys are given in the papers quoted, in reports of numerous surveys conducted by CSIRO and published in that organization's Land Research Series, and in the reports of surveys published by State organizations, such as the Technical Bulletins of the Division of Land Utilization, Queensland, and the various reports on public lands by the Victoria Soil Conservation Authority.

The general sequence of operations for a land system survey by an interdisciplinary group follows:

1. Study available information, maps, reports, and data.
2. Delineate on air photos, at scales of 1:50,000 to 1:80,000, all major features including discernible geomorphological divisions and all distinctive and consistent tonal patterns within them (preliminary land systems). Make preliminary interpretation of patterns with respect to geology, geomorphology and vegetation. Full use is made of stereoscopy in this process.
3. Plan series of field traverses to sample all types of areas delineated on air photos.
4. Examine biophysical features of sample sites and along traverses. This is done by the group of specialists concurrently who confirm or correct preliminary photo interpretations of geomorphic divisions and land systems, record observations, and collect rock, soil, and vegetation samples. The classification methods for each attribute are those normally adopted by the discipline concerned.
5. Discuss as a group the boundaries of areas having different geomorphic origins, the validity and content of land systems, and other classification conclusions.
6. Collaborate in office revision of photo interpretation and in final delineation of land systems surveyed by interdisciplinary group; each specialist will compile land system and land unit descriptions, based on field data and information from samples.
7. Prepare geomorphological and land system maps; collate scientific data, such as vegetation ecology; produce generalized maps of individual components such as soils and vegetation as extrapolated from land system mapping.
8. Publish final report on the land system.

The land systems are illustrated by topographic cross sections (figs. 4 and 5), block diagrams (fig. 6), plans (fig. 7), or stereo pairs of photos (fig. 8). Land units are indicated on each. Each land system illustration carries a brief description of its geomorphology, geology, climate, resources and land use, and for each land unit within it, there is an estimate of the proportion of the land system that unit occupies as well as information on its landforms, soils, vegetation, and any special aspects such as drainage.

The reports of land system surveys contain a general historical and descriptive account of the region, a description of techniques used, a discussion of land systems and land units, regional accounts of geology, geomorphology, hydrology, soils, vegetation, resources, present land use, and capability assessments.

Land system surveys can be and are conducted at different scales, which are dependent upon the size of the area being surveyed, the time available, and the purpose and urgency of the land planners. The air photo scales commonly used range from 1:50,000 to 1:84,000, the same scales that are used for national planimetric map production; but larger scales are also used. With a very small scale it may not be possible to identify simple land systems. At a very large scale, photo patterns tend to become diffused and difficult to recognize. The scale of mapping is in part a matter of choice but at the usual scale of available photography, map scales of 1:250,000 to 1:1,000,000 are appropriate.

To a large extent the method of interpretation is flexible in scale, with respect to both land systems and land units. Thus complex land systems may be mapped in a very broadscale survey and their land unit descriptions will be correspondingly "crowded" or complex. At a more intense mapping level these same complex land units may themselves be seen as discrete entities and be mapped as simple land systems. The simpler land units within the now simple land systems are then identified and described in more detail. However, at a very large scale the objectives of a system survey can and more often may be such specific landscape attributes as slope or soil. Hence specialist-type or thematic surveys may then be more appropriate.

It is desirable that land system data be as quantitative and as precise as possible. However, when very large areas are being surveyed, time usually imposes limitations on the amount of data that can be collected. For such areas a very broad reconnaissance is required first and detailed data are

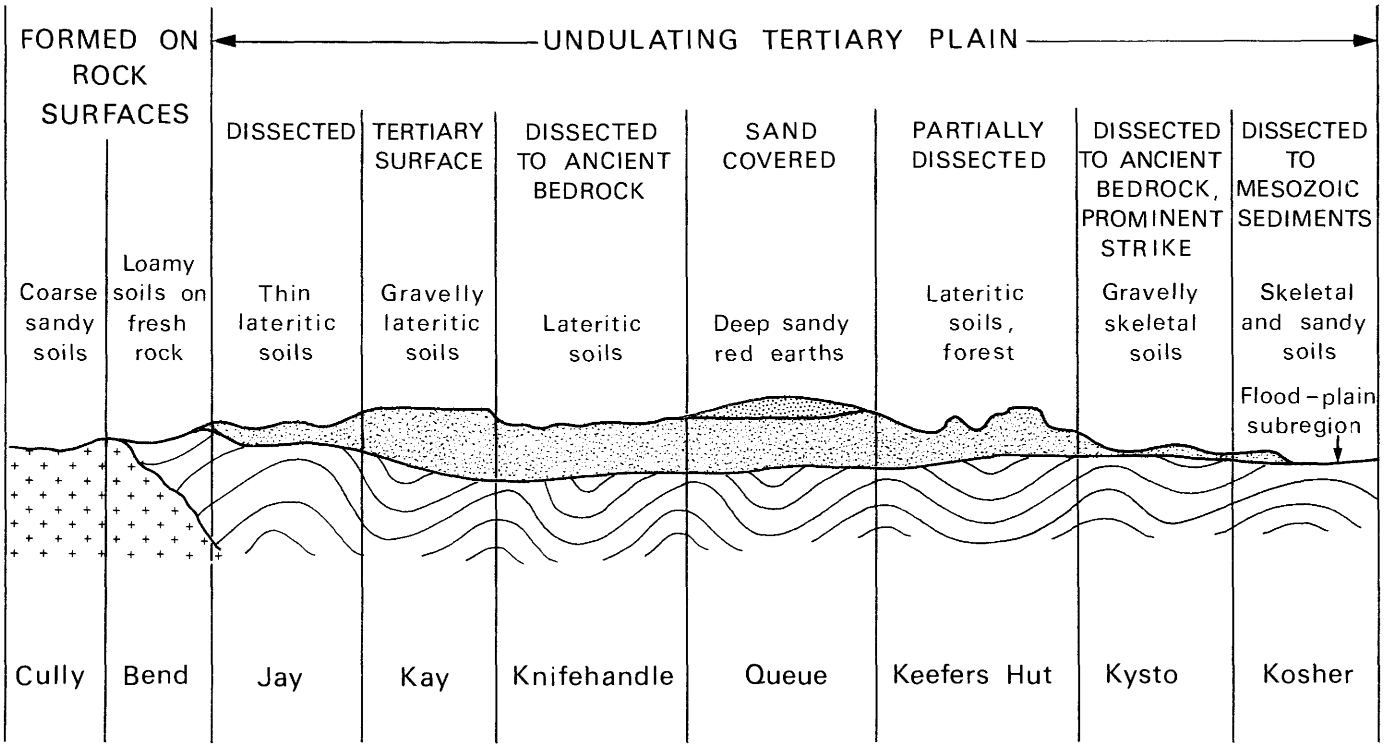


Figure 4 A typical sequence of land systems (name at bottom of each column) in the lowlands of the Alligator River Region, Northern Territory, Australia.

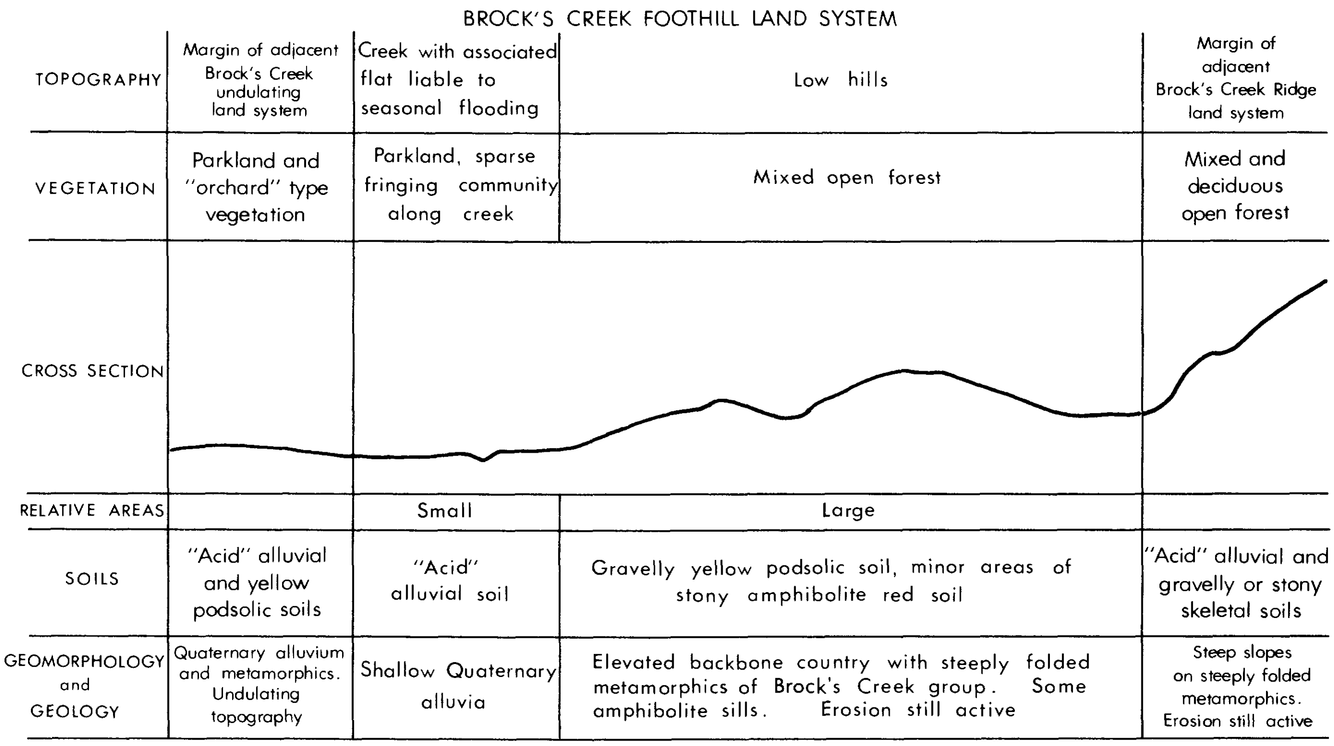
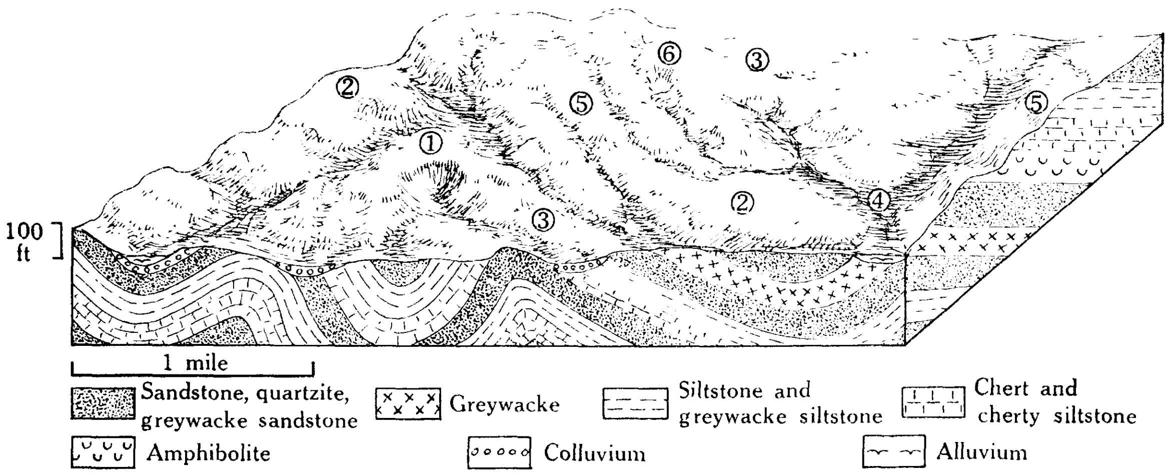


Figure 5 Cross section and characteristics of Brock's Creek foothill land system, Northern Territory, Australia. Only the two central columns apply to Brock's Creek foothill land system. The outer columns indicate which other land systems adjoin Brock's Creek (Christian and Stewart, 1953).



Unit	Area and Distribution	Geomorphology	Soils	Vegetation
1	35% Throughout	Sandstone, greywacke, greywacke sandstone and siltstone, and quartzite hills and strike ridges: 50–200 ft high, slopes to 60%, stony to rocky, much outcrop; gullying, diffuse wash	Skeletal soils and outcrop	Woodland, height 30 ft, visibility 200 yd, eucalypts over tall or mid-height grass (*E. dichromophloia*, *E. miniata*, *E. bleeseri*, *E. tectifica*, *E. terminalis*, *Livistona*, *Petalostigma*, *Cochlospermum*, *Ampelocissus*, *Terminalia ferdinandiana*, *Grevillea heliosperma*, *Heteropogon triticeus*, annual *Sorghum*, *Themeda*, *Chrysopogon*)
2	30% Throughout	Siltstone and weathered sandstone hills: 40–70 ft high, gentle convex summits or narrow strike crests with up to 25% outcrop, linear to convex hill slopes to 30%, even stony to gravelly regolith up to 2 ft deep; minor gullying, diffuse wash	Skeletal soils and outcrop, rare red sandy Cahill soils, and shallow Munmarlary yellow-red sand to clay; gradational soils associated with lateritized outcrop	
3	15% Throughout	Colluvial wash slopes at foot of units 1, 2, and 6: linear to gently concave, up to 600 yd wide, slopes to 5%; up to 5 ft of sandy to silty colluvium with ½ in. even veneer of fine gravel and siltstone flakes over bevelled rock; minor laterite benches 2 ft high, 20 yd wide, 10 ft above unit 4; scalding, minor gullying	Skeletal soils, shallow grey Cullen soils, and rare Cahill soils as in unit 2	
4	10% Throughout	Alluvial flats: less than 200 yd wide, slopes to 2%, channels up to 30 ft wide, ill defined or incised through 4–5 ft sandy or loamy alluvium into rock; local outcrops, river laterite	Skeletal soils (colluvium), with minor Elliott (yellow sand to clay, hard-setting)	Flats grassland or open savannah (*Eriachne burkittii*, *Themeda*, scattered *E. alba*, *E. polycarpa*); channels sometimes fringed with *Pandanus* and non-eucalypts
5	5% Mary–McKinlay area	Chert and cherty siltstone hills: 70–100 ft high; convex summits above 20–30% linear slopes; 6–12 in. angular scree up to 2 ft deep; rare outcrop; dissection by closely spaced, sharply incised, V-shaped gullies up to 60 ft deep, 150 ft apart, with side slopes to 50%	Skeletal soils	Woodland, height 25 ft, visibility 250 yd, eucalypts over tall or mid-height grass (*E. alba*, *E. dichromophloia*, *E. clavigera*, *E. tectifica*, *Xanthostemon*, *Cochlospermum*, *Petalostigma*, *Grevillea heliosperma*, *Heteropogon triticeus*, annual *Sorghum*, *Themeda*, *Chrysopogon*)
6	5% Chiefly in south and south-west	Hills of varied lithologies, especially dolerites and amphibolites: 50–150 ft high, smoothly convex, bevelled or irregular summits, benched, linear or convex slopes up to 40%; stony to rocky; frequent outcrop; gullying, sheet wash, eluviation, and basal sapping	Skeletal soils, stony krasnozems on amphibolite (not described), and Cahill soils as in units 2 and 3	As for unit 1

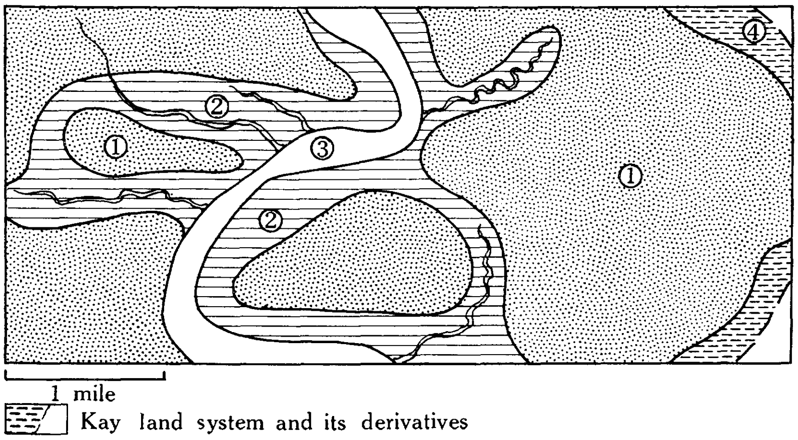
Figure 6 Baker land system, Northern Territory, Australia (Story and others, 1969). [Baker land system (965 sq. miles, 51 observations): Dissected uplands and isolated strike ridges of greywacke, sandstone, and siltstone mainly in the south and west of the area; skeletal soils and outcrop with minor sandy red and yellow gradational soils; woodland (evergreen or semideciduous eucalypt).]

needed only where land use capability justifies closer attention. It is more economical therefore to restrict detailed data collection to a second stage specialist-type survey of selected areas either by a land-unit or a single-component survey method.

In the early surveys of Australia, much detailed information was lost by using generalized descriptions of land systems and land units. The trend in more recent surveys has been to store much of the information from individual observations in forms that permit easy retrieval and analysis. The availability of high-speed digital and analog computers over the last 30 years has contributed to this technical improvement.

Modifications and derivatives of the land system approach: The land system survey and mapping method has been in use in Australia for over 30 years and during that time its application has been extended far beyond its original purpose and to a wide range of mapping scales. As is to be expected, various modifications and adaptations have been introduced for particular purposes.

Several trends are evident. The original surveys were designed for large areas of undeveloped country. Many subsequent surveys have had to be adapted to regions where present land use is a major influence and also where more immediate decisions on land matters have to be made at the local level. Data collection therefore has had to meet



Unit	Area and Distribution	Geomorphology	Soils	Vegetation
1	75% Mainly southern half	Higher, seasonally dry plains: slopes 0·3–0·8%, elevation 10–40 ft, relief to 4 ft; occasional shallow pans and buffalo wallows; freshwater clays over estuarine clays, in places with subfossil gastropods (*Turritella* spp.); 2-4 miles, in places up to 6 miles wide; flooded 3–6 months to depths up to 1 ft, rapid drying once rains cease; very slow aggradation; rare subparallel dunes up to 4 ft high with slopes to 5%, minor levees	Black cracking carbonate rich clays (Carmor) near old channels and higher areas: Wildman (clays over gleyed muds) in lower sites; Adelaide (self-mulching) soils on old levees; minor Cairncurry (gypsic clays) on former swamp sites; minor dune sands	Sedge land, dense robust sedges up to 2 ft with occasional scattered or patchy *Sesbania*, rarely dense mid-height grassland (*Ischaemum*); dunes, mixed scrub over short grass (*Acacia*, *Pandanus*, *Ficus*, *Canarium*)
2	15% Mainly northern half	Low, ill-drained, seasonally tidal plains; similar to unit 1 of Copeman land system	Predominantly Wildman soils and organic clays (Dashwood) in wet sites. Carpentaria saline clays near areas of tidal influence	Herbaceous swamp vegetation as for unit 1 of Copeman land system
3	5% Trending south to north at broad intervals	Main channels: up to ½ mile wide and 30 ft deep; minor tributaries up to 6 ft deep and 40 ft wide, over ½ mile apart; bed-load of silt and clay; lower reaches tidal in dry season		Open water, or herbaceous swamp vegetation rooted in mud or floating; occasional clumps of *Barringtonia* or *Melaleuca cajaputi* and *M. leucadendron*
4	5% Southern margins next to Kay land system and its derivatives	Up to 400 yd wide, slopes to 0·8%; elevation *c.* 30–45 ft; freshwater clays over buried sands and ironstone gravels derived from adjacent deeply weathered lowlands; minor channels and billabongs up to 6 ft deep and 50 ft wide; rare gilgai areas, puffs 3–4 ft across, 6–12 in. amplitude	Acid to neutral clays over sands or rock (Counamoul)	Sedge land: fine sedges up to 12 in., scattered *Melaleuca argentea*, or *E. papuana*, *Panicum trachyrachis* in gilgai depressions, *Heteropogon contortus* on rises; low-lying areas, herbaceous swamp vegetation as for unit 1 of Copeman land system

Figure 7 Cyperus land system, Northern Territory, Australia (Story and others, 1969). [Cyperus land system (1,225 sq. miles, 26 observations): Seasonally flooded coastal plains, freshwater clays over estuarine clays, north of area; black cracking clays over mainly calcic estuarine muds; sedge land.]

such requirements, but this has also been accompanied by greater amounts of information available from prior studies of geology, soils, and vegetation.

A hierarchy of landscape subdivisions has been retained although subdivision names may have been changed where subsequent surveys identified specific needs. In general, the land system or its equivalent remains the major mapping unit in Australia.

In land system surveys of developed country, where survey areas are usually smaller and where data more closely relevant to immediate local land use and management decisions have been required, a finer, more uniform landscape unit has been introduced into the hierarchy. A general trend has also been to prescribe the limits of each landscape unit in the hierarchy more precisely.

With increased experience, survey techniques have become more efficient, the sampling more systematic, the data collection more detailed and precise for each land attribute, especially at the land unit level, and we have adopted improved data storage and retrieval systems.

The study of morphogenesis tends to be less emphasized and is replaced by direct measurement of terrain characteristics. However, the morphogenetic implications remain an inherent characteristic of the procedures, and mapping usually takes note of geomorphic divisions. More interpretation of processes is made in order to understand either land deterioration or land stability. In areas where large-scale information is required for defined objectives, the land system subdivision becomes less significant. Then land resource surveyors are more concerned with specific landscape components, such as soils or vegetation; they adopt classification systems appropriate to these components, rather than to the landscape as a whole.

Because of this methodological flexibility, the subdivisions adopted in different surveys are not always comparable, but we are trying to reconcile these differences.

Two other developments are noteworthy. One is the application of the same general principles to the mapping of regions for land use planning, but mainly by using and aggregating existing information, with a minimal amount of new data acquisition. This was done in the survey of South Australia that we discuss later. The other development is the recognition of a need to relate biophysical information to the existing land area boundaries imposed by socioeconomic decisions, such as land tenure boundaries, rather than to natural boundaries alone. This is important partly because available statistics relate to these boundaries and also because these areas are the units to which information is applied in planning and management.

Some areas originally mapped as complex and compound land systems have been resurveyed at a larger scale into simpler land systems. The land system survey was initially seen as the first stage in a sequence of events in land appraisal. It was envisaged that, after the initial identification by the reconnaissance survey of the important parts of a region, specialist-type studies or surveys would be made

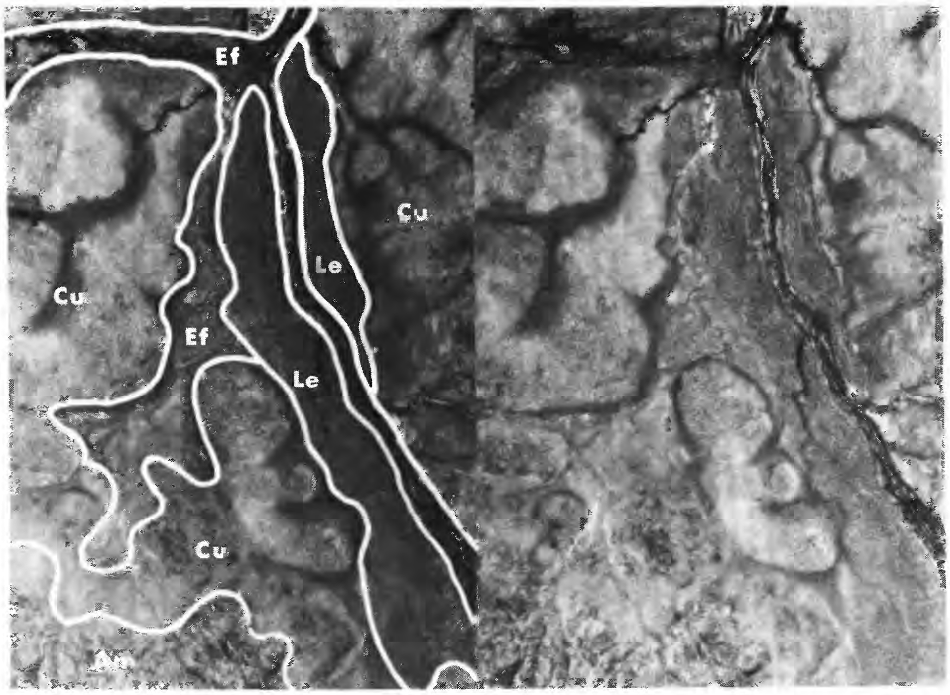


Figure 8 Stereo pair of photographs of the Cully I (Cu), Effington I (Ef) and Levee (Le) land systems in the Alligator River region, Northern Territory, Australia (Story and others, 1976). (The air photographs in figure 8 are Crown Copyright and have been reproduced by courtesy of the Director, Division of National Mapping, Department of National Development, Canberra, Australia.)

in selected areas, to map and assess specific resources in detail (Christian and Stewart, 1968). This procedure has been followed in principle more closely in the Northern Territory than elsewhere. Following the survey of the Katherine-Darwin region, research stations were established in the Tipperary land system and near Darwin. Following some years of research, land unit surveys were conducted in a number of areas which had previously been mapped at the land system level (Aldrick and Robinson, 1972; Fogarty and Wood, 1978). These land unit surveys are at scales ranging from 1:10,000 to 1:100,000, and provide much more detailed information of direct value to both rural and urban land users. Their purposes range from pastoral and agricultural planning, through erosion assessment and wildlife habitat studies, to urban planning.

Other modifications of the land survey system are described below:

1. In Western Australia, the survey of the Gascoyne Catchment was made for the purpose of assessing soil erosion and the degree of degradation of rangelands (Wilcox and McKinnon, 1972). The mapping unit was called the "rangeland type." In most instances rangeland types were identical to land systems, but in some instances geology and soil differences were obscured by the vegetation response and a rangeland type overlapped land systems. In other instances, one land system was divided into two rangeland types. Payne, Kubicki and Wilcox (1974) report on the use of a land system survey of the West Kimberley area for assessing range condition, and Kubicki and Beer (1973) describe the re-survey of parts of the north Kimberley for assessing the suitability of land for pasture improvement.

In areas closer to socioeconomic development, surveys tend to be of a landform-soil type, or to be based on some other specific attribute.

2. Most of Queensland has been covered by some form of land system mapping. Surveys of extensive pastoral areas have been made in Western Queensland at a map scale of 1:250,000. These conform to the general land system-land unit concept, but mapping is done in greater detail than for earlier surveys and includes mapping land units where feasible. Sampling is arranged systematically within land system boundaries and also to establish relationships between adjacent land systems. Checks are made to test sampling bias.

The above-mentioned surveys are characterised by improvements in data acquisition, storage and retrieval and by investigating each land attribute in considerable detail.

Land systems are grouped into land zones on the basis of similarity in physiography, soils, vegetation and geomorphic development. Landsat imagery for different growth periods is used to examine regional variability. It assists both differentiation and mapping.

Emphasis is placed on the collection of data for land unit descriptions because of their importance as units of land management. The survey reports include much of the original information on each landscape attribute. Further, survey data are permanently stored on microfile.

These survey reports include extensive information on these Western Arid regions in addition to the biophysical data, with discussions of resources and problems of a kind which have direct relevance to land management (Department of Primary Industries, 1974, 1978).

Similar surveys are conducted in the mixed agricultural and grazing areas at a larger scale with more intensive field sampling. Map scales range from 1:50,000 to 1:250,000. In intensive agricultural areas, surveyors usually employ reconnaissance survey methods but are concerned more particularly with soils. An alternative technique is to sample key areas intensively and to extrapolate from them.

In coastal areas where operational information is required, surveys are made at the land unit or site scale but data may be grouped into land systems for general use.

3. In central Queensland, three adjacent areas of the Fitzroy region previously surveyed by CSIRO were reexamined by Gunn and Nix (1977). Because they had been surveyed separately, and because of the procedural flexibility inherent in the system-unit concept, it was difficult to collate similarly-named units of these three surveys for applied land-use purposes. In the three original surveys a total of 120 land systems and 863 land units had been recorded; many of the described land units were of a complex type. The 863 land units were reclassified according to type of land surface, subdivided by terrain type (landform, relief, and slope), landform element (position on slope), soil, and vegetation. This produced 142 simple land units, many of which recur in numerous of the 120 land systems. They were regrouped into 19 geomorphic categories for regional mapping purposes.

Next, the proportion of each land system occupied by the relevant land units was determined. A small index map for each land unit located it in the study area, and appropriate shading indicated whether it occupied more than 40 percent, 10 to 39 percent, or less than 10 percent of the land system in which it was represented.

The Fitzroy example draws attention to the desirability of standardizing the scale of subdivisions and of developing correlation procedures, at least between closely related surveys, where data are to be used directly for land use planning. In the three Queensland survey areas referred to, common elements of geomorphological history were largely responsible for the structural similarities that the reappraisal revealed; and because these were important similarities, the need arose for collective planning.

There is a degree of subjective judgement involved in recognizing dividing points between land units. It is attractive to consider the adoption of the parametric approach for this purpose. This may be appropriate at large scales but it is an approach dependent on additional information such as precise contour data, which is not usually available in areas where extensive land system surveys are appropriate. Landscape mapping is still required in order to show the spatial relationship of the parameters selected for study. The time required for such intensive study is also an important limiting factor. Decisions also have to be made on how much detail is to be acquired in the initial survey and how much is to be left to be acquired, for selected areas, in a subsequent specialist survey.

4. In eastern coastal Queensland, the land system-land unit concept was used for a comprehensive study of the ecological subdivision of the lowlands area. This ecosystem study is reported by Coaldrake (1961).

5. In Victoria, a relatively intensively developed State, land system surveys have been used for a variety of purposes. They are a viable and useful part of mapping and appraisal procedures for planning and land use decisions, and about two-thirds of the State has been or is being mapped. Land system information is applied in numerous ways including land capability ratings, and for determining reserve areas of crown land to be set aside for conservation, or other purposes. Here the land system is the mapping unit used. A broader unit, the land zone, is an aggregation of land systems with some common features of land form, geological material, and climate. It corresponds more or less to a geomorphic division or category (see item 3 above). The land system is divided into areas termed land components, roughly equivalent to simple land units. Simple and complex land components are recognised. Soil and vegetation toposequences are identified in order to help explain ecological relationships. The various landscape units are defined in terms of degree of uniformity or variability of geology, landform, soil and native vegetation.

Land systems are illustrated by block diagrams that identify the land components. Given in tabular form, land system descriptions include general data on climate, geology, and topography, with more detailed information for each component, including landform, slope, native vegetation, and soil. Present land uses are listed, as well as information specifically related to soil deterioration, such as critical land features, processes, and forms. These land system surveys are published either by the Soil Conservation Authority in a Technical Communication series (as no. 12, Nicholson, 1978) or by the Land Conservation Council of Victoria in reports of regional land studies for multi-land use purposes.

To identify and briefly describe land systems, a numerical system has been adopted. Each major land attribute is classified on a numerical scale in which each number defines the attribute. For example, there are 8 numerical classes for average annual rainfall, 5 for geological age, 4 for surface rocks or sediments, 7 for average altitude, and 6 for land forms. Identifying the appropriate class for each attribute yields a five-digit numerical description which classifies the land system. Should different land systems have identical five-digit descriptions, they are further distinguished by an additional digit.

6. In the Western District area, the New South Wales Soil Conservation Service has a program of land system mapping that occupies about half of the State. About one-quarter of the whole State has now been mapped. Mapping is usually done first on individual leases, such as the livestock grazing properties (ranches). The primary objective is to obtain information on topography, soils and vegetation, and soil erosion and range condition, for land management purposes. Supplemented by additional air photo interpretation, the individual lease surveys are then aggregated into standard map sheet areas. In more intensively developed areas in the eastern part of New South Wales, the land system survey is usually replaced by a more detailed soil survey.

7. In Tasmania, the first stage of a land system mapping program for the State has just been concluded (Richley, 1979). The method conforms closely to that used in Victoria. (See item 5 of this listing.)

8. For recording terrain data for engineering purposes, an interesting adaptation of the same principles is that by the CSIRO Division of Applied Geomechanics (Grant, 1973, 1974; Grant and Finlayson, 1978). The terms used are terrain pattern, terrain unit, and terrain component. While these terms correspond in concept very closely to land system, land unit, and site, they are defined within narrower limits of variation. A numerical system is used for identification and the kinds of data to be acquired for terrain analysis are prescribed. Precise instructions are given on procedures.

9. Two studies initiated by CSIRO were designed to examine the development of new technologies. One is a study of the environments of South Australia (Laut and others, 1977) and the other a study on the south coast of New South Wales (Austin and Cocks, 1978).

ENVIRONMENTS OF SOUTH AUSTRALIA

At the request of the then Commonwealth Department of Environment and Conservation in 1975, the CSIRO initiated a feasibility study in South Australia to devise and demonstrate a methodology for an ecological survey of Australia and to assess the suitability of Landsat imagery for the purpose. The pilot study was extended to the whole State, an area of about 900,000 square kilometres. Completed in a two-year period, the study attempts to provide a consistent level of information throughout the State (Laut and others, 1977).

The approach, a modified integrated reconnaissance survey, depended largely on the compilation and mapping of existing information, using Landsat imagery as a base map. A large-to-small environmental hierarchy was arranged by province, region, association, and unit.

The State of South Australia was first divided into 8 provinces, mainly on a geographic basis. Below the province level, increasingly detailed information was given for region, association, and unit. Environmental units were defined primarily by geomorphic criteria. Associations are aggregates of environmental units. Regions consist of groups of associations. At each level, definitions include, as appropriate, such factors as landforms, climate, native vegetation, land use, ground water, surface water, soil, and cultural features.

The following account of the mapping procedure is taken from Laut and others (1977):

> "Mapping is based on LANDSAT imagery. For each subject mapping is a compilation exercise wherever previously published research is available, but it also involves interpretation of LANDSAT imagery both to identify boundaries used by previous researchers, frequently at different scales and levels of generalization, and to extrapolate these to wider areas and to identify pattern boundaries not associated with previous research. Field work was generally limited to checking data rather than acquiring new data, although there were numerous occasions when new data were obtained during field checking, especially in the north of the State.
>
> "In practice, for each environmental province, team members compiled previous research data, undertook reconnaissance field work, and interpreted LANDSAT imagery to prepare a map for each subject. Boundaries were examined, modified, extended or rejected by common consent until a set of environmental boundaries proved satisfactory to all disciplines. The environmental association delineated in this way usually represented distinctive patterns on LANDSAT imagery. The environmental units within each association were identified and described but not mapped.
>
> "Experiment indicated that black and white LANDSAT imagery could be used readily for pattern recognition as if it were a pseudo air photo mosaic, from scales of 1:1 million to approximately 1:200,000. * * * Two scales of mapping were adopted; 1:250,000 for those provinces in the agricultural areas and 1:1 million for the pastoral and sparsely settled areas."

THE SOUTH COAST SURVEY, NEW SOUTH WALES

This study area of about 6,000 square kilometres centred on one Local Government Authority area or Shire in New South Wales and adjacent parts of Shires to the north and south. It includes farmlands and grazing areas, national park reserves, and areas of forest and fishing industries. Increasing pressure for recreational use from nearby regions results in the area's urbanisation and land subdivision, particularly near the coast. The survey was an experimental study of a mapping methodology that could provide environmental information about the resources of the area for "a rational basis for planning decisions on a wide variety of land uses." In this respect it differed from many former reconnaissance surveys that did not aim to be so explicit about planning information at the local level (Austin and Cocks, 1978).

The survey was a study of both biophysical features and socioeconomic aspects within a framework of land boundaries already established for social and administrative purposes, or imposed by distinctive biophysical features. Within these constraints, the survey set out to determine the various land use options for each area and to demonstrate how to select a preferred use. The study included fauna, and intertidal and sub-littoral zones, as well as terrestrial areas and water bodies.

The region was first divided into "Functional Districts" on the basis of gross geological, relief, and land use characteristics. For each district, all occurrences of the smallest identifiable uniform photo patterns were delineated on air photos. Termed "unique mapping areas" (UMA), these correspond to simple land systems. Fifteen lithologic and twelve terrain types were identified. Each UMA was also subdivided into "Functional Units" or areas of land with boundaries determined either by former land tenure or by land use zoning decisions. The study aimed at providing information about each of the 3,854 Functional Units that were identified and mapped.

"Facets" (simple land units or sites) were determined by subdividing landforms into simple, uniform sectors. They were identified from 1:250,000 maps with 10-m contours or from air photos. Individual facets were not mapped but fifty broad facet types were identified and included 12 kinds of erosional terrains, 7 of coastal rock, 15 of depositional terrains, and 16 of water bodies. Many were further qualified according to lithology and terrain type, increasing the number to 311. Additional types had to be created for special, usually small, situations such as a beach type facet in a coastal functional unit. These raised the total to 504 facets.

Facets were described in terms of landform, lithology, aspect, rockiness, soils, and vegetation. Descriptions were prepared with information from 693 sample sites and from topographic maps. The number of sample sites was allocated to the Functional Districts in proportion to each District's size, complexity, and "importance." The distribution of sample sites within each district was calculated on the basis of the uniqueness and extent of different types of UMAs within each District. The samples were finally located in the UMAs subjectively according to their landscape pattern and accessibility.

Although there was a general correlation between facet type and soil and other attributes, there was a geographic range in the occurrence of a given facet due to climatic and other factors. An idealized description or paradigm was constructed for each facet type unless known variants were present.

The Functional Unit was the mapping unit. Each belonged to a given lithologic and terrain type, although in some circumstances a Functional Unit had two terrain types represented. Each such Functional Unit contained from one to 11 facets and was given a biophysical description based on the idealized descriptions of the facets present and their relative proportions.

The large volume of data associated with 800 UMAs and 3,854 Functional Units required an appropriate computer data storage, retrieval, and analysis system. This consisted of a map system and a Functional Unit attribute system, with intercommunication to facilitate presentation of data search results. Within the map base the graphic elements are points, lines, and regions, but only the last, expressed as Functional Units, were used in this exercise. The attribute base stores information compatible with the Functional Units.

It is possible to retrieve data from the attribute base to answer complex questions about the distribution of 150 attribute characteristics with respect to the 3,854 Functional Units. Information can be delivered either in tabular or in cartographic form, and the mapping system incorporates a number of advanced concepts including file storage, line deletion and addition, and various map search procedures. It gives considerable flexibility to the manner in which map data can be analysed and used.

However, maps produced by the computer system depict the facet paradigms and do not necessarily indicate the precise biophysical attributes of an individual unit on the map, although the Functional Unit data bank can be updated as more information is obtained.

Compared with most other comprehensive land resource surveys, this study was restricted to a relatively small area. It was conducted at a much more intensive scale by a larger number of investigators and was more comprehensive and collected more explicit information than traditional surveys do. It also utilised a systematic sampling procedure; facet analysis of the landscape was possible because 10-metre contour maps had already been made of this region. Computer storage and data processing was essential. To a degree this storage replaces the permanent framework of mapped land types of the early land system surveys. Primarily an experiment, the study was expensive for Australia. Whether this high-technology approach can be applied as a routine for other Shires remains to be seen. Subsequent efforts have been made to adapt the technology to the minimal time, resources, and limited skills of staff available for planning exercises by local and regional governments. The information is of more value to and is more easily accessible to regional planners and researchers than it is to individual land users.

Using the study's attribute information as a guide, specialist surveys, or at least examinations, would still probably be necessary at the level of the Functional Unit for local land use management purposes. But the high-technology approach could have direct application to areas of intensive development such as planned growth centres intended to stimulate regional development.

OTHER SPECIAL LAND RESOURCE STUDIES

An Inventory of Coastal Lands

Coastal lands have a special importance in Australia. Apart from defence and customs matters, they are subject to a variety of land use conflicts arising from demands for urban development, recreation, rutile mining, forestry, conservation, and Aboriginal rights. CSIRO is conducting an inventory of the coastal zone, which is defined generally either as the area extending inshore for 3 km from the high tide mark or to the landward boundary of the marine, estuarine, or wind-blown deposits formed in the last few thousand years. Where mangroves occur their seaward boundaries are included.

At the "continental" scale of 1:1,000,000, these coastal lands cover a map strip a few millimetres wide and over 30 metres long. Such maps are therefore not satisfactory for storing and presenting data for the coastal strip as a whole.

Using computer-stored information, a system for spot sampling each 3 km was developed. First, successive 10-kilometre sections around the coast were numbered consecutively. Then, the inner boundaries, and section limits separated by lines orthogonal to the coast, were marked on 1:84,000 air photos. A grid of points, spaced one per 3 km, was next marked on these photos with a circle 3 mm in diameter around each. Geology, landform, vegetation and land use data from both published information and from photo interpretation were then recorded for each encircled area. The nature of the coastline for each 10-kilometre strip was then defined. A file of soil data for each section stated the proportion of soil types delineated in the Atlas of Australian Soils. Another file contains the population for each section.

These data files are linked to a mapping subroutine so as to produce a simple map of occurrence of any nominated type of coastal land recorded in the system. Information is given down to the level of the 10-kilometre sections (R. W. Galloway, personal commun.).

Wetland Survey

A feasibility study was made of the practicability of surveying the wetlands of Australia (Paijmans, 1978). To define the problem, classification systems and reconnaissance surveys were reviewed, and it was found that we needed a system appropriate to the wide range of Australian conditions that often include a considerable seasonal fluctuation in water level. Therefore, a pilot study of 200,000 square kilometres in northwestern New South Wales is being made by CSIRO and the New South Wales National Park and Wildlife Survey. The joint project involves a study of plant ecology and water-bird habitats and will classify and map the wetlands of the area.

Australian Biophysical Regions

At the request of the Department of Urban and Regional Development, the CSIRO (Laut and others, 1975) made a study of the regionalisation of Australian biophysical environments and their distributions on the continent. The continent was divided into major climatic zones, and the catchment area was chosen as the basic unit of information subdivision and storage. Information was derived from existing compilation maps for terrain and lithology, soils, vegetation, and climate. Catchment areas were also grouped according to similarity of attributes, landform and lithology, soils and vegetation type and structure, using numeric codes. The results are presented in a four-part map of the continent at a scale of 1:250,000 and in a catalogue summarising the soil, topography, and vegetation information which characterises the 300 biophysical regions which were mapped.

The Australian Environmental Statistics Programme

In order to establish a framework for an environmental statistics program that will help in dealing with the pressures on the environment that arise from human activity, or from environmental conditions themselves, it was necessary to subdivide the continent into regions. This provides a spatial base for the organisation of statistics. CSIRO and the Environment Division of the Department of Science are now defining a set of these "environmental" regions based on aggregations of adjacent local government areas with similar environmental characteristics. Land use, climate, geology, and natural vegetation are the characteristics used for aggregation. These environmental boundaries do not always conform to biophysical boundaries (K. McHenry, personal commun.). Unlike the biophysical regions described earlier, this program has to take into account both the areal basis on which statistics are gathered and the administrative boundaries within which information is used.

Satellite Imagery and Data

Several references have been made earlier to the use of Landsat imagery for Australian mapping. Some further comments are appropriate, although the full scope of Landsat use cannot be explored. In the past, its use was inhibited by uncertainty of coverage, delays in obtaining imagery, and the poor quality of some imagery. The last problem has been largely overcome by CSIRO's development in its Division of Mineral Physics of an effective computer enhancement program. The problems of delay and coverage as of 1979 should be diminished in 1980 when Australia's own data receiving station will be operating.

So far Landsat imaging has not replaced conventional stereoscopic photography for small scale mapping; however, it has proved to be an important complement. The largest area for which Landsat has been used is the South Australia survey already described. There its imagery served successfully as a base map and reference, the survey depending very largely on the use of established data, but Landsat permitted checks and extrapolations to be made. Robinove (1979) has tested the feasibility of producing a land system map from Landsat data by using contrast stretching of images to make them more easily interpreted visually, and by digital classification of data into distinct spectral classes. The digitally classified map so produced corresponds to the general geographic patterns of many land systems mapped in semiarid Western Queensland. Thus it was concluded that the digital mapping of terrain, preceding field work, could act as a guide to field sampling and to detailed terrain unit description as well as for measuring the location and extent of each unit. Woodward (personal commun.) has similarly found close correlation between patterns identified on Landsat imagery and land systems previously mapped in Central Australia.

Landsat imagery has been used successfully for a number of specific mapping and monitoring exercises, and many experimental and operational target studies by research and private organisations are now in progress. Many of these were reviewed in the Landsat 79 Conference held in Sydney in May 1979. Honey (1978) had already reported its use for soil erosion monitoring, identification of rangeland vegetation types, surface water and wetland studies, animal habitat studies, forest condition mapping, and observation of the effects of water buffalo on the forest and flood plains of the South Alligator River region in the Northern Territory.

Clearly the technique has an important role in the study of time dependent changes, such as biological responses to season or to landscape interferences, and wherever unambiguous signatures can be identified for specific attributes either from imagery or by data processing.

Simpson and Perry (1979) found in a study of severe floods in Northern Australia that Landsat imagery provided an excellent record of the distribution of both clear and silty flood waters and, coupled with data from aerial observation, provided information on water movement and its geomorphic implications that could not be obtained from aerial observation alone, or from dry season aerial photographs, or topographic maps.

Currey also reports (*in* Honey, 1978) its use in conjunction with aerial photography for flood mapping and the identification of flood prone areas.

With respect to its use for geological and mineral exploration, we have previously mentioned its value as a complement to traditional mapping from aerial photography. Huntington (1979) states that "It does demand a basic understanding of the physical characteristics of the data and above all an appreciation of how geology, 'sensu lato', is expressed in the landforms, soils and vegetation of an area of study" and that "The practical use of Landsat variously involves photogeological interpretation, digital image enhancement, data integration and multispectral classification more or less in order of increasing complexity and possibly decreasing cost effectiveness."

It is evident that Landsat information is another tool for environmental mapping whose full scope will only appear after much more research and investigation.

Other satellites give greater coverages, at shorter intervals, for similar processing costs, but they provide poorer resolution. Their possible contributions to small scale mapping of special targets have not been adequately explored so far.

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Sidelooking Airborne Radar as a Tool for Natural Resources Mapping— The Brazilian Approach

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First, I would like to thank the U.S. Geological Survey for the honor of receiving an invitation to participate in this symposium. I am going to talk about some aspects of the use of sidelooking airborne radar in the mapping of natural resources, principally in the Amazon environment.

When mapping natural resources in the Amazon environment, it is necessary to produce information for the legislators regarding resource distribution and potential in order to achieve the best use of the land. But at this point, to furnish this kind of basic information you have to go through different kinds of maps—soil maps, geologic maps, climate maps, and so on. To produce these maps we have to acquire some basic information concerning nonrenewable resources (geology), and renewable resources—climate, soil, relief, and vegetation (fig. 1). Most of this information is collected by field work that is indicated in the middle columns of figure 1. The columns indicate how to obtain the necessary information by means of sensors, field work, or laboratory studies. As one can see, most of the basic information can be obtained from field work and some of it from laboratory studies. Some information, relating to relief, comes directly from the sensor.

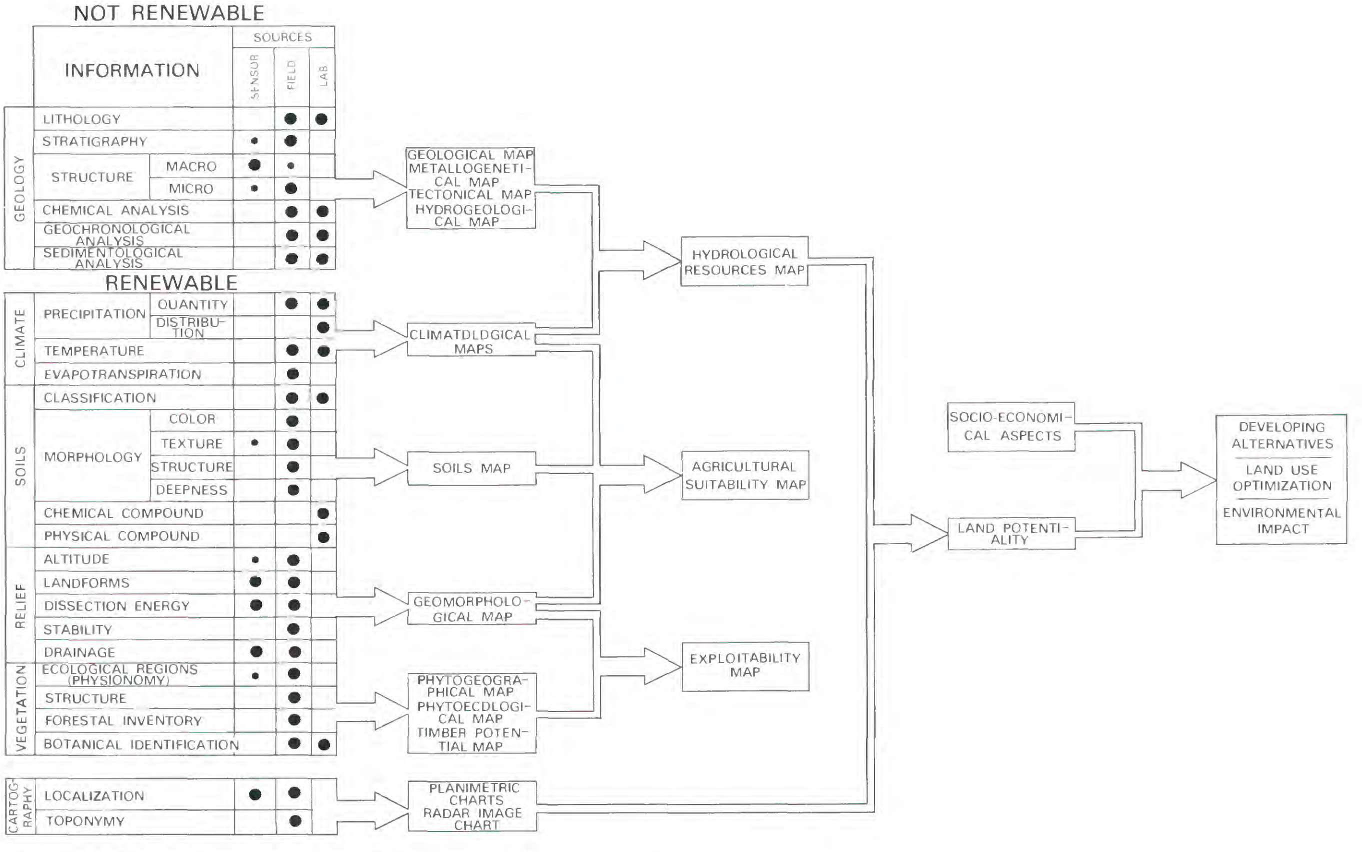

Figure 1 Natural resources mapping sequence and methods.

The great advantage of any sensor, in our case radar, is that it is a precise indicator of where you should make your field observations and the possibility of the extrapolation of that information.

The aspect of radar which led us to use it is its capability of penetrating fog, smog, clouds and light rain. Figure 2 shows an example of an aerial photograph taken with infrared film simultaneously with the radar survey. The cloud cover was penetrated by the radar in the Amazon environment.

Mapping natural resources with radar follows the same conventional method of mapping as with other sensors; that is, interpretation, field work, re-interpretation, and final reports and maps. For example, there is one very homogeneous area that represents 10 percent of the Amazon (500,000 square kilometers). With limited sampling you can extrapolate for the rest of the area and produce a reliable classification of the land features (fig. 3). Other areas have very complex geology or climate that produce very complex soils and vegetation. For such areas, it takes longer to produce land classification of the same reliability (fig. 4). Though these are very complex areas, and not homogeneous, it demonstrates one of the advantages of radar: it gives you a general idea as to where you have to do most of your field work.

After the entire area of the Amazon was surveyed by radar, it became easy to separate what is forest from what is not forest (fig. 5). The forested area is located on the middle and bottom of the figure and the savanna on the middle top.

Another aspect of the radar system is the emphasis on relief. On the left (fig. 6) a radar image is enlarged to the same scale as the aerial photograph on the right. The difference in visible relief is easily seen.

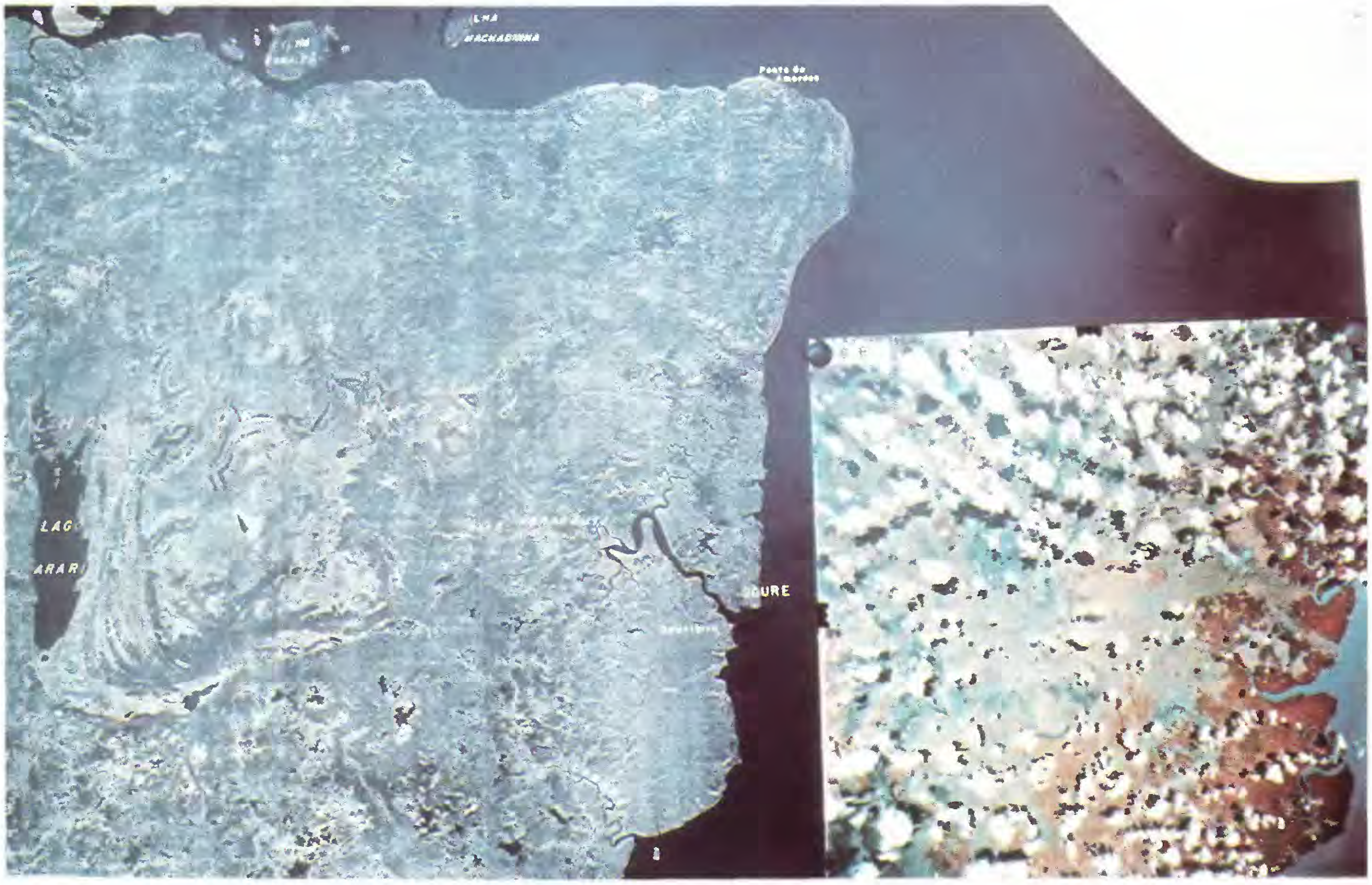

Figure 2 Radar image (left) and infra-red aerial photo (right) taken simultaneously showing the penetrability of radar radiation through the clouds.

	Information Obtained		Obtained by: Sensor	Field	Laboratory
Geology	Lithology			●	●
	Stratigraphy		•	●	
	Structure	Macro	●	•	
		Micro	•	●	
	Analysis	Chemistry		●	●
		Geochro-nology		●	●
		Sedimen-tology		●	●
Climate	Precipitation	Quantity		●	●
		Distribu-tion			●
	Temperature			●	●
	Evapotranspiration			●	
Soils	Classification			●	●
	Morphology	Color		●	
		Texture	•	●	
		Structure		●	
		Depth		●	
	Composition	Chemical		●	●
		Physical		●	●
Relief	Altitude		•	●	
	Landforms		●	●	
	Dissection Energy		●	●	
	Stability			●	
	Drainage		●	●	
Vegetation	Ecological Regions		•	●	
	Structure			●	
	Forest Inventory			●	
	Botanical Identification			●	●
Cartog-raphy	Localization		●	●	
	Toponymy			●	

Figure 3 Tertiary and Quaternary cover as they appear in radar image. A very simple area for regional mapping; with few samples it is possible to "map" large areas.

	Information Obtained		Sensor	Field	Laboratory
			Obtained by		
Geology	Lithology			●	●
	Stratigraphy		•	●	
	Structure	Macro	●	•	
		Micro	•	●	
	Analysis	Chemistry		●	●
		Geochro-nology		●	●
		Sedimen-tology		●	●
Climate	Precipitation	Quantity		●	●
		Distribu-tion			●
	Temperature			●	●
	Evapotranspiration			●	
Soils	Classification			●	●
	Morphology	Color		●	
		Texture	•	●	
		Structure		●	
		Depth		●	
	Composition	Chemical		●	●
		Physical		●	●
Relief	Altitude		•	●	
	Landforms		●	●	
	Dissection Energy		●	●	
	Stability			●	
	Drainage		●	●	
Vegetation	Ecological Regions		•	●	
	Structure			●	
	Forest Inventory			●	
	Botanical Identification			●	●
Cartog-raphy	Localization		●	●	
	Toponymy			●	

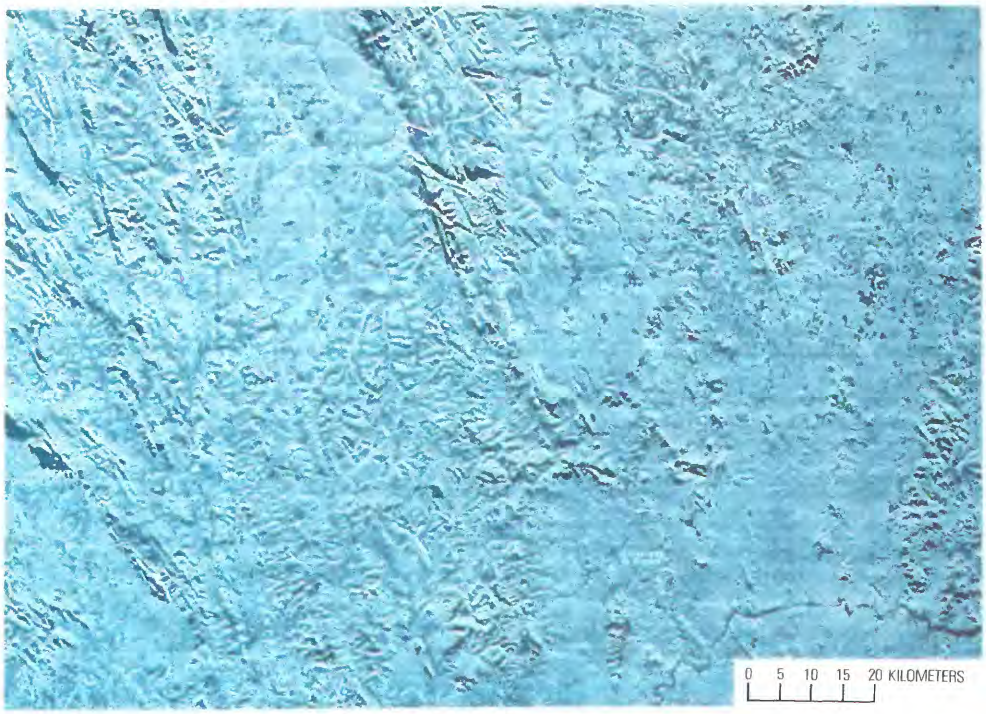

Figure 4 A complex area to be mapped. Here a greater number of field missions is necessary to obtain the same reliable level of information of figure 3.

	Information Obtained		Sensor	Field	Laboratory
Geology	Lithology			●	●
	Stratigraphy		●	●	
	Structure	Macro	●	●	
		Micro	●	●	
	Analysis	Chemistry		●	●
		Geochronology		●	●
		Sedimentology		●	●
Climate	Precipitation	Quantity		●	●
		Distribution			●
	Temperature			●	●
	Evapotranspiration			●	
Soils	Classification			●	●
	Morphology	Color		●	
		Texture	●	●	
		Structure		●	
		Depth		●	
	Composition	Chemical		●	●
		Physical		●	●
Relief	Altitude		●	●	
	Landforms		●	●	
	Dissection Energy		●	●	
	Stability			●	
	Drainage		●	●	
Vegetation	Ecological Regions		●	●	
	Structure			●	
	Forest Inventory			●	
	Botanical Identification			●	●
Cartography	Localization		●	●	
	Toponymy			●	

Figure 5 In the Amazon region the different types of major units of vegetation are clearly seen. On the middle top there is a savanna, contrasting with the dense forest on the rest of the photo.

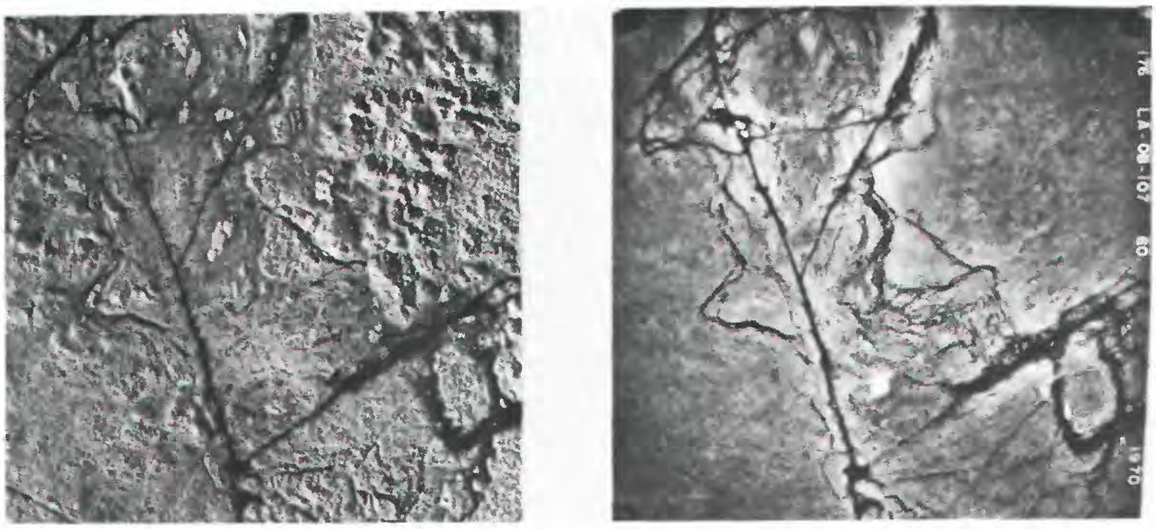

Figure 6 Emphasis on relief is one of the advantages of the radar image. On the left, a portion of the radar image was enlarged to the same scale as B-W infra-red to the right.

Figure 7 The possibility of visualization of large areas helps the understanding of the whole region. Here an area of 240,000 sq. km shows its main physiographic aspects.

The synoptic view that can be obtained with radar facilitates the understanding of the region as a whole. In figure 7 we see an area of 240,000 square kilometers, and the principal aspects of the region that are reflected by the relief are easily identified.

Because field study was necessary and most of the areas were inaccessible by land, we had to use helicopters. There was a very intensive use of them in order to open clearings in the places preselected by the technicians for field examination. More than 3,000 clearings had to be opened during the seven-year job, in addition to the missions along the rivers and the few existing roads (fig. 8). A specialized team trained for forest survival went down from the helicopter by rope to open the clearing (fig. 9). That was a one- or two-day job. On the following day geologists, pedologists, forest engineers, geomorphologists, ecologists, and so on, joined them and made their observations.

Now, in order to recommend the best use of Amazon land we had to know the way of life of the natives who live there (figs. 10 and 11). We learned about their customs, their views, why they do not get malaria, why they do not have more than three children, why they do not allow the community to become larger and larger. How do they live in equilibrium with the Amazon environment? This helps a lot in recommending new settlement in the Amazon.

Figure 8 Clearing opened to allow the technicians to make field observations in inaccessible regions.

Figure 9 The use of helicopters turned out to be the only way to reach inaccessible localities.

Figure 10 Indian house in the Amazon region.

Figure 11 Knowledge of Indian customs helped in suggesting how to live in harmony with the forest.

Another very useful aspect of radar imagery is the possibility of the user being able to compare the maps produced from it with the radar image. The user can differentiate what is a known fact or reliable data from what is interpretation or extrapolation. In the image shown in figure 12, some aspects of the relief can be seen that are reflected in the maps made from this image. The circular structure in the central part of figure 12 is immediately identified on the geological maps, geomorphological maps, soil maps, soil capability maps, vegetation maps, and potential land use maps (figs. 13–18). Thus, if the user has the maps and also can have the original image he can more easily judge what can or can not be trusted on the maps.

Figure 12 Portion of radar image to be compared with the thematic maps, figs. 13–18.

Figure 13 Geological map of the area of figure 12.

Figure 14 Geomorphological map of the area of figure 12.

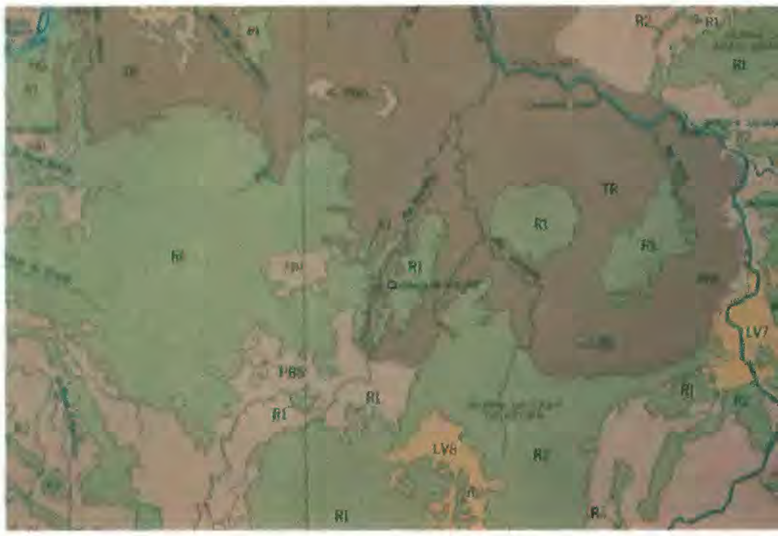

Figure 15 Soil map of the area of figure 12.

Figure 16 Suitability for agriculture map of the area of figure 12.

Figure 17 Phytoecological (vegetation) map of the area of figure 12.

Figure 18 Potential land use map of the area of figure 12.

One of the most unexpected phenomena in the geology of the Amazon was the number of circular structures found in the mapping. At least 200 of them were located and claims have been filed for most of them. Figure 19 shows the location of some of the circular structures. The colors represent the different rock types. Figure 20 is an example of how these structures appear in the radar imagery. The structure shown on figure 20 contains important amounts of cerium, niobium, thorium, and zinc, and is supposed to be a carbonatite.

Figure 21 shows a very interesting structure on the border of a big graben; it was unknown before the radar image came out.

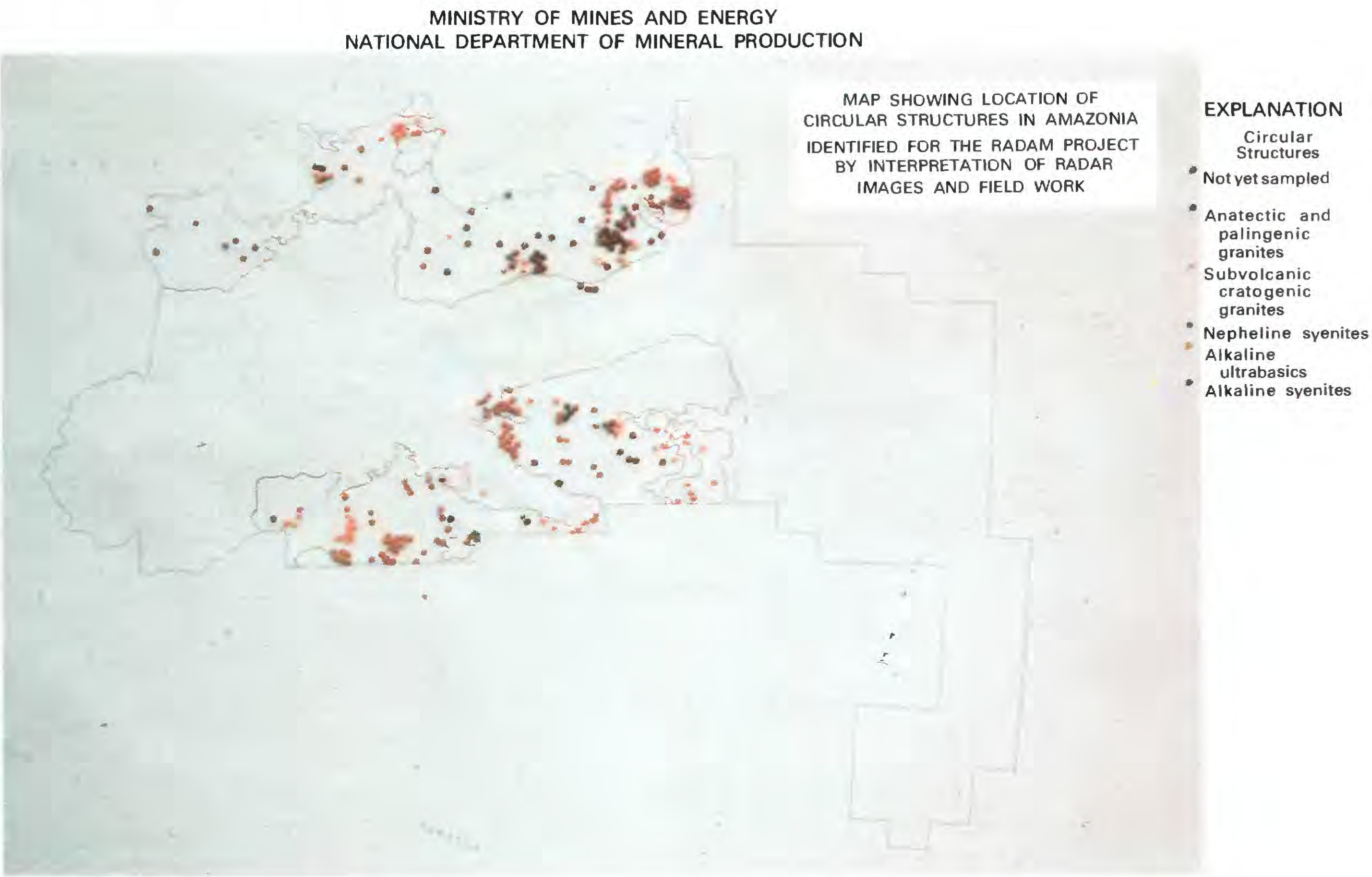

Figure 19 Circular structures mapped in Amazon. Different colors mean different geochemical characteristics.

Figure 20 Circular structure discovered during the mapping survey. This particular one turned out to be a carbonatite. It is 5 kilometers in diameter.

Figure 21 Circular structure associated with a graben shown by radar image for the first time. The structure is 5 kilometers in diameter.

As a final result of the job in the Amazon, maps of its natural resources were prepared. The area that has already been published corresponds to 4 million square kilometers. Figure 22 shows the geomorphological units that were grouped in the map and represents the distribution of the main relief forms.

Timber resource maps (fig. 23) represent vegetation groups with differential amounts of timber. The total amount of Amazonian timber was estimated at 10 billion cubic meters.

Conservation is one of the most important items of natural resources exploitation. Areas like the one shown in figure 24 have to be preserved. Here a very dense and rich forest is underlain by a sandy soil. No more nutrients are present here. If this forest were cut down no other vegetation like this would grow, and erosion would degrade the terrain rapidly. A lot of environmental problems occur all over the Amazon. The unstable equilibrium must be maintained in the regions under these conditions; therefore those areas with unstable ecosystems are proposed for protection as national forests, national parks, and so on. Forty or fifty percent have been proposed for preservation because they present ecological problems (fig. 25).

MINISTRY OF MINES AND ENERGY
NATIONAL DEPARTMENT OF MINERAL PRODUCTION

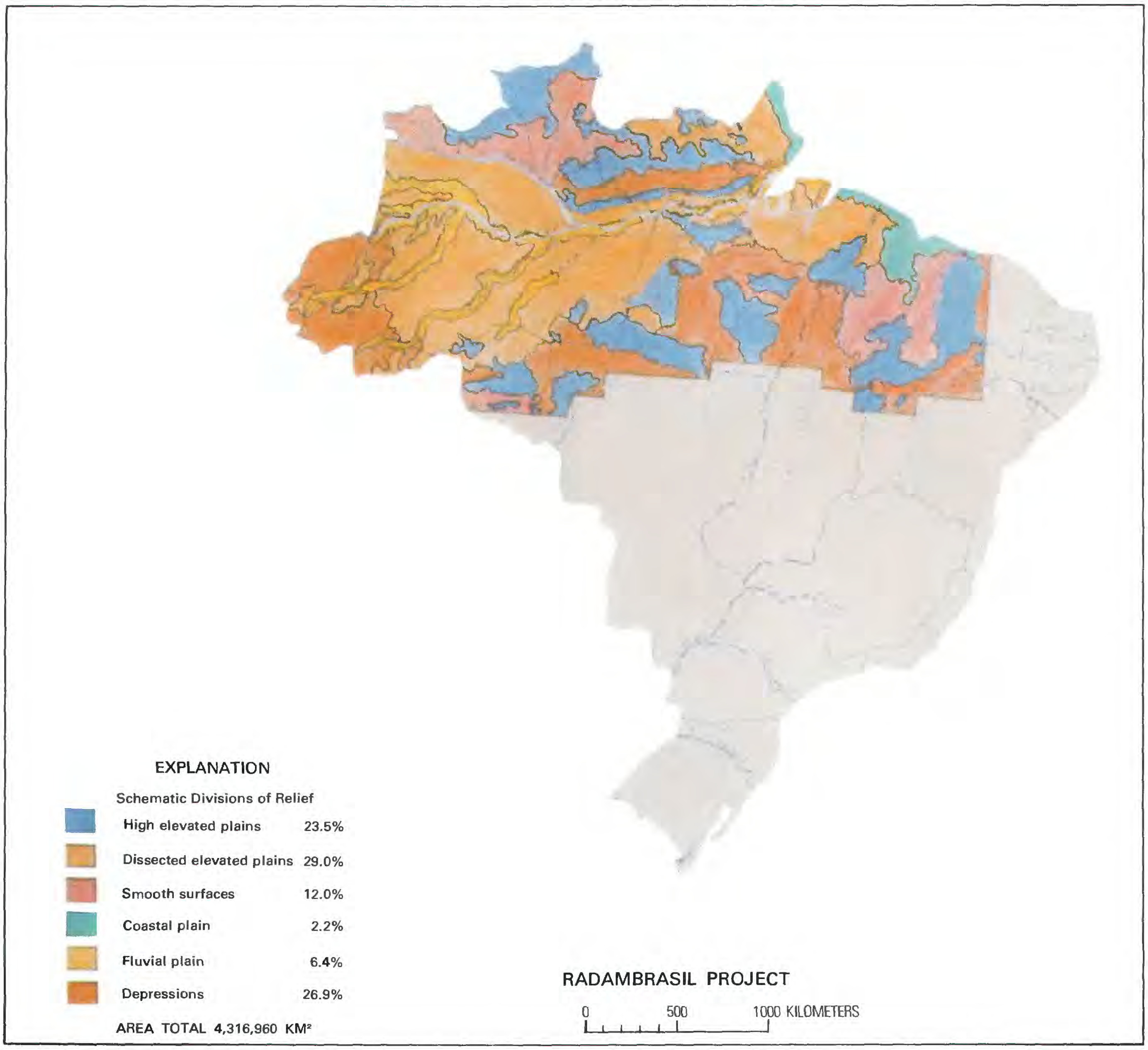

Figure 22 Geomorphologic units of the Amazon based on RADAM survey.

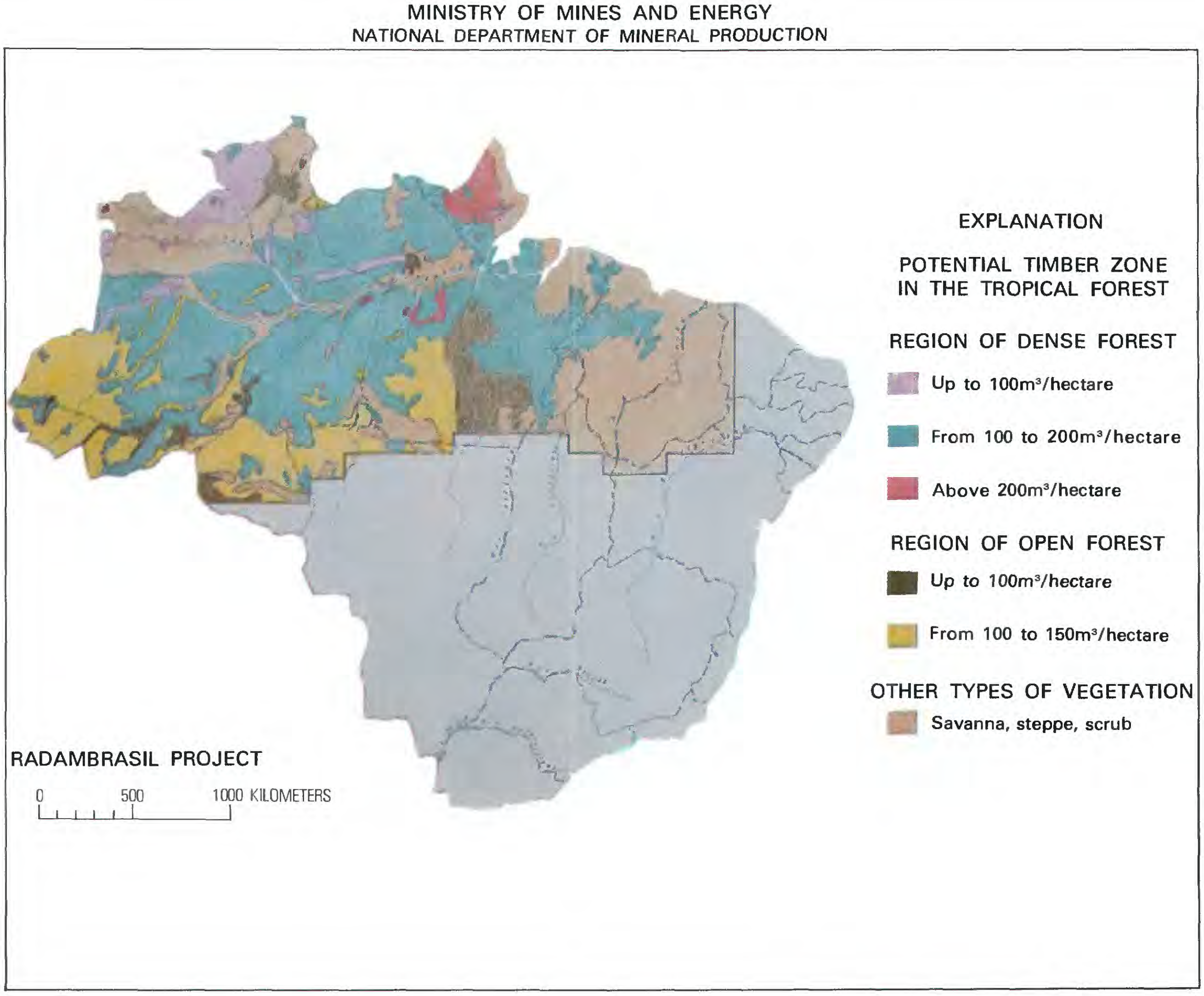

Figure 23 Potential timber exploration map of Amazon.

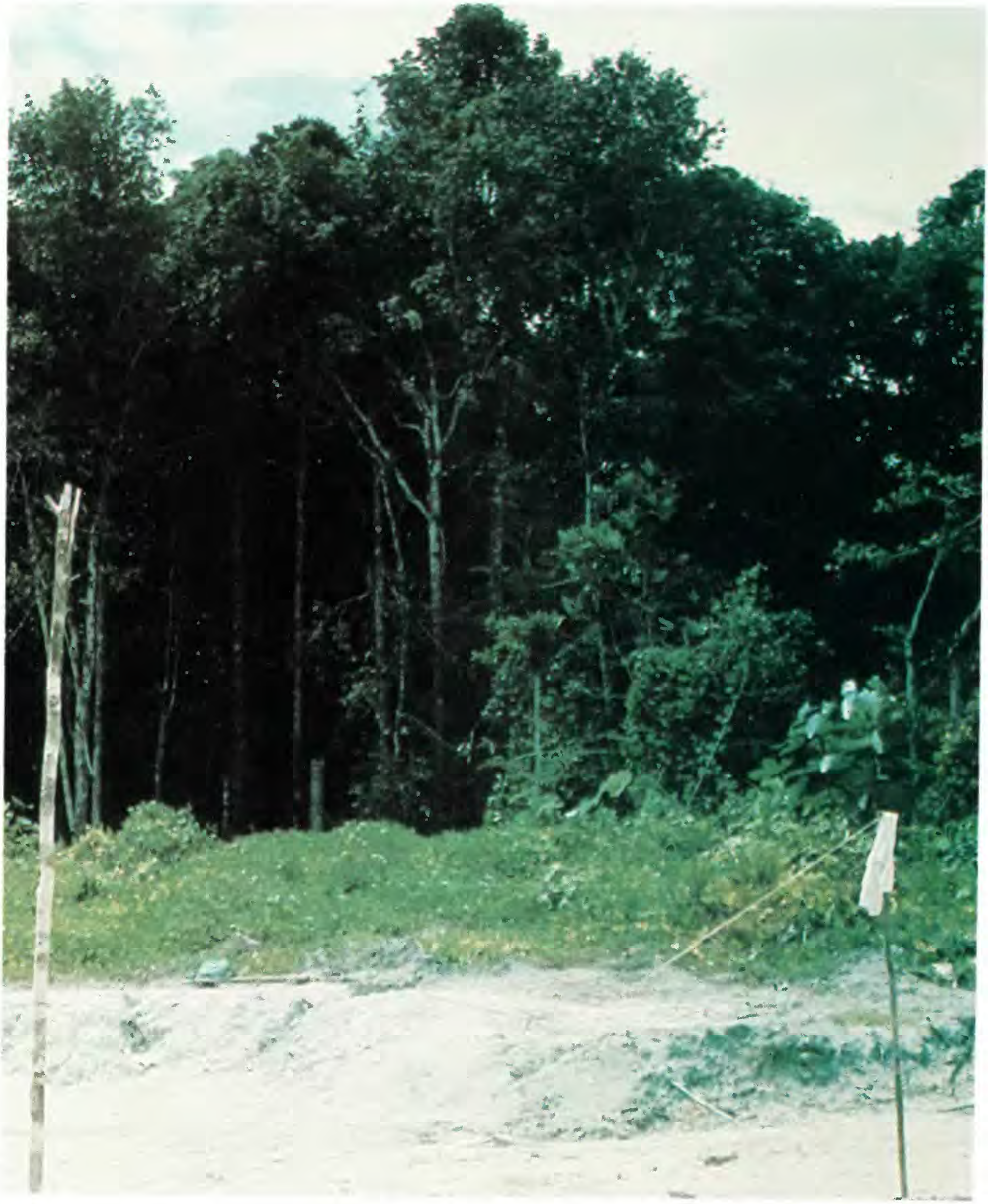

Figure 24 Very unstable area that must be preserved where a dense forest lies over a sandy soil area.

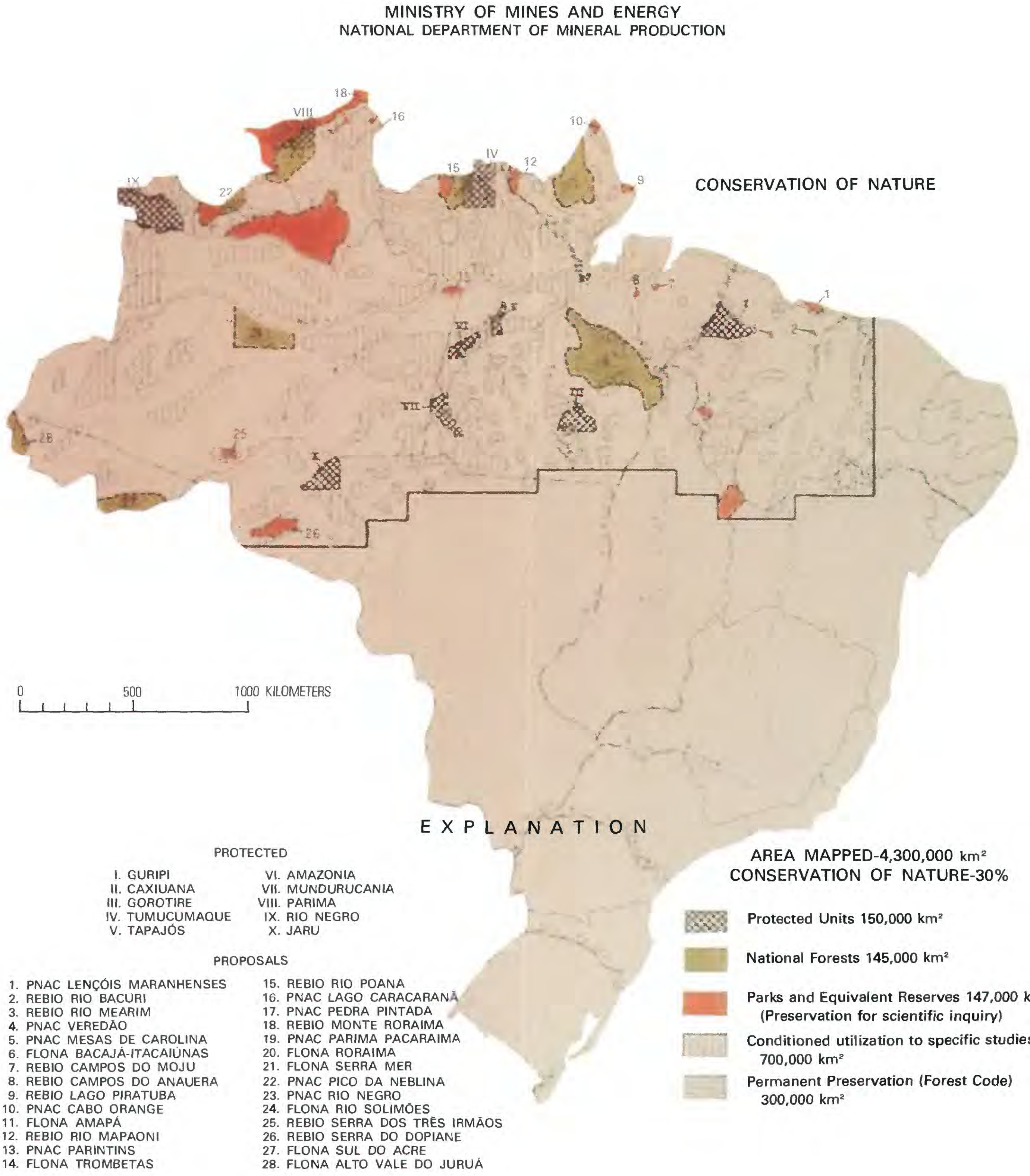

Figure 25 Areas of unstable ecosystems that require preservation.

Radar imagery has also been used for other purposes in order to help in the exploration for natural resources. Figure 26 is an instructive example of the use of radar in the location of dam sites for hydroelectric power plants. It is easy to identify the two natural "shoulders" that should be linked by a dam in order to build a reservoir.

Radar imagery has also been used in selecting the best routes for road construction. One should never recommend building a road on the edge of the plateau shown in the right half of figure 27, because of accelerated erosion. This is precisely why the existing road should never have been built.

The use of geophysical maps enlarged to the same scale as the radar helps to locate anomalies (fig. 28).

Some attempts have been made to print information directly over the imagery. This is a kind of accessibility map (fig. 29). The green represents forested areas, and the white indicates parks. The topography is seen very easily; one can identify the flat terrain and so on.

In another field of research we are trying to print all planimetric information directly over the radar image (fig. 30). This is being done with the collaboration of the U.S. Geological Survey staff, specifically Francis Lopez and E. W. Vickers. Additional test maps will be made to determine what area tint design is best to print over the radar maps to clearly show thematic data without detracting from the details of the terrain.

Some research is being done to combine radar and Landsat images. The research is in the beginning stages and, although the first results are not good, they are very promising. The main idea is to combine the advantages of the relief of the radar with the spectrum given by Landsat.

The Amazon region represents 60 percent of Brazilian territory. The challenge we are facing now is how to transform this huge natural resource area into actual benefit for all, while keeping in mind that man has to be a builder and not a spoiler of nature.

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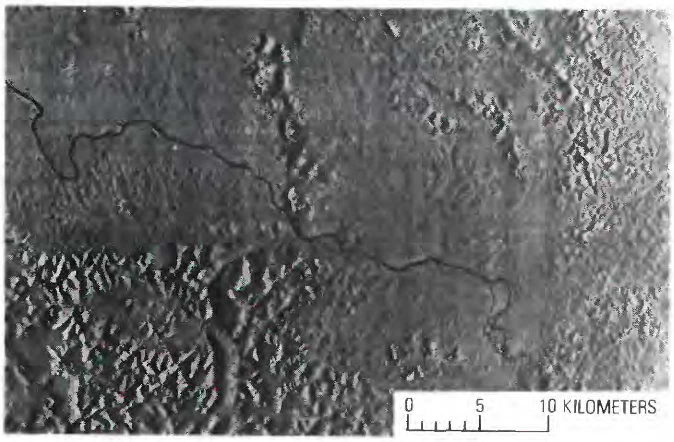

Figure 26 Natural "shoulders" that can be used if a dam must be constructed in this area.

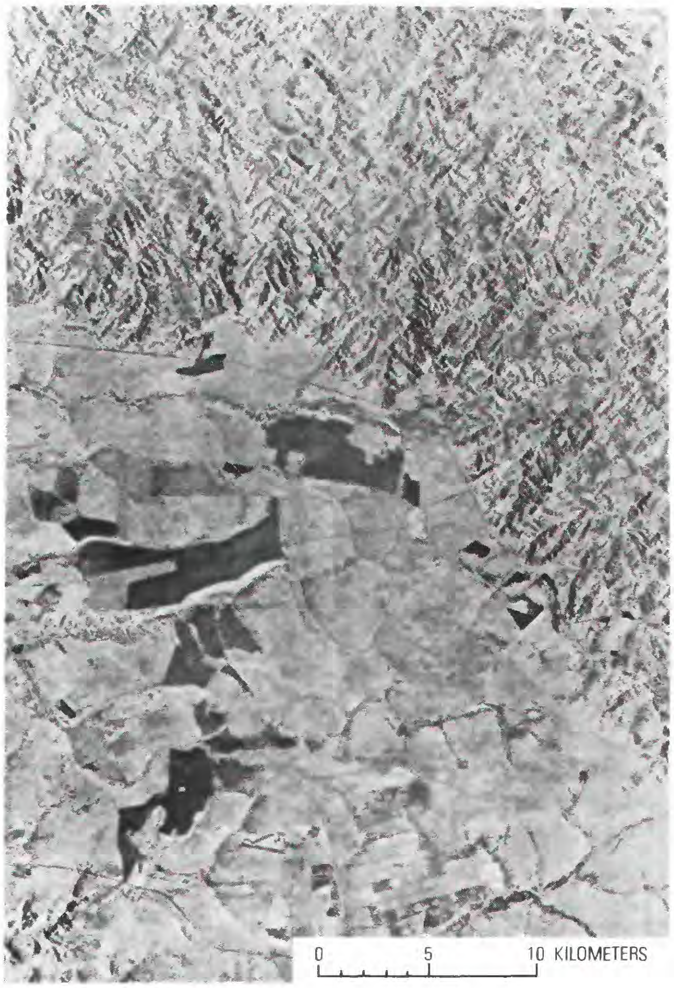

Figure 27 Areas of great risk of erosion (plateau border). Note road skirting edge of dissected area.

Figure 28 Comparison between radar image (right) and magnetometric map (left) showing the similarity between the geologic structures.

Figure 29 Accessibility map. The relief is easily seen and it is not difficult to separate the flat from the hilly terrain. Green areas mean dense forest cover contrasting with the savannas and parks represented by the white color.

CUIABÁ

Folha-teste executada durante a Pesquisa-Curso, realizada sob os auspícios da Universidade Federal Fluminense (UFF) com a cooperação do CNPq, no período de 19 de março a 12 de abril de 1979 nas dependências do Centro de Operações Cartográficas - Diretoria de Serviço Geográfico M. Ex., e da Aerofoto Cruzeiro S.A.

Figure 30 Planimetric information overprinted on radar image.

Comments from the Floor

J. Balsley (USGS): I would like to ask our guest from Australia if your maps are now available for distribution? How many geologists know of their existence? Have they been listed in the bibliographic indices?

C. Christian (Australia): The land system maps are produced in a series called "Land Research Series" by CSIRO for its surveys. The State authorities such as the Western Australia and Queensland Departments of Agriculture, the State Soils Conservation Commissions, etc., all produce maps – but not from just one source. They have been distributed quite widely.

L. Sodre (Brazil): How long have you been using the wonderful, elaborate method in Australia? How does it work in practice?

C. Christian: The work started in 1946, with 27,000 square miles being completed in that first year. Maps were produced in 1947. That was a rapid survey and none has since been completed so quickly. Work has been continuing since by CSIRO or the State Departments. The method has also been used quite widely in Africa, Asia, and parts of South America.

J. Balsley: Has it resulted in improvement?

C. Christian: CSIRO being a Federal government authority has no responsibility for the next stage of implementation. That depends on the government of the State. In the case of the Northern Territory, detailed follow-up work proceeded. There was a research station set up and agriculture research done, and subsequently land unit surveys in areas to apply those results. In Victoria, surveys were started by the Soil Conservation Commission primarily for soil conservation purposes. The results have been applied directly to State land use planning and used for surveying of grazing and livestock lands and determining safe carrying capacities and management programs. Queensland has used it similarly. Western Australia has a rehabilitation program for overgrazed areas and plans for pasture improvement. These are some examples only. Its application has been varied but it has been very wide.

J. Jones (USGS): What interface is there between the geologists, the soils scientists, and the soils engineers to control the very severe problem of soil erosion and also to utilize the soils in the country's best interest?

M.V.N. Murthy (India): In the district work that the Geological Survey of India undertook, fortunately for us, the district had already been soil mapped. They then interacted with the scientists who had worked on it and their geologists and geomorphologists established a dialogue with them. Open discussion and interaction occurred. The Geological Survey does not do any soil mapping but we have close interaction.

O. Bittencourt (Brazil): In our country, soils maps are made just for agricultural purposes. Some geologists do soil surveys for engineering.

K. Minden (USGS): What do you foresee as the main land uses that you recommend in the Amazon area of Brazil in the next ten years?

O. Bittencourt: Forestry. There are 10 billion cubic meters of timber. On an average of 50 dollars per cubic meter, Brazil has 500 billion dollars' worth of timber. There will be a serious ecological problem when they cut down the trees. What they are doing is a kind of zoning – categorizing vegetable oil exploration, tree resources for alcohol, mineral prospects. Fish is a very underdeveloped resource in the Amazon. Mining is already a reality.

F. Lopez (USGS): You suggest that some areas are very poor in soil and therefore have to be reserved. Are your recommendations going to be acted upon or is there a law that assures that the area won't be touched – or will this be debated in Congress or by various interests?

O. Bittencourt: No. We just make recommendations for the legislators. There are many agencies in charge of these different aspects. The Brazilian Institute for Forest Development is in charge of the national parks and forests. The biggest problems now are the companies who are in there right now. They just do not take anything into consideration. They just cut the timber down.

F. Lopez: There is no law that prevents them from doing this?

O. Bittencourt: There are too many laws – that's the problem.

D. McLaren (Canada): In regard to Dr. Kursten's very interesting definition of the environment, has he noticed something that appears to be a law in my country? There seems to be an inverse relationship between concern for the environment and the number of people around. The area where I live seems to matter very much less than that land occupied by the polar bear. Can it be that in virgin country we have a better opportunity of insuring that we don't make the same mistakes that we have already made in our cities?

M. Kursten (Federal Republic of Germany): First, your observation is true. The less people, the larger the land, the less the environmental questions will be of concern. In developing a region of the country today we should pay attention to what will be the long-term effects, according to our bad experiences we have had in the industrialized regions.

B. Hageman (The Netherlands): In respect to McLaren's question, I think it is rather dangerous when a country does not pay attention to the environment. When you are trying to build an infrastructure, which becomes rich at a certain moment, which is not based on such a consideration, it is lost forever. We know it in the Netherlands. It is one of the worst infrastructures costing a lot of money every day. I think that that kind of money can be saved in the developing countries from the beginning, basing the infrastructure on geologic considerations. It should start today, not tomorrow.

T. N. Basu (India): The problems of developing countries, insofar as environmental control is concerned, are somewhat different. We use 45–50 percent of the total energy as non-commercial in the form of vegetable waste and cow dung. Unless we can find an alternate source, we are making deforestation with resultant soil erosion leading to floods causing great problems; all this is done to meet the rural needs of energy which is absolutely non-monetized today.

L. Sodre: In regard to the developed versus the underdeveloped countries, everyone is in different stages of development—even the United States and Europe. There are different problems but of different natures. We should consider development in different steps. Deforestation, pollution—we should learn from others who are having these problems.

J. Balsley: There are areas in the United States that are less developed than many parts of the world (northern Maine and Alaska). I think that the theme of this whole conference is that there is a great unanimity of the need to bring the information to the people who make decisions. We are going to publish the proceedings of this conference and I am personally going to do everything that I can to have a short version prepared so that we can each take it back to our own legislators and hope to get the word to them. We all agree and have a common feeling that there is much information that can be brought to the attention of the people who make the decisions, whether it is the engineers building the roads in the wrong place or whatever. We've got to get the word back to the people who make the decisions. We will do everything we can from this conference to summarize that feeling into a short, we hope simple, presentation that the non-scientist can understand. It is the decision makers in our own countries who have not gotten the message.

Prospects for the Future

The *Glomar Explorer*. Photograph courtesy of Terry Edgar, U.S. Geological Survey.

New Opportunities for Geologists

Philip H. Abelson
Editor, *Science* Magazine
Washington, D.C.

It is a privilege to participate in this great occasion, celebrating the Centennial of the United States Geological Survey. The presence of distinguished geologists from many lands attests to the respect and affection that all of us hold for this institution. During the past hundred years, it has been a leader in the development of geology, both in the United States and in many other countries.

Today, the USGS, as well as world geology in general, faces new tasks and new opportunities. Demands for new sources of energy and raw materials have come at a time when the easy-to-discover resources have already been found. Geologists must probe more avidly and effectively than ever before. They must find means of discovering hitherto hidden reserves of oil, gas, and mineral deposits. Fortunately, a large number of tools have been created or will soon become available, that will enable geologists to obtain the kinds of information they need to aid them in discovering resources and attaining a better understanding of the Earth and the processes that have brought it to its present state.

This afternoon I will discuss some recent developments and describe some tools for providing better insights. I will begin by talking about discoveries at the East Pacific Rise, then speak about a prospective drilling ship that is likely to be a successor to the *Glomar Challenger*. I will point to achievements and prospects for reflection seismometry. I will then turn briefly to discussion of the prospective impact of advances in data processing, storage, and retrieval.

A most remarkable recent set of observations by the submersibles, *Cyana* and *Alvin*, at the East Pacific Rise has provided insight with respect to mechanisms of ore formation. At latitude 21°, fluid with a temperature of 400° C emerges from an undersea ridge. This is above the critical temperature of water, but the ridge lies 2,500 meters beneath the surface and the pressure of about 250 atmospheres is above the critical pressure (fig. 1).

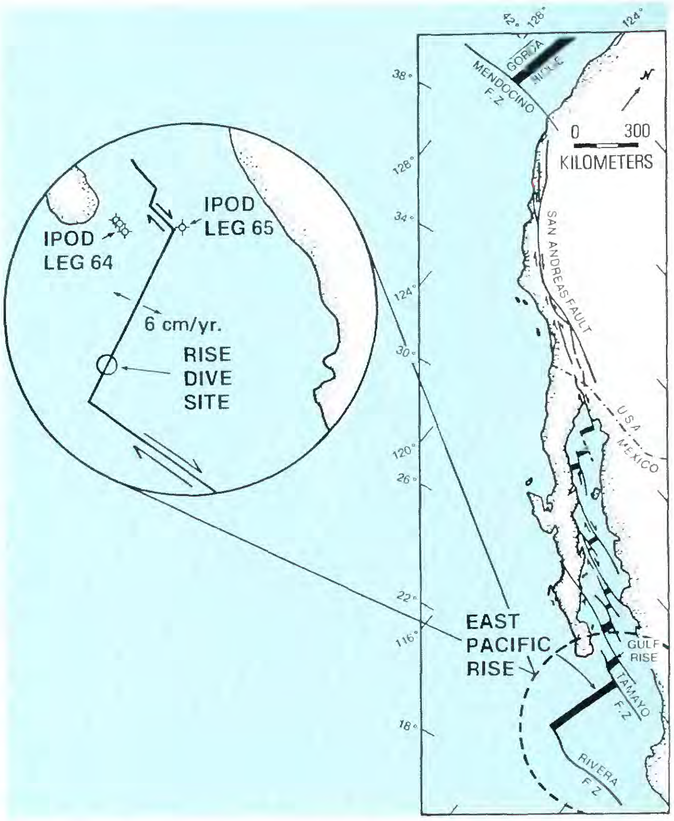

Figure 1 Regional map showing site of dive by the submersible *Alvin* in March 1979 to explore vents on the East Pacific Rise (figure courtesy NSF; caption courtesy of IUGS, *Episodes*, v. 1979, no. 4).

Near the sea floor vents are massive sulfide deposits. Elements present include iron, zinc, lead, copper, silver, gold, and platinum. If the sulfides were present in quantity on land, the deposit would constitute a very valuable ore body.

It seems evident that very hot sea water under pressure is an effective agent for mobilizing transition elements from silicates and that sulfides are soluble in the fluid. Already James Bischoff of the U.S. Geological Survey has come up with an interesting explanation for what is occurring. He has applied laboratory data developed by Professor Heinrich Holland and co-workers at Harvard University. Bischoff points out that at 400° C and 450 atmospheres, the solubility of sphalerite is about 35 orders of magnitude greater than it is at 400° C and 250 atmospheres. At 450 atmospheres the fluid has a density approaching 0.8, while at 250 atmospheres the density is only about 0.25. Bischoff believes that sea water penetrates to a depth of 2 kilometers below the sea floor to the vicinity of a magma chamber. There it attains its elevated temperature and is under a pressure of 450 atmospheres. The hot water dissolves some silica and liberates trace-metal cations. Sulfide is obtained in part from reduction of sulfate in sea water by ferrous silicates and in part from sulfides in basalt.

Bischoff does not mention the important variable, pH, which is influenced by the nature of the host rock. At elevated temperatures the pH tends to be lowered and this would lead to a lower activity of doubly ionized sulfur. In addition, the ionization constants for dissociation of H_2S may be quite different in water, depending on pressure and temperature. Thus, there is much we still do not know about the mechanisms involved. Information obtained at the East Pacific Rise is not directly transferable to ore formation involving, for example, granitic rocks. However, the observation that hot water under pressure is a remarkable solvent opens the door to new concepts of ore formation.

We can expect that other explanations will be offered for the sea bottom sulfides at the East Pacific Rise. We can look forward to intensive interaction between field observations and laboratory experiments and to further crucial discoveries by observers on *Cyana* and *Alvin*. In consequence, within a few years a markedly improved understanding of ore-forming processes should be attained.

During the past 12 years, the *Glomar Challenger* has probed much of the ocean floors outside the Arctic. Some 750 holes have been drilled at 500 sites. All sediments examined have been no older than Jurassic. The younger rocks have been found at the midocean ridges and older ones distant from them. The Deep Sea Drilling Program has made many other discoveries but, while a tremendous success, has been forced to avoid some important areas, particularly ocean margins where sediments are likely to contain gas and oil.

A proposal is now being considered at high U.S. levels to equip an existing larger ship with risers and blowout preventers. This ship would have the capability of reaching depths 11,000 feet below sea level. The length of the riser would be 4,000 meters. Since the ocean margins contain about half of the world's volume of sedimentary rocks the renovated ship, the *Glomar Explorer*, could be expected to provide information leading to development of important petroleum reserves. One function of the drilling ship would be to provide "ground truth" that would interact very favorably with new and future powerful tools of seismic exploration. Another potential result of the exploration would be discovery of ore deposits. Studies of the ocean margins could be expected to provide valuable insights to geologists concerning the origin and evolution of continents.

Drilling would not be confined to the margins. The ship would have the capability of drilling deep into the floor of the oceans. It would also be expected to examine the ocean ridges and to obtain from them information about mechanisms of ore formation.

Until a few years ago, knowledge about the subsurface geology of the United States was limited largely to information obtained in drilling for oil in sedimentary basins. But during the last few years a program has been supported that is probing the Earth to a depth of 30 to 70 kilometers. The equipment being used was originally developed by Continental Oil Company for oil exploration. A group of university scientists led by Professor Jack Oliver of Cornell has applied it to deeper strata.

The equipment, which bears the trade name Vibroseis, is designed to observe reflected sound waves with frequencies of 8 to 30 hertz vibrators. An array of 96 stations, each with 24 geophones, forms the observing network. The data thus obtained are processed by computers. The consortium of universities called Cocorp has made nine major traverses of important geological features, such as the uplift at Wind River in Wyoming.

Perhaps the most important advance has been made in studies of the eastern United States. In 1978 Cocorp completed a traverse extending from the Valley and Ridge Province of Tennessee to the contact between the Piedmont and Coastal Plain in Georgia. The results proved the presence of sedimentary rocks beneath crystalline rocks. The observations together with some made by the U.S. Geological Survey show that there has been large-scale overthrusting of the Paleozoic continental margin of the proto-Atlantic. Overthrusting may have been 260 kilometers horizontally. Apparently the overthrusting has involved a very large area and the sediments that have been covered are a potential source of substantial amounts of natural gas.

During the past year I made 2-day visits to 16 leading industrial research and development laboratories of this country, including leaders in electronics such as IBM, Bell Laboratories, General Electric, Texas Instruments, Hewlett-Packard, and Xerox. I was shown advances in microelectronics and instrumentation, some of which have not yet been publicly announced. New and more powerful tools will become available for all branches of earth sciences.

Basically, what is happening is a continuing rapid increase in capabilities for computation and information storage. In addition, there have been created far more efficient methods of design and fabrication of special microelectronic circuits. These new types of circuits are being used in conjunction with instrumentation to give it enhanced capabilities. For example, I saw a spectrophotometer capable of measuring the entire spectrum from 2,000 to 8,000 angstroms in 1 second. The equipment includes a microcomputer with a memory that can store known spectra and compare them to the absorption caused by a complex mixture of elements. Results are stored in the computer but can be displayed on a screen or printed out. This equipment will become especially useful in the analysis of trace elements.

At Texas Instruments, which owns Geophysical Services, I was briefed on their new development and procedures in reflection seismometry. The equipment incorporates advances in microelectronics and in computational capability. They have expanded the number of geophones in an array to as many as 1,024 and are contemplating as many as 3,000. In addition, they utilize closely spaced traverses and thus accumulate an enormous amount of detailed data. Using such procedures, one can obtain greatly improved resolution and information about the nature of the different strata involved. They can distinguish, as examples, between gas-sand, gas-oil, shale, and limestone.

The observational data are processed by a computer with enormous computational capabilities. It can incorporate ground truth from existing wells. In any event, the final result is equivalent to well logs. Three-dimensional information can be presented on a screen. That is, geologists can examine sections at any angle to the horizontal or vertical.

An item in the Oil and Gas Journal for August 6 of this year [1979] has given a practical example of the power of the new equipment. The article describes the discovery of a gas field in the Gulf of Siam that contains 1.3 trillion cubic feet proved, 5.9 trillion proved and probable. The field is in a hinge line area characterized by complex faulting that controls hydrocarbon entrapment. The concessions involved had previously been owned and explored by Tenneco and British Petroleum. Using older methods of seismic exploration, they had failed to discover the reserves. The new three-dimensional methods of exploration involved towing a string of 250 geophones on 130 lines, 100 meters apart. Following processing of the information, four wells were drilled with 100 percent success. The first well flowed at a rate of 62 million cubic feet per day plus 1,129 barrels per day of condensate. Other wells cut faults within 20 feet of predicted depths and flowed nearly comparable amounts of gas and condensate. The owners of the concession are sufficiently confident in the seismic data that they feel they can proceed with planning the development of the field with a minimum of further exploratory wells.

The usefulness of this type of equipment will not be confined to exploration for oil and gas. R. J. Graebner of Geophysical Services is naturally enthusiastic about additional applications of the three-dimensional equipment. He believes that it will have important roles in both coal and mineral exploration and development.

Some of the tools and developments arising out of electronics are predictable, but still in the future. You are all familiar with results that have been obtained with remote sensing imagery, including side-looking radar and Landsat satellites. Further increases in capabilities of such equipment are on their way.

The Landsat–D satellite that is scheduled for late 1981 will include additional sensors using the wavelengths 2.2 and 1.6 microns in addition to the channels used earlier. The 2.2 micron spectral scan will facilitate mapping of limonite-bearing rocks and groups of minerals associated with hydrothermal alternations.

Equipment has been proposed for the Space Shuttle designed to look at fairly narrow spectral bands in the wavelength region 0.4 to 2.5 microns. A total of ten spectral bands is contemplated.

Another opportunity involves the use of thermal infrared techniques employing sensors for 8 to 14 micron radiation. One looks at diurnal heating and cooling. From the spectral emissivity, one can distinguish silicate from nonsilicate rocks.

Improvements in information storage and retrieval will come as a most welcome development to geologists and all scientists. We are faced with an enormous proliferation of facts and literature. The quantity is so great as to be disheartening. Yet it constitutes an enormous resource if it can be selectively retrieved and presented. Developments are occurring that portend a revolution in data analysis and retrieval.

In the United States a number of organizations, both governmental and commercial, are moving to place vast quantities of information in electronic storage. For example, at Science magazine, we were recently approached by a company that proposed to store the complete text of the magazine. They even plan to begin with issues 4 years back. Customers for this material are corporations engaged in research and development who can afford to pay.

Another example involves Science magazine as a user of electronically-stored material. We have a computer terminal that allows us to tap into the world's biomedical literature. The compiler of it is the National Library of Medicine. We can quickly locate desired material through use of key words.

Some earth scientists have been aware of opportunities for applying electronic storage and retrieval to geology, and are enthusiastic about its potential usefulness.

Consider, for example, the problems faced by an earth scientist wishing to make comparisons of the chemical analyses of rocks. A tremendous amount of information exists but the more than 100,000 analyses are scattered among many thousands of volumes of journals. Even if the information were gathered together and printed in books, all the data, including rock type, location, age, mineralogy, methods of analysis, trace elements, and other pertinent information, would occupy a bookshelf perhaps 2 meters long. Such a data bank would still be unmanageable. But suppose all the information were stored in an electronic memory. A computer could then be used to do any kind of sorting of the analyses. For example, one could ask the computer to prepare a list of all Miocene basalts possessing 3 percent or more titanium. Many other sets of sorting criteria could be employed.

Preparation of this new information resource is just beginning. The work will require efforts of many people in many countries. It is fitting, therefore, that the effort which is headed by Felix Chayes of the Geophysical Laboratory in Washington is being conducted as a project of the International Geological Correlation Program.

Another potential tool, but one that is some distance from achievement, is to place the world's geological maps in electronic storage. There now exist all the techniques for accomplishing the deed, and for subsequent display of colored maps on video screens. Hard copies could be obtained from the stored information.

One of the advantages of electronic storage of information is, of course, the relatively instantaneous availability of a selected piece of information, whether it is a map or a chemical analysis. The major advantage, though, lies in the ease and speed with which one can sort the data and, if desired, make comparisons among selected classes of data or other kinds of manipulations.

At the moment, these potentialities are some distance away, and they can be expensive, given today's level of electronic technology. However, costs of memory and computation have been decreasing rapidly and prospects are good for a continuation of this trend. Furthermore, as interested earth scientists become more proficient with computers, they will develop improved methods of making the cogent kinds of data available.

In the short time available, I could only touch lightly on a few of the developments that will affect geology in the years ahead. The methods by which geologists examine the Earth will increase to include new tools. Particularly helpful will be opportunities to see the crust in three dimensions and the development of new knowledge concerning ocean margins, the genesis of ore deposits, and the evolution of continents. As geologists help fill great needs of society, they will also enjoy participating in exciting developments at the frontiers of knowledge.

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Earth History as Moral Science

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Swiss and professors share one detestable habit—their moralizing attitude. Being thus doubly afflicted, I can, of course, not resist from indulging in this vice.

My intention is to speak up for the historical side of geology, for the side that gives its unique flavor to our science, with its glorious uncertainties which are so exciting to the mind and so difficult to explain to companies, to ministries, to students, and to our fellow citizens at large. There is some tendency to play down the importance of historical geology, to consider it as an old-fashioned and almost obsolete branch of the earth sciences and to minimize its role in teaching curricula. In some ways, this is understandable, as some of the greatest progress in geology in the last decades has come from its non-historical branches, such as geophysics and physical chemistry. But geology is more than physical chemistry applied to the Earth (and even more than physical chemistry plus spherical trigonometry). It is our task to integrate the findings on the present state of the Earth into their historical context. The present is the key to the past, but the past is also the key to the present and, hopefully, to the future. This of course leads up to the age-old question of uniformitarianism. Physical laws have not changed in the course of time; the same will hold for most physical constants. But we realize of course more and more that boundary conditions have changed in a very drastic manner, and that the present moment of Earth history is a rather exceptional one. These changes, some of them of cyclical and others of irreversible nature, have affected all geological and biological events. The simple extrapolation of present-day conditions fails to account for a large number of geological features. Local and global changes in the geothermal regime of the Earth are certainly among those that will have had the most significant effects. One of the challenges of the coming years, and one which has enormous impact on the study of economic deposits, is the more reliable determination of ancient geothermal gradients. On a recently published metamorphic map of the Canadian Shield, no symbol for high pressure/low temperature metamorphism occurs—no blueschist is found in this vast expanse of Precambrian rocks—whereas half of California and half of Japan are blue.

In the biological approach, the timing of geological events becomes of prime importance. We must have more reliable information on the contemporaneity and succession of geological phenomena, for instance on the question whether crustal movements are really synchronous in various parts of a chain or even in different parts of the world.

If you allow me just one reference to my native Alpine playground: we are now fairly sure that the European rift system started to open precisely at the same time when the rate of crustal shortening in the Alps was at its maximum. The constant refining and standardization of the stratigraphical scale is not a mere academic exercise, but an essential prerequisite for answering such questions.

The same is true for transgressions and regressions of the sea. Great progress has been made in recent years, especially through the application of seismic stratigraphy, in unravelling the interplay between world-wide eustatic fluctuations and local influences, and again the economic implications are encouraging. But these preliminary results have to be calibrated more closely and their correlation with other events has to be examined.

Paleo-oceanography is on the way to becoming one of the most fascinating subjects of the geological sciences. Changes in the general regime of the oceans have had fundamental effects not only on the character of sedimentation but also on the development of life. It may or may not be a coincidence that the largest phosphate deposits were formed at times that also correspond to crises of biological evolution—near the Precambrian-Cambrian boundary, in the upper Permian and near the Cretaceous-Tertiary boundary.

Plate tectonics has given a tremendous boost to geological thinking and has at last provided a coherent model for the history of the Earth—certainly back to the mid-Permian, when the present cycle began, almost certainly back to the late Precambrian or, as some people believe, even further back. Plate tectonics has now come of age; it has become sadder but wiser—sadder in the old English sense, i.e. more earnest. We are beginning to realize that the simple and convincing original model works well enough for Atlantic-type oceans and for Circumpacific-type fold belts, but much less so for the Alpine-Himalayan belts, for the areas with intermediate types of crustal structure, including the Gulf of Mexico, and that it fails to account for most features of intracontinental deformations. There are also some troubling facts of regional geology, such as the apparent lack of an active plate boundary between northeastern Asia and northwestern North America.

The lateral variations in the mantle—below oceans, margins, young and old foldbelts and cratons—appear to be much more considerable than was supposed. In some areas, even the concept of lithosphere is becoming elusive.

One cannot reasonably doubt the basic truths of plate tectonics, especially after the overwhelming proofs brought back from the deep-sea drilling cruises. But the theory of plate tectonics is still imperfect, and a number of complex mechanisms, which have been overlooked or even banned in the enthusiasms in the long-overdue breakthrough of mobilism, will have to be considered.

Oceanization, whatever that may mean, is a concept which appeals very much to me but not to many of my friends. The dogma of the absolute rigidity of plates, especially continental ones, is becoming more and more doubtful. More attention will have to be paid to the dynamics of continents, where after all most of us live and draw our resources from.

The heuristic value of plate tectonics is only beginning to emerge. Only a relatively small number of economic deposits, especially porphyry coppers and metals linked to the ophiolite suite, have hitherto been discovered by conscious reasoning along plate tectonics lines. The task of linking the very unequal distribution of resources is far from complete. As to natural hazards, the plate tectonics theory has been very successful in analyzing, and hopefully soon predicting, earthquakes in the Circumpacific belt. The latitudinal foldbelt and the interiors of the great continents, especially Asia, seem to obey less simple rules.

One of the inherent dangers, not only of plate tectonics but of any successful model, lies in the readiness of scientists to apply the model to cases of which the basic facts are badly known. Models should be modified to fit the observations, and not vice versa. Jargon is another pitfall, and every so often the coining of a term will be a useful substitute for understanding. Here, the historical aspect of our interpretation can teach us humility and a healthy scepticism. Nobody, not even a white, male, francophile, liberal, Protestant-raised agnostic of advanced age and stable income can be perfectly objective; the utmost we can do is to become aware of our own bias.

The moral lesson of Earth history lies of course partly in its staggering duration. Everyone has one's own favorite device for reducing geological time to comprehensible dimensions. My personal favorite is one that I published a few years ago, and in which we simply take one second as equivalent to one year. Human lifetime thus lasts for one minute or a little longer. Our count-up begins at midnight of New Year's Eve, 1979.

On this scale, nuclear energy started twenty seconds ago, the use of petroleum products, two minutes ago. Fossil fuels were burnt fifteen minutes ago, and the water mill is about half an hour old. What is called history, that is, writing and the tradition of names such as King Lugalzaggesi of Eridu, date from 10:30 P.M. Mining started at 9:00 P.M., but fire had already been used for much longer—since Christmas. Homo appeared in late November, preceded by his cousin Australopithecus in mid-November. Mammals are known from 1972, vertebrates from 1965, metazoa from the late 1950s, and eucaryotes from the mid 1940s. Life already existed in 1880, and the origin of the Earth goes back to 1831. This period, the time of King Louis Philippe and of President Monroe, may appear hazy and far away to us; but we also know very little about Archaean dynamics and geochemistry.

Apart from the miracle of evolution itself, one of the remarkable facts is the stability of the complex equilibrium which has allowed the development of life. Of the multiple crises which have affected our planet, none has hitherto been able to wipe out life, or even the eucaryotes with their delicate genetic mechanism. Only in these days has one species acquired the potential to destroy itself and all others.

The moral lesson again is humility and responsibility. Discouragement is widespread, and progress is considered a dirty word in these days. Nevertheless, in the last one and a half hours of their existence, human beings have done a number of marvelous things, along with some pretty foul ones. They should be given the chance of lasting another hour or so. Under this aspect, the question of resources takes a different and less rosy color.

It is almost preposteous to admit a moderate degree of sceptical optimism in these days, where an energy, resources, environmental, food and sheer numbers crisis of humanity appears inevitable. Apart from the fact that despair is no very effective working hypothesis, the reasons for this little spark of optimism lie in the capacity for rapid advance of technology and in the first, still feeble signs of a global conscience.

The tasks ahead are formidable. Geologists alone will certainly not be able to solve them, but every one of us can make infinitesimal contributions. Development of new techniques and new ways of thinking for improved discovery, assessment and management of finite and renewable resources is one aspect; closely linked to it is the need to make the concerns of the geological community intelligible to the decision-makers at all levels, in the last instance to the people.

The other aspect is the rise of a feeling of planetary responsibility which has been brought home to many of us by looking at the photographs of the Earth seen from space. But here, we need to examine ourselves very closely. A patronizing attitude is deeply ingrained in many of us scientists from industrialized countries. We have to learn from the scientists in developing countries themselves what their real needs are, in the way of direct cooperation and especially in the way of training. The people of these countries must themselves decide on the balance they want to strike between the preservation of their environment and industrialization, between conservation and exploitation of reserves. The sacrifices that certainly lie ahead of us should not be borne in the first line by the poor—meaning both poor countries and poor people in poor and rich countries.

In the foregoing enumeration—very incomplete and limited to the time aspect of geology—you may find many areas of concern to the scientific commissions of the International Union of Geologic Sciences, of the International Geological Correlation Program (with UNESCO), of the Geodynamics Program (with the International Union of Geology and Geophysics) and of a new inter-union program that is now under study. We try to make geologists from many countries share the excitement along the moving frontiers of the science and the responsibility of bringing a little relief to some of the problems of mankind. IUGS is a very small organization operating on a tiny budget, and must limit itself to the task of bringing geologists together. Its only chance of achieving a small part of its aims lies in enlisting the help of international agencies and especially of the much stronger national bodies. The U.S. Geological Survey has contributed in a remarkable way to these aims, and on entering its second century it is well-equipped to continue playing a leading role both in the adventure and in the commitment of earth scientists.

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