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I

Mineral Exploration in Less Developed Countries

by

Robert George Patterson, B. A.

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C

A thesis submitted to the Faculty of
Graduate Studies and Research in partial
fulfillment of the requirements for the degree of
Master of Arts
in International Affairs

The Norman Paterson School of International Affairs
Carleton University
Ottawa, Ontario
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February 22, 1980

The undersigned recommend to the Faculty
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March 21, 1966

II
ABSTRACT

Many Less Developed Country (LDC) governments are presently in the position of knowing little more about their mineral resources than the fact that these have been exploited, often by foreigners, in ways that have not contributed to their countries' well-being. LDC governments are now looking for alternative mineral development patterns in order to change the nature and impact of mining operations on economic development. Mineral exploration is one area which provides an interesting alternative. By engaging in mineral exploration on their own behalf, the governments of LDC's can maintain international investment interest and at the same time enhance their own bargaining position with any potential investor.

Many stages and methods of mineral exploration can be co-ordinated into a sequential programme aimed at the identification and evaluation of economic mineral deposits. Using domestic and international personnel, sometimes financed by development assistance, mineral exploration programmes can be executed on behalf of LDC governments. In Kenya, 1977, one such programme was successfully executed. With the resulting geological information the LDC government has increased its mineral development options. Further, if the LDC government so desires, it is now in a position to approach prospective international investors on a much more equitable basis.

IV

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MINERAL EXPLORATION IN LESS DEVELOPED COUNTRIES

Something hidden, go and find it
Go and look beyond the ranges
Lost and waiting for you
Go.

Rudyard Kipling
The Explorer

INTRODUCTION

1.

This paper is an examination of the nexus between natural resource information and the economic development of Less Developed Countries (LDC's) as illustrated by the mining industry and mineral exploration. It is the argument of this thesis that a programme of mineral exploration, induced by the government of a Less Developed Country,* can significantly change the basis for mineral exploitation in that country and, hence, can increase the developmental value of this extractive industry.

The broad subject, natural resource information, includes knowledge about the ecological, geological, hydrological, pedological and climatological situation which can provide a fertile ground for agricultural, industrial, social and technological development planning and implementation.¹ Natural resource information can be "physical", concerning our natural environment, or "socio-economic", involving man's use of this natural environment and the impact of such use on society. For maximum effectiveness, both physical and socio-economic natural resource information should be brought to bear in developmental decision making. In LDC's the need to acquire and analyse natural resource information is immed-

* Government-induced exploration refers here to that exploration activity which is specified and sought by government agencies and executed on their behalf. The exploration activity may be carried out by the agency itself, or by contractors, or under the auspices of international development assistance agencies.

¹ Gupta, R. K., Planning Natural Resources, (New Delhi: Navayu Traders, 1971), page 18.

ately apparent. Natural resource information is an essential prerequisite to sound planning for economic growth, whether it is as basic as satellite photographs and topographic maps, or as detailed as drilling records or the results of seed adaptability tests.

The techniques employed in the gathering of natural resource information can often be costly in time, money, and human resources. Herfindahl and Kneese have written that, in general,

Natural resource information (exploration) costs should be considered like any others: The object is to spend as little as possible as late as possible, making appropriate adjustments at margins where inputs may be substituted. These adjustments refer to the composition and timing of different types and sources of expenditures for natural resource information.²

It is not often a simple matter to assess the value of natural resources or the costs of gathering sufficient information before the exploitation of these resources, but developmental planners should not become enamoured with the accumulation of information for its own sake. Rather, as Herfindahl noted in his classic work on natural resource information,

The whole process of increasing and extending information of natural resources should add up to the exploitation of good opportunities for investment at all stages of information so as to maintain a flow of natural resource investment projects which enter the stage commensurate with the general range of investment opportunities open to the country.³

² Herfindahl, O. C., and Kneese, A. V., Economic Theory of Natural Resources, (Columbus: C. E. Merrill, 1974), page 133.

³ Herfindahl, O. C., Natural Resource Information and Economic Development, (Baltimore: Johns Hopkins Univ. Press, 1969), page 118.

This paper will focus on one aspect of natural resource information, namely, mineral exploration. Before introducing the research design of this paper we should deal very briefly with several general issues related to the international mineral industry.

Over the course of the 1970's there was considerable concern expressed in the industrialized countries about future trends in world mineral supplies.⁴ This concern arose as the OECD countries began to perceive a significant reduction in the quantity and quality of their own mineral reserves. Likewise, at times, the roles and objectives of the governments of LDC'S came under close examination from the industrialized world as the latter felt threatened by the proposals of the New International Economic Order.*⁵

To date, contrary to some conceptions, LDC's have not been the major source of internationally traded mineral commodities.

* Resolution A/RES/3201 (S-VI), May 9, 1974, of the United Nations, entitled "Declaration on the Establishment of a New International Economic Order" declares that "action is to be taken on fundamental problems of raw materials and primary commodities as related to trade and development". Included are proposals "to facilitate the functioning and to further the aims of producers' associations, including their joint marketing arrangements, orderly commodity trading, improvement in the export income of producing developing countries and in their terms of trade".

⁴ Govett, G.J.H., and Govett, M.S., "The Inequality of Distribution of World Mineral Supplies", Canadian Institute of Metallurgy Bulletin, Aug. 1977.
⁵ Bergsten, C.F., "The Threat From the Third World", Foreign Policy # 11, Summer, 1973; Mikdash, Z., "Collusion Could Work", Foreign Policy # 14, Spring, 1974; de Montbrial, T., "For a New World Economic Order", Foreign Affairs, vol. 54, # 1, October, 1975.

LDC's do, however, represent a considerable portion of production and reserves of certain mineral commodities (see charts below).⁶

0.1

SHARES OF WORLD MINE PRODUCTION OF 14 NONFUEL MINERALS, 1976
(Percent)

Commodity	OECD	South Africa	Yugoslavia	Developing Countries	Communist Countries	Other Non-Communist Countries*
Bauxite	39.3%	—	2.5%	44.1%	14.1%	—
Chromium	7.9	27.0%	—	11.2	34.8	19.1%
Cobalt	15.1	—	—	71.5	9.8	3.8
Copper	33.7	2.5	1.5	39.0	22.8	0.5
Iron ore	35.1	—	—	17.6	37.0	10.3
Manganese	6.6	23.3	—	22.1	41.7	6.3
Mercury	37.5	—	4.9	17.9	39.5	0.2
Lead	44.8	—	3.4	19.5	30.3	0.9
Molybdenum	75.7	—	—	11.3	12.7	0.3
Nickel	47.1	2.9	—	28.1	23.0	0.8
Platinum group	8.0	45.7	—	0.4	45.5	0.4
Tin	7.0	1.1	—	73.2	18.7	—
Tungsten	17.7	—	—	19.9	49.0	13.4
Zinc	46.9	1.3	1.8	20.3	27.4	2.3

* Data includes production of non-Communist countries not included in data available for OECD, South Africa, and developing countries categories.
Sources: Commodity Data Summaries, 1977 (Bureau of Mines, 1977); Yearbook, 1977, American Bureau of Metal Statistics; and Metal Statistics 1966-76 (Frankfurt, Germany: Metallgesellschaft, 1977).

0.2

SHARES OF WORLD MINE RESERVES OF 14 NONFUEL MINERALS, 1975
(Percent)

Commodity	OECD	South Africa	Yugoslavia	Developing Countries	Communist Countries	Other Non-Communist Countries
Bauxite	31.1%	—	1.0%	67.3%	2.6%	3.0%
Chromium	0.7	74.1%	—	22.2	1.0	2.0
Cobalt	8.1	—	—	42.5	22.1	27.3
Copper	28.9	—	—	37.7	8.9	24.5
Iron ore	34.5	1.2	—	28.1	34.2	2.0
Manganese	8.0	44.7	—	8.9	38.3	—
Mercury	62.6	—	10.1	7.0	20.3	—
Lead	68.1	—	1.8	13.3	16.0	0.8
Molybdenum	63.9	—	—	17.0	19.0	0.1
Nickel	25.7	—	—	59.0	15.3	—
Platinum group	1.4	83.4	—	—	15.1	—
Tin	5.4	—	—	64.7	29.9	—
Tungsten	30.9	—	—	10.1	69.0	—
Zinc	69.1	—	2.4	18.0	10.5	—

Sources: Mineral Facts and Problems Bicentennial Edition (Bureau of Mines, 1975), Bulletin 667; Mineral Commodity Summaries, 1978 (Washington, D.C., U.S. Department of Interior, 1978).

⁶ Mikesell, R.F., New Patterns of World Mineral Development, (London: British-North America Committee, 1979), pages 86-87.

It has recently been argued that the LDC production share is on the rise and will significantly increase in at least six mineral commodities: a sharp increase in nickel; moderate increases in bauxite, copper, iron ore, lead and phosphate.⁷ Harkin, of the United Nations, says that "there is a general consensus that the major new sources of minerals will increasingly be located in the developing countries which have not been well explored in the past; these countries have some 40 - 45% of the world's non-fuel mineral resources" ⁸ (see Appendix A).

We should note, however, that any growth in mineral production or change in trade patterns will be determined primarily by the rate of real growth of income in the industrialized countries. Bosson and Varon have noted that the Developed Market Economies presently consume over two-thirds of the world mineral output and they import 90% of the exportable surplus in order to meet 60% of their requirements. Less Developed Countries consume less than 10% of the global mineral output, yet they account for over one-third of total production and supply fully one-half of the requirements of the Developed Market nations.⁹

⁷ Takeuchi, K., et al, "Investment Requirements in the Non-Fuel Mineral Sector in the Developing Countries", Natural Resources Forum, vol. 3, April, 1977, p. 267.

⁸ Harkin, D.A., "Mineral Exploration and Technical Co-operation in the Developing Countries", in G.J.H. Govett and M.S. Govett, editors, World Mineral Supplies, (New York: Elsevier Scientific Publishing Co., 1976), page 319.

⁹ Bosson, R., and Varon, B., The Mining Industry and the Developing Countries, (New York: Oxford Univ. Press, 1977) pages 9-10.

For some LDC's questions of international mineral supply and demand, prices, and production levels are crucially important. Bolivia, Chile, Morocco, Zaire, and Zambia, among others, rely on mineral resources for over one-half of their export income.¹⁰ The governments and people of these countries shall increasingly be wary of mineral developments in their countries; the pattern of mineral development can be a highly-charged political issue. Mikesell has commented,

Taking minerals from the soil and carting them away to foreign countries tends to stir the emotions of people, especially when it is done by foreigners. Such activity is seen as depleting the national patrimony...¹¹

Of course every government is concerned with maximising benefits and revenue from its country's primary resources. Thus, much attention is now being paid to the contribution to economic development from mineral production.

There exists, within the literature of economic development, a debate over the question of whether or not a significant contribution can be made to an LDC by the large scale primary resource industries in general and by the mining industry in particular. This debate has proven, over the years, to be of considerable value, especially in exposing such negative impacts from mining as the rise of dual economies, the lessening benefits from trade for

¹⁰ Mikesell, New Patterns of World Mineral Development, page 1.

¹¹ Mikesell, R.F., Non-Fuel Minerals: U.S. Investment Policies Abroad, (Beverly Hills: Sage Publications, 1975), page 48.

LDC's, and the dangers of economic or technical dependence. Some of the critics¹² of large scale mineral development in LDC's argue that LDC development planners should reject these foreign-owned extractive industries because of the difficulties in controlling the rate and direction of change which results from their impact upon the host country economy and society.

Opposing this point of view are others who argue that there are substantial benefits which can accrue to an LDC from a properly structured and carefully administered mineral industry.

Mining activity earns foreign exchange and produces additional revenues through taxes and royalties; it can stimulate the development of depressed regions, improve the professional and technical skills of nationals and provide a nucleus for development.¹³

One recent analysis concludes that for many of the least developed countries mineral discovery and development "is about the last best hope of anything which might be termed a non-marginal change in their economies".¹⁴

- ¹² Girvan, N., Corporate Imperialism: Conflict and Expropriation, (White Plains, New York: M.E. Sharpe, Inc., 1976).
 Ochala, S., Minerals in African Underdevelopment, (London: Bogle-L'Ouverture Ltd., 1975).
 Sklar, R., Corporate Power in an African State, (Berkeley: Univ. of California Press, 1975).
 Stewart, F., Technology and Underdevelopment, (London: MacMillan, 1977).
 Szentes, T., The Political Economy of Underdevelopment, (Kisado: Budapest Akademia, 1971).

- ¹³ Bosson and Varon, The Mining Industry and the Developing Countries, page 98.

- ¹⁴ Crabbe, J., Governments and Mining Companies in Developing Countries, (Boulder, Col.: Westview Press, 1979), page 4.

The underlying assumptions in this paper concerning the developmental contribution of the mineral industries are that mineral operations, like all undertakings in LDC's, have to be carefully assessed in relation to all other available opportunities. Of course this assessment is more critical here, especially in times of scarce investment capital, because most LDC's have few available alternatives. The margin for error is narrow.

Mineral development in terms of its potential contribution to economic development is neither inherently "good" nor "bad". Here we are in parallel with Mikesell, who has written,

For most developing countries today, the relevant question is not whether they will produce primary commodities for export or engage in manufacturing for home use or for export. They recognize the need for both types of activity. Rather the significant questions are how the export-oriented primary commodity can make the maximum contribution to broadly based development, and what kind of policy will best serve this goal.¹⁵

The question is HOW? and, at least to a certain extent, the answer to this question must be based on KNOWLEDGE. This returns us to the subject of natural resource information, or more particularly, mineral exploration.

The approach to mineral exploration in LDC's, as presented in this paper, is perhaps best described as "operational". We are

¹⁵ Mikesell, R.F., Foreign Investment in the Petroleum and Mineral Industries, (Baltimore: Johns Hopkins Univ. Press, 1971), page 18.

dealing here primarily with the techniques, activities and options available to those LDC's which are interested in acquiring more information about their mineral resources.

In organising the research for this paper I was fortunate to benefit from interviews with explorationists and policy makers in both private industry and the government. I gratefully acknowledge their time and support.

The structure of this paper is as follows. Chapter One, "The Nature of the Mineral Industry", begins with a discussion of mining operations and continues with an outline of the primary characteristics of the international mineral industry. These characteristics have combined to create an industrial structure which, at present, is dominated by a relatively small number of large, vertically integrated corporation.

In Chapter Two we examine "The Mineral Industry in Less Developed Countries". This chapter, with the first, completes our foundation and introduces the argument in favour of government-induced mineral exploration.

Chapter Three is a descriptive look at "Mineral Exploration Programmes". Many different types and scales of activity can be combined in an exploration programme which, ideally, follows a sequence from reconnaissance to deposit evaluation and, subsequently, to mineral development. The choice of exploration technique and

scale of application can be decisive in determining the value of the exploration effort.

In Chapter Four our attention turns to "Exploration Options for Less Developed Countries". Here we are dealing with the costs of exploration and the availability for LDC's of capable exploration services. Two development assistance agencies which provide mineral exploration projects, the Canadian International Development Agency and the United Nations Development Programme, are illustrated here.

The Fifth Chapter is a case study of "Mineral Exploration in Kenya, 1977". This case study describes a bilateral development assistance exploration effort which proved very successful from the perspectives of all parties involved. Most important, this case study illustrates how a carefully designed and flexible exploration programme can increase the developmental potential of an LDC's mineral sector.

As mentioned above, the approach of this paper is "operational". However a theoretical undercurrent must accompany every paper on development, if only tacitly. This theoretical perspective has to do with one's perspective on, or definition of, development. We shall be operating under a simple definition here, as development is meant to be the increasing of a country's ability to grow and to choose. Natural resource information, including that gained through mineral exploration is well suited to this definition.

Natural resource information and mineral exploration can contribute, if only indirectly, to an increase of an LDC's productive capacity. Natural resource information and mineral exploration does contribute directly and strongly to an increase of an LDC's ability to choose its future course.

CHAPTER ONE THE NATURE OF THE MINERAL INDUSTRY

The primary characteristics of the international mineral industry are its immense scale in terms of investment requirements and its high degree of uncertainty. Together these characteristics have shaped mineral investments, production, and marketing to the present point at which these functions are dominated by a small number of giant international mining corporations. In this chapter we shall examine the nature of the modern mineral industry - its goals, processes and operations - and the international corporate structure of the industry.

The goal of the mineral industry is to earn a return on an investment through the discovery of minerals and by the conversion of these minerals from geologic resources to marketable products. B.W. Mackenzie has graphically outlined this conversion process as follows:¹

¹ B.W. Mackenzie, "Quantitative Economic Analysis Applied to the Mineral Industries," in Economics of the Mineral Industries, W.A. Vogely, (ed.), New York: American Institute of Metallurgical and Petroleum Engineers, 1976, p. 318.

1.1 The Mineral Conversion Process

- A. The physical occurrence and market demand provide the basic stimuli.
- B. The conversion process embodies a number of sequential stages: exploration, the development of mineral deposits and mineral processing facilities and, consequently, productive activity to supply market demand.
- C. Changes in demand and the depletion of deposits illustrate the dynamics of the process.

Mining operations are essentially repetitive processes of drilling, blasting, loading, rock support, and hauling. These activities are followed by various steps of milling, refining, beneficiation, etc., depending on the type of ore and its future uses.² Most modern mining facilities are either underground or open pit operations (although technical advances are making solution mining an attractive alternative, as in some Saskatchewan potash mining). The choice is usually dependent upon the geology of the deposit, vein deposits not being suited to open pit mining.

² R. Bosson and B. Varon, The Mining Industry and the Developing Countries (New York: Oxford University Press, 1977), p. 36.

Underground mining involves the highest degree of capital expenditure and, of course, these costs mount rapidly as the depth of the mine increases. But underground mining is not subject to climatic whims, and activity can usually continue under any conditions (the Sudbury nickel mines are a good illustration). One problem with underground mining is that often, as the depth of operations increases, the type and quality of ore will change (or perhaps run out) requiring new methods of extraction or processing. However, underground mining, with numerous shafts following various veins, offers the benefit of "selective mining". Various veins of differing ore grades can be exploited at different times, depending on the prevailing prices. Underground mine operators are free to concentrate, in times of depressed prices, on only the richest, highest quality veins. This practice is referred to as "picking the eyes out of a mine"³, and may be counterproductive in the long run.

Open pit mining is a much less selective, more "mass-mining" operation. Often lower-grade ore is being extracted, therefore success depends on highly efficient mechanisation. The problems associated with open pit mining usually occur in the removal of overburden, extraction of ore, and removal of material from the pit. Open pit mines now reach depths of over one thousand feet, with resulting drainage and haulage expenses rising to over fifty percent of total production costs. Open pit operations have been

³ These descriptions of mining operations are indebted to K. Warren, Mineral Resources, Devon: David & Charles Ltd., 1973, pp. 37-40.

known to shift to underground shaft mining when these expenses rise inordinately.

In recent years the dominant choice of mining investors has been open pit mining. In 1968, of fifty-two large scale new mining operations started world wide, almost one half were underground mines. But of the twenty-seven largest operations (more than one million tons of ore production per year), only six were underground mines.⁴ Bosson and Varon have estimated that some 65-70% of all ore mined worldwide comes from open pits - in the United States the portion is 90-95%.⁵

The mineral conversion process and mining operations may initially seem straightforward. Similarly, a logical approach is brought to mineral investments. In the process of mineral investment can be recognized five sequential stages:⁶

1. THE SELECTION OF AN INVESTMENT ENVIRONMENT: the fundamental strategic decision to invest in mining.
2. THE DISCOVERY OF MINERAL DEPOSITS: the identifying of potentially economic orebodies.
3. THE DELINEATION OF SELECTED DISCOVERIES: examining the extent and value of a particular reserve.
4. THE EVALUATION AND PRODUCTION DECISION: whether or not to develop the reserves; if so, how?
5. THE MINERAL PRODUCTION PROCESS: commencement of production and ongoing operations.

⁴ K. Warren, Mineral Resources, p. 44.

⁵ Bosson and Varon, The Mining Industry..., p. 35.

⁶ B.W. Mackenzie, "Investment in Information for the Assessment of Mineral Value: Some Guidelines for Mineral Leasing Policy," in Mineral Leasing as an Instrument of Public Policy, M. Crommelin and A. Thompson, (eds.), (Vancouver: University of British Columbia Press, 1977), p. 105.

The first three stages here are basically information gathering activities; these activities are the focus of this paper and will be discussed in detail in later chapters. The information is evaluated in the fourth stage and, with favourable indications, mineral production is commenced. In the fifth stage more information is generated regarding the efficiency and value of the operations.⁷

A mineral investment will be undertaken when surplus value and economic rent are recognized, based on the perceived value of geologic resources. The surplus value and economic rent are determined by the "time distribution of cost, risk, and return characteristics through all stages from primary exploration to mineral production."⁸ The long-term profitability of the investment must be assured in terms of net cash flow. Of course, "this flow will be negative at the start, as the mine is built up and run in, but will (the investors hope) become positive; that is, profit will be made as time passes."⁹

With such a logical, straightforward, "systems" approach to mining and mineral investments, why are analysts continually commenting that the mineral industry operates "at levels of risk - physical, commercial and political - which are significantly higher than those for other industries"?¹⁰ The answer is to be

⁷ Mackenzie, "Investment in Information...", p. 106.

⁸ Mackenzie, "Investment in Information...", p. 106.

⁹ Warren, Mineral Resources, p. 36.

¹⁰ Bosson and Varon, The Mining Industry..., p. 24.

found in an examination of three characteristics which are inherent to the mineral industry: the necessary huge investment in both capital and time; the geological uncertainty of mineral resources; and the price instability which seems a permanent fixture in world mineral markets. It is to these three characteristics that our attention will now turn.

Scale of Mineral Operations

Modern mining operations require large capital outlays - in the order of many tens of millions of dollars. And, as in many sectors of manufacturing, operating costs rise less quickly than does the scale of operations. In short, economies of scale operate in the mining industry which favour the development of large operations. Bosson and Varon have illustrated these advantages as follows:¹¹

¹¹ Bosson and Varon, The Mining Industry..., p. 36.

12

COMPARISON OF COSTS AND SIZE OF OPERATION

Note: Cost base of unity: annual mine output of 1 million tons a year (3,300 tons a day).

source: Bosson and Varon, The Mining Industry and the Developing Countries, page 37.

Further, as for all industries now, the mining industry is finding that changing technology, increased automation, and inflation are making the capital requirements higher still.

1.3 Price Indexes of Principal Metal Mining Expenses

1967 = 100

Year	Total	Labour	Supplies	Fuel	Electrical Energy
1971	119	123	116	114	114
1972	127	133	120	119	122
1973	136	142	128	146	129
1974	172	180	157	208	163
1975	196	205	177	245	196

Source: U.S. Bureau of Mines, Minerals Yearbook, Vol. 1, 1975, p. 56.

Bosson and Varon have also outlined mining investment requirements by selected commodity.¹²

1.4 Typical Capital Investment Requirements for
Mining and Processing Facilities: 1975

<u>Mineral and Facility</u>	<u>Capital Investment per metric ton of annual output (\$U.S.)</u>
ALUMINUM	
Bauxite Mining	25-30
Aluminum Refining	200-300
Aluminum Smelting	1,000-1,500
COPPER	
Mining, Beneficiating, Smelting and Refining	3,000-5,000
LEAD	
Smelter expansion	100-500
NICKEL	
Mining and Smelting	8,000-15,000
ZINC	
Blast furnace and electrolytic refining expansion	300-700

Please note: These 1975 costs are subject to inflation and can be expected to be much higher today.

Some examples of recent investments will indicate the scale of capital required in the modern mining industry.

In 1971 it was calculated that \$355 million would be required to bring the Cujone property in Peru into production; five years later that stage was reached at a cost of \$680 million.¹³

A state-owned, high-grade open pit copper mine (porphyry deposit)

¹² Bosson and Varon, The Mining Industry..., p. 47.

¹³ J. Carman, Obstacles to Mineral Development (New York: Pergamon Policy Studies, 1979), p. 27.

at Cerro Verde, Peru, came on stream in May, 1977. Production started at a very small scale but the investment amounted to \$187.4 million.¹⁴ In the Philippines, the open pit Carmen copper mine, also of a modest scale (128,775 tons/year) was completed in October, 1977, at a cost of \$95.6 million.¹⁵ In Kamloops, British Columbia, Teck Corporation's new Afton Mine, another open pit copper mine, capable of producing 7,000 tons/day started production in November, 1977. This came thirteen years after the commencement of exploratory drilling, and at a cost of \$85 million.¹⁶ Mine expansion can also be very expensive. The cost of the recent expansion of the Caranea (Mexico) copper mine from 41,000 tons/year to 70,000 tons/year was estimated at \$125 million.¹⁷ Finally, the United Nations has projected that the exploitation of the copper porphyry deposits such as those recently discovered in Panama, Mexico and Iran will each require an investment in the range of \$700 million.¹⁸

The investment in time which is necessary for modern mining operations can also be intimidating. The elapsed time between the beginning of detailed exploration and the start up of commercial mineral production averages more than ten years and has often

¹⁴ Mining Magazine, March 1978, p. 184.

¹⁵ Mining Engineering, Vol. 31, No. 8, August 1979, p. 1189.

¹⁶ Mining Magazine, January 1978, p. 14.

¹⁷ World Mining, Vol. 31, No. 10, September 1978, p. 65.

¹⁸ Cited by G. Govett and M. Govett, "The Inequality of Distribution of World Mineral Supplies," in Canadian Institute of Metallurgy Bulletin, August 1977, p. 67.

been as long as twenty years.¹⁹ An industry spokesman has noted that, to gain a profitable return on investment, an additional ten years of investment longevity is required, giving a total of twenty to thirty years from the inception of exploration.²⁰

In sum then, the scale of modern mining operations is such that it favours those corporate entities capable of sustaining large, long-term investments. In fact, although there are some eight thousand producing mines in the non-communist world, 90% of all mineral output (excluding coal) is accounted for by 1,052 mines.²¹

Geological Uncertainty

The second characteristic of the mineral industry also gives advantages to larger operations. This has to do with the geological uncertainty of the mineral industry.

The incompleteness of geological information and the difficulty of geological interpretation always cast doubt on mineral reserve and grade statistics; generally, the true value cannot be known until the deposit is depleted.²²

This "incompleteness" of knowledge further complicates investment decisions; this is a very important factor considering the scale of modern mining investments. Timing again plays a role here as

¹⁹ Bosson and Varon, The Mineral Industry..., p. 8.

²⁰ T. Walthier, St. Joe Minerals Corp., "The Shrinking World of Exploration," Mining Engineering, Vol. 28, No. 5, April 1976, p. 29.

²¹ Mining Magazine, March 1978, p. 229.

²² Bosson and Varon, The Mining Industry..., p. 25.

often the availability of knowledge about geological resources is dependent upon prevailing prices. It is not too difficult to make incorrect investment decisions, as Smith and Wells have pointed out.

Raw materials are alternately "abundant" with declining terms of trade, or scarce with ever-increasing prices projected for the future. The short-term characteristics have usually turned out to be wrong for the medium term.²³

In order to counter the investment risks associated with geologic uncertainty the corporate response has been to apply economies of scale to mineral exploration and to spread their operations over large geographic and commodity areas. Larger corporate exploration programmes naturally have a higher probability of success and, by avoiding concentration on a single commodity, the risk of loss to the firm due to depressed prices is somewhat reduced. The result has been that the bulk of world-wide mineral exploration expenditures (estimated at \$300-\$500 million annually)²⁴ come from large multinational mining companies. An illustration from the Canadian exploration experience is indicative of this trend.

²³ D. Smith and L. Wells, Negotiating Third World Mineral Agreements (Cambridge, Mass.: Ballinger Publishing Co., 1975), p. 13.

²⁴ Govett and Govett, "The Inequality...", p. 66. The figure excludes exploration expenditures in centrally-planned economies.

Source: F. G. Kruger, "Mining—A Business for Professionals Only," *Mining Engineering* (September 1969), p. 87.

- The diagonal dashed lines show exploration costs as a percent of annual sales.
- Most mining companies spend from 0.1-1.0% of sales on exploration.
- Oil companies are included for comparison, and as a signal to smaller and medium-sized mining companies, because recent trends show that almost all of the oil companies are in the process of forming solid mineral divisions.

Geologic uncertainty then, is more easily overcome by the larger firms. Further, as Bosson and Varon have noted, the probability of discovery is a crucial variable for smaller companies as a few unsuccessful exploration ventures can mean financial ruin.²⁵ The geologic risk factor cannot be ignored as it is one of the

²⁵ Bosson and Varon, *The Mineral Industry...*, p. 32.

principal characteristics of the international mineral industry. Again, it is this area of activity that will be the focus of this paper. At this point, however, it is sufficient to note that this "unknown factor" is one of the central causes of corporate conservatism in the mineral industry.

Mineral Price Instability

In the last two decades a constant feature of the international mineral industry has been price instability. The dramatic price fluctuations have had profound effects on both producers and consumers, and also on the amount of activity and investment in the mineral industry. K. Warren, in his Mineral Resources, points to the example of the wolfram market in the 1950's as being the epitome of this price instability.²⁶

Wolfram ore is the main source of tungsten, of importance primarily to the steel industry. During and after the Korean War the market for wolfram was brisk and there were many mines producing wolfram; in 1955 there were over seven hundred. The price for wolfram dropped drastically in the mid-1950's and by 1958 there were only two wolfram mines still operating. Subsequently, in a two-week period in 1959, world prices for wolfram shot up from one hundred to one hundred and sixty shillings per unit due to its scarcity.

The price fluctuations for the more "mainstream" minerals may not be so immediate, but often the range and impact are no less serious, as the following chart indicates.

²⁶ K. Warren, Mineral Resources, p. 48.

1.6 SELECTED MINERAL PRICES - 1966-1979

LONDON METAL EXCHANGE

Of course with minerals, as in all industries, prices are a function of supply and demand. But a number of factors affect mineral supply and demand, contributing to the high level of price instability. Briefly, these can be outlined as follows:²⁷

1. The unresponsiveness of supply in the short run to increases in price once full capacity is reached. Exploration financing, contracting and constructing facilities make for long lead times.
2. There is unresponsiveness of demand in the short run to changes in price. Demand in the mineral industries is essentially a function of the business cycle in the advanced, industrialized countries.
3. There is unresponsiveness of demand in the short run to changes in income due to stockpiles and long term start up of operations.

The mineral price situation in competitive markets can be illustrated as follows:

²⁷ The following is derived from J.E. Tilton, "Impact of Market Instability for Mineral Materials," The World Economy, Vol. 1, No. 4, October 1974, pp. 370-375.

1.7 COMPETITIVE MARKETS

Supply expands significantly in response to price increases as long as there is unused capacity. Approaching full capacity, little additional supply can be elicited.

Shown are three different stages in the business cycle. This curve is steep since changes in price do not greatly affect demand on the short run. The substantial shifts in this curve from the trough to the peak in the business cycle reflect the sensitivity of demand to changes in income.

At the peak of the business cycle, production is near capacity and price is high. Total revenues are large and profit is usually high ($Q_p P_p$).

At the trough, output, price, revenues, and profits are all down.

At the trough, as Tilton notes, "since mineral industries are highly capital intensive, losses can be substantial."²⁸

As is the result of the characteristics discussed earlier, the large necessary investment in capital and time and the high level of geological uncertainty, the corporate response to

²⁸J. Tilton, "Impact of Market Instability...", p. 374.

mineral price instability has been a reliance on larger scale operations. Here the goal is to create something of a "producer's market", where the number of significant producers is limited, and a more or less common price is sought by these producers. Again, we turn to Tilton's study for an illustration of this phenomenon.²⁹

1.7 PRODUCER'S MARKETS

The attempt is made to keep the price fixed over the business cycle.

The supply curve is horizontal, stopping at full capacity.

The same "typical" demand curves appear here.

The change in price is far less. Output, on the other hand, changes substantially through the business cycle.

At the trough, output is far below capacity (production might conceivably be halted); at the peak, production is constrained by capacity. It is not unusual, in producers' markets, for shortages to appear at peak periods. Extended delivery schedules, rationing, or other such mechanisms are required at such times to allocate the available supply.

²⁹ J. Tilton, "Impact of Market Instability...", p. 374.

Producers' markets strive for less price instability as demand falls although revenues and profits will decline, essentially due to unresponsiveness of price.

There is less danger of the lower demand which occurs during downturns in the business cycle and which causes larger reductions in revenues in the competitive markets. We should note that this thrust by international mining companies towards the establishment of producers' markets remains an ideal. Its achievement would, in fact, be very difficult, in light of the myriad of factors which affect this industry. However the fact that this remains an ideal, or a goal, is of primary significance here. It points to an industrial structure and to corporate strategies which appear to be, as some analysts have noted, "oligopolistic in nature".³⁰

Each of its major characteristics - the huge, long term investments, the geological unknowns, and the price instability - has given the mining industry a bias in favour of the largest firms. The many uncertainties and variables surrounding decisions in the mineral industries can act to deter new mining investments. Similarly, these characteristics have caused many firms to adopt a high degree of vertical integration. An assured supply and outlet of ore production within one corporate entity makes both pricing and the large scale logistical planning more efficient. There are strong incentives for mineral extraction

³⁰ Bosson and Varon, The Mining Industry..., p. 40.
See also R. Mikesell, Foreign Private Investment in the Mineral and Petroleum Industries (Baltimore: Johns Hopkins University Press, 1971), p. 11.

and processing to be linked and, once such a linkage is achieved, the arrangement seems to be self-perpetuating.³¹

Very large mining companies, international in outlook and sophisticated in financial and technical analysis and operations, control the mining cycle from exploration to marketing of the refined minerals, even to fabrication and production of consumer goods.³²

The mining industry has become the operating ground for such corporate giants as:³³

ALCOA (Aluminum Company of America)
capitalisation...\$3.44 billion
net sales and
operating revenue (1977)...\$3.41 billion
Alcoa is involved in mining, refining, and fabricating finished goods.
Alcoa operates mines in seven countries on four continents.

AMAX (American Metal Climax Incorporated)
capitalisation...\$2.57 billion
revenue (1977)...\$1.33 billion
AMAX is involved in the mining of molybdenum, coal, natural gas, petroleum, iron ore, copper, lead, zinc, and potash.
Among other countries, AMAX operates in Australia, Canada, Liberia, Namibia, and Zambia.

Kennecott Copper Corporation
capitalisation...\$2.09 billion
sales (1977)...\$925 million
In addition to copper, Kennecott operates gold, silver, molybdenum, lead, and zinc. Mines are owned in Argentina, Australia, Brazil, Canada, Colombia, India, Mexico, New Zealand, Puerto Rico, Spain, and South Africa.

³¹ B. Smith, "Security and Stability in Minerals Markets - the Role of Long Term Contracts," The World Economy, Vol. 2, No. 1, January 1979, p. 269.

³² Bosson and Varon, The Mining Industry..., p. 40.

³³ The other information comes from Moody's Industrials, 1979.

Rio Tinto - Zinc Corporation Limited
 total revenue (1975)... £1.20 billion
 Copper, gold, iron, lead, uranium and zinc mines are
 operated in many countries, including Australia,
 Canada, Netherland Antilles, Papua New Guinea, South
 Africa, and the United States.

Many of the smaller and medium sized mining firms are disappearing; often they are being replaced by the new "cash-liquid oil companies" seeking to extend their activities in the resources field.³⁴

The presence of such large international corporations in the mineral industries can have a tremendous impact on the economic development of the environments in which they operate. This impact, of course, could be either positive or negative. The potential for a serious negative impact from these large firms tends to be lessened as the economic environment in which it is operating becomes more sophisticated, that is, with a more elaborate secondary industrial structure as a surrounding economy.

K. Warren has commented that the advanced nations are substantially less affected by the vagaries of the international mineral industry; mineral producing less developed countries can "suffer much more".³⁵ Further, some analysts have pointed to a failure of the international mineral industry's market and structure which "encourages the domination of large, international firms,

³⁴ K. Takeuchi et al, "Investment Requirements in the Non-Fuel Mineral Sector in the Developing Countries," Natural Resources Forum, Vol. 3, April 1977, p. 269.

³⁵ K. Warren, Mineral Resources, p. 151.

reduces the rate of exploration, and subtracts from government revenues."³⁶

While we shall address the role of the mineral industry in the economic development of less developed countries in the following chapter, we should conclude this chapter with a few comments in that direction. The nature of the modern mineral industry is that it is large, complex and highly concentrated - some have even said oligopolistic. This results from the numerous corporate strategies aimed at overcoming the problems associated with the high levels of investment, geological risk and price instability which are inherent to the industry. But the international mineral industry is also profitable. Even when all the exploration expenses are included, the industry shows from average to above average profitability.³⁷ Herein lie some of the difficulties for less developed countries.

The international mining industry seems to demand a considerably higher return on investment from their less developed country-based operations than from those in more "stable" environments.

³⁶ F.M. Peterson, "The Role of Governments in Mineral Exploration," in Crommelin and Thompson, editors, Mineral Leasing..., p. 149.

³⁷ Bosson and Varon, The Mining Industry..., p. 9.

19 Direct Private Investment of the U. S.
in Foreign Mining and Smelting Industries, 1974
(millions of dollars)

Area or Country	Book Value at Year End	Net Capital Outflows	Undistributed Earnings of Subsidiaries	Earnings	Income
Developed countries	4,024	112	153	418	272
- Canada	2,793	46	82	197	122
- Europe	47	6	-2	-10	-8
- Australia, New Zealand, and South Africa	1,184	60	74	232	158
Developing Countries	2,100	-148	32	376	363
- Latin America (total)	1,037	-136	27	175	161
- Mexico	84	-25	25	36	10
- Chile	343	n.a.	-1	-1	4
- Peru	411	-5	2	45	41
- Other Western Hemisphere	402	-86	--	96	102
- Other Asia and Pacific	216	n.a.	n.a.	n.a.	n.a.
Total	6,124	-36	185	794	636

source: U.S. Bureau of Mines, Minerals Yearbook, 1974, vol. 1, page 61

Bosson and Varon have illustrated this difference on rates of return as follows:³⁸

Note: Earnings defined as the sum of the U.S. share in net earnings (or losses) of foreign corporations and branch profits after foreign taxes and before U.S. taxes.

Source: U.S. Department of Commerce, Office of Business Economics, *Survey of Current Business* (October 1968), p. 28; and *Balance of Payments Statistics Supplement*, pp. 190, 193, 212, and 215.

The considerable difference on expected returns on investment is but one indicator of the gap that often exists between the mineral developmental goals of the Less Developed Countries and the corporate objectives of the international mineral industry. It is to this problem that we shall now turn our attention.

³⁸ Bosson and Varon, *The Mining Industry...*, page 214.

CHAPTER TWO
THE MINERAL INDUSTRY IN LESS DEVELOPED COUNTRIES

Each geologist was accompanied by about seven Africans: to run the traverse wheel, to act as gun-bearer, to carry a gold pan, sample bag and specimens, and to allow four to be deployed on either side of the line of march to look for rock exposures.

The equipment supplied to the field men was always of excellent quality and, without being unduly lavish, permitted each man to maintain a high degree of mobility and more than a modest degree of comfort in camp.

J. A. Bancroft
Mining in Northern Rhodesia

Mineral investments and operations, as noted in Chapter One, are undertaken at high levels of commercial risk and uncertainty. This has been a major contributing factor to the typically capital-intensive, highly-concentrated, and vertically-integrated corporate structure of the modern mining industry. When mineral investments and operations in Less Developed Countries are being considered these levels of uncertainty are greatly intensified, and high levels of political risk also enter the investment picture. Perhaps these uncertainties - commercial and political - can seem a natural outcome of this industry.

Given the high financial stakes, the complexity of financial and developmental issues, the continually changing concessions environment, and the host country's constantly nagging doubts about yielding too much sovereignty, it would be remarkable if conflicts did not arise.¹

In this chapter it will be argued that mineral exploration, promoted by and executed for the LDC government which is interested in mineral development, can act to reduce the uncertainty, risk, and conflict which seem so often to accompany mineral operations in LDC's.

Together with Chapter One, this chapter will complete the background necessary for our more detailed examination of mineral exploration in LDC's. To begin, we shall trace briefly a historical perspective of the international mining industry in the

¹ Smith, D., and Wells, L., Negotiating Third World Mineral Agreements, (Cambridge, Mass.: Ballinger Publications Ltd., 1975), page 121.

Less Developed Countries. This will bring us to the modern-day relationship between LDC governments and international mining firms. This relationship has been a difficult one in recent years, marked by suspicion, conflict and, finally, inertia. At present international mining firms are reluctant to invest in many LDC's, and many LDC governments* regard the firms as a new and dangerous form of imperialism. Any amelioration of this situation for both the mining firms and the LDC governments will only result from a long and arduous bargaining process. Here is where our central topic, mineral exploration, will be introduced.

The product of mineral exploration is information. The appropriation and control of this information is a pivot point in the negotiations between mining firms and LDC governments. In closing this chapter we shall focus on the exploration stage of the mineral conversion process, thus recognizing its considerable potential for affecting mining firms and mineral producing LDC governments in a way which is mutually beneficial.

* LDC governments are (as are all governments) diffuse and hold different values and objectives. It can be dangerous to consider them as a homogenous group. One is advised not to take generalisations in this regard too literally. An interesting perspective on this subject can be found in Crabbe, Governments and Mining Companies in Developing Countries, chapter four, "Governments in Less Developed Countries", pages 74-94.

A Historical Perspective

Many Less Developed Countries, in particular those of Latin America and Africa, have long histories of contact with the international mining industry.² Unfortunately this long contact has seldom contributed to these countries' well-being. A brief look at the "good old days" of the international mining houses provides a valuable starting point for an understanding of the present-day difficulties of the LDC mineral industries.

The halcyon days of the large mining houses came at the end of the nineteenth and first half of the twentieth centuries. The mining firms, headquartered in Western Europe, Britain and the United States, were able to obtain mining concessions to exploit any economically viable mineral deposit that might be discovered within their concession areas in Latin America, Africa, Asia, and the Pacific Rim. These traditional concessions were essentially "one-shot deals" in which a fixed set of rewards was divided in a single set of negotiations. One party was the "winner" and one the "loser" on specific issues for the life of the contract. Further, because oftentimes these concession areas were colonially-adminis-

² Murphy, E.J., History of African Civilization, (New York: Dell, 1972) Chapter 14, "Exploration, Exploitation, and Conquest", and Chapter 15, "The Imposition of Colonial Rule".

Ochala, S., Minerals in African Underdevelopment.

Girvan, N., Corporate Imperialism: Conflict and Expropriation.

tered territories, it was quite common that the indigenous interests were not even represented at the negotiations.³ Smith and Wells have noted that during this period the mining concessionaires were given "almost unrestricted rights".

The concessionaire was typically granted extensive rights over a very large land area, often much larger than an investor could be expected to develop over a reasonable period. The period of the contract was, however, seldom reasonable: in many cases the terms were to run fifty or sixty years or more.⁴

Commenting on one such concession, the 1906 agreement between the colonial administrative body, Congo Comité Spécial du Katanga and the Belgian/French corporation, Union Minière du Haut Katanga, Wetter and Schwebel have written that "the Company's rights were so extensive as to partake of quasi-governmental powers".⁵ This agreement granted the Company "full ownership of one-third of the tracts of State land and a concession, for ninety-nine years, to exploit the subsoil".⁶ The Company had extensive restrictive rights as well, including the right to dictate the uses of all watercourses crossing over and originating within the concession area.

Highly favourable arrangements for the mining houses were the rule, not the exception, during this period. For example, the Anglo-

³ Smith and Wells, Negotiating Third World Mineral Agreements, page 3.

⁴ Smith and Wells, Negotiating Third World Mineral Agreements, page 31.

⁵ Wetter, J., and Schwebel, S., "Some Little Known Cases on Concessions", British Yearbook of International Law, vol. XL, 1964, page 193.

⁶ Wetter and Schwebel, "Some Little Known Cases on Concessions", page 184.

American Corporation and Rhodesian Selection Trust were, in the 1920's, granted a concession involving 203,000 square miles of south-central Africa. This amounted to over seventy percent of what was then known as Northern Rhodesia (Zambia).⁷ Even in those countries which were free of colonial rule during this period indigenous mining firms often fared poorly against the large international mining companies. The case of Chile provides a good example.

In 1876 Chile produced 62% of the world's copper, all from Chilean-owned mines. By 1950, 90% of the Chilean mines were American-owned.⁸ John Crabbe attributes this dramatic shift to two factors:⁹ 1/ It was the foreign firms who were aware of the demand for mineral products in the industrial centres of the world. These foreign firms came to the LDC's (e.g. Chile) to buy rather than the indigene going overseas to sell.

2/ A vicious circle of sorts appeared. An indigenous firm could not become large enough to compete internationally without using the new technologies of large scale mining which required both foreign engineers and capital for their installation. However, to get the advantages of either of these factors the LDC firm required a measure of the other. If the LDC firm had neither the modern tech-

⁷ Bancroft, J., Mining in Northern Rhodesia, (Bedford, U.K.: The Sidney Press, 1961) page 81.

⁸ Crabbe, Governments and Mining Companies in Developing Countries, page 8.

⁹ Crabbe, Governments and Mining Companies in Developing Countries, page 8 - 9.

nological skills nor the available capital, the firm was unlikely to grow large enough to compete successfully in the international market-place. Crabbe notes that the Chilean situation was not an isolated case.

If we look at the situation in about 1950 we find that virtually every significant extractive enterprise in the less developed countries was owned by a foreign firm, of industrialized country origin.¹⁰

The operations of the "good old days" were also highly profitable. Taxes were generally low, at times virtually non-existent. The income tax on copper producers in Chile in the 1920's was 12%. This allowed the international mining firms a considerable rate of return, as illustrated by Kennecott Copper Ltd.'s El Teniente mine in Chile which returned each year between twenty and forty per cent on its investment.¹¹

Agreements of this nature have also reached forward into our era. The 1958 Agreement Between the Republic of Liberia and the Gewerkschaft Exploration Company of Dusseldorf, West Germany, stated that "The Government...grants to the Concessionaire...the exclusive right and privilege to...exploit deposits of all kinds of ore".¹² As well, enormous returns are not entirely foreign to the agreements of the modern era. The initial agreement for the Bougainville

¹⁰ Crabbe, Governments and Mining Companies in Developing Countries, page 9.

¹¹ Moran, T., Multinational Corporations and the Politics of Dependence: Copper in Chile, (Princeton: Princeton Univ. Press, 1974), page 22.

¹² cited by Smith and Wells, Negotiating Third World Mineral Agreements, page 27.

Copper project in Papua-New Guinea returned to its owners (Conzinc-Rio Tinto of Australia and New Broken Hill Consolidated) forty per cent of their investment in the first year of production, primarily due to a tax "holiday".*

Thus, over time, a recognizable structure has been firmly set. The international mining firms' operations in Less Developed Countries clearly became heavily weighted in favour of the foreign investor. When this historical perspective is coupled with the present characteristics of the mineral industry mentioned in Chapter One - its necessarily large scale capital investment, its high degree of corporate concentration, and the ever-present commercial uncertainty - we can recognize a very powerful industrial structure which is not likely to be responsive to LDC government demands for change. However such demands are now stridently being made, as the governments of Less Developed Countries seek to use the extraction of their mineral resources in a manner which contributes much more effectively to their national developmental goals than what has happened in the past.

* The tax holiday had been granted when Papua-New Guinea was an Australian protectorate. The government of newly-independent Papua-New Guinea promptly imposed an excess profits tax and tore up the existing agreement. A long period of inconclusive negotiations and manoeuvring has ensued.

- Tilton, J., The Future of Non-Fuel Minerals,
(Washington: Brookings Institute, 1977), page 32.

LDC Government / International Mining Company Relations

i. Renegotiation for Development.

The 1962 United Nations Resolution "Permanent Sovereignty Over Natural Resources" * is perhaps the clearest bench-mark indicating the new willingness of the governments of Less Developed Countries to take a "hands-on" approach with regard to their primary resources. The Resolution clearly signalled that many of the LDC governments were no longer willing to negotiate long-term contracts with foreign investors and then live with the consequences. The governments were no longer willing to permit foreign mining corporations to operate in their territory more or less without controls or interference beyond the basic commercial laws of the country. Mikesell has commented,

The major resources of the subsoil have come to be regarded as part of the public domain, not only de jure but in practice, and governments have exercised increasing control over these resources for the realization of national objectives.¹³

For some LDC's, this question of gaining and maintaining control over the extractive industries is of paramount importance. Here, of course, we are referring to those heavily dependent on mineral

*Resolution A/RES/1803 (XVII), Dec. 19, 1962, of the United Nations, entitled "Permanent Sovereignty Over Natural Resources" declares that,

The right of peoples and nations to permanent sovereignty over their natural wealth and resources must be exercised in the interest of their national development and of the well-being of the people of the State concerned.

¹³ Mikesell, Foreign Investment in the Petroleum and Mineral Industries, page 424.

based revenues. Examples of such countries appear in the chart below.¹⁴

2.1

Examples of Countries Heavily Dependent on
Nonfuel Mineral Exports

Country	Commodity	Commodity share of total country exports, 1974-76 average, %
Gilbert Islands (Nauru)	Phosphates	98.4
Zambia	Copper	92.1
Mauritania	Iron ore	79.8
Namibia	Copper	77.3
Guinea	Bauxite	70.2
Liberia	Iron ore	70.1
Togo	Phosphates	66.3
Chile	Copper	59.3
Zaire	Copper	59.3
Morocco	Phosphates	52.0
Papua New Guinea	Copper	45.2
Bolivia	Tin	39.8
Jordan	Phosphates	35.2
Guyana	Bauxite	26.0
Suriname	Bauxite	20.6
Senegal	Phosphates	20.0
Jamaica	Bauxite	18.4
Peru	Copper	17.5
Namibia	Lead	15.9
Haiti	Bauxite	12.8
Malaysia	Tin	12.0
Swaziland	Iron Ore	11.6
Philippines	Copper	11.3

Source: IBRD, Commodity Trade and Price Trends (1978 Edition)
(Washington, D.C.: IBRD, 1978), Table 11.

The new awareness of developmental needs and expectations now possessed by the LDC governments has caused many of them to present the international mining companies operating in their territories with demands for the renegotiation of existing mineral exploitation contracts. For the most part the strategy has been to arrange new

¹⁴ cited by Crabbe, Governments and Mining Companies in Developing Countries, page 42.

ad hoc agreements with each company for each project, rather than to attempt to institute wider ranging and binding mining legislation.¹⁵ Smith and Wells give as reasons for this approach: 1/ the special nature of each mining company; 2/ the major role that the foreign extractive company typically plays in the general economic development of the country; and 3/ the legal tradition (or lack of it) of the country.¹⁶

The mining agreement renegotiation sessions cover many issue areas, touching on many aspects of the mining operations and also on the problems of the surrounding region and the country. Issues often included are: exploration, financing, distribution of earnings, foreign exchange transactions, employment, advancement of locals in management, imports, marketing, taxation, relations with the community, environmental controls, and safeguards requested by the investor against further contractual changes.¹⁷ The negotiation and renegotiation process can be difficult for all parties; certainly long and detailed bargaining sessions often become heated. They do not always contribute to a harmonious relationship between governments and investors.

Obviously, for both parties much is at stake. In these situations, where there is a high degree of suspicion and a strong sense of investor risk (commercial, geological and political), it

¹⁵ Brown, R., and Faber, M., Some Policy and Legal Issues Affecting Min-Legislation and Agreements in African Commonwealth Countries, (London: Commonwealth Secretariat, 1974), page 72

¹⁶ Smith and Wells, Negotiating Third World Mineral Agreements, page 29.

¹⁷ see Mikesell, New Patterns of World Mineral Development, Section IV, "Conflicts and Accommodations Between Foreign Investors and Host Country Governments".

may simply not be possible to draft an initial agreement that will both appear attractive to the firm and still seem equitable to the government when uncertainties disappear, profits grow and the risks are forgotten.¹⁸ As a result, long series of negotiations now seem to evolve whenever major mining projects in LDC's are being considered. Smith and Wells have called these negotiations a "dynamic bargaining process", in which negotiations are on-going for the life of the contract and in which changing sets of rewards can be recognized for each party.¹⁹ But such extended bargaining can tend to "harden" both parties, and can "set" the gap between them. Richard Powell, a lawyer well accustomed to the "dynamic bargaining" after representing Bethlehem Steel in its negotiations with the government of Liberia, called this "a painful process".

The signing of the concession agreement is only the invitation to the ball...

The foreign investor may at times feel that he has entered into a contract to make concessions rather than a concessions contract.²⁰

ii. Stalemate and Inertia

The difficulties with such bargaining procedures are compounded when the negotiating teams fail to recognize and comprehend the myriad of financial, economic, social and political criteria valued by the other. Too often the bargaining posture of LDC's has been

¹⁸ Smith and Wells, Negotiating Third World Mineral Agreements, page 142.

¹⁹ Smith and Wells, Negotiating Third World Mineral Agreements, pages 3-5.

²⁰ Powell, R., "LAMCO: A Case Study of a Concessions Contract", Proceedings of the American Society of International Law, vol. 61, 1967, pages 89, 92.

steeped in the rhetoric of anti-imperialism, with unrealistic threats of expropriation looming over the conference table. Less Developed Country governments have also, at times, exhibited a destructive rush to get production underway as soon as possible. The foreign investor has often been perceived as obstructing or delaying these objectives, and the legislative wrath of the country has soon been brought into play.* Of course, some action by LDC governments has often been necessary to gain control of mineral resources, but there have been cases where, as a United Nations spokesman has suggested, there is a tendency for Less Developed Countries to "cut off the nose to spite the face".²¹

Likewise, mistakes are made on the corporate side.

Companies have often relied on engineers and lawyers as their negotiators. As a result, many company teams have often lacked the critical economic, business, and political data on which the governments of developing countries rely, either implicitly or explicitly, in negotiations. For similar reasons companies have on occasion been slow to recognize and plan for inevitable change.²²

* In 1970 Peru cancelled concessions for a mine at Michiquillay when ASARCO did not start production within a specified time. In 1974 the Nigerian government asked Texaco to cease oil production, reportedly because the government considered oil production too low. And Dahomey nullified an agreement made in 1964 with the Union Oil Company charging that the company had unduly delayed bringing an oil deposit into production.
- Smith and Wells, Negotiating Third World Mineral Agreements, page 115.

²¹ Carman, J. "Notes on Impediments to Mining Investments in the Developing World", in Laming, D. and Akajaiye, A., editors, New Directions in Mineral Development Policy, (Ibadan: The Caxton Press, 1976), page 125.

²² Smith and Wells, Negotiating Third World Mineral Agreements, page 153.

The most significant result the more difficult and more complicated relationship between mining investors and LDC governments has been an increasing suspicion of one another's motives and a slow-down of activity in the LDC mineral industry. In a recent study of international mineral investment patterns, Mikesell illustrated this trend as follows:²³

2.2

BOOK VALUE OF U.S. DIRECT INVESTMENT IN MINING AND SMELTING, 1966-77
(Millions of current dollars)

	Developing Countries		Developed Countries		Developing Countries as % of Total
	Value (\$ millions)	Change from Previous Year (percent)	Value (\$ millions)	Change from Previous Year (percent)	
1966	\$1,655		\$2,328		42%
1967	1,791	+ 8.2%	2,658	+ 14.2%	40
1968	1,962	9.5	2,875	8.2	41
1969	1,970	0.4	3,029	5.4	39
1970	2,119	7.6	3,286	8.5	39
1971	2,218	4.7	3,569	8.6	38
1972	2,267	2.2	3,400	- 4.7	40
1973	2,285	- 0.1	3,773	+ 11.0	38
1974	1,784	- 21.2	4,007	6.2	31
1975	2,150	+ 20.5	4,398	9.8	33
1976	2,309	7.4	4,750	8.0	33
1977	2,285	- 1.9	4,802	1.1	32

* No entries here since new series began with 1966.

Sources: 1966 through 1975. *Selected Data on U.S. Direct Investment Abroad, 1966-76*, Bureau of Economic Analysis, U.S. Department of Commerce (1977); 1976 and 1977 U.S. Department of Commerce, *Survey of Current Business*

2.3

ESTIMATES OF PROPERTY, PLANT AND EQUIPMENT EXPENDITURES IN MINING AND SMELTING BY MAJORITY-OWNED AFFILIATES OF U.S. COMPANIES: 1965-69; 1970-74; AND 1975-78 AVERAGES AND 1975-78 ANNUALLY
(Millions of current and 1972 dollars)

	Millions of Current Dollars			Millions of 1972 Dollars			Developing Countries as % of Total
	Developing Countries	Developed Countries	Total	Developing Countries	Developed Countries	Total	
1965-69 average	\$244	\$482	\$ 726	\$305	\$803	\$ 908	34%
1970-74 average	292	916	1,208	287	900	1,187	24
1975-78 average	227	613	840	164	442	606	27
1975	306	809	1,175	288	636	924	31
1976	262	672	934	198	502	698	28
1977	128	502	628	89	356	444	20
1978	156	470	625	102	309	411	25

Sources: U.S. Department of Commerce, *Survey of Current Business* (September 1974), pp. 25-31; September 1975, p. 34; September 1976, p. 24; September 1977, p. 26; and March 1978, p. 35. The GNP deflator used to convert current to 1972 dollars is given in the *Economic Report of the President* (January 1979), p. 188.

²³ Mikesell, New Patterns in World Mineral Development, pages 26, 27.

The rapid decline in 1973-74 reflects the nationalization of American-owned mining investments in Chile, Peru, Zambia and elsewhere.²⁴ Recovery past 1972 levels had not been achieved over the ensuing five years, and the LDC total share of investment has dropped ten per cent over the eleven year period. New mineral investment can be described as vigorous only in Australia, Canada, South Africa, the United States (together these countries accounted for about 80% of worldwide mineral exploration expenditures in the early 1970's)²⁵, and a very select group of LDC's.²⁶ Dr. Carman, of the United Nations, has noted that there presently exists a "climate of indifference and fear, with the major mining companies marking off most of the developing world as being unsafe for investment."²⁷

This narrow focussing of mineral investment can have an impact in two important ways: 1/ It reduces the developmental potential for some Less Developed Countries (in other words, lost opportunities).

²⁴ Mikesell, New Patterns of World Mineral Development, page 24.

²⁵ Bosson and Varon, The Mining Industry and the Developing Countries, page 31.

²⁶ The select group includes Brazil, Chile, Indonesia, and the Philippines. Mikesell, New Patterns of World Mineral Development, page 28.

²⁷ Carman, "Notes on Impediments to Mining Investments in Developing Countries", page 121.

"Noranda has tended to shy away from basic exploration in most developing countries because of the perceived or real political risks".

- N. Powis, President, Noranda Mines, Northern Miner, Sept. 13, 1973.

"There simply are relatively fewer and fewer places left where sizeable mining investments can be considered prudent."

- T.N. Walthier, St. Joe Minerals Corporation, "The Shrinking World of Exploration", Mining Engineering, vol. 28, # 4, April, 1976, page 27.

2/ It can result in substantially higher world prices for minerals due to the reliance on and development of what would normally be considered uneconomic mineral deposits. In the United States porphyry copper deposits of a grade as low as 0.29% are being mined. In Chile and Peru about a dozen deposits running on average about 1% copper now lie neglected.²⁸ It is with this background of suspicion and conflict, and stalemate and inertia that we now turn directly to the subject of mineral exploration in Less Developed Countries. It is suggested here that government-induced mineral exploration in the LDC's can affect the pattern of mineral development in ways that are welcomed by all concerned.

Mineral Exploration and LDC Government / Mining Corporation Relations

~~The~~ quantity and quality of information which is available to both parties is one of the most important factors in the determination of how mineral exploitation rights will be parcelled out.²⁹

Although the structure of the industry, the requirements of the particular firm, the economic and political forces in the host country set the boundaries on the kind of agreement that will be concluded, the information available to each side and the negotiating skills and strategies of the parties are nevertheless significant determinants of the kind of bargain which is struck within these boundaries.³⁰

Of course in bargaining over mining developments it is geologic information - the product of mineral exploration - which is highly valued.

²⁸ Carman, J., Obstacles to Mineral Development, B. Varon, editor, (New York: Pergamon Policy Studies, 1979), page 3.

²⁹ Brooks, D.B., editor, Resource Economics: The Selected Works of O. C. Herfindahl, (Baltimore: Resources for the Future, Inc., 1974) page 328.

³⁰ Smith and Wells, Negotiating Third World Mineral Agreements, page 153.

Exploration constitutes one of the high risk stages of mineral investment; no returns can be assured or even assumed. Traditionally mineral exploration has been carried out by the international mining companies, generally under licenses which denoted time and minimum expenditure limits (though these were not always enforced). These licenses awarded the holder the right to exploit any mineral deposit found, in accordance with the country's mining code.³¹ It has been, and remains, in the mining companies' interest to obtain comprehensive exploitation rights prior to the undertaking of what might become costly and disappointing exploration work. The traditional exploration pattern is less common today. The mining firms are wary of demands which might be pressed by host governments after exploration and, naturally, are reluctant to invest the risk capital. Two illustrations can be noted here.

Exploration at the Cerro Colorado copper deposit in Panama was carried out by a large international firm on the understanding that it could acquire exploitation rights in the future. After exploration was complete, negotiations regarding exploitation became drawn out and inconclusive. Finally the Government took over the property and told the firm it could expect some indemnification, at least to the amount spent on exploration. As Carman notes, "this could hardly be considered as satisfactory by the company because the recoverable value of the copper in the deposit approaches ten thousand million dollars." ³²

³¹ Harkin, "Mineral Exploration and Technical Co-operation in Developing Countries", page 321.

³² Carman, "Notes on Impediments to Mining Investment in the Developing World", page 126.

In Papua-New Guinea, negotiations between the Government and Kennecott Copper Limited became stalled for over two years because the Government demanded more geological information before finalising exploitation rights. The firm refused to spend the \$6.8 million necessary for exploration until it knew the terms of the contract.³³

Another obstacle in the way of exploration in LDC's by the international mining companies is the governments' disagreement with the firms' strategy of rationalizing worldwide exploration costs.

Corporations say they must secure (exploitation) terms which would permit returns sufficiently high to cover the cost of their unsuccessful exploration activities. Most governments are, however, reluctant to concede that successful mineral operations in their territories should subsidize exploration in other countries.³⁴

The exploration activity carried out by the international mining companies has not always been helpful. Indeed the results have not always been available, to the Less Developed Countries. Bosson and Varon note that, "in the past, announcements of discoveries in these countries were withheld and underplayed to minimize political and marketing risks".³⁵

³³ Crabbe, Governments and Mining Companies in Developing Countries, page 115. Crabbe also notes, "The Papua-New Guinea government may have been particularly obstinate because they were "burnt" before; it is alleged that they were misled into thinking that Bougainville was only a marginally profitable venture, when an Australian government team was negotiating was negotiating on their behalf with Rio Tinto Zinc." page 131n.

³⁴ United Nations, Negotiation and Drafting of Mining Legislation, (London: Mining Journal Books, 1976), page 5.

³⁵ Bosson and Varon, The Mining Industry and the Developing Countries, page 31.

In a number of instances the multinationals have been less than candid with regard to the results of exploration... Host governments have thus been deprived of knowledge about their own resources and of the basic tools with which to evaluate decisions deeply affecting their self-interest.³⁶

As noted earlier, we are now witnessing a serious slow-down of mineral investment in LDC's. Of course this slow-down includes exploration activity. Harkin comments that "a gap has appeared and widened in the exploration sequence of a number of developing nations; on a global basis there has been a reduction in the level of primary exploration that might otherwise have been reached".³⁷ Political risk and uncertainty play a large part in the cause of this slow-down. But some analysts have also pointed to a "vested interest" which has further reduced LDC mineral exploration activity.

The strong (vertically integrated) mining concerns - which already have assured supplies for the needs of their fabricating subsidiaries or relatively secure long-term sales contracts - can hardly be expected to welcome new mining operations either at home or abroad that would make sizeable contributions to the supply of metals. One suspects that in more than a few cases, major mining houses seek new deposits in the developing world merely to keep them out of the hands of their competitors, and thereby avoid the embarrassing questions at shareholders' and directors' meetings.³⁸

Mineral exploration is the essential seedcorn of mineral development, but this seedcorn will not be sown without sufficient in-

³⁶ Bosson and Varon, The Mining Industry and the Developing Countries, page 11.

³⁷ Harkin, "Mineral Exploration and Technical Co-operation in Developing Countries", page 323.

³⁸ Carman, "Notes on Impediments to Mining Investment in the Developing World", page 127.

centive. The indications are now that private industry, at least as represented by the international mining firms, recognizes little of this incentive in many Less Developed Countries. From a corporate perspective, this may turn out to be a short-sighted view. From a broader social perspective, Uhler comments,

Firms will tend to invest suboptimally in exploration... because the marginal private benefits of information are less than the marginal social benefits... Firms (will) hold back investment as they wait for other firms to provide full valuable (geological) information to them. If this behaviour is widespread, it leads to underinvestment (in exploration) by the industry as a whole.³⁹

For this reason alone, government-induced mineral exploration programmes can help; they may be necessary because it seems that no one else will do it.

It has long been recognized that such natural resource information activities as large scale topographical mapping are the responsibilities of the State. In those jurisdictions where the government is interested in promoting mineral development but where private exploration investments are not forthcoming, the natural resource information responsibilities of the government can be expanded into geologic mapping and through to the more detailed mineral exploration activities (see Chapter Three, "Mineral Exploration Programmes). O. C. Herfindahl has commented,

³⁹ Uhler, R., "Comment on the Government Role in Mineral Exploration", in Crommelin, M. and Thompson, A., editors, Mineral Leasing as an Instrument of Public Policy, (Vancouver: Univ. of British Columbia Press, 1977), page 156.

In practical terms, the attainment of a flow of natural resource investment in the later stages, where private investment may be the dominant form of organization, will necessitate some judicious effort by government agencies to provide information about prospects for which returns are very uncertain.⁴⁰

The government which undertakes mineral exploration programmes and which is rewarded with a measure of success (in geologic terms) will find that the configuration of its relationship with the international mining companies will change significantly. Bosson and Varon have written that "the bargaining position of each party changes according to the amount of knowledge about the resources to be exploited available at the time of negotiations."⁴¹ Negotiations carried out at the very early stages of mineral exploration will favour the international mining company, but the host government's bargaining position will be enhanced as its level of geological knowledge increases. This points to a real need, on the part of many LDC governments, to promote mineral exploration on their own behalf.

Advantages from exploration for the LDC government can be easily recognized. Traditionally, international mining companies entering a new investment environment at a low level of geological information have, understandably, sought high rates of return on their investment. But a government-induced exploration programme heightens the level of information without cost or risk

⁴⁰ Herfindahl, Natural Resource Information for Economic Development, page 118.

⁴¹ Bosson and Varon, The Mining Industry and the Developing Countries, page 13.

to the firm. We can assume that a lower rate of return would be acceptable to the firm, and that higher revenues from mineral extraction would accrue to the government.

Secondly, if the exploration programme succeeds in finding and delineating mineral reserves the government will find itself in a position to promote competitive bidding. It is in the government's interest to involve as many potential investors as possible (of course the government also gains the option of developing the mineral deposits indigenously if it perceives itself to have the necessary skills and resources). In addition, after a government-induced exploration programme the geological information can be distributed to the smaller and medium-sized mining firms which might not otherwise have been available as potential investors due to their lower exploration budgets. Further, a smaller or medium-sized mining firm might be more amenable to the LDC government's mineral and economic development objectives. Finally, regardless of the success of the exploration effort in outlining deposits, the programme will provide sound and reliable geological information upon which development plans can be made with a greater degree of confidence.

On the corporate side, the advantages of a government-induced mineral exploration programme are evident mainly in terms of reducing uncertainty. Crabbe has noted that a "desire for steady and predictable costs will lead the (mining) firm to seek to have as much information and control with respect to its extractive

sources as possible".⁴² While most obviously the government's exploration programme assists here in terms of reducing commercial and geological uncertainty, the measure of political risk is also reduced. Whereas with an investment at low levels of geological information the rates of return for the firm are high, so is the risk of demands coming from the government for the renegotiation and, perhaps, expropriation. In situations where the government has carried out mineral exploration this political risk is alleviated because the mineral investment agreement can be expected to be more equitable. Thus operations will continue in an atmosphere of greater stability. Further, the simple fact that the government has assumed the investment of risk capital in exploration shows to the potential investors both an interest in and a commitment to orderly mineral development.

In summary, we have seen that mineral investments and operations in Less Developed Countries have often been less than satisfactory from the perspectives of both the international mining firms and the LDC governments. The differing outlooks and contrary objectives of both parties have led to long and complex bargaining procedures and have generated an extremely uneasy atmosphere. At present the relationship between these parties is marked by "indifference and fear" and, finally, stagnation in LDC mineral investment. Mineral investment in LDC's has now been significantly reduced and the bulk

⁴² Crabbe, Governments and Mining Companies in Developing Countries, page 69.

of the international mining firm's exploration capital goes elsewhere.

Mineral exploration provides a focal point for the improvement of this situation. Government-induced exploration provides both parties with a common ground in their negotiations, and advantages from the government's exploration efforts can be seen for the companies and the LDC's. From the global perspective of efficient exploitation and consumption of resources, increased mineral exploration by the governments of LDC's can also be beneficial, providing valuable information for long-term planning.

This chapter has provided the foundation for answering the question of why LDC governments should promote, or induce, mineral exploration. Let us now turn to the more "operational" aspects of mineral exploration in LDC's, beginning with a description of exploration techniques and the organization of mineral exploration programmes.

CHAPTER THREE
MINERAL EXPLORATION PROGRAMMES

Therefore a miner, since we think he ought to be a good and serious man, should not make use of an enchanted twig, because if he is prudent and skilled in the natural signs, he understands that a forked stick is of no use to him for, as I have said before, there are natural indications of veins which he can see for himself without the help of twigs.

-from De Re Metallica,
by Agricola, 1556

Mineral exploration continues to evolve from a more or less haphazard scratching of the earth's surface to a systematic examination of an area's mineral potential.¹

Mineral exploration is the first vital step in the mineral conversion process (see Chapter One). Mineral exploration involves the acquisition and analysis of geological data upon which mineral investment decisions will be made. A successful exploration programme will transform available capital resources into a new form of capital: mineral deposits.²

In the past mineral exploration has been called a "gamble"; the phrase "ore is where you find it" was commonly heard. However, years of research and the accumulation of geological data now tell us that the distribution of minerals is not random. Rather, minerals are distributed "in relatively orderly patterns related to the geologic history of the earth's crust".³ Of course this is not to say that mineral exploration is now a straightforward exercise; many, many exploration attempts result only in disappointment. Mineral exploration remains highly risky, but its characterisation as a "gamble" is, as W.C. Peters notes, "only a handy figure of speech".

Risk is recognized, odds are taken into account, money is put on the table and the need for persistence is accepted, but exploration is not a game of chance. Even the "chance discoveries" so widely reported in the history of mining required someone

¹ Bosson and Varon, The Mining Industry and the Developing Countries, p. 37.

² P.A. Bailly, "Mineral Exploration Philosophy" in Mining Congress Journal, Vol. 58, No. 4, p. 31.

³ O.C. Herfindahl, Natural Resource Information and Economic Development, 1969, Baltimore, Johns Hopkins U. Press, p. 29.

with self-taught or formally acquired skills in geology and engineering to recognize the economic significance of the discovery.⁴

In this chapter we shall examine, in very general terms*, some of the many and varied techniques now employed in mineral exploration. These range from applications of space technology, to the age-old practice of panning in rivers and streams. We shall also outline how these techniques can (ideally) be integrated and co-ordinated into a mineral exploration programme, involving the following of ordered steps and using increasingly discriminating methods to focus progressively more sharply on the target - an economically viable mineral deposit. Our examination of exploration techniques and programmes will provide the foundation for a discussion of less-developed country exploration policies and options in later chapters. By breaking down the process of mineral exploration into its various levels and types of activity, we can begin to see how a government-induced exploration programme can be a key factor in any subsequent mineral investment decision.

* It will become immediately apparent that the author is not a "geo-scientist". Much of the technical information in this chapter is indebted to several texts, including the following which are recommended: Govett and Govett, World Mineral Supplies
D.S. Parasnis, Mining Geophysics
W.C. Peters, Exploration and Mining Geology
W.M. Telford, et al, Applied Geophysics
London, Cambridge U. Press, 1976.

⁴ W.C. Peters, Exploration and Mining Geology, (New York: J. Wiley & Sons, 1978), p. 533.

Exploration Techniques

Mineral exploration involves a series of activities which take place both within the offices of the exploration organization* and in the field (including airborne, surface, and direct underground activities). These activities are designed so as to reject for further exploration effort those areas which are deemed low in mineral potential, and to concentrate on the progressively more detailed, and expensive, techniques in areas showing the highest potential. Within this approach several different levels of exploration activity can be recognized:

1. Exploration Programme Design: Based on considerations of mineral supply and demand, the existing state of geological information, and the available exploration techniques, objectives are formulated and the regions for exploration activity are defined. An exploration model will be designed which includes timing and budgetary limitations.

2. Regional Reconnaissance: A "broad-brush" level of exploration activity giving structural geological information. Peters notes that "all of exploration is identified in some way with geomorphology, but in reconnaissance the association has always been especially close."⁵ The goal here is to identify likely areas of mineralisation.

* In the context of this chapter an exploration organisation can be a national or regional minerals department, a mining firm, or an exploration contractor.

⁵ Peters, Exploration and Mining Geology, p. 290.

3. Follow-up: Specific target areas are identified and examined. This level of exploration activity can often be dominated by one or several kinds of geophysical or geochemical survey technique (possibly both airborne and surface activity).

4. Detailed Target-Area Investigating: At this stage the goal is to outline particular mineral deposits and to assess their economic value. This level of activity can involve many different techniques and will surely include the most expensive exploration techniques - drilling and trenching.

The chart below is meant, in a generalised manner, to illustrate the different scales, types and areas of mineral exploration activities. Of course in practice each block would not be equal to the others in terms of the value of the information acquired nor in the cost of completing the activity. Neither is each block a necessary step in any particular exploration programme. The information programme, as it is gathered and analysed, will tell the exploration organisation which of the following steps to emphasize and which to reject.

3. / METHODS AND STAGES OF EXPLORATION ACTIVITY

Method Stage of Exploration	Research and Geological Literature Review	Geological Mapping	Geophysical Methods	Geochemical Methods	Direct Under- ground Methods
Programme Design	Office * Activity, Prelimin- ary Review	Office * review of maps	Not ap- plicable	Not ap- plicable	Not ap- plicable
Regional Reconnais- ance	Target id- * entification, Mining Case Histories	Office and * field in- vestigation and mapping	Airborne * regional surveys	Reconnais- * ance samp- ling	Not usually applicable
Follow-up	Literature less avail- able	Larger * scale, de- tailed field work	Detailed * airborne, and ground surveys	Target * area sampling	Possible, but expensive.
Detailed Target- Area In- vestigation	Usually data not available	Target and * Underground Mapping	Detailed ground and borehole geophysics	Highly localized sampling	The proving * step - gives grade, extent, and depth of deposit.

* Denotes most common stage for
this method

We shall now examine, in closer detail, the methods and operations
which make up each of the above exploration techniques.

Research and Geological Literature Review

Here we are considering the state of existing information,
prior to the undertaking of any active exploration effort.
Modern exploration organisations are now finding that their
efforts can be greatly assisted by a regular review of current
geological literature and research data. The information garnered

from such reviews can act as indicators or catalysts in their exploration efforts, especially at the regional reconnaissance and, at times, at the follow-up level. It is not often the case however, that detailed target area information is publicly available.

There has been, in recent years, a shift in the approach of mineral explorationists putting more initial emphasis on geological provinces and regional geological structures than on individual prospects.⁶ One result of this shift has been that the academic research being carried out by structural geologists and paleontologists has become more of a factor in the considerations of explorationists. Of this shift in emphasis O.H. Rostad has written:

Concepts of ore deposits have become increasingly important, as most exploration is now conducted as part of the search for specific types or models of deposits. A geological concept of the desired target is a major factor in determining the regions to which exploration effort is directed.

As geological research continues apace, as our knowledge of the earth's crust increases in both quality and quantity, mineral explorationists are becoming better equipped to apply these geological concepts and models to the search for economic deposits.

A review of geological literature can also be of considerable benefit at a more detailed level. Before embarking on the

⁶ O.H. Rostad, "Changing Concepts, Approaches and Techniques in Mineral Exploration," National Resources Forum, Vol. 3, No. 3, April 1979, p. 292.

⁷ Rostad, National Resources Forum, p. 291.

involved (and more costly) mineral exploration activities, the state of existing information concerning the exploration locality should be assessed. By this point in history it seems unlikely that there are many cases in which nothing is known of an area and, as Herfindahl notes, even "the limited information which exists will often permit a less than complete survey to be made - in many cases much less."⁸ J. Bancroft's history, Mining in Northern Rhodesia, points to copper discoveries in the 1920's and 1930's made much simpler as a result of studies of the mining operations and techniques of the ancient Zimbabwe kingdom.⁹ Further, W.C. Peters has noted that "one of the most significant mineral discoveries of the Southwest Pacific", that of copper ore at Mount Carstenz in New Guinea, was made on the basis of a literature search and a careful examination of information gathered twenty years earlier by two geologists on holiday.¹⁰ Granted, all previously accumulated data will have an element of another explorer's subjectivity*, but the potential to cut corners and save exploration efforts and costs can be significant.

*"Even an aerial photograph represents someone else's choice of flight path, time of year, etc...Geophysical and geochemical data are collected at chosen intervals..." Peters, p. 282.

⁸ Herfindahl, Natural Resources Information, p. 22.

⁹ J. Bancroft, Mining in Northern Rhodesia, (Bedford, U.K.: The Sidney Press, 1961), p. 71.

¹⁰ Peters, Exploration and Mining Geology, p. 282.

The review of geological research data and literature is, of course, an "in office" activity. The ability to utilise this technique successfully will depend to a large extent upon the regularity and thoroughness with which it is undertaken. Obvious sources of geological data include the geological and engineering collections of government libraries, such as that of the Geological Survey of Canada or the Institute on Mining and Metallurgy in London. Most national departments dealing with minerals and natural resources maintain a body of geological data (perhaps unedited) in maps and reports. Other sources include the regular Geoabstracts and Chemical Abstracts, gazetteers, and the many periodicals dealing with the earth sciences (see Appendix B). This task of reviewing such a large and diverse body of information could easily seem tedious and not particularly rewarding, yet it would be rare for a modern exploration programme to be undertaken without this step. Further, modern exploration organisations can save time by benefitting from recent advances made in data storage and retrieval by computer (Canada's GEODAT programme or the U.S. Geological Survey's GRASP: Geological Retrieval and Synopsis Program, for example).

Geological Mapping

This is the primary and ever-present activity of mineral exploration. Virtually all the other exploration activities are

designed to enhance knowledge and detail as presented on geologic maps; geologic maps are the "workhorses" which lead to mineral investment decisions. Geological maps are used in mineral exploration at each of the three levels mentioned earlier, reconnaissance, follow-up, and detailed target areas. These maps, and the techniques used in their preparation and analysis, change considerably as the scale increases, but at each level the geological maps combine structural information with the results of field sampling, the observation of outcrops, and detailed mineralogy.

Small scale topographical and geological maps (1:500,000 to 1:20,000) are used extensively in reconnaissance and follow-up work. The purpose of these maps is to provide a "synoptic view".

These maps provide a basis for preliminary field visits, for the planning of photogeology studies and for planning the actual reconnaissance...The choice of scale depends on the conceptual model of the target; the scale must be large enough to show the anticipated geologic associations without too much exaggeration and yet small enough to emphasize regional patterns rather than intricate geological detail...Detail comes later, when it can be digested in a few well-chosen localities.¹¹

In conjunction with regional reconnaissance sampling by field geologists, for the past several decades explorationists have relied heavily on airborne photography in determining this synoptic view. These activities cannot directly detect mineral deposits, but are used "to permit the inference of conditions favourable for economic mineralisation..."¹²

¹¹ Peters, Exploration and Mining Geology, p. 288.

¹² J.E.G.W. Greenwood, "Air Photographs in Economic Mineral Exploration" in E.R.W. Neale, (ed.), Some Guides to Mineral Exploration, British Commonwealth Geological Surveys, London, 1964, p. 24.

...Such conditions may include the presence of fault or fracture zones, lithological contacts, unconformities, major intrusions, dykes and pegmatites. Successful exploration commonly depends on locating favourable structural conditions. Structural data are among those most reliably obtained from air photographs.¹³

Many governments now provide black-and-white aerial photographs from which the photogeologic interpretation is done by analysing tonal contrasts, textures and geomorphic features in shades of gray. The landforms can be quite distinct, and a stereoscopic view will emphasize the more subtle variations in terrain.¹⁴

Recent advances have been made in photogeology using colour and infra-red film, giving a new dimension in interpretation. It can be expected that since the act of flying comprises the major cost in photogeology, these technical advances will become more competitive and more common.¹⁵

A further advance in the field of small scale geological mapping is the application of satellite-borne remote sensing techniques.

LANDSAT* products are particularly suited for mapping topography and structure and for correcting existing geologic maps. Terrain is presented dramatically and lineaments are more clearly defined on MSS (multi-spectral scanners) spectral images than on any other image except by computer reprocessing of LANDSAT

*LANDSAT series is but one of several orbiting platforms capable of providing geological information to mineral exploration organisations, e.g. E.O.S. (Earth Observation Station), E.R.O.S. (Earth Resources Observation Satellite).

¹³ Greenwood, "Air Photographs in Economic Mineral Exploration", p. 24.

¹⁴ Peters, Exploration and Mining Geology, p. 302.

¹⁵ Peters, Exploration and Mining Geology, pp. 302-306.

images with specialized optical equipment...Simple observation of LANDSAT images using light tables, manual plotting methods and simple diazchrome techniques may permit a preliminary interpretation of structural patterns and allow the observer to visualize the responsible forces or possible structural patterns below the surface.¹⁶

The application of these remote sensing techniques to geologic work is particularly direct and immediate. Whereas many of the other applications of satellite imagery (agriculture, oceanography, hydrology) require frequent surveys, remote sensing for geological information may require fewer cloud-free images to fulfill the user's needs. As Smith notes, repeat coverage is highly desirable due to changes in surface conditions, but it is not such a crucial factor in mineral application.¹⁷ And of course this also reduces the cost.

It is not expected that satellite-borne remote sensing techniques will replace aerial photography in the near future except perhaps at the smaller scale reconnaissance level. Still, remote sensing has been called "an indispensable first step"¹⁸ in geological survey and assessment. Likewise aerial photogeology

¹⁶ W.L. Smith, "Remote Sensing Applications for Mineral Resources," in Remote Sensing Applications for Mineral Exploration, W.L. Smith (ed.), (Stroudsburg, Penn.: Dowden, Hutchinson and Ross, Inc., 1977), p. 73.

¹⁷ Smith, "Remote Sensing Applications for Mineral Resources," p. 17.

¹⁸ K. Walton, "Satellite Remote Sensing of Natural Resources: Some Issues to be Resolved," in Natural Resources Forum, Vol. 1, No. 3, April 1977, p. 221.

will not replace the work of the field geologist. It merely makes better use of his time and reduces the overall costs of exploration. The field geologist will always be necessary for the in situ sampling and exploration, and in the preparation of the highly detailed maps of mineral deposits.

As the exploration programme proceeds through the follow-up and detailed target stages, geological maps are required at larger and larger scales: from 1:10,000 - 1:2,000 with trenching and drilling information sometimes mapped at even larger scales (1:600, 1"= 50').¹⁹ The geological mapping process then, continues from a "coarse-grained" to a "fine-grained" level, involving different objectives and different information gathering techniques as the mapping scale increases. This is a necessary progression in which the geological information gradually becomes useful for management purposes. W.C. Peters comments that the multiplicity of map scales adds confusion to a project, but as would be expected, an early chosen scale will have to be replaced by a better one as more of geology becomes known.²⁰

Finally, we should note that geological mapping does not take place in isolation. The other exploration activities (geophysics, geochemistry, drilling and trenching) will also be progressing within the exploration programme. The information from these other activities is included together with that of the geologist -

¹⁹ Peters, Exploration and Mining Geology, p. 317.

²⁰ Peters, Exploration and Mining Geology, p. 318.

either on the geological maps, or on transparent overlays, or separately - to provide a complete basis for mineral exploration decisions.

Geophysical Survey Methods

Geophysics has to do with many aspects of the physics of the earth and the atmosphere. Applied geophysics for mineral exploration is based on the principle that mineral ore should possess some physical property that differs significantly from that of the host rock.²¹ The physical properties which are investigated are: 1) magnetic susceptibility, 2) density (gravitational properties), 3) electrical conductivity, 4) electromagnetic characteristics (EM), 5) radioactivity, 6) elasticity (seismic properties), and 7) thermal conductivity. In mineral exploration the first five are the most important; 6) elasticity, involves seismic operations, which are much more a priority in petroleum exploration. Thermal conductivity is presently only of very limited exploration significance.

A key factor in successful geophysical exploration is the choice of technique.

The choice of technique or techniques to locate a certain mineral depends upon the nature of the mineral and of the surrounding rocks. Sometimes a method may give a distinct indication of the presence of the mineral being sought, for example, the magnetic method when used to find magnetic ores of iron or nickel; at other times the method may only indicate whether or

²¹ D.S. Parasnis, Mining Geophysics (London: Elsevier Publishing Co., 1973), p. 5.

not the surrounding conditions are favourable to the occurrence of the mineral being sought.²²

In determining geophysical techniques to be used, and in interpreting geophysical data, careful guidance by geological indicators is necessary. The data must be interpreted with attention paid to the characteristics of the orebodies being sought and to the variables of the geological environment. L.S. Collett warns us that too often "little use is made of geology by geophysicists in the final geophysical interpretation. Frequently, geophysical techniques are chosen without an appreciation of the mineral composition of the materials being measured."²³

Geophysical techniques, as noted, are widely varied. We shall briefly examine the different methods below. Also, geophysical exploration techniques are adaptable to the many levels of exploration activity.

The direct application of geophysics to the search for orebodies - radiometric prospecting for uranium ore, magnetic prospecting for iron ore, and electrical prospecting for base metal deposits - is generally considered to be a part of exploration in virgin areas. But the application is much broader; geophysical prospecting has provided many discoveries in older mining districts. Deep, concealed orebodies in productive districts are tempting geophysical targets because new ideas and new techniques can be more easily applied in searching for orebodies with relatively well-known characteristics. Established mining districts have the special advantage of allowing geophysical access into deep mine workings,

²² Telford et al, Applied Geophysics, p. 3.

²³ L.B. Collett, "Future Trends in Geophysical Mineral Exploration," in Govett & Govett, World Mineral Supplies, p. 381.

but there is an inherent disadvantage as well - that of stray electrical currents and other industrial-connected noise.²⁴

Airborne and ground geophysical methods are used at both the reconnaissance and follow-up stages of exploration. Ground geophysics are also used in local target area investigations and, in conjunction with drilling techniques, underground. There are both advantages and disadvantages to be considered in a decision whether to employ airborne or ground techniques. Airborne geophysical surveys are fast and relatively inexpensive in terms of unit area of coverage. Second, these surveys provide continuous readings and thus complete coverage of each flight line. Third, recent equipment advances have reached the point at which several kinds of information (Magnetic, Electromagnetic, Radiometric) can be gathered simultaneously in an airborne geophysical survey.

The relative drawbacks of airborne surveys are the ever-present uncertainty of position, the decreased resolution of information*, and the reduced depth of penetration**. Both

* Parasnis, Mining Geophysics, p. 310. "Two neighbouring indicators may tend to merge into one another giving the impression of only one indication." In all geophysical methods, both in ground and airborne surveys, much attention is paid to the quality of SIGNAL. A signal is comprised of NOISE (extraneous effects due to the instrument, magnetic storms, terrain, etc.) and MESSAGE (the information sought). A cliché among explorationists says that "One man's message is another man's noise".

**The question of depth penetration by geophysical method is not at all clearly answered. Some say the maximum reliable depth is 100 metres, others claim reliable depths to 300 m. for certain electrical (IP) or EM (AFMAG) surveys. See Peters, Exploration and Mining Geology, p. 368.

²⁴ Peters, Exploration and Mining Geology, p. 364.

airborne and ground geophysical surveys can be extremely versatile and useful. The qualitative difference between them can perhaps be summarised by recognizing that one would not engage in target area drilling on the basis of airborne geophysical survey data alone. Let us now turn our attention to the various geophysical survey methods.

Magnetic Methods:²⁵ The magnetic methods are by far the most versatile of geophysical exploration techniques. Magnetic surveys are well established ways of finding lithologic contrast, faults, folds and concentrations of magnetic ore.²⁶ Telford notes that "one can hardly imagine a geophysical programme in which magnetics would not be employed at least in reconnaissance".²⁷

The magnetic method relies on the detection of variations of the geomagnetic field which result from the differing intensity and orientation of magnetism in the underlying rocks.²⁸ Magnetic surveys can be carried out on the ground, at sea, or by airborne means. For larger areas, reconnaissance by air-or-sea-borne magnetometer is relatively simple and inexpensive.* The airborne instruments are generally more sensitive than those used in ground surveys. The instruments are housed in a cylindrical container ("bird") connected by cable to the aircraft. Altitudes are

*By 1971 the Canadian government had completed aerial magnetic surveys of well over one-half of the country. Telford et al., Applied Geophysics, p. 140.

²⁵ Telford et al., Applied Geophysics, pp. 105-217.

²⁶ Peters, Exploration and Mining Geology, p. 371.

²⁷ Telford et al., Applied Geophysics, p. 106.

²⁸ Collett, "Future Trends in Geophysical Mineral Exploration," p. 379.

continually recorded (as in all airborne geophysical surveys) and surface location is often recorded by continual film strips showing time intervals. Flight lines can be spaced from one-eighth to several miles apart and will be, where possible, normal to the main geological trends of the areas. Because both the sensitivity of the magnetometer and the earth's magnetic field may change over time, it is customary to make repeat readings over several stations during a day's flight so as to make corrections in the data. These characteristics can be considered common to all airborne geophysical surveys.

Ground surveys with magnetic instruments are used in more detailed applications. The station spacing is usually 50-200 feet, but can be as close as 20 feet. The instruments are self-contained and very lightweight, and the surveys can be carried out with a minimum amount of extraneous equipment. The data derived by magnetic surveys are presented in a set of profiles or contour maps, which can then be interpreted by referring to geological models and by matching whatever geologic information which is available with the magnetic pattern.

Gravity Methods:²⁹ Gravity prospecting involves the measurement of variations in the gravitational field of the earth. This method is similar to magnetic methods in that both measure extremely small differences in a force field which is relatively large. However the degree of sensitivity of gravity instruments

²⁹ Telford et al, Applied Geophysics, pp. 7-104.

is much higher (one part in 10^8 as compared to one part in 10^4). Gravimeters can be adapted for air, sea, and ground surveys, although in the air and at sea, stabilisation of the instruments can present problems.

Gravity prospecting is used as a reconnaissance tool in oil exploration, where it is considerably cheaper than seismic methods. In mineral exploration a gravity survey is usually employed at the follow-up level and in detailed target area investigation. Gravity methods are, of late, becoming more popular for detailed follow-up of magnetic and electromagnetic anomalies during integrated base-metal surveys.³⁰

Radioactivity Methods:³¹ The measurement of ionizing radiation from the spontaneous decay of radioactive minerals forms the basis of radioactivity geophysical methods. The instruments used include Geiger counters, scintillation meters, and gamma ray spectrometers and, again, are applicable to both ground and airborne work (the bulk of radioactivity surveys are airborne surveys). Airborne radioactivity surveys are carried out in search of uranium and thorium and can be adapted to indirect exploration for titanium and zirconium bearing minerals. Telford also notes that carbonatites have become an interesting target for gamma ray spectrometry work, and that the distinctive signatures of kimberlites make this type of survey applicable to the search for diamonds.³²

³⁰ Peters, Exploration and Mining Geology, p. 385.

³¹ Telford et al, Applied Geophysics, pp. 736-770.

³² Telford et al, Applied Geophysics, p. 758.

The major problem associated with radioactive survey methods is the lack of depth penetration.

Electromagnetic (EM) Methods:³³ With the exception of magnetics, electromagnetic survey techniques are the most commonly used in mineral exploration. EM methods depend upon the imposition of an electromagnetic field at the surface causing an electrical current to be generated in any subsurface geological conductor. The magnetic or electrical characteristics associated with the induced field are then measured.³⁴ A number of airborne EM systems exist (AFMAG, VLF, Tridem, INPUT) offering varying advantages depending on the objectives of the exploration programme. One of these airborne systems - INPUT - is a central feature of the Kenyan case study presented in Chapter Five. The INPUT method offers the advantage of additional depth (up to 400 feet). Easily portable ground EM equipment is also available.

Airborne EM surveys have had considerable success in locating anomalies from orebodies, but they are generally more expensive than magnetic or radiometric surveys. They tend to be used more in the direct search for deposits rather than in geological mapping (follow-up rather than reconnaissance).³⁵ A further advantage of airborne EM is that it is easily combined with aeromagnetics and radiometrics.

³³ Telford et al, Applied Geophysics, pp. 500-631.

³⁴ Collett, "Future Trends in Geophysical Mineral Exploration," p. 379.

³⁵ Peters, Exploration and Mining Geology, p. 383.

Electrical Methods:³⁶ Telford writes that...

Electrical prospecting involves the detection of surface effects produced by electrical current flow in the ground. There is a great variety of techniques available...Using electrical methods, one may measure potentials, currents and electromagnetic fields which occur naturally - or are introduced artificially - in the earth.³⁷

Electrical methods, carried out at the surface, can provide significant information at the follow-up level, but their largest contribution is at the detailed local exploration stage. One electrical method, induced polarization (IP) is the most popular ground geophysical method used in mineral exploration. It has been noted that this popularity certainly is not due to the speed or inexpensiveness of IP surveys.³⁸ The apparatus is considerably more bulky and expensive than that used in ground EM or magnetics. The popularity of IP is based on results, especially with base metal discoveries and in areas of disseminated mineralization (such as with porphyry copper deposits).

Seismic Methods:³⁹ Seismic exploration methods measure the different elastic properties of rocks by means of shocks generated by explosives, or percussion and are by far the most important geophysical techniques in terms of world wide expenditures.

³⁶ Telford et al, Applied Geophysics, pp. 442-499.

³⁷ Telford et al, Applied Geophysics, p. 442.

³⁸ Telford et al, Applied Geophysics, p. 724.

³⁹ Telford et al, Applied Geophysics, p. 218.

These huge expenditures (\$802 million in 1972)⁴⁰ are, however, virtually all for petroleum exploration. Seismic exploration activity can have an important application to mineral development in the areas of detailed survey and in studies of geotechnique and mine design.

This completes our description of geophysical survey techniques in mineral exploration. There are a great number of methods, and many levels at which geophysics can be included in mineral exploration programmes. In the last two decades much attention has been paid to integrating geophysical methods. Telford has described such an integration attempt as applied to base metal exploration.

If the area is large enough and the money available, the programme would normally start with a combined airborne magnetic and EM survey. On a more modest scale the work might proceed from a study of the acquired airborne data or from a reconnaissance geochemical survey. In either case the follow-up would include magnetics, one or more EM techniques and possibly gravity. IP may replace EM or follow it, particularly where the mineralization appears to be diffuse or low-grade. There are, of course, other possibilities, e.g. tellurics, and magnetotellurics (electrical methods). In any event, the base metal programme...appears either pleasantly flexible or somewhat fuzzy, depending on the attitude and experience of the exploration manager.⁴¹

In light of all the order and optimism which may seem to accompany this discussion of geophysical exploration, two brief caveats are worth noting: there is a complicating time element

⁴⁰ Telford et al, Applied Geophysics, p. 4.

⁴¹ Telford et al, Applied Geophysics, p. 820.

which, via suppliers, contractors, logistics and the weather, can make an ordered and controlled exploration sequence practically impossible. Secondly, geological information must exert the paramount influence on any geophysical programme. Without accompanying high quality geological information, the geophysicists will be, as Telford says, working in the dark.⁴²

Geochemical Survey Methods

Geochemical and geobotanical surveys are based on the premise that the material of the earth which surrounds a mineral deposit - the rocks, soil, stream and lake waters and sediments, vegetation, and even vapours in the air - may be expected to differ in chemical composition from similar materials where there is no mineral deposit present.⁴³ Geochemical surveys involve the gathering of samples and their laboratory analysis. Geobotany is more a "visual geochemistry", in which the patterns of plant growth, the presence of indicator plants, and morphological or mutational changes in vegetation are taken as evidences of geochemical anomalies.⁴⁴

⁴² Telford et al, Applied Geophysics, p. 820.

⁴³ G.J.S. Govett, "The Development of Geochemical Exploration Methods and Techniques," in Govett and Govett, World Mineral Supplies, p. 346.

⁴⁴ Peters, Exploration and Mining Geology, p. 398. See also P.R. Brooks, Geobotany and Biogeochemistry in Mineral Exploration (New York: Harper and Row, 1972).

Geochemistry is a relatively new applied science which gained popularity in mineral exploration in the Soviet Union in the 1930's and in Scandinavia in the 1940's. Geochemical surveys are becoming more common today primarily because they can be carried out relatively quickly, and because, as Govett notes, those "techniques (which are) dependent on obvious surface expression of a mineral deposit are becoming progressively less important as techniques which are capable of detecting hidden and buried deposits are taking their place."⁴⁵

Similar to geophysical methods, one of the advantages of geochemistry is that anomalies and unusual features can be detected far beyond the limits of economic ore. Thus "a large target is provided for further exploration, and the possibility of detecting ore deposits which are hidden by overburden is greater."⁴⁶ Further, geochemistry signals are directly related to the ore itself. Once the signals are detected, the goal is to determine the size and concentration of the source deposit.

⁴⁵ Govett, "The Development of Geochemical Exploration Methods and Techniques," pp. 343-344. D.R. Derry reports that though 85% of Canadian mines in production in 1955 were found by surface prospecting, in the period 1956-68 only 22% of the new discoveries were made by conventional prospecting. "Exploration Expenditures, Discovery Rate and Methods," Canadian Institute of Mining and Metallurgy Bulletin, Vol. 63, No. 694, p. 366, 1970.

⁴⁶ Govett, "The Development of Geochemical Exploration Methods and Techniques," pp. 346-347.

3.2

The Basic Principles of Geochemical Exploration

Schematic Representation
of Element Dispersion
Around an Orebody

The basic principles of geochemical exploration are simply stated above. Changes in the chemistry of the host rock, due either to processes associated with the mineralizing event in the past, or with the secondary processes which post-date mineralisation, will give rise to PRIMARY HALOS in the rock adjacent to an ore deposit which can be recognized by abnormal concentrations of elements (wall-rock anomalies); in some cases the host rock itself may show an abnormal background content of elements on a regional scale. SECONDARY HALOS of abnormal element concentration will occur in the soil and the vegetation overlying a mineralized occurrence and, through dispersion in solution in groundwater and sediments of the drainage system. Abnormal concentrations of some elements may also be found in the atmosphere above a mineralized occurrence.

Source: Govett, "The Development of Geochemical Exploration Methods and Techniques," pp. 346-347.

Geochemical surveys follow our familiar pattern from reconnaissance through to localized, highly detailed work. W.C. Peters has outlined an exploration sequence which is often followed when using geochemical methods.⁴⁷

1. Selection of methods, elements to be sought, sensitivity and precision to be required, and sampling pattern. Selections are to be made on the basis of cost, known or suspected geologic conditions, laboratory work on similar material and, most important, an ORIENTATION SURVEY or equivalent experience in similar terrain and with orebodies similar to those being sought.
2. Preliminary, or first coverage, field sampling program, with occasional check samples and depth (profile) samples to establish a level of reliability and to analyse noise factors.
3. Sample analysis, in the field (where possible) and in the laboratory, with check analysis made by several methods.
4. Statistical treatment and geologic evaluation of the data, always in connection with available geological and geophysical data.
5. Confirmation of apparent anomalies; follow-up sampling; and analysis and evaluation in smaller areas, using closer sampling intervals and additional geochemical methods.
6. Target investigation, with a provision for resampling and for additional analysis of stored samples.

Peters notes that the provision for resampling and for additional analysis is important: "geochemistry, like geophysics, relates anomalies to a conceptual model of an orebody, and the first few drill holes may change the entire model."⁴⁸

⁴⁷ Peters, Exploration and Mining Geology, p. 400.

⁴⁸ Peters, Exploration and Mining Geology, p. 400.

Modern exploration programmes combine several diverse techniques, so it is not easy to point to economic mineral discoveries which are singularly attributable to geochemical surveys. However it has been noted that reconnaissance geochemistry has been "particularly helpful in indicating the larger, more attractive targets in areas having small isolated ore mineral occurrences."⁴⁹

Examples here include the Panguna porphyry copper discovery in Papua, New Guinea⁵⁰ and the La Cándida porphyry deposit in Sonora, Mexico.⁵¹ Geochemical methods have reached such a point of value and effectiveness that they are now an accepted part of nearly all exploration programmes. Their popularity is indicated by the fact that over eight million geochemical samples are collected annually in the Western nations, and over ten million are collected annually in the Soviet Union.⁵²

⁴⁹ Peters, Exploration and Mining Geology, p. 399.

⁵⁰ F.F. Espie, "The Bougainville Copper Project," Australian Institute of Mining and Metallurgy Proceedings, No. 238, 1971, pp. 1-10.

⁵¹ D.F. Goolbaugh, "La Cándida: Mexico's Newest and Largest Porphyry Copper Discovery; An Exploration Case History," American Institute of Mining, Metallurgical and Petroleum Engineers' Transcripts, Vol. 250, No. 2, 1971, pp. 133-138.

⁵² J.S. Webb, "Applied Geochemistry and the Community," Institute of Mining and Metallurgy (London) Bulletin, No. 800, July 1973, pp. 23-24.

Direct Underground Exploration

Drilling and trenching operations are the last stages of exploration activities, undertaken to verify the presence of a deposit and to determine the extent and grade of ore. At times drilling and trenching have been included with success at the reconnaissance level to determine the geological orientation. Lightweight drilling equipment is making this a more feasible option, but generally drilling and trenching are highly localized, highly detailed exploration activities. Drilling and trenching are expensive, especially in relation to the other exploration activities, and these expenses rise quickly when drilling and trenching operations are undertaken in areas having an undeveloped infrastructure and/or heavy overburden.

Trenching involves the digging of pits, or trenches, to a depth of several metres through the overburden and across a suspected deposit area to obtain geologic information. Trenching operations are carried out using bulldozers and backhoes, explosives and manual labour. The best sites for trenching can be determined by recording small hammer-activated shocks using seismic equipment to indicate shallow bedrock.⁵³

Target area drilling is a more sophisticated operation in which a pattern, based on an assumption of the shape of the ore deposit, must be followed.⁵⁴ The key elements of such a pattern

⁵³ Peters, Exploration and Mining Geology, pp. 290-291.

⁵⁴ Peters, Exploration and Mining Geology, Chap. 15, "Drilling for Geologic Information."

are the spacing of the drill holes and the angles at which these are bored. The drilling pattern will likely be simple at first - a common practice is to drill at a spacing that will allow two neighbouring holes to penetrate the minimum size ore zone.

Generally the "fence" (the line of drill holes) will be at a high angle, close to vertical, as vertical holes might miss a steeply dipping orebody or follow a steep vein without indicating its thickness. The results of this preliminary drilling activity will permit the outlining of a more systematic drilling grid pattern. The extent and range of drilling activity will be determined by the results accruing and by financial resources.

The characteristics of the various drilling methods have been compiled by W.C. Peters.⁵⁵

Exploration Drilling Methods and Normal Characteristics

	Diamond Core	Rotary	Continuous Coring	Downhole Rotary	Downhole Hammer	Perforation	Churn
Geologic information	good	poor	fair	poor			
Sample volume	small	large	small	large	small	large	
Minimum hole diameter	30 mm	50 mm	120 mm	50 mm	100 mm	40 mm	130 mm
Depth limit	3000 m	3000 m	1000 m	3000 m	300 m	100 m	1500 m
Speed	low	high				low	
Wall contamination	variable		low	variable			
Penetration—broken or irregular ground	Poor	fair			good		
Site, surface and underground	S + U	S	S	S + U	S + U	S + U	S
Collar inclination, range from vertical and down	180°	30°	0°	30°	180°	180°	0°
Deflection capability	moderate		none	high	none		
Deviation from course	high		little		high	little	
Drilling medium, air or liquid	L	A + L	L	A + L	A	A + L	L
Cost per unit depth	high	low	moderate	low			high
Mobilization cost	low	variable				low	variable
Site preparation cost	low	variable				low	high

The most popular of these methods are diamond core drilling, rotary drilling and percussion drilling. In diamond drilling a sample is cut by a diamond-armoured bit, recovered in the inner tube of the core barrel, and brought to the surface on a string or a rod. The core sample can be recovered without removing the drill tubes from the hole. A circulating medium (usually water and mud, but which may be diesel fuel in permafrost conditions) is used to lubricate the bit and core. Although a larger diameter core is preferable to analysing purposes, the costs here will be higher; further, the attainable drilling depth is greater with a small core diameter.

Rotary drilling is usually a faster process than diamond core drilling; thus, expensive labour costs can be saved. But rotary drilling provides rock chips or cuttings rather than a neat core sample.* Rotary drilling rigs are heavier than diamond drill rigs, and they are usually mounted on trucks. These rigs tend to be less flexible as to possible sites and available drilling angles.

Percussion drilling is a popular method for outlining shallow orebodies and for probing out from mine workings. It provides quick and inexpensive samples of finely broken rock chips. The maximum depth for conventional percussion drilling is about 100 metres. The advantages of percussion drilling are that the equipment is relatively lightweight, and drilling can be undertaken at almost any angle.

*Core sampling can be done by rotary drilling methods, but only with special equipment and for short runs in soft rock. This can become very expensive as well.

2

A

Drilling provides information which is used in a number of ways. The primary use is, of course, the analysis of samples from various depths to permit the outlining of the orebody. As well, geophysical equipment can be combined with drilling techniques to detect ore mineralization between drill holes and between points at depth and on the surface. Finally, drilling activity provides some of the valuable geotechnical (rock mechanics, strength and stress, etc.) information which is necessary in mine design.

This description of drilling techniques completes our review of exploration activities. We shall now turn to the subject of exploration programmes, in which the various techniques are integrated and co-ordinated into a systematic search for minerals.

The Exploration Sequence

Because the objective of exploration is the discovery of economically viable mineral deposits, exploration operates in a decision-making framework which is itself economic. The number of stages of exploration activity to be carried out, the level of investment at each stage, and the degree of selectivity assigned to the exploration programme are all relative to costs, expected values and geological uncertainties.⁵⁶ Mineral exploration organisations have come to look at exploration as a

⁵⁶ Mackenzie, The Theory of the Mining Firm, p. 51.

sequential process in which the mineral objectives are defined, the areas for exploration activity are chosen, and the various exploration techniques are applied in increasing detail. O.C. Herfindahl has called this sequential process "incrementalism"; a series of adjustments are made by the exploration organisation based at each point of time on what can be known with reasonable assurance.⁵⁷ Decisions are made, and exploration activity continues if these decisions are positive. This practice of "incrementalising" can help the exploration organisation to avoid the large losses that could be incurred if exploration activity is allowed to proceed unheeded.

We have noted in our earlier descriptions that many of the exploration techniques can be undertaken at various levels of detail. We have also noted that the techniques can provide complimentary information. As the exploration effort proceeds, of course, many decisions are made which can result in revisions and rejections of the programme. Finally, the decision to "cut one's losses" can be made at any point in the process. These characteristics are combined in the outline of a generalized exploration programme which appears on the following page.

⁵⁷ Herfindahl, Natural Resource Information and Economic Development, p. 2.

3.4 The Exploration Sequence⁵⁸

This is an "idealized" illustration. All exploration programmes will not (nor necessarily should they) follow a neat sequential path which includes all these stages. Naturally, mistakes will be made and there will often be disappointment. Confusion, too, has been known to set in. Yet such a sequence of activities offers the best approach to finding economic mineral deposits.

⁵⁸ See also Mackenzie, The Theory of the Mining Firm, p. 53.
 Peters, Exploration and Mining Geology, p. 526.
 Fortescue, "Exploration Architecture", in Neale, op.cit., p. 5.

The keynote to an exploration programme is successive change as demands change, as resources change, and as capabilities change.⁵⁹ Mineral exploration programmes should emphasize flexibility. Herfindahl has noted that each exploration objective, and all the different areas of investigation...

...should constantly be reassessed in the light of information that has been added to that already available, in the light of new techniques and changes in prices, or any other factors affecting the value of deposits that may be found.⁶⁰

In this chapter we have devoted considerable attention to the description of mineral exploration activities and techniques. The purpose has been to provide the foundation for a better understanding of the role of mineral exploration in the relationship between the less developed country and an international mining company.

Mineral exploration, as we now see, is a multi-dimensional undertaking. There are many different levels and types of exploration activity. Both the host government and the international mining firm will act differently at different stages in the exploration process. Each will value and seek to pursue mineral exploration activities according to its own definition of the risks involved and according to its own objectives. By breaking down the mineral exploration process into its various stages and types of activity, we can begin to recognize the different points

⁵⁹ Herfindahl, Natural Resource Information and Economic Development, p. 3.

⁶⁰ Herfindahl, Natural Resource Information and Economic Development, p. 138.

of interest and value for each party.

As we shall see in our case study, the choice of exploration technique and the level to which government induced exploration will have a crucial impact on the success or failure of the exploration programme. In some situations regional reconnaissance may be enough incentive for a mineral investment on terms agreeable to all parties. In others, exploration activity all the way through to drilling might be necessary.

Our descriptions in this chapter give us the basic material necessary for understanding the technical choices available to those less developed country governments which are interested in undertaking mineral exploration. Large questions remain however. How much will mineral exploration cost, and how can these exploration services best be provided in less developed countries? We shall turn our questions now to the various exploration options available to Less Developed Countries.

CHAPTER FOUR - EXPLORATION OPTIONS FOR LESS DEVELOPED COUNTRIES

To this point we have addressed quite a diverse range of topics. We have discussed the characteristics of the international mineral industry and the impact of this industry on the Less Developed Countries. We then turned to the subject of mineral exploration and noted that significant benefits can result from an increase in LDC mineral exploration activity: 1/ The country can become a much more attractive environment for mineral investment, 2/ the LDC government's bargaining position can be expected to be stronger due to the enhanced knowledge of its mineral resources, and 3/ any subsequent mineral investment will be undertaken in a less uncertain, less suspicious and, therefore, more stable atmosphere.

In the preceding chapter we approached the more technical side of mineral exploration. A great variety of methods, applicable at different levels of detail, work together in the exploration sequence from initial research to mineral deposit evaluation and development. This range of topics now brings us to another major question for Less Developed Countries - how is the exploration effort to be executed?

The next issues to be dealt with concern the exploration policy options available to Less Developed Countries. Assuming that the government of an LDC wishes to promote mineral exploration by means of some form other than a traditional concession with one of the in-

ternational mining companies, how could this best be undertaken? How much will it cost? Who is willing and who can best finance the exploration effort, the government, or bilateral or multilateral development assistance? Finally, who will be in the field gathering and co-ordinating the data? We shall attempt to deal with these questions in this chapter, discussing first the costs and then the organizations involved in LDC mineral exploration. Included here are illustrations of two development assistance agencies, the Canadian International Development Agency (C.I.D.A.) and the United Nations Development Programme (U.N.D.P.). Both these organizations have long associations with LDC mineral exploration. We shall also examine the direct use by LDC governments of exploration contractors and consultants in fulfilling their information needs. This chapter on exploration policy options will prepare the way for our case study of a mineral exploration programme in Kenya, 1977.

Mineral Exploration Costs

Mineral exploration costs have been increasing significantly in recent years. In a broad sense however, it can be said that the cost of geological information has become cheaper in relation to other mineral development costs. To a large extent this is a result of a cumulative effect, making relevant geological information more easily identified and sought. Herfindahl has written that "it

is now possible to reject more effectively than formerly areas thought to be unsuitable, reserving the most expensive and efficient means of verification...for quite good prospects.¹ The savings which result from this cumulative effect are more easily realized in the industrialized world where the vast bulk of mineral exploration has taken place. Similar savings might accrue to LDC's in the future, after a considerable increase in exploration there. At present, for LDC's the costs of exploration are still very high; they can be intimidating.

Exploration equipment and the accompanying labour costs have not, themselves, become less expensive. In recent years the only major breakthroughs in exploration costs have been permitted by the use of airborne survey techniques. We have also witnessed some savings through a refining of existing survey methods and through improvements in transport to areas of difficult access (primarily through the use of helicopters).² W. C. Peters has compiled a list (reproduced below) of unit costs at each stage of the exploration sequence.

¹ Herfindahl, Natural Resource Information for Economic Development, page 35.

² Bosson and Varon, The Mining Industry and the Developing Countries, pages 37,38.

4.1 Mineral Exploration Costs, Western United States, 1977

1. *Manpower* (including company overhead)

Senior geologist	\$100-\$150/day
Geologist	\$ 80-\$100/day
Field assistant	\$ 40-\$ 60/day
2. *Office Studies*

Aerial photography (stereo-coverage)		
Government black-and-white		\$0.05-\$0.25/km ²
Contract black-and-white, per km ²		

Area (km ²)	1:20,000 scale	1:10,000 scale
10	\$30	\$35
100	20	30
500	12	20
1000	8	15
3000	5	10

For color, add 20 percent
For near infrared, add 20 percent

Photogeologic interpretation, add to cost of photography	
Generalized	\$ 1-\$ 5/km ²
Detail	\$ 5-\$ 20/km ²

Photogrammetric maps, add to cost of photography	
25 to 50% km ² , 1:10,000 scale	\$ 60-\$120/km ²
1: 5,000 scale	\$120-\$200/km ²

- 3. *Laboratory* (commercial laboratories, including sample preparation)

Geochemical (AA or colorimetric) analysis	
—4 to 5 elements	\$ 5-\$ 10/sample
X-ray diffraction mineralogy	\$ 10-\$ 50/sample
Semiquantitative spectrography	\$ 20-\$ 45/sample
Assays	\$ 5-\$ 12/element
Thin-section preparation	\$ 3-\$ 5/sample
Polished-section preparation	\$ 5-\$ 10/sample
Thin-section study	\$ 20-\$ 30/sample
K-Ar age determination	
—routine service	\$300-\$400/sample
—priority service (48 hours)	\$700-\$800/sample
Isotope ratio, rock samples	
—oxygen, carbon, or sulfur	\$ 40-\$100/sample

- 4. *Field Geology*

Transportation:	
2-wheel drive	\$175-\$250/month + gasoline + \$0.06-\$0.08/km
4-wheel drive	\$250-\$350/month + gasoline + \$0.08-\$0.10/km
Small fixed-wing aircraft and pilot	\$ 50-\$ 80/hour

4.1 Mineral Exploration Costs, Western United States, 1977 (cont'd)

Small helicopter and pilot (4 hour/day minimum)	\$125-\$300/hour \$500-\$1,500/hour
Cargo helicopter and pilot	
Field (camp) cost per person	\$ 14-\$ 25/day
Town (motel-based) cost per person	\$ 30-\$ 35/day
Unit geologic mapping costs	
Reconnaissance (1:10,000 or smaller)	
—Simple terrain	\$ 20-\$ 60/km ²
—Complex terrain	\$ 60-\$200/km ²
Detail (1:5000 or larger)	
—with few existing prospects	\$300-\$600/km ²
5. Geochemical Sampling (without geologic mapping or drilling)	
Field sample collection, general	\$ 2-\$ 20/km ²
Field sample collection, reconnaissance	
Stream sediment, accessible terrain	\$ 2-\$ 20/km ²
Stream sediment, difficult terrain	\$ 25-\$ 50/km ²
Field sample collection, detail	
Soil, accessible terrain	\$ 70-\$200/km ²
Soil, difficult terrain	\$300-\$700/km ²
6. Geophysics (including mobilization)	
Airborne, fixed-wing	
Multiband camera and infrared scanner	\$ 3-\$ 7/line km
Radiometric	\$ 10-\$ 40/line km \$15-\$30
Magnetic	\$ 6-\$ 13/line km \$10-\$15
Electromagnetic	\$ 11-\$ 25/line km \$15-\$25
Electromagnetic + magnetic + radiometric	\$ 16-\$ 25/line km \$18-\$35
Helicopter Geophysics: add 50-150 percent to fixed-wing cost	
Ground Geophysics	
Radiometric	\$ 10-\$ 20/line km
Magnetic	
—Detail	\$ 90-\$ 200/line km
—Road traverse	\$ 4-\$ 16/line km
—Reconnaissance	\$ 12-\$ 60/line km
Gravity	\$120-\$250/line km
Induced polarization	
—Reconnaissance	\$100-\$300/line km
—Detail	\$400-\$950/line km
Electromagnetic	
—Reconnaissance	\$ 50-\$120/line km
—Detail	\$250-\$500/line km
Shallow seismic	\$200-\$750/line km
Borehole geophysics	
Base charge	\$0.30-\$0.05/m
Logging charge, per parameter	\$0.30-\$1.00/m

4.1 Mineral Exploration Costs, Western United States, 1977
(cont'd)

7. *Drilling*

Noncoring	
to 300 m	\$ 10-\$ 30/m
to 1,000 m	\$ 30-\$ 50/m
Coring	
to 300 m	\$ 40-\$ 50/m
to 1,000 m	\$ 50-\$ 80/m

Mobilization, sampling, site preparation,
miscellaneous cost (access roads and helicopter
service not included)

at 100 m	add 60 percent
at 1,000 m	add 30 percent

8. *Access Roads and Trenches*

Road building	
Flat to gentle terrain	\$ 300-\$2000/km
Moderate terrain	\$2,000-\$4,500/km
Rugged terrain	\$4,500-\$6,000/km

9. *Test Pitting*

Trenching with bulldozer or backhoe	\$ 10-\$ 30/linear meter
Test pits to 3 m	\$ 10-\$ 30/meter depth

Source: Peters, Exploration and Mining Geology, pages 538-540.

Please note: although 1977 prices are presented here, an interview with Mr. D. Wagg, of Geoterrex Surveys in October, 1979, revealed that, for the most part these prices still apply. Several revisions suggested by Mr. Wagg are included.

We can expect, in most cases, that the costs presented above will be considerably higher in Less Developed Countries³ In such countries there is often only a low level of existing survey control (maps and geological data) thus making scale, accuracy, and degree of detail more difficult and more expensive than in the industrialized countries. It is also likely that in LDC's there will be a greater degree of isolation from urban centres, skilled or semi-skilled labour, international communications, maintenance facilities

³ Peters, Exploration and Mining Geology, page 537.

also Bosson and Varon, The Mining Industry and the Developing Countries, page 149.

and laboratories. Finally, as many of the components of the exploration programme may have to be imported into LDC's, the costs increase again. Mr. Rattew, President of the Canadian exploration contracting firm, Geoterrex, has commented that exploration costs in the LDC's can be generally estimated at fifty to a hundred per cent higher than those in North America.⁴

The "time factor" has also become an important consideration in the calculation of mineral exploration and development costs.⁵ Whereas forty or fifty years ago high grade, outcropping deposits could be brought into production in three or four years, the important new mineral finds now often have no surface expression and are of lower grade ore. Carman writes that while modern geophysical and geochemical techniques are "accelerators", no technique developed in recent years is capable of speeding up the exploration work required for quantitative and qualitative deposit evaluation. Laborious and costly investigations using diamond drills and underground workings are still required.⁵ Of course, time is money, and this "time factor" will seriously increase the financial burden of mineral exploration and development. (see chart, next page)

⁴ Personal interview, May, 1979

⁵ Carman, Obstacles to Mineral Development, page 44.

4.2 Time Lag in the Development of Major United Nations Discoveries

Country	Deposit	Commence- ment of Exploration	Commence- ment of Production*
Somalia	Wabo - uranium	1968	Unknown
	Mirig - uranium	1968	Unknown
	Dusa Mareb - uranium	1968	Unknown
Sudan	Hofrat en Nahas - copper	1968	Unknown
Mexico	La Caridad - copper	1966	1979
Malaysia	Mamut - copper	1965	1975
Chile	Los Pelambres - copper	1969	Unknown
Panama	Petaquilla - copper	1966	Unknown
	Botija - copper	1966	Unknown
Ecuador	Chaucha - copper	1969	Unknown
Guinea	Mt. Nimba - iron	1970	Unknown
Upper Volta	Tambao - manganese	1966	1981
Indonesia	Bangka - tin	1969	1975
Solomon Islands	Rennell Island - bauxite	1967	Unknown
Burundi	Gitega Area - nickel	1971	Unknown
Morocco	Barrechid Basin - salt	1971	1978
	Khemisset Basin - potash	1967	Unknown
Burma	Heinze Basin - tin	1971	1980
Togo	Marble quarries	1962	1969
	Limestone, cement plant	1962	1972

* Estimates for developments which are planned to reach the production stage after 1977 are based on data available in 1977

Source, Carman, Obstacles to Mineral Development, page 46.

Carrying Out The Project

The exploration effort carried out by Geoterrex in Kenya in 1977 comprised three elements. The primary element was, of course, the INPUT survey in Nyanza Province. Also included were an investigation of the freshwater/salt water interface along the Indian Ocean coastline north and south of Mombassa and a continuation of the regional reconnaissance magnetometer survey mentioned earlier.

In the Spring of 1977 Geoterrex had an aircraft, equipment, and a crew available in Saudi Arabia which were sent on to Kenya. The crew for this survey consisted of two pilots, a mechanic, two electricians, a geophysicist and two geophysical technicians. CIDA had also sent along their geophysical advisor to Kenya, Mr. Johnston, to monitor Geoterrex's work and to stay on afterwards to assist in the ground follow-up. The Geoterrex contract in Kenya was completed after six months; this was slightly over schedule due primarily to frequent thunderstorms in the final two months of surveying. There were few logistical problems, the major one being the necessary replacement of one of the aircraft engines.

While the actual data from Geoterrex's exploration in Kenya remains confidential, as required by the contract, it is apparent that the project was successful. In the primary element, the INPUT survey, some 20,000 line kilometers were flown in the search for the massive sulphide formations which would indicate the presence of base metals. For some of this survey, magnetometer readings were also being logged. This airborne survey was followed up almost immediately by ground geophysical and

in North America, involved both individual and governmental exploration efforts on a large scale, for over a hundred years.*

A United Nations report on mineral resources development points out, however, that conditions in LDC's are quite different, and the likelihood of such a pattern being repeated there is slim.

In most developing countries the individual prospector has not had the same impact on mineral resources development as in the industrialized countries. The natural conditions are often less favourable, particularly in the tropics where visible outcrops may be scarce and (where) surface examination (is) rendered difficult either by dense vegetation or sandy desert conditions.⁷

Optimistically, this same report says there is some potential for an exploration impact from individual "grass-roots" prospectors in LDC's. These would be in the form of "herdsmen and nomadic tribes, who cover a great deal of ground in short periods of time".⁸ Of course, any impact from these sources will require a certain amount of training in geological observation and rudimentary exploration techniques.

The lack of trained personnel remains one of the largest obstacles to indigenous mineral exploration efforts in many LDC's.

* By 1867 the exploration work of the Geological Survey of Canada was well underway. By 1970, over one-half of the vast Canadian land surface had been surveyed by airborne magnetometer at the behest of the Geological Survey of Canada.

- Peters, Exploration and Mining Geology, page 6.

⁷ United Nations, Mineral Resources Development With Particular Respect to the Developing Countries, (New York: United Nations, 1970), page 2.

⁸ United Nations, Mineral Resources Development With Particular Respect to the Developing Countries, page 2.

Ochala writes that in Africa the situation is particularly acute.

Chad does not have a single professional in the earth sciences; the same is true of Libya, where lack of skilled manpower exists at every level. Ghana lacks the technical staff in the Ministry of Lands and Mineral Resources which results in the country spending considerable amounts of foreign exchange on importing expatriates.⁹

Ironically, it has been suggested that some LDC's are, in fact, well-equipped or even over-supplied with earth science personnel. Mentioned in this regard are Brazil, India, and Nigeria.¹⁰ An effort towards a greater interchange of LDC earth science personnel, who would be more accustomed to cultural and geological differences than would be industrialized country personnel, might facilitate LDC mineral exploration.

The education and training of an adequate pool of indigenous mineral exploration personnel has to be regarded as a valuable objective for many LDC's, albeit a long-term one. Regional training centres such as the Centre for Applied Geology in Jeddah, Saudi Arabia, are one step in this direction. Another interesting attempt is the Zambian JETS programme (Junior Engineers, Technicians, and Scientists) which introduces the earth sciences on a practical level at the secondary school age.¹¹ It has also been strongly suggested that those earth science students studying abroad should return home for their graduate or practical work.¹² The training and education

⁹ Ochala, Minerals in African Underdevelopment, page 139.

¹⁰ Berger, Geoscientists and the Third World, pages 9-10.

¹¹ Cooray, P., "Training of Earth Science Personnel in LDC's", in Berger, Geoscientists and the Third World, page 24.

¹² Cooray, "Training of Earth Science Personnel in LDC's", page 25.

of LDC personnel is an essential prerequisite for improved LDC mineral exploration. However this objective cannot be accomplished quickly, and does little to fulfill the demands of LDC governments which are interested in mineral exploration in the near future.

We can assume that an exploration programme financed, designed, carried out and interpreted indigenously by fully qualified personnel would be the most effective and most efficient route for an LDC. Unfortunately at present this seems to be the least available option for many Less Developed Countries. In the shorter term, for the more immediate exploration demands of LDC's, the inclusion of foreign components - people and equipment, institutions, and financial resources - can play an important role.

Mineral Exploration as a Form of Development Assistance

i Bilateral

Many industrialized countries, notably Austria, Britain, France, the United States, and the Soviet Union have provided mineral exploration projects as a form of development assistance. Perhaps the largest bilateral effort in this sector, however, has come from Canada.

Since the early 1950's Canadian resource surveyors have been active in the Less Developed Countries performing, for the most part, airborne surveys but also carrying out more sophisticated and detailed earth science investigations. Between 1953 and 1974

some sixty million dollars was spent on Canadian earth science development assistance.^{13*} While there have been criticisms of the Canadian effort, it has often been well-received. A Pakistani Geological Survey official once told his Canadian counterpart that a Canadian-sponsored geological mapping project carried out in his country was "the single most valuable aid project that his country had ever received".¹⁴

Canadian development assistance in mineral exploration is executed by Canadian contracting firms under the guidance of the Canadian International Development Agency. When CIDA receives a request from an LDC for a mineral exploration project the request is studied by the planning officers responsible for that region and by the technical staff in the engineering and resources division of CIDA. If the request is approved by these officials, proposals for the contract are sought from among the ninety-five earth science contracting and consulting firms registered with CIDA. These firms' proposals are then assessed by CIDA (and by the recipient

* Earth science assistance refers here to that given in the fields of geological mapping and related techniques, mineral exploration, and mining development, engineering, geology, hydrology, surveys and mapping.

¹³ Malhorta, S., Canadian Mineral Aid and Private Investment in the Developing Countries, (Ottawa, Department of Energy, Mines and Resources, 1974)

see also, Tremblay, M., "Canadian Earth Science Aid" in Earth Science Aid to Developing Countries, (Montreal: Report of the 24th International Geological Congress, 1972),

¹⁴ interview with Mr. B. Manistre, Geoscience Aid Co-ordinator, Geological Survey of Canada, March, 1979.

country in some cases) in terms of each firm's ability to carry out the project and in terms of the cost estimates. At this stage it is not uncommon for the advice of experts in the Department of Energy, Mines, and Resources to be included in assessing the proposals' technical merits.* If final approval is given, the project will be carried out according to a timetable agreed upon by the recipient, the contracting firm, and CIDA.

Very often included in CIDA's earth science development assistance projects are training clauses for recipient country personnel. Success here has been mixed, depending on the content of the exploration project. Little training can be imparted, for instance, in a small and noisy aircraft which is cramped full of sophisticated equipment. Likewise, on the ground, the resulting volumes of geological data may make very little sense to anyone not already trained in the earth sciences.

Canadian resource survey firms have operated in over one hundred countries.¹⁵ Canadian-funded mineral exploration projects have been completed in the South Pacific, Asia, the Middle East, Africa, South and Central America, and in the Caribbean. Examples of these efforts include an aerial photography project in Malaysia, 1956 -

* The Overseas Development Section (of E.M.&R.) maintains information files dealing with natural resources and mineral industries in each of the developing countries. The main object of this exercise is to make comprehensive information available to researchers, planners, and policy makers.

- Malhorta, Canadian Mineral Aid and Private Investment in the Developing Countries, page 28.

¹⁵interview with D. McLarty, President, Canadian Association of Aerial Surveyors, March, 1979.

1958 and 1965 - 1968, at a cost of \$1.5 million¹⁶, a "natural resources survey" of Sri Lanka, 1955 - 1960, costing \$2.49 million¹⁷, an "aerial survey and topographic mapping" project in Guyana, 1966 - 1970, which cost \$1.8 million¹⁸, and a series of topographic mapping and airborne geophysical surveys (Tanz 1 - 4) in Tanzania over the period 1965 - 1974 which has cost \$7.5 million.¹⁹

The Canadian government and CIDA have appeared very enthusiastic about natural resource information and mineral exploration projects as forms of development assistance. In 1966 the Department of External Affairs called resource surveys a "Canadian specialty", noting that "country after country has turned to Canada" because of "Canadians' international reputation as development experts using methods perfected in Canada's north to chart the rocks, rivers, soils and forests of Asia and Africa."²⁰ The Canadian recognition of and commitment to this sector of development assistance was reinforced in the CIDA Sectoral Guidelines of 1976.

Canada is a leading designer and manufacturer of airborne and ground geophysical prospecting and drilling equipment which is sold and used around the world...
Canada excels in airborne and ground geophysical sur-
(cont'd)

¹⁶ Report on the Use Being Made of Aerial Surveys Done Under the Canadian External Aid Programs, 1950 - 1967, (Ottawa: External Aid Office, 1967) page 17

¹⁷ External Aid Office Report...1950 - 1967, page 26.

¹⁸ External Aid Office Report...1950 - 1967, page 47.

¹⁹ Thompson, D., Skyview Canada, (Ottawa: Information Canada, 1975), page 192.

²⁰ "Resource Surveys - A Canadian Specialty", External Affairs, vol. XVIII, # 8, page 338.

veys, in the follow up ground work leading to drilling, and it drilling itself...In the field of metallogeny (the relationship of ores with their environment and the means and approaches required to recover these ores) the record of Canada is enviable.²¹

Though these statements seem enthusiastic and the record may be "enviable", Canada's commitment to LDC mineral exploration has been on the wane in the 1970's.

In 1971 earth science programmes totalled roughly four per cent of CIDA's entire expenditures.²² The Science Council of Canada recommended in that year that the earth science portion be increased to five per cent.²³ However in 1978 CIDA funded resource surveying and exploration programmes at a value of \$4.8 million, or only 0.5% of CIDA's total expenditures.²⁴ While CIDA's total budget did undergo a massive increase during this period, the decline in CIDA's earth science and exploration activity is nonetheless dramatic. The reasons for this decline cannot be pin-pointed exactly, but several contributing factors can be suggested. In light of the need and value of mineral exploration development assistance projects in many LDC's and of the Canadian expertise and experience in this sector, a very brief summary of these factors is worthwhile.

²¹ C.I.D.A., Sectoral Guidelines, (Ottawa: 1976), vol. III, page D - 9.

²² Tremblay, "Canadian Earth Science Aid", page 7.

²³ Blais, R., et al, Earth Sciences Serving the Nation, Science Council of Canada Special Study # 13, (Ottawa: Information Canada, 1971), page 292.

²⁴ interview with D. McLarty, C.A.A.S., March, 1979.

The CIDA Sectoral Guidelines of 1976 stress a commitment to "basic needs" and rural development in future Canadian development assistance programmes. It is likely that mineral exploration and mining projects are not seen by Canadian development assistance policy makers as being entirely consistent with these priorities. A second possible factor has to do with this type of project's "visibility". In his study of development assistance agencies George Cunningham notes that,

"Seeing the results" is the most compelling need of donors; it is as if they did not themselves believe in the value of their efforts and needed visible proof to sustain their will.²⁵

Unfortunately the immediate products of mineral exploration projects are not highly "visible".

Surveying and mapping are not generally regarded as the most glamorous of the disciplines associated with economic and social development, nor are they rated as being of particular importance... Even so, they are fundamental...²⁶

A final suggestion as to why mineral exploration has suffered a reduced priority in Canadian development assistance involves competition in international mineral markets. A recent Canadian Department of Energy, Mines, and Resources publication noted that,

Funds have been committed for resource development and exploration in developing countries by industrialized countries. Similar types of concessional financing
(cont'd)

²⁵ Cunningham, G., The Management of Aid Agencies, (London: Overseas Development Institute, 1974), page 8.

²⁶ Smith and Wells, Negotiating Third World Mineral Agreements, page 92.

are not presently available to the Canadian mineral sector.²⁷

This clearly points to a concern that Canadian minerals might become less marketable in the face of "subsidized" competition from LDC's. CIDA officials have also expressed this concern, saying that CIDA will not encourage projects "which will conflict with the Canadian economy".²⁸ While this may seem contrary to CIDA's international mandate, one cannot deny that the potential for economic conflict exists.

The Canadian record in providing mineral exploration to LDC's has been good. While some criticisms are necessary (and will be included below) and some adjustments in the CIDA approach should be made, our case study will show that CIDA is not inflexible and that this form of bilateral development assistance can prove very successful. It is hoped that the Canadian effort in this sector will not suffer from a further reduction of priority. Let us turn our attention to the long experience of the United Nations in providing mineral exploration services to LDC's

ii. Multilateral

Since its initial involvement with mineral exploration in 1959, until a lack of finances forced serious cutbacks in these efforts in 1976, the United Nations Development Programme (originally called

²⁷ Dept. of Energy, Mines, and Resources, Canadian Minerals and International Economic Interdependence, Mineral Policy Series # 162, (Ottawa: March, 1977) page 78.

²⁸ confidential interview.

the U. N. Special Fund) has completed, put into operation, or set aside funds for some 184 mineral exploration projects in Less Developed Countries. The total cost of these projects has been \$263 million, 53% of which has been contributed by the United Nations.²⁹

Unlike the bilateral agencies, which employ contracting firms, the vast majority of UNDP exploration efforts are executed by United Nations and recipient country personnel through ECOSOC's Office of Technical Co-operation and through the U. N. Centre for Natural Resources, Energy, and Transport. At the point of maximum activity these United Nations departments employed some three hundred geoscientists.³⁰ Below is a list of the major discoveries and the subsequent investments which result from the United Nations mineral exploration effort. (For a more complete record of U. N. exploration activities, please refer to Appendix C)

²⁹ Carman, Obstacles to Mineral Development, page 29.

³⁰ Carman, Obstacles to Mineral Development, page 31.

4.3 Reported Investment Incurred or Considered for
United Nations Discoveries*

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Country and Status of Project	Deposit	U.S. \$ Equivalent
<u>Completed</u>		
Malaysia	Mamut copper	82,000,000
Togo	Marble	6,000,000
Togo	Cement plant	43,000,000
Indonesia	Offshore tin	15,000,000
<u>Assured Developments</u>		
Mexico	La Caridad	500,000,000
Morocco	Berrechid Basin - salt	182,000,000
Burma	Heinze Basin - tin	27,800,000
<u>Probable Developments</u>		
Solomon Islands	Rennell Island - bauxite	300,000,000
Upper Volta	Tambova - manganese	170,000,000
<u>Preinvestment Studies</u>		
Ecuador	Chaucha - copper	4,700,000
Panama	Botija-Petaquilla - copper	4,000,000
Trinidad	Petroleum	1,300,000
Total		1,335,800,000

Source: Carman, Obstacles to Mineral Development, page 58.

*Please Note: "Discovery can be a very vague term. Here it can mean anything from the Malaysian copper or Solomon Islands bauxite, where exploration began "from scratch", to the Upper Volta manganese and Guinea iron ore deposits, which were known to exist in some form. At the risk of being too general, discovery, in the sense of the above, can be termed an action which moved a mineral deposit, known or unknown, appreciably closer to development.

Financial difficulties have forced considerable cutbacks on UNDP-funded mineral exploration programmes since 1976.³¹ In fact, Carman has written that,

The UNDP can no longer be viewed as a relatively affluent source of mineral exploration funds... It would be risky to expect that the UNDP will ever again achieve the prominence it has had in regard to mineral exploration in the developing world.³²

The United Nations has been attempting to overcome the financing problems, and has put its hopes for future exploration financing in the United Nations Revolving Fund for Natural Resources Exploration.

iii. Multilateral Financing for LDC Mineral Exploration

Created by a resolution of the United Nations General Assembly in December, 1973, the Revolving Fund holds as its principal objective the extension and intensification of...

...the activities of the U. N. system in the field of natural resource exploration in developing countries, utilizing for this purpose voluntary contributions and funds generated through the production of resources discovered or developed with the assistance of the Fund in such a manner as to ensure its revolving nature derived from the self-help principles for the mutual benefit of developing countries.³³

³¹ Carman, Obstacles to Mineral Development, page 31.

³² "Sadly, in 1976 it became evident that UNDP was in serious financial difficulties. Worldwide inflation had caught up. The programme was cut back everywhere. A considerable number of good men were lost, some of whom had been on as many as four projects - that is to say, with the organization for ten years or more". > Carman, Obstacles to Mineral Development, page 31.

³³ Carman, Obstacles to Mineral Development, page 144.
The following description of the Revolving Fund comes from Carman, pages 64 - 73.

The Fund is designed to revolve, or become self-sufficient, by means of a "replenishment contribution" of 2% of the gross value of production from each discovery for a period of fifteen years from the commencement of production. The Fund will pay all costs of exploration; no counterpart financing from recipient LDC's will be necessary. The financing of exploration via the Revolving Fund will, initially at least, be available only for hard minerals. This is due to the extremely high costs of hydrocarbon and geothermal exploration, and to the fact that groundwater discoveries could not provide a "replenishment contribution".

In 1976 the voluntary contributions to the Revolving Fund totalled \$11 million, principally from Japan, Canada, the Netherlands, Belgium, and Iraq. By 1978 this total had reached \$23.8 million, and the United States had become a major contributor.

The central criteria for the dispersal of the Fund is the geological situation. It is hoped that by following this "objective" principle the Fund can avoid wastage and "dubious" projects which might be pursued on the basis of "geographically equitable" or "least developed country" considerations. But we should note that the Fund's perception of geological considerations is meant to be significantly different from that of private industry.

Whereas a private concern will rarely make a first commitment in developing countries for early-stage exploration amounting to more than...a quarter of a million dollars, the Governing Council of the Fund
(cont'd)

has already authorized a project for which the first phase cost over \$1.2 million.³⁴

It is hoped that this willingness to take risks and to advance exploration activities beyond the most rudimentary level will provide mineral development opportunities for those LDC's without access to exploration investment capital - public or private.

The Revolving Fund is still a very new phenomenon - its success is yet to be determined. Dark clouds can be seen on its horizons however, in the form of a recent decision to impose a ceiling on total "replenishment contributions" from each discovery. This ceiling has been suggested to be fifteen times the Fund's original investment at constant prices. John Carman regretfully opines that "the Governing Council, by introducing the ceiling concept, effectively ensured that the Fund will never have a chance to revolve".³⁵

Other multilateral sources of mineral exploration financing are available, but not on terms as favourable as those of the Revolving Fund. The World Bank has funded mineral exploration; for example a \$13 million, twenty-year loan was recently supplied to Indonesia for geological mapping. The interest rate was 8.5% - not prohibitive.³⁶ Through its agencies, the International Develop-

³⁴ Carman, Obstacles to Mineral Development, page 67.

³⁵ Carman, Obstacles to Mineral Development, page 66.

³⁶ Carman, Obstacles to Mineral Development, page 70.

ment Association and the International Finance Corporation, the I.B.R.D. has more readily provided funds for projects such as town sites and transport facilities at Shashe, Botswana (\$32 million, 1971) and beneficiation plant, transport and port facilities at a potash project in the Congo (\$30 million, 1967).³⁷ In the period 1957 - 1978 the I.B.R.D. has provided some \$750 million in loans for mineral development related projects. Although some of these loans have been made directly to governments, the majority have been to incorporated bodies (private and public).³⁸ When considering multilateral financing sources for exploration alone, however, few are available.

International financial institutions, such as the World Bank, have taken the position that since capital for the extractive industries is available from private sources, the international institutions should employ their own limited funds for transportation, power, and other industries for which private capital is not normally available.³⁹

iv. Problems in Exploration Assistance

Our discussion of mineral exploration development assistance should not end without mention of some of the criticisms which have been made. Criticisms have been put forth in several areas, but the most important area might be termed "co-ordination problems".

³⁷ Carman, Obstacles to Mineral Development, page 33.

³⁸ Carman, Obstacles to Mineral Development, page 33.

³⁹ Mikesell, Foreign Investment in the Petroleum and Mineral Industries, page 26.

A co-ordination problem can arise from what Carman has called the "what's good for you" syndrome, wherein LDC exploration projects are modelled on the basis of those which worked well in the donor country's exploration experience. Unlike undertakings in the industrialized countries, mineral exploration in many LDC's is often hampered by desert, or heavy vegetation, or deep overburden, or extreme weather conditions.* In approaching LDC mineral exploration, geoscientists will have to remain flexible, not bound by their home country experiences. Further, as the exploration requirements of each LDC can vary extensively there can be little advantage in a donor organization's offering of a "stock exploration package".

A second and more serious co-ordination problem (for which both the Canadians and the UNDP have been guilty) involves a lack of follow-up after reconnaissance exploration. As noted in the previous chapter, an effective exploration effort follows sequenced stages, each building on the positive indications of the former. However due to complications or "dispersal of funds" problems donors can become more concerned with providing a maximum number of

* Interestingly, the techniques developed in Canadian Arctic mineral exploration have proven highly adaptable to tropical exploration. Specifically here we are referring to all-terrain vehicles, durable geophysical instruments, and extreme weather shelter.

survey line miles rather than a more co-ordinated exploration programme.* The completion of tens of thousands of line miles may, ultimately, prove very valuable but the question is when? M. Tremblay has noted that although the Canadian government in 1971 had, for over twenty years, been offering natural resource surveys to LDC's, 75% of this effort had gone toward large scale reconnaissance work without plans being entertained for any follow-up.⁴⁰

The UNDP has also been accused of placing too much emphasis on regional airborne geophysics. Carman reports that a much stronger attempt is now being made to provide an approach to exploration which includes activity at levels much further along the sequence, through detailed work to drilling.⁴¹ In solving these

* N. Paterson, Canadian consulting geophysicist with the firm Paterson, Grant and Watson, reports,

"I have seen wonderful proposals of great value, carrying the full support at the technical level of both donor and recipient countries, become distorted, delayed, and eventually either shelved or carried out in such a diluted fashion that they are of questionable value. In particular, I have observed the plea for on-the-job professional training become distorted into so many line miles of geophysical survey simply because of the bureaucratic machinery. Certainly it is easier to provide a geophysical survey than to round up a team of professionals to consult, plan, organize, supervise, teach, and recommend; but it is still easier to ship the equivalent value in copper pipe or nickel alloy; but which, in the end, provides the most benefit to the recipient country?"

- cited in Berger, Earth Science Aid to Developing Countries, page 22.

⁴⁰ Tremblay, "Canadian Earth Science Aid", page 7.

⁴¹ Carman, Obstacles to Mineral Development, page 32.

exploration co-ordination problems it is also hoped that donor organizations will make the necessary efforts to include training provisions for LDC personnel.

A final criticism is one common to nearly all bilateral development assistance projects - that of "tied aid". Donor countries are often criticized for being more concerned about subsidizing sagging industry at home than about meeting the recipients' needs in planning development assistance. In many sectors this is a valid and necessary criticism. However in terms of Canadian mineral exploration assistance the dilution of the value of this project to the recipient due to a high Canadian content is minimal. Canadians are world leaders in mineral exploration and resource surveys;⁴² if a country's development assistance is to be "tied", at least in this case it is tied to a sector of comparative advantage.

We have seen then, that by means of both bilateral and multi-lateral development assistance mineral exploration projects can be financed and carried out in LDC's. The ultimate value to the recipients of these projects will depend on a number of factors - not the least of which are geological - but assistance is available. There are valid criticisms of this form of assistance but, as we shall see in our case study, these can be overcome. Finally, for some LDC's development assistance may be the only available option

⁴² "Two-thirds of the internationally organized mapping projects in the 1970's have been carried out by Canadians".
D. McLarty, C.A.A.S., interview, March, 1979.

in acquiring mineral exploration. Let us now turn to another exploration option for LDC's which involves foreign components - the direct hiring of contractors and consultants.

Contractors and Consultants

Those Less Developed Countries with adequate financial resources should find little difficulty in obtaining contractual services for their mineral exploration needs. For the most part, the reputations of the independent consultants and private contracting firms are good, and these organizations are well-positioned to offer the "competent and disinterested advice" which Herfindahl says is so important in the acquisition of knowledge about mineral resources.⁴³

Exploration services may be acquired in the form of individuals but more frequently they are in the form of independent firms of professionals. While these firms are relatively small in terms of numbers of employees, they are usually large enough to possess the expensive but necessary exploration hardware (often including aircraft). Oftentimes these firms can offer not only mineral exploration capabilities, but also related services such as an endin-

⁴³ Herfindahl, Natural Resource Information for Economic Development page 22.

engineering surveys and socio-economic studies⁴⁴; but herein lies a potential problem.

John Roberts has closely studied the role of consultants in Less Developed Countries. He has written,

In developing countries, consultancy organizations virtually substitute themselves for the owner during planning and design stages of new projects... Their intervention therefore (can be) almost totally determining and crucial.⁴⁵

In hiring contractors and consultants the LDC government must avoid deferring its decision-making responsibility. In this regard, concerning exploration, Herfindahl has made a distinction which is very important for LDC's.

The developing country that decides to raise the level of (geological) information by survey should distinguish
(cont'd)

⁴⁴ One of the largest of these firms, Kenting Earth Sciences Limited, describes its capabilities as follows:

Kenting Earth Sciences is committed to aiding the developing nations, particularly in the areas of water resources and agriculture, forestry, mineral exploration, transportation, and economic planning. The company's team of specialists has on many occasions identified development projects, subjected them to analysis, and produced feasibility reports to international lending agency standards.

Kenting Earth Sciences' capabilities include: economics, socio-economics, agriculture, soils mapping, land use and land capability mapping, geological and geomorphological studies, hydrology and groundwater studies, forestry, property mapping, regional planning, integrated river basin studies, project management and liason with international agencies. Projects have already been carried out in the Mediterranean Basin, South-East Asia, Latin America and Africa, and the Indian subcontinent.

- from a brochure entitled Kenting,
produced by Kenting Earth Sciences Ltd., Ottawa, Canada.

⁴⁵ Roberts, J., "Engineering Consultancy, Industrialization, and Development", in Cooper, C., editor, Science, Technology and Development, (London: Frank Cass Ltd., 1973), page 43

between the task of making basic decisions and the physical execution of the (exploration) programme... The difficulties and dangers of having these decisions made by outside advice seems clear enough... The purchase of physical execution, on the other hand, may turn out to be considerably cheaper than execution by the government itself.⁴⁶

Less Developed Countries which decide to employ contractors and consultants are advised to shop carefully. The hiring agency should monitor the progress at each stage of the exploration programme. Thus, it can be expected that the LDC with some indigenous technical expertise will be better able to benefit from contractors and consultants. The local geoscientists will be familiar with both the national exploration objectives and with the methods and jargon of the contractors.

In hiring contractors, LDC's should avoid firms which promote major reconnaissance surveys without mention of the costly and time-consuming follow-up work which will be required to identify mineral deposits⁴⁷. Another problem to be avoided is the lack of long-term commitment which might result from the use of some contractors⁴⁸. In selecting a contractor or consultant the agency of the LDC should insist on a firm with a solid background in LDC exploration. Such firms will be aware of the logistical difficulties which can be associated with such projects and, more

⁴⁷ Bosson and Varon, The Mining Industry and the Developing Countries, page 149.

⁴⁸ Solo, R., Organizing Science for Technological Transfer in Economic Development, (Ann Arbor, Mich.: Michigan State University Press, 1975)

important, such firms will not be willing to damage a hard-earned international reputation for the sake of an additional few thousand survey line miles in a "one-shot deal".

Private contractors and consultants present an interesting exploration option for LDC's though it must be recognized that their services will not be inexpensive. There are many firms available, with good reputations, which can without too much difficulty provide the exploration services required by LDC's. In fact, many of these firms are the same ones employed by the international mining corporations. The work they carry out will be recognized as first-rate by any potential investor. We shall close this discussion of contractors and consultants on a positive note, as pointed out in a recent paper to the Association of Geoscientists for International Development.

Probably the greatest advantages of the independent consultant are that he normally operates alone, or with a small unit, and the client country's relationship is with the individual or unit, devoid of all bureaucratic encumbrances. The consultant, if recruited from private sector practice or industry, will conduct himself with the same dispatch and efficiency common to the industry and, moreover, his judgement will have an important economic orientation.⁴⁹

Summary: Exploration Options for Less Developed Countries

In their quest to undertake mineral exploration programmes LDC's have a number of potential routes to follow. Exploration can be done

⁴⁹ Joubin, F., "The Role of the Independent Consultant in Mineral Resource Development in the Developing Countries", in Laming and Akajaiye, editors, New Directions in Mineral Development Policies, page 190.

without foreign involvement, but unfortunately few LDC's possess the necessary combination of technical skills, equipment and financial resources to do so in the near future. Further, it is often the case that the LDC government is not in a position to devote the long term effort which is necessary to build up this indigenous exploration capability. Some effort in this direction however, will prove very rewarding. As local exploration capabilities increase it will heighten the effectiveness of any foreign components included in the LDC's mineral exploration effort.

LDC's can definitely benefit from foreign involvement in mineral exploration whether this involvement takes the form of equipment, services, or capital. This foreign involvement can be sought from a variety of sources, including bilateral and multilateral development assistance, private firms and consultants, or a combination thereof. In their decision as to how these foreign components should be best utilized, LDC planners must pay attention to their availability and acceptability to the LDC, and to domestic factors. Any foreign involvement in LDC exploration should be monitored constantly both to gain expertise through example and to ensure that the programme is being carried out as specified.

In assessing the exploration options for LDC's it is important to recognize that each represents some sort of investment. In Chapter Two we dealt with the question of why this investment should be made. The investment in exploration will be necessary for any subsequent mineral development. F. M. Peterson

says that government-induced mineral exploration is a good investment; he likens it to a governmental investment in industrial Research and Development.

By performing the early geophysical and drilling work...the government could reduce the risk to firms by decreasing the size of the outlay required and increasing the profitability of success on a given venture...The arguments resemble those used, quite correctly, to justify government in R and D...Neither R & D nor mineral exploration is conducted at optimal levels without government.⁵⁰

However like all investments, an investment in mineral exploration has an opportunity cost; LDC development planners must initially assess the exploration investment in relation to all other development options. This, of course, also applies to exploration carried out via development assistance. It would not be wise to accept a mineral exploration development assistance project simply because "it's there". Further, this form of international development assistance seems to be less and less available.

The real range and effectiveness of each of the mineral exploration options will be a result of the LDC's indigenous capabilities and resources. If no technical expertise exists, it would not be surprising if that geological data which has been acquired through exploration were to lie neglected and remain of little value in furthering mineral development. If some expertise is present, each of the options presented here should be available in some form.

⁵⁰ Peterson, F.M., "The Government Role in Mineral Exploration", in Crommelin and Thompson, editors, Mineral Leasing as an Instrument of Public Policy, pages 150-155

If, in an LDC, financial resources are available alongside some indigenous technical expertise, the horizon of exploration options is expanded considerably.

With all of the exploration options mentioned in this chapter we have been dealing with the notion of the acquisition of information - in this case, geological information. At the risk of being too simple, we can say that the acquisition may not, itself, be too difficult. For many Less Developed Countries however, an equally important and perhaps more demanding problem will be assuring the acquisition of the right information; choosing the exploration scale and methods, managing the exploration programme, and digesting the resultant data. The acquisition of the right information, it is hoped, leads to mineral investment and development. In our next chapter, the case study of a Kenyan exploration project, we shall see how this more demanding problem can arise, and how it was overcome in one instance.

CHAPTER FIVE
MINERAL EXPLORATION IN KENYA' 1977

In the early 1970's the government of the Republic of Kenya expressed an interest in rapidly expanding its level of knowledge about Kenyan mineral resources. This would, it was hoped, assist in the attraction of international investment capital to the Kenyan mineral industry. For various reasons, not the least of which was a lack of interest on the part of the community of international mining companies, the Kenyans decided to undertake this exploration under the auspices of the Kenyan Mines and Geology Department rather than via the more traditional route of concession agreements. With funding in the form of bilateral development assistance a series of exploration projects and geoscience training programmes were carried out. One of these projects, financed by a loan from the Canadian International Development Agency and contracted to the Canadian exploration firm Geotrex in 1977, produced positive and possibly very fruitful results.¹

In this chapter we shall first outline the state of the mineral industries in Kenya before the decision was made to undertake a government-induced exploration programme. We shall also profile very briefly the parties involved here. An examination

¹ Much of the information for this chapter is the product of interviews with the participants of this exploration effort. For providing me with their time and assistance, I am indebted to Mr. A. Rattew and Mr. D. Wagg at Geotrex, Mr. A. Tait, Mr. J. Orton, Mr. A. Turkeli and Mr. Gdnedinger at C.I.D.A., and Mr. B. Thompson and Mr. B. Manistre at the Department of Energy, Mines and Resources.

of the process involved in organizing and carrying out the 1977 exploration programme follows. In organizing this exploration effort various scales and methods of exploration activity had been suggested to the Kenyans but a careful study of the Kenyan requirements and a welcome degree of flexibility on the part of all involved contributed to the choice of the most appropriate and most beneficial exploration techniques. In closing, this chapter will address the results and implications of the Kenyan experience. While each and every exploration effort in the less developed countries is unique, it is possible to draw some important conclusions from this Kenyan example.

The Kenyan Mineral Industry

Unlike many African countries, Kenya has no long tradition of association with the mineral industries.

Explorers of Kenya in the 1880's and 1890's, as well as the Imperial British East Africa Company and later Protectorate officials, had not learned of any exploitable mineral deposits that might have offered a solution to the Protectorate's early economic problems. The lack of any mineral resources - other than the large trona (soda ash) deposit at Lake Magadi - was confirmed by comprehensive surveys in 1902-3 and experts and the government concluded that agriculture for export was the only way to make the Protectorate pay for itself.²

Although evidence of occurrence exists in Kenya for over one hundred minerals³, and production has included among others, bar-

² I. Kaplan, et al, Area Handbook for Kenya, (Washington, American University, 1976) page 27.

³ Kaplan, et al, Area Handbook for Kenya, page 62.

ite, diamotite, fluorspar, gold, gypsum, lead, limestone, magnetite and vermiculite, Kenya's recent experience with mining operations has been described as 'rather discouraging'.⁴ For example, gold production in Kenya over the period 1940-1960 declined in value from over £500,000 to barely £100,000 per year.⁵ A World Bank report published in the early 1960's concluded that "No mineral wealth of great consequence has been discovered in Kenya...The prospects for export earnings from mining look dim."⁶ Nonetheless, this same report recommended that Kenya should "maintain the staff of the Mines Department at a high level of technical competence" and should "consider providing some financial support to encourage genuine prospectors to follow up discoveries where the prospects are promising but where 'risk money' is lacking."⁷ As we shall see, the Kenyans a decade later followed this advice in a somewhat unique and rewarding manner.

The most valuable minerals in terms of production in Kenya in the early and mid-1970's were the non-metallics, soda ash and salt. These are both mined at Lake Magadi, southwest of Nairobi. Fluorspar and lead/silver production have recently been expanded, with the principal markets being Japan, the Soviet Union and the United States.⁸ The fluorspar reserves have recently been estim-

4 E.H. Leavy, editor, The Economic Development of Kenya, an IBRD Report, (Baltimore: Johns Hopkins University Press, 1963) p. 146

5 Leavy, The Economic Development of Kenya, p. 146.

6 Leavy, The Economic Development of Kenya, p. 146.

7 Leavy, The Economic Development of Kenya, p. 147.

8 Lloyd's Bank Ltd., Economic Report: Kenya, (London, December, 1977) p. 11.

ated at seven million tons, and it has been noted that "Kenya has the potential to become a major world fluorspar producer."⁹ Kenya also exports small quantities of precious and semi-precious stones (e.g. sapphire, tourmaline) and recent exploration in Kenya is reported to have discovered the world's largest ruby deposit.¹⁰

131.

5.1 KENYAN MINERAL PRODUCTION
(selected minerals)

	1972	1973	1974	1975
Soda Ash (metric tons)	164,160	250,800	166,933	n.a.
Salt (metric tons)	37,000	35,000	36,000	6,000
Silver (troy ounces)	-	6	19,818	n.a.
Lead (metric tons)	2	-	20	177
Copper (metric tons)	100	100	100	100
Gold (kilograms)	-	-	7	3
Magnetite (metric tons)	n.a.	2,000	10,000	17,000
Fluorspar (metric tons)	10,457	48,000	30,000	49,000

Source: R.A. Pelletier, Mineral Resources of South Central Africa, Europa Year Book, vol. 2.

⁹ Kaplan, et al, Area Handbook for Kenya, p.350.

¹⁰ Kaplan, et al, Area Handbook for Kenya, p. 349.

In the 1970's mining and quarrying has played only a very minor role in the Kenyan economy, and was by far the smallest industrial sector listed in the recent World Bank memorandum on the Kenyan economy.¹¹

52 Kenya - Gross Domestic Product by Industrial Origin, 1972-77
(Kl million at current prices)

	<u>1972</u>	<u>1973</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>
Agriculture, forestry and fishing	214.1	233.9	267.0	324.0	428.3
Mining and quarrying	2.2	3.2	3.1	3.3	4.2
Manufacturing	77.9	94.6	119.1	127.1	167.4
Electricity and water	13.9	14.5	15.7	20.0	23.1
Building and construction	6.5	51.6	58.2	63.8	68.1
Wholesale and retail trade	66.3	80.6	115.9	121.9	144.5
Transport and communication	38.2	44.2	53.7	60.2	69.2
Finance, insurance, real estate and business services	31.4	34.5	46.8	54.7	68.0
Ownership of dwellings	40.2	46.0	54.2	65.8	75.5
Private services	19.8	23.5	26.6	30.6	35.7
Government services	107.2	113.6	135.0	156.7	178.9
Total Gross Domestic Product at factor cost	657.6	740.1	895.3	1028.0	1262.9
Memorandum:					
Monetary Agriculture ^{1/}	94.4	107.4	123.1	135.4	219.6
Semi-monetary Agriculture ^{2/}	114.8	120.9	13.7	181.0	200.0

^{1/} Excludes forestry and fishing

^{2/} Includes forestry and fishing

Source: Ministry of Finance and Planning, Economic Surveys.

¹¹ I.B.R.D. Report no. 2331 Ke, Kenyan Economic Memorandum, March, 1979, page 71.

Mineral Producing Areas of Kenya
(selected minerals)

133.

Beginning in the period covered by the 1974-78 Development Plan the Kenyan government decided to give a much higher priority to the mineral sector. One factor for this stronger emphasis was the rapid price increases of many minerals and commodities in the early 1970's. The new approach was outlined in the Third Kenyan Development Plan:

The contribution of mineral resources to the national economy has been growing steadily as several minerals known to be present have come into commercial demand. In many cases, a relatively small change in world market prices will make the exploitation of known deposits economically feasible. This fact and the fluctuating pattern of world demand for economic minerals place a high premium on a thorough and comprehensive knowledge of the national mineral resources. Only with such knowledge can the opportunities for exploitation presented by shifts in commercial demand be seized and the highest benefits from mineral development be gained.¹²

In order to gain this "thorough and comprehensive knowledge" of mineral resources the Kenyans had to institute a new and vigorous exploration effort. A two-level approach was planned. At the regional reconnaissance level, the Kenyans wanted to complete an airborne magnetometer survey which was three quarters complete as of 1973.¹³ This type of exploration conforms to level Two of our Exploration Sequence (Chap. 3), and is common to that most often carried out at the request of government departments.

¹² Republic of Kenya, Development Plan 1974-78, (Nairobi: Government Printer, 1974) Vol. 1, p. 272.

¹³ Kaplan, et al, Area Handbook for Kenya, p. 62 and Republic of Kenya, Development Plan 1974-78, Vol. 1, p. 276.

The second and more important level of exploration planned involved "projects emphasizing the economic investigation of known or suspected mineral deposits to determine the conditions under which exploitation is economically viable."¹⁴ This objective demanded more detailed exploration and survey techniques. Here the exploration effort would be more directly targeted to suspected areas of mineralisation, and would involve the co-ordination of activity at several stages further along the exploration sequence, well beyond the reconnaissance level.

The Kenyans recognized that the undertaking of these more detailed exploration projects demanded a higher level of expertise within the Kenyan Mines and Geology Department. As noted in the Development Plan,

because these projects are to be carried out at a much greater scale and level of sophistication than has been true in previous years, a substantial in-service training programme will also be undertaken during this Plan period.¹⁵

Appendix D lists the project names and budgetary allotments planned for the Mines and Geology Department in the period 1974-78. Of the total K£ 3.9 million, those project areas most significant are those concerned with exploration:

¹⁴ Republic of Kenya, Development Plan 1974-78, Vol. 2, p. 147.

¹⁵ Republic of Kenya, Development Plan 1974-78, Vol. 2, p. 148.

Prospecting, Kf 143,000; Mineral Feasibility and Survey, Kf 426,000; Training, Kf 144,600; and Airborne Geophysical Survey, Kf 1,298,500. A good portion of the Mines and Geology Department's budget, roughly Kf 1.7 million, the Kenyans hoped would originate as development assistance funds.¹⁶ It is via this development assistance that the contracting firm, Geoterrex, and the Canadian International Development Agency enter the Kenyan mineral exploration picture.

Organizing Exploration in Kenya

Before addressing directly the exploration activity carried out in Kenya in 1977, we should look very briefly at the three parties involved: the Kenyan Mines and Geology Department, the Canadian International Development Agency, and Geoterrex.

The Kenyan Mines and Geology Department was, as noted in the midst of a five year plan to undertake exploration activity to fulfill the goal of securing investments in mineral developments. Mineral exploration can be a costly venture; Kenya was in the fortunate position of being able to channel development assistance funds to cover these costs. Exploration also needs skilled earth scientists, and here the Kenyans were not so fortunate. As of 1976 there were no qualified Kenyan geophysicists in the Mines and Geology Department. The United Nations had been providing the services of Mr. Duncan Dow, a New Zealand

¹⁶ Republic of Kenya, Development Plan 1974-78, Vol. 2, pp. 147-149.

geologist, as senior technical advisor to the Department. There were several Kenyans studying geology and geophysics both in Kenya and in universities abroad, including Queen's University in Kingston, Canada, but their contribution to the Mines and Geology Department was not yet readily available. In general, the level of local expertise was low; this prompted one visiting development assistance project officer to describe the Kenyan Mines and Geology Department "a disaster"

We have seen that by the mid-1970's the Canadian International Development Agency had compiled a long and fairly impressive record of providing mineral exploration and development assistance. However this type of assistance was undergoing a reduction of priority in the eyes of CIDA's policy makers. Further, we should remember that the vast bulk of CIDA exploration projects had been large scale regional reconnaissance surveys. Most of CIDA's exploration experience, then, was not consistent with that required in Kenya's goal of identifying and evaluating deposits.

The third party in our case study, Geoterrex Limited, is a Canadian consulting/contracting firm with expertise in geological and geophysical survey and interpretation techniques, photogrammetry, geodetic and engineering surveys, route location studies and terrain analysis from aerial photographs and

other remote sensors.¹⁷ Owned by the geophysicists and engineers who make up the professional staff, Geoterrex was established in 1966. Since then the firm has expanded internationally, with associated offices opened in Australia, South Africa and the United States. Geoterrex has now accumulated much international experience; Mr. A. Rattew, the president of the firm, has estimated that forty percent of Geoterrex's contracts are from outside Canada. In fact, the Northern Miner has noted that "Geoterrex has been responsible for the majority of airborne work done in the United States in the past several years."¹⁸ There is a Geoterrex agent/representative located in Nairobi, and it is via this conduit that the firm became aware of Kenya's new interest in mineral exploration.

In 1974, as part of a K£ 35 million aid programme, CIDA received a request from Kenya to continue the regional reconnaissance airborne magnetometer survey which had already covered the major portion of the country.¹⁹ CIDA sent a staff consultant, Mr. Alec Taite, to Nairobi to investigate and report on the merits of the request. On this trip contact was made with Mr. Dow, of the Kenyan Mines and Geology Department.

¹⁷ Northern Miner, "Adaptability of Terra/Geoterrex Results in World-Wide Capability," September 18, 1975, p. 46.

¹⁸ Northern Miner, September 18, 1975, p. 46.

¹⁹ Lloyd's Bank Ltd., Economic Report: Kenya, p. 7.

Mr. Taite's report to CIDA recommended that the request for an exploration activity be rejected, or at least postponed for a period. He concluded that any further exploration activity would prove to be much more effective and valuable after an effort had been made to improve Kenya's earth sciences capabilities - both in expertise and in equipment. To this end CIDA approved the provision of a geochemist and his field laboratory, with the geochemist spending three years in Kenya engaged in both training and in surveying. Provided on similar terms was Mr. Alan Johnston, a geophysicist. CIDA also purchased two diamond drill rigs and provided a Canadian drill crew foreman to oversee and instruct in their use. University scholarships were also included in this development assistance package, so as to further the education of young Kenyans who were interested in the earth sciences.

The objective of CIDA was to greatly enhance, over a period of two or three years, the Kenyans' ability to carry out the necessary follow-up stages of exploration, and drilling, after the expensive airborne geophysical surveys (both reconnaissance and *detailed*) were completed. Mr. Taite concluded that once this initial assistance had been provided to Kenya, CIDA "could begin to examine sensible requests for airborne surveys". (interview, June 1979).

In late 1976 Mr. Rattew, of Geoterrex, was on a "routine visit" to Kenya. Mr. Rattew contacted the Mines and Geology Department where Mr. Dow informed him of their interest in

exploration. Mr. Dow explained the Kenyans' wishes to encourage mineral development via the investigation of "known or suspected deposits". In particular, they discussed the merits of exploring for base metals in Nyanza Province.

The area of interest was of pre-Cambrian geology: there had been gold mining operations in the area and copper was presently being produced (though only in small quantities). Mr. Rattew visited Nyanza and inspected the target areas. More importantly, however, Mr. Dow showed to Mr. Rattew some data from a previous airborne geophysical survey of Nyanza Province. This was an electromagnetic (E.M.) survey completed by the British firm, Hunting, in the 1950's. The results of the Hunting survey, when examined years ago, had been discouraging, but Mr. Rattew was not convinced that there was nothing there in the way of economic mineral deposits. Mr. Rattew recognized that the disappointing results of this early survey was due primarily to a lack of sophistication of the geophysical equipment available in the 1950's. A much greater degree of penetration and detail could now be achieved in a Nyanza survey, with prospects for much better results, by using the Barringer INPUT electro-magnetic method. Mr. Rattew described the INPUT equipment as "ideal" for the Nyanza survey. Together with Mr. Rattew, the Kenyan Mines and Geology Department proceeded to draw up a second, very different, request for Canadian development assistance.

The Canadian International Development Agency had never before financed an electromagnetic INPUT survey. As noted, CIDA had much more experience at the broad-brush reconnaissance level, usually airborne magnetometer surveys. Upon receiving the second Kenyan request for exploration development assistance, the CIDA officials were faced with something of a dilemma. Now CIDA was being asked to change their exploration assistance pattern, and to focus exploration activity in detail on particular areas of interest in Nyanza Province. The use of the INPUT method would constitute a much more direct exploration effort; one which would specify target areas for ground follow-up and drilling and which would provide potential investors with accurate information about mineral deposits. For CIDA then, this was something new. If CIDA approved the request, it would have a direct hand in fulfilling the Kenyan objective of spurring mineral development. As Mr. Rattew has said, "The existence of a magnetic survey is often not enough to bring in the mining companies. Interpreted magnetic is better, but with Barringer INPUT EM you have direct targets."

Once again CIDA sent consultant experts to Kenya to assess the viability of a request for mineral exploration. The opinion in Ottawa was that the exploration infrastructure projects - the training and equipment already provided by CIDA - were now well enough along to make an airborne survey worthwhile. The first of these consultants, Mr. Spector, a geophysicist from Toronto, recommended that CIDA provide only a continuation of the regional airborne magnetometer survey. The second consultant,

Mr. H. Limian, was an economic geologist. Mr. Limian reported that there was considerable potential for success with the INPUT survey, saying the Nyanza region was "just like Noranda". Mr. Limian, together with Kenyan officials, selected five zones in which it was suggested to carry out airborne INPUT surveys.

Faced with conflicting recommendations from the consultants, a key, pivotal factor in CIDA's determination of what type of survey to provide was the financial arrangement of this particular development assistance package. The mineral exploration activity was to be paid for by a \$1.1m "soft" loan to the Kenyan government. Because this was a loan, and not a grant, the Kenyans had much more say in the final components of the assistance package. The Kenyans were adamant about including the INPUT survey as a major part of that package. To a certain extent, then, this arrangement can be said to be a "mix" of the bilateral development assistance and direct use of contractor options discussed in the previous chapter. One of the CIDA officials closely related to the organisation of this project has commented that the fact that this was a loan gave the project planners "much more elbow room", and the result was a more flexible and, therefore, more valuable use of development assistance.

The request which had been submitted by the Kenyan Mines and Geology Department - which included the Nyanza INPUT survey - was forwarded by CIDA to the Canadian Department of Energy, Mines and Resources for an assessment of its technical merits. With only

several minor changes the project was approved by Energy, Mines and Resources, and CIDA set about letting the contract.

In the winter of 1976-77, CIDA was aware of only two firms in Canada with the equipment and expertise to carry out a Barringer INPUT survey. One was a Toronto-based contracting firm; the other was Mr. Rattew's Geoterrex. The Kenyans had the final choice because of the financial arrangements. Mr. Dow, of the Kenyan Department of Mines and Geology, chose Geoterrex because this firm had considerable African exploration experience whereas the other firm had none. No doubt the familiarity and good working relationship which had been established between the Kenyans and Geoterrex was also a contributing factor in their winning of the contract. An interesting coincidence in this regard is the fact that one of the Kenyans who had been studying geophysics at Queen's University had also been working with Geoterrex over the summer vacation.

Details of the exploration programme were finalized quickly, and the contract was signed. Again, in part, the speed with which details were completed can be attributed to the fact that this was a CIDA loan, not a grant. One of the CIDA project officers commented that this allowed them to cut through a lot of "red tape"; he said, "If we do it, it takes months." The project was slated to commence in June, 1977.

Carrying Out The Project

The exploration effort carried out by Geoterrex in Kenya in 1977 comprised three elements. The primary element was, of course, the INPUT survey in Nyanza Province. Also included were an investigation of the freshwater/salt water interface along the Indian Ocean coastline north and south of Mombassa and a continuation of the regional reconnaissance magnetometer survey mentioned earlier.

In the Spring of 1977 Geoterrex had an aircraft, equipment, and a crew available in Saudi Arabia which were sent on to Kenya. The crew for this survey consisted of two pilots, a mechanic, two electricians, a geophysicist and two geophysical technicians. CIDA had also sent along their geophysical advisor to Kenya, Mr. Johnston, to monitor Geoterrex's work and to stay on afterwards to assist in the ground follow-up. The Geoterrex contract in Kenya was completed after six months; this was slightly over schedule due primarily to frequent thunderstorms in the final two months of surveying. There were few logistical problems, the major one being the necessary replacement of one of the aircraft engines.

While the actual data from Geoterrex's exploration in Kenya remains confidential, as required by the contract, it is apparent that the project was successful. In the primary element, the INPUT survey, some 20,000 line kilometers were flown in the search for the massive sulphide formations which would indicate the presence of base metals. For some of this survey, magnetometer readings were also being logged. This airborne survey was followed up almost immediately by ground geophysical and

geochemical surveys, and by preliminary drilling activity. That this was so quickly accomplished by the Kenyan/Canadian teams points to a certain measure of success in CIDA objective of building up the Kenyan exploration capability.

By the end of 1978 the data from the Nyanza exploration effort had been analysed by the Mines and Geology Department and by Geoterrex. It has been disclosed that the results of the INPUT survey included the identification of "possible volcanic plugs - Kimberlites". These appeared as very distinctive signatures using the INPUT method. The discovery of these geologic formations has been called "one step away from the discovery of diamonds". While previously unknown in Kenya, similar formations have been discovered in neighbouring Tanzania where diamond production had been underway for some time. By May 1979, "exploratory drilling operations had been carried out successfully in four sites as identified by the INPUT survey". (Rattew, interview, May 1979).

The second element of Geoterrex activity in Kenya in 1977 grew out of the "on-site" consultation with the Kenyans. Along the Indian Ocean coastline, both north and south of Mombassa, the towns and villages had been suffering from a lack of fresh water. The Kenyans had been drilling more or less randomly for fresh water, with less than satisfactory results. The objective of this element of the exploration effort was to discover whether the INPUT method, which provides a clear distinction between the

signatures of fresh water and salt water, could point to useable resevoirs of fresh water. This, it was hoped, would also point out areas of salt water "seepage" which were causing the destruction of fresh water.

The results of this second Geoterrex survey were also encouraging, although more ground follow-up is needed. Some of the potential fresh water areas indicated by the INPUT survey have already been confirmed by successful drilling. This successful use of airborne geophysics in the search for fresh water gives grounds for optimism. The on-the-spot organisation and carrying out of this second element points to the necessity and value of remaining flexible and responsive to local needs when approaching less developed country exploration.

The final element of the Geoterrex contract in Kenya, the continuation of the regional magnetometer survey, was included after surplus funds in the development assistance package were seen as being available. Some 30,000 line kilometers of magnetometer survey were flown in eastern Kenya, in some areas combined with a broad-brush spectrometer search for uranium. The interpretation of the data from this third element was not included in the contract. The Kenyans are considering paying for it themselves directly and Geoterrex is one of the firms bidding for this interpretation contract.

Results and Implications of the 1977 Kenyan Exploration Effort

As mineral exploration can only be a catalyst, an "essential seedcorn", to subsequent mineral investment and development, the real value of the 1977 exploration activity in Kenya will be better assessed in the future. There are, however, significant benefits which can presently be identified for those involved.

Mr. Rattew, of Geoterrex, reports that no profit was realized as a result of their work in Kenya in 1977. He did, however, point to such "long-term positive effects" for his firm as valuable contacts in an expanding market, and in the proven technical advances demonstrated by the INPUT method. While in Kenya Geoterrex engaged in some "on-the-spot R&D work" in the form of test flights over known mineral deposits so as to better understand the potential of the INPUT method. In spite of the lack of immediate financial returns, the people at Geoterrex spoke of this exploration programme as being among their most satisfying.

For the Canadian International Development Agency this exploration project represented an important step forward, one which showed a willingness to progress beyond established policy when the situation warranted it. After several years of laying a foundation for effective exploration, CIDA agreed to move along the exploration sequence to approve the choice of an INPUT survey. The direct result of this decision put the Kenyans in a good position to entertain offers for mineral investment on terms concurrent with their development objectives. It is hoped that

this pattern can be repeated elsewhere. The Canadian government can provide valuable and effective bilateral development assistance in the form of mineral exploration. Perhaps with the success of this particular project as an example, natural resource information and mineral exploration projects will not suffer a further reduction of priority in CIDA planning. We should note further that the operational flexibility of the Kenyan project, as represented by the on-site decision to undertake the investigation of the fresh water/salt water interface, provided results which are entirely consistent with CIDA's often-stated commitment to small scale rural development.

Finally, and most importantly, this exploration effort is of substantial benefit to the Kenyan government. The benefits from the fresh water survey are straightforward, and the regional magnetometer survey will help contribute to Kenyan resource planning in toto. We shall focus here on the Nyanza INPUT survey and the stated objectives of the Kenyan Mines and Geology Department to investigate areas of known mineral occurrence so as to be able to encourage subsequent investment and development.

We noted in Chapter Two that the primary rationale behind government-induced mineral exploration was to affect the relationship between host governments and international mining corporations and to enhance the government's bargaining position. We also noted the severe slow-down of exploration investment in Less Developed Country's. In the Kenyan case, simply no bargaining

process or mineral investment had been under consideration. Since late 1978, when the joint Geoterrex/Kenyan Mines and Geology Department report was made available for public sale, some twenty-two international mining companies have travelled to Nairobi to purchase the data. One condition of sale of the exploration report stated that a mining company representative may, in person, purchase the report in Nairobi only after discussion with government officials about the Kenyan approach to mineral development.

Steps related to mineral investment such as changes in taxation policies, were being taken in the period of the Third Kenyan Development Plan. The new taxation policies were aimed at attracting investment in those large scale projects for which Kenya did not have sufficient capital. A recent Lloyd's Bank report noted:

Foreign capital will in general be welcomed in such fields as mining, manufacturing and tourism, whereas small business which need neither substantial amounts of capital nor specialized skills will become the preserve of the Kenyans...
Tax allowances are granted on capital expenditures for industrial buildings, plant and machinery and in mining works...
Taxes are lower for mining corporations than for most.²⁰

This shift in taxation policy does not mean the Kenyan government will neglect the maximisation of mining's potential contribution to national revenues or economic development. The Kenyan government is very much interested in entering into joint venture

²⁰ Lloyd's Bank Ltd., Economic Report: Kenya, December 1977, pp. 7-8.

resource extraction projects and informs all interested investors of its option to acquire fifty percent equity in any development project.

The presentation of the Nyanza exploration report and its sale to 22 mining firms is in itself an indicator of success. By September, 1979, two proposals for the development of the Nyanza deposits had been received by the Kenyan government. Certainly the 1977 exploration effort has provided the potential for a significant change in the state of the Kenyan mining industry.

We should not go too far, however, in ascribing benefits to Kenya's 1977 mineral exploration. The provision of geological knowledge and the enhancement of the potential of a country's mineral sector is one thing; a successful management and administration of mineral investments and developments is quite another. Kenya has experienced some problems in the mineral sector in the past. Difficulties have arisen as a result of such factors as a vague mining code and a poor transportation infrastructure. The Area Handbook for Kenya comments in this regard that, "production of soda ash in 1973 was 250,000 tons...but could easily have been doubled if rolling stock had been available to transport it."²¹

The Kenyans are hoping that the training of earth scientists and other professionals will help in clearing up some of these difficulties. Mr. Rattew of Geoterrex has commented that the

²¹ Kaplan et al, Area Handbook for Kenya, p. 350.

scholarship students he has met both in Canada and in Kenya are "of quite impressive calibre". Further, the Kenyans have recognized that certain "capability" shortcomings could impede their objectives in mineral development. In an attempt to rectify this, CIDA has recently been asked by the Kenyan Mines and Geology Department to provide a senior geophysicist and a senior advisor on mining legislation. This request has been approved by CIDA. While noting the importance of developing qualified Kenyans to fill these posts, it is hoped that the provision of these foreign advisors can assist in fulfilling the more immediate goals of the Kenyan government.

In summary then, several important points can be drawn from the Kenyan case study:

1. Despite "dim prospects", the Kenyan government suspected a mineral potential which could be exploited. After deciding to encourage mineral investment, the Kenyans chose a "self-induced" approach to exploration rather than the more traditional concession arrangements.
2. Lacking both capital and expertise, the Kenyans were able to acquire a development assistance package which provided training, equipment, and internationally respected contractors with related experience. Further, the financial arrangements of this development assistance package, it being a loan, not a grant, permitted the Kenyans considerable decision-making power.
3. A careful review of the existing geological data about Nyanza Province led to the choice of a more "direct" exploration method than might otherwise have been made. The use of the Barringer INPUT EM equipment clearly delineated areas for follow-up ground work, which was successfully carried out.

4. After interpreting the data from Nyanza Province, it was presented for public sale in a manner that assured that potential investors would be immediately aware of Kenyan mineral development objectives. Twenty-two international mining companies purchased the information. Two proposals for mineral investment have been received thus far.
5. The flexible contractual arrangements and close contact with local officials led to the valuable INPUT survey of the fresh water/soft water interface, thus contributing to rural development needs via previously untried methods.

Ultimately, any headway that will be made in the mineral sector in Kenya will not be won through an investment in exploration alone. Progress will only result from a careful application of exploration, followed by wise use of the appropriate geological information, and in conjunction with an effective administration of a clear and consistent mineral policy. While we cannot at present assume from this case study that minerals will become a major, or even a more important, sector in the Kenyan economy, we can recognize that an important and necessary step has been taken in that direction.

CHAPTER SIX
SUMMARY AND CONCLUSIONS

Truth doth lie in deep pits
and when it is got, needeth much refining.
Democritus

The primary approach of this paper has been "operational". We have been concerned with the techniques, activities and options which together comprise mineral exploration programmes for Less Developed Countries. In this concluding chapter we shall first summarize this operational approach and then move briefly to a broader perspective of mineral exploration in LDC's.

Summary: The Appropriation of Geological Information

Many LDC governments are presently in the position of knowing little more about their mineral resources than the fact that these have been exploited, often by foreigners, in ways that have not contributed to their countries well-being. As Peterson argues, governments should perform themselves, or contract out, exploratory work in order to gain knowledge about the value of their mineral resources and to improve their mineral developmental potential.

Information spill-overs, scale economies and risk aversion prevent the (mineral) market from functioning properly. Failure of the market encourages the domination of large international firms, reduces the rate of exploration and subtracts from governmental revenue.¹

Some LDC governments are now taking this exploration step themselves. Once the decision to induce mineral exploration has been made, important questions have to be dealt with by the country's development planners in order to ensure the appropriation of the right

¹ Peterson, "The Government Role in Mineral Exploration", page 149.

geological information in the most efficient manner.

The first task is the outlining of an exploration programme. Here the various scales and methods of exploration have to be specified and co-ordinated into a sequence of exploration activities. The concentration on one or two exploration methods, for example geological mapping or airborne geophysics, may not provide sufficient geological information to make an investment or development decision. Choices of technique will have to be made to determine both the "gross" and the "finer" distinctions of geological information.

Exploration outlays may be of a number of different types, some coming early in a sequence of sifting activities, designed to make gross distinctions among areas; and others designed to make finer distinctions, down to identifying particular deposits and determining their detailed characteristics.²

Government-induced exploration programmes, using small-scale geological mapping techniques and regional airborne geophysics, have for many years been involved in making the "gross" distinctions. It is now becoming apparent that, for many LDC's, there is considerable value in expanding the role of government-induced mineral exploration into the area of the "finer" distinctions. With international investment capital presently hard to obtain in the mineral industries of many LDC's, and with the special developmental concerns

²Herfindahl and Kneese, Economic Theory of Natural Resources, page 134.

of development planners, an exploration effort which more clearly identifies and delineates the extent of mineral deposits will prove worthwhile. Our Kenyan case study proves that, whereas regional airborne exploration (three-quarters of the country) had attracted little investment attention, exploration activity several steps further along the sequence spurred a flurry of interest. For international mining companies which are looking for "special incentives" before they will consider an investment in LDC's few incentives seem better than a clear indication of the presence of economic mineral deposits.

As Herfindahl has emphasized, the design and organization of an exploration programme should feature flexibility, with the body of geological information being continually augmented.³ This will allow the exploration effort to reject quickly those areas of little interest, and to go forward where there are positive indications. In the Kenyan example a welcome degree of flexibility on the part of the project organizers and the exploration team in the field made direct contributions to the success of the effort in two ways:

- 1/ The decision to proceed with the Barringer INPUT EM survey rather than to continue the more traditional regional exploration approach put the project much closer to the identification and evaluation of the mineral deposits.

- 2/ On-site discussion led to the successful first-time application

³ Brooks, Resource Economics: Selected Works of O. C. Herfindahl, page 251.

of an airborne EM survey to the search for the fresh water/salt water interface. The many and varied natural resource information needs of the LDC's make this flexible approach a prerequisite. It will not be enough, in maximizing the benefits from mineral exploration for LDC's, to simply duplicate or repeat those methods and techniques which comprised the exploration efforts of the industrialized countries.

A second task for LDC governments which are interested in acquiring geological information will be the determination of how their exploration programme will be carried out (of course, this task may have to precede the first). Mineral exploration has become expensive and highly sophisticated. In many cases LDC mineral exploration will necessitate the involvement of foreign equipment, personnel, or capital. The single most important factor in determining how to carry out an LDC exploration programme will be the quality and quantity of local exploration personnel. For those LDC's with a serious lack of exploration expertise, each and every opportunity to enhance the ability of local personnel must be seized. Where trained geoscientists and exploration technicians are already present in the LDC the specification and operation of an exploration programme which includes foreign involvement will be much easier. The presence of local expertise will also result in the better comprehension of the exploration data, thus making it more valuable.

In the Kenyan example we noted that a lack of geoscience per-

sonnel made the Mines and Geology Department look to foreign explorationists. As a result CIDA, over a period of several years, provided equipment and training to Kenyans. The direct product of this exploration training was the ability to follow-up quickly on the INPUT data. We should also note that in the Kenyans' approach to CIDA, they were not willing to give up a measure of control in specifying their exploration needs. This control was represented by the project being financed by a loan. As a result the Kenyans were able to get the maximum impact from a development assistance package which, in a way, ~~included~~ the features of the direct hiring of exploration contractors.

By carefully choosing among the various exploration options, and by designing an exploration sequence which is both comprehensive and flexible, LDC's can acquire the geological information which is necessary for mineral development to proceed. Of course, the possibility always exists that exploration will prove fruitless and no economic minerals will be discovered. However a properly designed and executed exploration programme should recognize this before too heavy an investment has been made. As Herfindahl has written, "the keynote is successive change as demands change, as resources change, and as capabilities change".⁴ Even where no economic deposits are discovered, positive results from mineral exploration can be recognized in the strengthening of manpower and institutions and in the inventorizing of resources.⁵

⁴ Herfindahl, Natural Resource Information and Economic Development, page 3.

⁵ Harkin, "Mineral Exploration and Technical Co-operation in the Developing Countries", page 333, 334.

Finally, exploration programmes may be expensive, and they can continue over a number of years. A degree of patience may be required to reap the most valuable geological information and its benefits. Before concluding this brief summary we should note that while exploration remains valuable and necessary for LDC mineral development, there can be too much faith put in the techniques of exploration and in the power of information.

The facts that technique is so versatile, that surprising and spectacular things are frequently accomplished, and that the rate at which some tasks can be performed is much higher than formerly was possible, are now a principal source of unguarded statements to the effect that "now we can develop all the information we need". It is an easy step from here to the erroneous view that physical information about natural resources is the key to their development and, in the minds of a few benighted souls, to economic development itself.⁶

We have outlined in this paper the methods and options available to LDC's in their quest to acquire geological information through government-induced exploration. The Kenyan example proves that it is indeed possible to specify, pinpoint, gather, and interpret the right information. This completes the summary of the "operational" side of mineral exploration in LDC's. Let us turn briefly to a broader perspective, beginning with the issue of the control and management of information.

⁶ Herfindahl, Natural Resource Information and Economic Development, page 20.

Control and Management of Information

Geological information is necessary for mineral development. Through mineral exploration, the necessary geological information can be acquired by the governments of LDC's. The control and management of the geological information can, however, present complex and difficult problems.

Information is not a "concrete" good, a piece of hardware. Nor is the provision of information a straight-forward service like the building of a bridge. Information is easily and cheaply transmitted and, therefore, it is difficult for its discoverer to capture completely or to retain its full value.⁷ Information is subject to leakage, and steps must be taken to ensure its control.

We can assume that an LDC government would consider its geological information to be more secure, more easily controlled, if there was no foreign involvement in its acquisition. Certainly, in the involvement of foreigners, LDC agencies should carefully monitor the destinations of all the accumulated data. In situations of scarce LDC geoscience personnel perhaps a multilateral monitoring agency could be employed in this regard. By contractual arrangement, all working documents and data should become the property of the LDC agency which is promoting the exploration effort. There seems no "iron clad" method of ensuring the security of information. LDC's will have to scrutinize carefully the references and rep-

⁷ Uhler, R., "Comment on the Government Role in Exploration", page 156.

utations of any contractors, consultants or other foreign personnel involved in the project.

The extent of damage which results from the leakage of geological information will depend on the content of that information and on its intended use by the LDC government. Information which is very general, broad-brush, in nature can be considered less easily secured because of inferences which can be made about it by publicly available means (LANDSAT, aerial photos). The security of this type of information is for the same reason less vital. Presumably the leakage of information about deposits the government intended to develop indigenously would be the most damaging. When information concerning LDC mineral deposits which are destined for development by foreign investors is leaked, this is information which would probably have been made public by the government anyway. Some damage here may result from the potential investor having earlier access to the information, and the LDC governmental agency may find itself without the nominal fee it would have received for the sale of the information.

The Kenyan government made the information resulting from the 1977 INPUT survey and from the ground follow-up survey available as soon as possible. They also assured that their mineral development objectives were imparted to the potential investors at the outset by requiring company representatives to meet individually with government officials. This approach was meant to minimize the possibility of leakage and, more importantly, to reduce the levels

of uncertainty - geological, commercial, and political - which are such important factors in the considerations of the international mining companies. This approach also served the purpose of introducing to the Kenyans each of the potential investors.

While the control of geological information is important, the management of this information can be crucial. Here we are referring to the manner in which the newly acquired information is used in furthering national mineral objectives. If the LDC government decides to undertake mineral development itself, the geological information will be one of the most important factors in the assessment of the minerals' marketability. The geological information will be included in economic feasibility studies and, together with a myriad of other related factors, it will be used in the final cost - benefit analysis which determines the future of the mineral resources.

If the involvement of some form of foreign investment is being considered, the government will use its geological information to assess the strength and extent to which it can present its mineral-development objectives to prospective investors. In their management of geological information with respect to these investors, LDC governments should recognize that the product of their exploration efforts will be of most value when it is used to strike a balance between the interests of producers and consumers, between the possessors of the resources and those who have the capital and provide

the markets.⁸ This is not to say that the LDC negotiators will have to abandon or modify their objectives; the ability to present these objectives in a more equitable bargaining process was one of the most important reasons behind the exploration undertaking. The point here is merely that it is easy for the LDC officials to ask too much of the international mining companies. Bosson and Varon have noted that,

In imagining the ideal contribution of the industry and the multinationals one can easily fall into the trap of asking them to fill a role far beyond their purview. It is one thing to ask an industry not to aggravate the maldistribution of income - indeed to assist in its correction - quite another to look to it for a model.⁹

The management of geological information in LDC's can also have an important political dimension. In countries where resources are extremely limited, where poverty is high and opportunities are scarce, the discovery of economic mineral deposits will be a boon. As a result of this discovery there can be strong political pressure to rush the mineral deposits into production. No mineral development can be considered in isolation from the economic, social and political forces at work within the LDC. But short term gains should not blind development planners to the longer term benefits. Of course knowledge, once acquired, must be used. The strong political pressure which can accompany geological information in LDC's

⁸ British - North America Committee, Mineral Development in the Eighties: Problems and Prospects, page 22.

⁹ Bosson and Varon, The Mining Industry and the Developing Countries, page 8.

will make its management more difficult.

The Future of LDC Mineral Exploration

From both the corporate and the global perspective a good case can be made for an increase in Less Developed Country mineral exploration. The mineral resources of LDC's are now important factors in world mineral supplies; many analysts say that their importance will increase in the future. The enhancement of knowledge about LDC mineral reserves will improve planning for production and should help avoid another "roller-coaster ride" for mineral prices.

The future of mineral exploration in LDC's is not readily apparent. 12 - 6.1 Expenditures on Geophysical Exploration - Africa, 1972 - 1978

source: Geophysics. note 1973 figures not available.

However indications are that LDC exploration is on the decline. As noted in Chapter Four, the financing of exploration projects by development assistance organizations is waning. It would seem that for those least developed countries interested in their mineral development prospects the lack of development assistance will make the execution of government-induced mineral exploration programmes less and less probable. In this regard, some statistical analyses of the trends in LDC mineral exploration, particularly that executed via development assistance, would prove valuable. Likewise, an assessment of the progress of the U. N. Revolving Fund for Natural Resource Exploration is overdue.

The modern mineral industry is complex, involving vast amounts of capital, sophisticated technology, and an above average degree of uncertainty. There is little doubt that this industry is dominated by a relatively small number of vertically-integrated firms. The mineral industry, when operation in LDC's, has been the source of suspicion and conflict. As a result of attempts by governments to change the nature and impact of LDC mining operations, the international mining companies have turned away from these countries, labelling them unsound investment environments. While this may ensure that there will be less future conflict between foreign investors and host governments over the split of benefits from mineral developments, it does nothing to facilitate mineral or economic development in LDC's today.

Many LDC's now lack the capital, the technical and managerial

skills, and, importantly, the access to international markets which are required if their mineral resources are to be developed indigenously. Further, LDC's often lack the fundamental geological knowledge which is a prerequisite to mineral development. By acquiring the geological information themselves through government-induced exploration LDC's will find that their mineral development potential has been greatly increased. After an exploration programme the extent of mineral resources can be determined and any decision to promote mineral development can be made with confidence. LDC governments can control the rate and direction of exploration and, if they so desire, they can encourage the investment participation of a wide range of international mining firms - large, medium-sized, or small. For some countries, government-induced exploration will help create a new, more stable, and more equitable investment environment for the mineral industry. In Kenya, investment proposals are already forthcoming. Mineral exploration then, increases the developmental value of this extractive industry. In short, mineral exploration can further the LDC's ability to grow, and to choose.

WORLD RESERVES OF SELECTED MINERALS			
Mineral	Major reserves (percent of world total)	Major producers*	Value of world output, 1968 ^a (millions of dollars)
<i>Minerals with ample reserves</i>			
<i>Reserve life 150 years plus</i>			
Columbium	Latin America (45) Soviet Union (35) Africa (10) Canada (10)	Brazil (6) Canada (26) Nigeria (12)	29
Phosphorus	Morocco (42) United States (31) Soviet Union (12)	United States (42) Soviet Union (24) Morocco (13)	835
Potash	Centrally planned economies (45) Canada (38) Germany, Fed. Rep. of (7)	Centrally planned economies (19) Canada (17) Western Europe (27) United States (15)	370
<i>Reserve life 120 to 150 years</i>			
Magnesium	China, People's Rep. of (53) North Korea (31) New Zealand (6)	United States (45) Soviet Union (22) Norway (16)	115
<i>Reserve life 100 to 110 years</i>			
Chromium	South Africa (74) South Rhodesia (22)	Centrally planned economies (40) South Africa (23) Philippines (9)	190
<i>Reserve life 90 to 100 years</i>			
Feldspar	not available—widespread	United States (30) Europe (35) Soviet Union (12)	55
Iron	Soviet Union (32) South America (19) Canada (12) Australia (10)	Soviet Union (26) Western Europe (17) United States (11) Australia (8) Canada (6)	6,190
Vanadium	Soviet Union (59) South Africa (20) Australia (15)	United States (49) South Africa (25) Finland (13)	60

source: Bosson and Varon, The Mining Industry and the Developing Countries, pages 219 - 225

Annex. A | Continued.

	Major reserves	Major producers*	Value of world output, 1968*
Mineral	(percent of world total)		(millions of dollars)
Reserves presenting no serious problem			
Reserve life 50 to 60 years			
Cobalt	Zaire (31)	Zaire (59)	110
	New Caledonia (18)	Zambia (9)	
	Zambia (16)	Canada (8)	
Nickel		Morocco (4)	1,100
	Cuba (24)	Canada (40)	
	New Caledonia (22)	Soviet Union (22)	
	Canada (14)	New Caledonia (19)	
	Soviet Union (14)		
Reserve life 40 to 50 years			
Asbestos	not available— widespread	Canada (50)	323
		Soviet Union (30)	
		South Africa (8)	
Manganese	South Africa (38)	Soviet Union (38)	475
	Soviet Union (25)	South Africa (12)	
	Gabon (12)	Brazil (12)	
		India (9)	
Molybdenum	United States (58)	United States (70)	not avail- able
	Soviet Union (18)	Canada (21)	
	Chile (16)		
Reserve life 30 to 40 years			
Antimony	China, People's Rep. of (50)	South Africa (25)	66
	South Africa (6)	China, People's Rep. of (20)	
	Soviet Union (6)	Bolivia (18)	
		Soviet Union (10)	
Bauxite	Guinea (34)	Jamaica (20)	340
	Australia (34)	Australia (15)	
	Surinam (11)	Surinam (11)	
	Jamaica (5)	Soviet Union (10)	
	Soviet Union (3)	Guyana (7)	
Sulfur	Near East and South Asia (45)	United States (39)	710
	Eastern Europe (16)	Centrally planned economies (21)	
	United States (12)	Canada (20)	
Titanium	Norway (20)	United States (60)	60
	United States (17)	Japan (30)	
	Canada (17)		
	Soviet Union (17)		

Append. A Continued.

	Major reserves	Minor producers*	Value of world output, 1968 ^b (millions of dollars)
Mineral	(percent of world total)		
<i>Reserves that are tight or critical</i>			
<i>Reserve life 20 to 25 years</i>			
Barite	United States (40) China, People's Rep of (13) Other centrally planned econo- mies (15) Germany, Fed., Rep. of	United States (23) Western Europe (33) Centrally planned economies (6)	35
Bismuth	Japan (45) Latin America (21) United States (13) Centrally planned economies (10)	Latin America (48) India (18) Canada (8)	28
Copper	United States (28) Chile (19) Soviet Union (13) Zambia (10) Peru (8)	United States (23) Soviet Union (15) Zambia (13) Chile (12) Canada (8)	7,740
Tungsten	China, People's Rep. of (74) United States (7) Korea, Rep. of (4)	China, People's Rep. of (24) Soviet Union (20) United States (13) North Korea (7) Korea, Rep. of (6)	105
<i>Reserve life 15 to 20 years</i>			
Lead	United States (37) Canada (13) Australia (12)	United States (14) Australia (14) Soviet Union (14) Canada (9)	775
Tin	Thailand (32) Malaysia (14) Indonesia (12) Bolivia (10)	Malaysia (32) Bolivia (13) Soviet Union (12) Thailand (9)	750
Zinc	United States (27) Canada (20) Western Europe (11) Eastern Europe (11)	Canada (22) Soviet Union (12) Australia (10) United States (9) Peru (6)	1,450

Appendix A

Mineral	Major reserve	Major producers ^a	Value of world output, 1968 ^b (millions of dollars)
(percent of world total)			
<i>Reserves that are tight or critical (continued)</i>			
<i>Reserve life under 15 years</i>			
Fluorspar	not available— reserves mainly in Mexico and west- ern Europe	Mexico (27) Western Europe (27) Centrally planned economies (20) Thailand (7) United States (6)	81
Mercury	Centrally planned economies (35) Spain (31) Italy (22)	Western Europe (50) Soviet Union (17) United States (11) China, People's Rep. of (9)	125
Silver	Centrally planned economies (36) United States (24) Mexico (13) Canada (12)	Mexico (15) Canada (15) United States (14) Soviet Union (13) Peru (12)	595

a. In the late 1960s.

b. At the commonly accepted point of transfer in world markets.

Several revised estimates of some components of the demand and supply picture have appeared recently. In most cases, especially on the demand side, the revisions have been minor. While major new resource discoveries have been reported (especially in the Amazon region of Brazil, Oceania, Siberia, and south central Africa), these have not yet been reflected in the official statistics. Some sources give nickel and bauxite figures significantly higher than those in the following tables. Most mineral prices are higher than in 1970, despite the recession; some (like phosphate rock) having attained what appear to be new plateaus. On this score alone, many of the reserve estimates can be considered conservative.

Append. A
(cont'd) PRINCIPAL EXPORTERS OF SELECTED MINERALS AMONG
DEVELOPING COUNTRIES
(Five largest exporters in descending order of value)

Commodity, SITC ^a number, rank, and country	Value of exports, average 1970-72 (millions of dollars)	Country share of	
		Total developing country exports (percentage)	World exports (percentage)
Bauxite (283.3)			
1. Jamaica	89.4	44.3	32.2
2. Surinam	46.0	22.8	16.6
3. Guyana	19.2	9.5	6.9
4. Dominican Republic	15.3	7.6	5.5
5. Sierra Leone	6.9	3.4	2.5
Other developing	25.0	12.4	8.9
Total developing	201.8	100.0	72.6
All others	76.1		27.4
World total	277.9		100.0
Copper (283.1/682.1)			
1. Zambia	765.0	31.5	17.0
2. Chile	731.0	30.1	16.3
3. Zaire	449.0	18.5	10.0
4. Peru	208.3	8.6	4.6
5. Philippines	187.0	7.7	4.2
Other developing	90.3	3.6	2.0
Total developing	2,430.6	100.0	54.1
All others	2,064.4		45.9
World total	4,495.0		100.0
Iron ore (281)			
1. Brazil	226.0	22.7	8.5
2. Liberia	165.0	16.5	6.2
3. India	153.7	15.4	5.8
4. Venezuela	139.7	14.0	5.3
5. Mauritania	73.3	7.3	2.8
Other developing	240.2	24.1	9.1
Total developing	997.9	100.0	37.7
All others	1,650.9		62.3
World total	2,648.8		100.0
Manganese ore (283.7)			
1. Gabon	39.0	35.8	20.1
2. Brazil	31.4	29.3	16.5
3. India	15.2	14.0	7.9

a. Standard International Trade Classification.

Source: World Bank, *Commodity Trade and Price Trends*, August 1974.

Append. A | Continued.

Commodity, SITC ^a number, rank, and country	Value of exports, average 1970-72 (millions of dollars)	Country share of	
		Total developing country, exports (percentage)	World exports (percentage)
4. Ghana	7.6	7.0	3.9
5. Zaïre	5.9	5.4	3.0
Other developing	9.2	8.5	4.7
Total developing	108.8	100.0	56.1
All others	85.2		43.9
World total	194.0		100.0
<i>Lead (283.4/685.1)</i>			
1. Peru	32.0	30.7	6.5
2. Mexico	21.3	20.5	4.3
3. Morocco	13.3	12.8	2.7
4. Namibia	13.2	12.7	2.7
5. Bolivia	7.3	7.0	1.5
Other developing	17.0	16.3	3.4
Total developing	104.1	100.0	21.1
All others	389.6		78.9
World total	493.7		100.0
<i>Phosphate rock (271.3)</i>			
1. Morocco	124.9	54.5	29.2
2. Gilbert, Ellis Is.	32.1	14.0	7.5
3. Tunisia	21.4	9.3	5.0
4. Togo	16.6	7.3	3.9
5. Senegal	13.9	6.1	3.3
Other developing	20.2	8.8	4.7
Total developing	229.1	100.0	53.6
All others	198.0		46.4
World total	427.1		100.0
<i>Tin (283.6/687.1)</i>			
1. Malaysia	318.3	49.9	42.6
2. Bolivia	102.3	16.0	13.7
3. Thailand	77.3	12.1	10.3
4. Indonesia	63.3	9.9	8.5
5. Nigeria	36.3	5.7	4.9
Other developing	40.6	6.4	5.4
Total developing	638.1	100.0	85.4
All others	109.3		14.6
World total	747.4		100.0
<i>Zinc (238.3/666.1)</i>			
1. Peru	54.7	32.2	7.1
2. Mexico	49.7	29.2	6.4
3. Zaïre	25.3	14.9	3.3
4. Bolivia	14.0	8.2	1.8
5. Zambia	13.0	7.7	1.7
Other developing	13.3	7.8	1.7
Total developing	170.0	100.0	22.0
All others	602.9		78.0
World total	772.9		100.0

^a Standard International Trade Classification.Source: World Bank, *Commodity Trade and Price Trends*, August 1974.

APPENDIX B

SOURCES OF PRELIMINARY DATA AND INFORMATION FOR EXPLORATION PROJECTS

I. GUIDES TO LIBRARY INFORMATION SOURCES

Brewer, J. G., *The literature of geography: a guide to its organization and use*: Hamden, Conn., The Shoe String Press, 208 p., 1973.

Includes sources of regional information and maps.

Corbin, J. B., *An index to state geological survey publications issued in series*: Metuchen, N.J., The Scarecrow Press, 1965.

Falk, A. L., and Miller, R. L., *Worldwide directory of national earth-science agencies*: U.S. Geological Survey Circ. 716, 32 p., 1975.

Lists national agencies dealing with geology, cartography, and minerals, with addresses.

Geoscience Documentation, 1969—, List of geoscience serials: *Geoscience Documentation*, v. 1, no. 1, July 1969.

The list has been updated in each subsequent monthly issue.

Given, I. A., *Sources of information*, in Cummins, A. B., and Given, I. A., eds., *SME mining engineering handbook*: New York, Am. Inst. Mining Metall. Petroleum Engineers, v. 2, sec. 35, p. 35-1-35-34, 1973.

Lists departments of mines, geologic surveys, societies, institutes, and their publications, by country and by U.S. state. Also lists major periodicals, directories, and yearbooks.

Hoy, R., *Sources of information*, in Lefond, S. J., ed., *Industrial minerals and rocks*, ed. 4: New York, Am. Inst. Mining Metall. Petroleum Engineers, p. 1290-1305, 1975.

Lists industrial minerals publications and publishers.

605

source: Peters, Exploration and Mining Geology,
pages 605 -617.

Appendix B, continued

Kaplan, S. R., Guide to information sources in mining, minerals, and geosciences: New York, Interscience Publishers, 599 p., 1965.

Part I lists names, addresses, function, and publications of national, state, and private associations dealing with mining; U.S. and foreign bureaus of mines are included. Part II describes available literature in books and journals by country and subject.

National Referral Center, A directory of information resources in the United States—physical sciences and engineering: Washington, D.C., National Center for Science and Technology, 1971.

Ward, D. C., and Wheeler, M. W., eds., Geologic reference sources: Metuchen, N.J., The Scarecrow Press, 453 p., 1972.

Covers general information by subject (e.g., economic geology), regional information by country and state. The map bibliography is concerned with small-scale maps and atlases for each country rather than large-scale "quadrangles."

Wood, D. N., ed., Use of earth science literature: London, Butterworth and Co., 459 p., 1973.

This could be called "everything you might possibly want to know about geologic information sources." Detailed information is included on methods of literature search, with lists of regional geologic handbooks and maps, by region and country.

II. EXAMPLES OF DOCUMENTED AND GENERALLY AVAILABLE INFORMATION

A. Bibliographies and Indexes in Current Use

**Applied Science and Technology Index*, monthly-annually: New York, H. W. Wilson Co.

Bibliographic Index, semiannually: New York, H. W. Wilson Co.

**Bibliography and Index of Geology*, monthly: Boulder, Colorado, The Geological Society of America.

**Bibliography of North American Geology, 1919-1970*, monthly-annually: Washington, U.S. Geological Survey.

Business Periodicals Index, monthly: New York, H. W. Wilson Co.

Covers business policies, marketing, finance, and associated economics.

**Canadian Index to Geoscience Data*, with periodic update: Ottawa, Geological Survey of Canada.

Published and open-file data, by province.

Catalog of the United States Geological Survey Library, with supplements: Boston, G. K. Hall Co., 1964.

**Classed Subject Catalog of the Engineering Societies Library* (New York): Boston, G. K. Hall Co., 1963.

Commonwealth Index of Unpublished Scientific and Technical Translations: London, British Library, Lending Division.

* Available on magnetic tape and/or in remote terminal access.

Appendix B, cont'd

**Current Contents—Engineering and Technology*, monthly, and *Index to Scientific Reviews*, semiannually: Philadelphia, Institute for Scientific Information.
Dictionary Catalog of the U.S. Department of Interior Library, with supplements: Boston, G. K. Hall Co., 1967.

**Engineering Index*, monthly-annually: New York, The Engineering Index Co.

**F. and S. International Index*—Industries, companies, countries, monthly-annually: Cleveland, Ohio, Predicasts Inc.

Includes "mining" as a topic and as entries under countries and companies.

**Geotitles Weekly*: London, Geosystems (Lea Associates).

Cumulative in *Geotitles Repertorium* (annual) and on *Geoarchives* tapes.

Government Reports Index, monthly: Springfield, Virginia, National Technical Information Service.

Includes government-sponsored research projects and translations.

Publications of the U.S. Geological Survey, monthly;

Publications of the U.S. Bureau of Mines, monthly;

Catalog of United States Government Publications, monthly: Washington, Government Printing Office.

Many countries publish similar monthly or annual announcements.

Science Citation Index, quarterly: Philadelphia, Institute for Scientific Information.

TRANSDEX—Bibliography and index to the United States Joint Publications Research Service (JPRS), monthly: New York, CCM Information Corporation.

Translations Register-Index, annually: Chicago, National Translations Center, John Crerar Library.

VINITI Program Index, semiannually to biannually: Boston, G. K. Hall Co.

Translations of Russian research summaries and bibliographies.

World Index of Scientific Translations, annually: Delft, The Netherlands, European Translations Center.

Chronic, J. B., Bibliography of theses written for advanced degrees in geology and related sciences at universities and colleges in the United States and Canada through 1957: Boulder, Colorado, Pruett Press, 1958.

Chronic, J. B., Bibliography of theses in geology, 1958–1963: Washington, American Geological Institute, 1964.

Long, H. K., A bibliography of earth science bibliographies of the United States: Washington, American Geological Institute, 1971.

Ward, D. C., Bibliography of theses in geology: *Geoscience Abstracts*, v. 7, no. 12, pt. 1, p. 103–129, 1965.

Ward, D. C., Bibliography of theses in geology, 1967–1970: Boulder, Colorado, Geol. Soc. America Spec. Paper 143, 1973.

Ward, D. C., and O'Callaghan, T. C., Bibliography of theses in geology, 1965–66: Washington, American Geological Institute, 1969.

B. Sources of Abstracts

**Abstracts of North American Geology*, monthly, 1966–1971: Washington, U.S. Geological Survey.

Earlier abstract publications were *Geoscience Abstracts*, 1959–1966, and *Geological Abstracts*, 1953–1958, of the American Geological Institute.

Appendix B, cont'd

**Bulletin signalétique*, monthly: Paris, Centre de Documentation du Centre National de la Recherche Scientifique.

Published in numerous sections. Those of particular interest to exploration geologists are:

- Bull. 221, Géologie, économie minière
- Bull. 222, Roches cristallines
- Bull. 223, Roches sédimentaires, géologie marine
- Bull. 224, Stratigraphie, géologie régionale, géologie générale
- Bull. 225, Tectonique
- Bull. 226, Hydrogéologie, géologie de l'ingénieur, formations superficielles

**Chemical Abstracts*, weekly: Columbus, Ohio, American Chemical Society.

Topics include minerals, mining, geology, and specific metals.

Dissertation Abstracts International, monthly: Ann Arbor, Michigan, University Microfilms.

Economic Geology, Geology of ore deposits (abstracts of Russian Academy of Science articles) in several issues each year.

Geoabstracts, bimonthly: Norwich, England, University of East Anglia.

With a worldwide geographical and subject index in seven parts:

- A. Landforms and the Quaternary
- B. Climatology and hydrology
- C. Economic geography (including minerals)
- D. Social and historical geography
- E. Sedimentology
- F. Regional and community planning
- G. Remote sensing and cartography.

Geocom Bulletin/Programs, monthly: London, Geosystems (Lea Associates).

Abstracts and information on mathematical geology, exploration techniques, and computer methods in geoscience.

Geomechanics Abstracts, quarterly: Oxford, England, The Pergamon Press.

Successor to *Rock Mechanics Abstracts*. Combined in 1974 with issues of the *International Journal of Rock Mechanics and Mining Sciences*.

Geotechnical Abstracts, monthly: Essen, German National Society of Soil Mechanics and Foundation Engineering.

Includes engineering geology, site investigation, soil-and-rock mechanics. With "Geodex" punched keyword cards.

I.M.M. Abstracts, bimonthly: London, Institution of Mining and Metallurgy.

Includes economic geology, mining, mineral processing.

Mineralogical Abstracts, quarterly: London, Oxford University Press.

USSR Scientific Abstracts, periodically, and *East European Scientific Abstracts*, periodically: Washington, Joint Publications Research Service; Government Printing Office.

C. Guides to Regional Geologic Information

In addition to the sources cited in A and B, there are the following guides to regional information:

Beatty, W. B., Mineral resources data in the western states: Palo Alto, California, Stanford Research Institute, 1962.

Earth Sciences Research Catalog: Tulsa, Oklahoma, University of Tulsa
For the entire United States; indexed by area.

Geological Field Trip Guidebooks for North America. Washington, American Geological Institute, 1968.

Ridge, J. D., Selected bibliographies of hydrothermal and magmatic mineral deposits
Boulder, Colorado, Geological Society of America Mem. 75, 198 p., 1958.

Ridge, J. D., Annotated bibliographies of mineral deposits in the Western Hemisphere:
Boulder, Colorado, Geological Society of America Mem. 131, 681 p., 1972.

Ridge, J. D., Annotated bibliographies of mineral deposits in Africa, Asia (exclusive of the USSR), and Australia: Oxford, England, The Pergamon Press, 1976, 545 p.

Many countries have abstract journals devoted to their specific regions, for example,

British Geological Literature, new series, quarterly: London, Brown's Geological Information Service Ltd.

Most countries and states publish bibliographies, indexes and summaries of information in their areas from time to time. Beginning in 1963, summary volumes on mineral resources were prepared for each western state in the United States by the U.S. Geological Survey in cooperation with state geological and mining agencies; these reports contain extensive bibliographies. Example:

Mineral and Water Resources of New Mexico: New Mexico Bureau of
Mines and Mineral Resources Bull. 87, 437 p., 1965.

Gazetteers are published by most national and state governments. The U.S. Board of Geographic Names has compiled *gazetteers* for each foreign country.

D. Sources of Unedited Geologic Data

Many state and national bureaus of mines and geological surveys have preliminary reports, project files, and raw numerical data on open file for public inspection.

Open-file reports of the U.S. Geological Survey can be examined in Reston, Va., Denver, Colo., Menlo Park, Calif., and in the nearest district office to the area involved. They can also be examined in the offices of the appropriate state bureaus of mines, and copies can sometimes be made for the user at local blueprinting service companies.

Open-file reports of the Geological Survey of Canada can be examined in Ottawa and at the appropriate provincial departments of mines. In some cases, U.S. and Canadian geological survey open-file data in printed form, micromedia, or on magnetic tapes can be ordered by mail from the government or from a service company.

Appendix B, cont'd

E. Status Reports on Mines and Mining Districts

The Minerals Yearbook, annually: Washington, U.S. Bureau of Mines.

Contains state and country summaries, with news of developments at major mines as well as commodity reviews.

Mineral Trade Notes, monthly: Washington, U.S. Bureau of Mines.

Includes news of developments in foreign mining areas.

Annual summaries and yearbooks are published by most national and state bureaus of mines and also by some regional mining associations. These generally contain district-by-district reviews of mining progress. Examples:

Canadian Minerals Yearbook, annually: Ottawa.

Geology, Exploration and Mining in British Columbia, annually: Vancouver.

Mining Yearbook, Colorado Mining Association, annually: Denver.

Annual review issues of mining magazines contain summary comments on major mines and districts. The coverage may be worldwide or may be confined to a particular "home" area. Good sources of international status reports are the annual review numbers of the *London Mining Journal* (by commodity and country), *Engineering and Mining Journal* (by commodity), and *Mining Engineering* (by commodity). *Annales des mines* carries several annual summaries, such as the fairly detailed "Panorama de l'industrie minière du continent africain."

F. Mining Company Information

Coal Mine Directory of the United States and Canada, annually: New York, McGraw-Hill Book Co.

E/MJ International Directory of Mining and Mineral Processing Operations, annual: New York, Engineering and Mining Journal.

Jane's World Mining: Who Owns Whom: New York, McGraw-Hill Book Co.

Information on joint ventures, subsidiaries, investments, and management control.

Mines Register, annually: New York, American Metal Market Co.

Western Hemisphere mines.

Mining Companies of the World, annually: London, Mining Journal Books Ltd.

Mining International Year Book, annually: London, Walter B. Skinner Co.

Includes information on capitalization, operating properties, and some reserve figures.

Pit and Quarry Directory of Nonmetallic Minerals Industries, annually: Chicago, Pit and Quarry Publications.

For more detail on the operations of corporate firms, there are annual reports available from companies, "10-K" reports on file in major libraries, and the *F. and S. International and Business Periodicals Index* mentioned in IIA.

Appendix B, cont'd.

For current developments, three additional sources are:

- Moody's Industrial Manual—American and Foreign*, weekly, annually: New York, Moody's Investor's Service
- Standard and Poor's Corporation Records*, daily, monthly, annually: New York, Standard and Poor's Corporation.
- The Wall Street Journal Index*, monthly: Princeton, N.J., Dow Jones Books

G. Mineral Commodity Orientation and Production Data

In addition to the commodity reviews in magazines and national minerals yearbooks there are:

- Brobst, D., and Pratt, W., United States mineral resources: U.S. Geological Survey Prof. Paper 820, 722 p., 1973.
- Canada Department of Energy, Mines and Resources, Mineral Resources Branch, Mineral reports, mineral surveys, and mineral information bulletins, time to time: Ottawa
- Canada Geological Survey, Economic geology reports, time to time: Ottawa.
- Chemical Market Abstracts*, monthly: New York, Foster D. Snell Inc.

For "chemical" industrial minerals.

Department of Trade and Industry, Mineral dossiers, time to time: London.

Examples: No. 1, Fluorspar, 1971; No. 9, Tin, 1974.

Industrial Minerals, monthly: London, Metal Bulletin Ltd.

Keystone Coal Industry Manual, annually: New York, McGraw-Hill Book Co.

LeFond, S. J., ed., *Industrial minerals and rocks*, ed. 4: New York, Am. Inst. Mining Metall. Petroleum Engineers, 1360 p., 1975.

Metals Analysis and Outlook, twice annually: London, Charter Consolidated Ltd.

For major metals, a market analysis and forecast.

Metals Statistics, annually: New York, American Metal Market Co.

For each major metal, a profile, news highlights, and international trade.

U.S. Bureau of the Census, *Census of the mineral industries*, each 4 years: Washington.

Production statistics by county rather than mining district.

U.S. Bureau of Mines, *Commodity data summaries*, annually: Washington.

U.S. Bureau of Mines, *Materials surveys*, published from time to time: Washington.

For individual commodities, such as copper, nickel, lead.

U.S. Bureau of Mines, *Mineral facts and problems*, each 5 years: Washington.

Yearbook, American Bureau of Metal Statistics: New York.

H. National and State Mineral Policy

Up-to-date information on United States mineral policy is published in

Annual Report of the Secretary of Interior under the Mining and Minerals Policy Act of 1970: Washington, Government Printing Office.

Includes an appendix with status reports on supplies of each major mineral.

For foreign mining districts, *Mineral Trade Notes* and the annual review numbers of mining magazines mentioned under "Status Reports" carry news of developments in mineral policy.

AGID News, the quarterly newsletter of the Association of Geoscientists for International Development (Memorial University, St. John's, Newfoundland), also reports on changes in mineral policy involving "third-world" nations.

Journals of regional trade interest, such as *Africa Research Bulletin* (London), contain special sections on minerals and mineral policy.

A source of current bibliographic citations to government pamphlets and reports dealing with economic aspects of world regions and areas is:

Public Affairs Information Service Bulletin, monthly: New York, Public Affairs Information Service Inc.

For a very practical summary of history, economy, and political conditions in foreign countries, there are:

American University, Area handbooks series, time to time: Washington, Government Printing Office.

Compiled for individual countries by the American University.

U.S. Department of State, Background notes, time to time: Washington, Government Printing Office.

Brief summaries prepared by the U.S. Department of State for individual countries: up-dated frequently.

For mineral land laws in the United States, most western states issue "legal guides to prospectors" and digests of mining laws. For American mining law in general, there is a treatise compiled by the Rocky Mountain Mineral Law Foundation, American law of mining: Albany, N.Y., Mathew Bender Co. (5 volumes), 1960 with up-date.

For foreign mining laws, a series of U.S. Bureau of Mines Information Circulars, 1970-1974, includes:

- I.C. 8482, Western Hemisphere
- I.C. 8514, East Asia and Pacific
- I.C. 8544, Near East and South Asia
- I.C. 8610, Africa
- I.C. 8631, Europe.

III. INFORMATION RETRIEVAL SYSTEMS AND LITERATURE

The specific use of information retrieval systems in geology and mining is discussed in the following:

Bergeron, R., Burk, C. F., Jr., and Robinson, S. C., eds., Computer-based storage, retrieval, and processing of geological information, Section 16, International Geological Congress, 24th Session, Canada, 1972: Ottawa 222 p., 1972.

Calkins, J. A., Kays, O., and Keefer, E. K., CRIB—The mineral resources data bank of the U.S. Geological Survey: Washington, U.S. Geological Survey Circ. 581, 39 p., 1973.

Eimon, P. I., and Morris, D. B., An introductory review—data storage and retrieval, in Weiss, A., ed., A decade of digital computing in the mineral industry: New York, Am. Inst. Mining, Metall. Petroleum Engineers, pp. 277-283, 1969.

Fabbn, A. G., Design and structure of geological data banks for regional mineral potential evaluation: Canadian Mining Metall. Bull., v. 68, no. 70, pp. 91-98, 1975.

Hubaux, A., A new geological tool—the data: Earth Science Reviews, v. 9, pp. 159-196, 1973.

Hutchison, W. W. (chmn.), Computer-based systems for geological field data: Canada Geol. Survey Paper 74-63, 99 p., 1975.

Laffitte, P., *Traité d'information géologique*: Paris, Masson et Cie., 624 p.

Three periodicals concerned with information retrieval are of special interest to geologists:

Bulletin signalétique 101—Science de l'information, documentation, monthly: Paris, Centre de Documentation de Centre National de la Recherche Scientifique.

Includes a section on geology.

Geoscience Documentation, bimonthly: London, Geosystems (Lea Associates).

Journal for geology librarians and information specialists. Includes, in v. 1, no. 1, July 1969, a complete list of geoscience periodicals; up-dated in each subsequent issue.

Proceedings of the Geoscience Information Society, annual: Washington, American Geological Institute.

Some information retrieval systems in current use are:

**Canadian Index to Geoscience Data*, citations to Canadian localities and data: Ottawa, Canadian Centre for Geoscience Data.

*CAN/SDI, Canadian Selective Dissemination of Information, a profile service: Ottawa, Canada Geological Survey.

*COMPENDEX, and ORBIT, based on the *Engineering Index*: Santa Monica, California, System Development Corporation.

*CRIB, Computerized Resources Information Bank. Used within the U.S. Geological Survey, Washington, D.C.

*DATRIX, Direct Access to Reference Information, theses and dissertations: Ann Arbor, Michigan, University of Michigan.

**Geo-Archives*: London, Geosystems (Lea Associates Ltd.).

**GEODAT*, numerical results produced by laboratories in the Geological Survey of Canada, chemical, spectrographic, and age data. Available to users in the private sector. Geological Survey of Canada, Ottawa.

**Geo Ref*, a geoscience-oriented service provided by the American Geological Institute and the Geological Society of America; files date from 1966.

**GRASP*, Geologic Retrieval and Synopsis Program. Used within the U.S. Geological Survey, Washington, D.C.

- **MANIFILE*, data on the world's nonferrous metallic deposits⁷ Winnipeg, University of Manitoba.
- **PASCAL*, Programme appliqué à la sélection et à la compilation automatique de la littérature: Paris, Centre National de la Recherche Scientifique.
- **RASS*, Rock Analysis Storage System. Used within the U.S. Geological Survey. Files not available to the public but some data are released on magnetic tape. Washington, D.C.
- **SSIE*, Smithsonian Science Information Exchange; information on research in progress: Washington, Smithsonian Institute.

IV. SOURCES OF MAPS AND AERIAL PHOTOGRAPHS

A Topographic Maps

About 90 percent of the United States is covered by 1:62,500 (15-minute quadrangle) to 1:24,000 (7½-minute quadrangle) topographic mapping. Indexes to topographic mapping in each state are published quarterly by the U.S. Geological Survey. These and the topographic maps are obtainable by mail from the U.S. Geological Survey offices in Arlington, Virginia, for areas east of the Mississippi and in Denver, Colorado, for the western states. Copies of U.S. Geological Survey topographic maps and advance prints of preliminary quadrangle maps are also available (although not by mail) from district U.S. Geological Survey offices and from state geological surveys and bureaus of mines at the addresses shown by Wood (1973), Given (1973), and Ward and Wheeler (1972).

Smaller scale maps, such as the AMS 1:250,000 series, state-by-state 1:500,000 contour maps, and U.S. area sheets of the International Map of the World at 1:1 million, are available from the U.S. Geological Survey.

Small-scale topographic maps of foreign areas are also available in the United States. Total world coverage at 1:2 million and 1:1 million and partial coverage at 1:500,000, 1:250,000, and 1:200,000 are available from the Defense Mapping Agency Topographic Center in Washington. Aeronautical charts with contours and shaded relief topography are available for the entire world at 1:1 million (operational navigation charts) and for a large part of the world at 1:500,000 (pilotage charts) from the National Ocean Survey, Aeronautical Chart and Information Center, Washington.

Larger scale topographic maps for foreign areas, 1:100,000 to 1:10,000, are available from the national topographic surveys and cartographic offices listed in the Worldwide Directory of National Earth-Science Agencies, U.S. Geological Survey Circ. 716, 1975. A United Nations publication, *World Directory of Map Collections*, 1976, gives the location and extent of map and aerial photograph library holdings in 45 countries. New map coverage, topographic and some geologic, is listed annually in the publication *Bibliographie cartographique internationale*. For quick purchasing, there are private interna-

tional map companies that publish catalogs with index maps showing available coverage at various scales. Two of these companies are Geocenter in Stuttgart, Germany, and Edward Stanford Ltd. in London, England.

B. Geologic and Geophysical Maps

Government geologic mapping in the United States covers most of the country at a scale of 1:500,000 (state maps), about 40 percent of the country at 1:250,000, and about 25 percent of the country at 1:62,500 to 1:24,000. Unlike topographic mapping, some of this has been done by the state geological surveys; in addition, some areas have been mapped for universities by candidates for advanced degrees. Even though the maps are scattered through federal, state, and scientific association publications, most states have an updated index to geologic mapping compiled by the U.S. Geological Survey or by the state bureau of mines.

The principal U.S. Geological Survey large-scale map series are:

Coal Investigation Maps

Geologic Quadrangle Maps. This series is a continuation of the *Geologic Folios* published between 1894 and 1946.

Geophysical Investigations Maps. This series includes aeromagnetic and radiometric maps at 1:62,500 and 1:24,000 scale.

Hydrologic Investigations Maps

Mineral Investigations Field Studies Maps. This series includes preliminary tectonic, metallogenic, mineral deposits, and geological maps.

Mineral Investigations Resource Maps. These are mineral deposit maps.

Miscellaneous Geological Investigation Maps. This series includes photo-geologic maps, foreign country maps, and paleotectonic maps.

Oil and Gas Investigations Maps.

Large-scale foreign geologic maps are listed in many of the publications listed under "bibliographies and indexes in current use." The primary subject listing is generally by region or area, the second or tertiary heading is "maps." *Bulletin signalétique* (Section 224) and *Geoabstracts* (Section G) also list large-scale geologic maps.

Foreign geologic map coverage, 1:250,000-1:10,000, is summarized for individual countries from time to time in the quarterly journal *Geological Newsletter*, published by the International Union of Geological Sciences, Haarlem, The Netherlands. The Commission for the Geological Map of the World, 74 Rue de la Federation, Paris, publishes up-to-date bulletins on the activities of national geological surveys, including lists of new maps.

Geologic maps and indexes to geologic mapping can be obtained from the national bureaus listed in *Geological Newsletter* and in U.S. Geological

Survey Circ. 716 or, as with topographic maps, quick service can be obtained (providing the maps are available) from the private map companies listed under "Topographic Maps" or from Telberg Geological Map Service, Sag Harbor, New York 11963.

Magnetic, radioactivity, and gravity maps are available from several government geological surveys. Common scales for national gravity maps are 1:500,000 and 1:250,000; for aeromagnetic and aeroradioactivity maps, 1:50,000 and 1:25,000.

C. Aerial Photography and Spacecraft Imagery

Aerial photography coverage in the United States is shown on the U.S. Geological Survey quarterly indexes to topographic mapping for each state. Smaller scale indexes to aerial photography coverage of the entire country are also published from time to time. Indexes and advice on coverage by government agencies for specific areas can be obtained from the National Cartographic Information Center, U.S. Geological Survey, National Center (STOP 507), Reston, Virginia 22092.

Where photographs are held by another government agency, such as the Forest Service or the Soil Conservation Service, flight line maps, photo index sheets, and copies of the photographs can be obtained directly from the agency. Forest Service and Soil Conservation Service district offices, some universities, and some state geological surveys have aerial photographs on open file for their specific areas; these may be inspected and the exposure numbers can be selected for immediate purchase by mail without waiting for index sheets.

The U.S. Geological Survey EROS Data Center, Sioux Falls, South Dakota 57198, is the source for copies of geological survey aerial photographs, NASA photography and imagery, Landsat imagery, and Skylab photography and imagery. The abbreviations here are: EROS = Earth Resources Observation Systems; NASA = National Aeronautics and Space Administration; and Landsat = the former ERTS, Earth Resources Technology Satellite. Satellite imagery is available on magnetic tape and in photographic form. Standard catalogs and film strips as well as transparencies, paper prints, enlargements, and state image maps are available. A geographic search and inquiry system provides free information on specific photographic coverage. EROS applications assistance facilities and data reference files are located at more than a dozen offices throughout the United States.

Foreign aerial photography is generally obtainable from the national mapping, cartographic, and geographic offices listed in U.S. Geological Survey Circ. 716. Most countries publish indexes to aerial photographic coverage. In some countries, photographs are on open file at a central library; in others, access to aerial photography is closely restricted.

V. INFORMATION BY DIRECT INQUIRY

The headquarters and field offices of government geological surveys, bureaus of mines, and departments of natural resources are the prime locations for obtaining unpublished information and advice regarding new exploration areas. There are, in addition, some less obvious sources of geologic and mining information, such as:

- Newspapers (archives and current interest "clipping" services)

- Railroads (land and development offices)

- Regional development associations and commissions (example: Tennessee Valley Authority)

- Research foundations and institutes (example: Stanford Research Institute)

- State historical societies (archives)

- State mining associations

- Universities.

Preliminary information for foreign exploration programs can be obtained from:

- Country and regional trade associations

- Foreign embassy commercial officers in the United States

- National mining corporations (example: SONAREM, Algeria)

- United Nations Development Program, Office of External Relations,
United Nations, New York

- United States embassies in the foreign area

- United States State Department foreign area officers.

3 3
OF / DE

Country Mine Principal Material	Reserves (metric tons in thousands)	Grade (percent)	Recoverable Mineral (a) (metric tons in thousands)	Value (b) (U.S. \$ millions)
<u>Somalia</u> Mudugh Area Uranium	-	-	4,820	319 (c)
<u>Sudan</u> Hadrat en Nahas Copper	8,700 (e)	4.0	282	426 (d)
<u>Mexico</u> Caridad Copper	734,000	0.7	4,162	6,293 (d)
<u>Malaysia</u> Mamut Copper	178,000	0.48	692	1,046 (d)
<u>Chile</u> Palambras Copper	248,000	0.78	1,567	2,369 (d)
<u>Panama</u> Petaquilla and Botija Copper	300,000	0.7	1,701	2,572 (d)
<u>Ecuador</u> Chaucha Copper	60,000	63	340	514 (d)
<u>Guinea</u> Mt. Nimba Iron	400,000	36	486,000	2,741 (f)
<u>Upper Volta</u> Tambou Manganese	12,000	0.4 kg/m ³	9,720	793 (g)
<u>Indonesia</u> Bangka Tin	63 million m ³	0.22 kg/m ³	20	172 (h)
<u>Burma</u> Heinze Basin Tin	31 million m ³	0.22 kg/m ³	6	52 (h)
<u>Solomon Islands</u> Rennell Island Bauxite	30,000	43	24,300	364 (i)
<u>Burundi</u> Gitaga Area Nickel	116,000	1.44	1,228	6,321 (j)
<u>Morocco</u> Berrechid Basin Salt	3,000,000	98.6	2,430,000	1,822 (k)
				26,004

(a) Assuming a ten percent loss in mining and ten percent in beneficiation. Where no beneficiation has been involved, ten percent has been allowed for shipping losses.

(b) At point of sale to end users except for bulk materials.

(c) Based on \$30 per pound uranium (U₃O₈).

(d) Based on United States producer delivered price of refined copper, February 1977.

(e) Reserves measured only to the indicated and inferred stage; they are considered admissible as the potential for considerably greater tonnages is high.

(f) Based on Lake Superior Old Range ore at lake ports as given in Engineering and Mining Journal, January 1977, discounted by 75 percent.

(g) Based on \$15 per ton.

(h) Based on price of cathode nickel given in Engineering and Mining Journal, January 1977.

(i) Based on \$3 per ton discounted by 75 percent.

The value assigned to a mineral deposit has been obtained by multiplying the units of metal in the ground by the current market price and adjusting downward (as will be explained later). Admittedly, this is a simplistic approach. However, in this instance a number of deposits with a wide variety and mixes of commercial minerals are being considered. They are located in different countries, each with its distinctive level of development - economic, political, and physical. In effect, the variables predominate and the constants are few and far between. Under such circumstances, it is manifestly impossible to obtain the parameters needed for more sophisticated analyses such as discounted cash flow.

Investment in Mineral Projects Assisted by the United Nations Development Program (a)
A. Executed by the United Nations (b)

	Mineral Exploration			Institution Building			Other		
	# of Projects	UNDP	Government	# of Projects	UNDP	Government	# of Projects	UNDP	Government
		(thousands U.S. \$)	(thousands U.S. \$)		(thousands U.S. \$)	(thousands U.S. \$)		(thousands U.S. \$)	(thousands U.S. \$)
Argentina	3	3669	6749	-	-	-	-	-	-
Bahrain	2	1001	702	1	491	233	-	-	-
Bolivia	4	4389(c)	2179	2	2043	2206	-	-	-
Brazil	1	103	-	-	-	-	-	-	-
Burma	4	3613	1441	1	213	-	2	1818	431(d)
Burundi	2	3218	304	-	-	-	-	-	-
Central African Republic	1	246	43	-	-	-	-	-	-
Chad	1	876	-	-	-	-	-	-	-
Chile	3	5377	3064	-	-	-	-	-	-
Colombia	5	3034	171	-	-	-	-	-	-
Congo	1	776	548	-	-	-	-	-	-
Costa Rica	1	124	81	-	-	-	-	-	-
Cyprus	1	1340	1993(e)	-	-	-	-	-	-
Democratic Yemen	1	123	-	-	-	-	-	-	-
Dominican Republic	1	2290	(c)	-	-	-	-	-	-
Ecuador	4	4013	836	1	987	373	-	-	-
Egypt	2	2969	3459	-	-	-	-	-	-
El Salvador	1	640	354	-	-	-	-	-	-
Ethiopia	1	1246	214	1	1440	4814	-	-	-
Gabon	2	467	242	-	-	-	-	-	-
Ghana	4	1493	390	-	-	-	-	-	-
Guatemala	1	877	697	-	-	-	-	-	-
Guyana	1	806	410	1	679	384	-	-	-
Guinea Bissau	1	149	134	3	443	144	-	-	-
Guyana	2	1530	1691	-	-	-	-	-	-
Haiti	2	1436	431	-	-	-	-	-	-
Honduras	1	1033	378	-	-	-	-	-	-
India	5	2903	1046	2	1793	1979	-	-	-
Indonesia	1	1080	2381	-	-	-	-	-	-
Iran	-	-	-	3	2292	6194	-	-	-
Israel	1	493	-	-	-	-	-	-	-
Ivory Coast	2	1743	830	-	-	-	-	-	-
Jordan	1	898	637	1	423	393	-	-	-
Kenya	1	671	409	-	-	-	-	-	-
Lesotho	4	2091	574	-	-	-	-	-	-
Liberia	1	821	74	-	-	-	-	-	-
Madagascar	1	1492	819(e)	-	-	-	-	-	-
Malawi	2	442	222	-	-	-	-	-	-
Malaysia	1	170	790(f)	-	-	-	-	-	-
Mali	1	179	-	-	-	-	-	-	-
Malta	1	317	69	-	-	-	-	-	-
Mauritania	-	-	-	1	387	347	-	-	-
Mexico	1	897	1830	-	-	-	-	-	-
Morocco	4	2726	3981	-	-	-	-	-	-
Nepal	-	-	-	2	1219	636	-	-	-
Nicaragua	1	738	355	-	-	-	-	-	-
Niger	2	1938	1034	-	-	-	-	-	-
Nigeria	1	346	491	-	-	-	-	-	-
Pakistan	2	1916	303(g)	-	-	-	-	-	-
Panama	3	1348	1071	-	-	-	-	-	-
Philippines	1	379	498	-	-	-	1	704	699(h)
Poland	1	993	2423	-	-	-	-	-	-
Republic of Korea	1	606	354	-	-	-	-	-	-
Rwanda	2	2173	403	-	-	-	-	-	-
Senegal	3	1788	1083	-	-	-	-	-	-
Solomon Islands	1	896	634	-	-	-	-	-	-
Somalia	2	1444	1013(e)	-	-	-	-	-	-
Sudan	3	2179	938(c)	1	19	-	-	-	-
Swaziland	1	463	372	-	-	-	-	-	-
Thailand	1	280	134	-	-	-	-	-	-
Togo	1	1327	313(e)	1	370	170	-	-	-
Trinidad and Tobago	1	443	100	-	-	-	-	-	-
Tunisia	1	922	500	-	-	-	-	-	-
Turkey	2	1563	3682	1	467	111	-	-	-
United Republic of Cameroon	1	314	208	-	-	-	-	-	-
United Republic of Tanzania	2	961	347	-	-	-	-	-	-
Upper Volta	3	3133	1241(e)	-	-	-	-	-	-
Yugoslavia	1	438	277	-	-	-	-	-	-
Zaire	1	803	73	-	-	-	-	-	-
Zambia	1	831	746	-	-	-	-	-	-
Subtotals	123	93,184	39,334	22	13,439	18,234	3	2,522	1,150

source: Carman, Obstacles to Mineral Development,
pages 49, 50.

Appendix D.

Kenyan Mines and Geology Department
i. Finances and Expenditures, 1973 - 1978

	K£'000					
	1973/74	1974/75	1975/76	1976/77	1977/78	Total
Recurrent Expenditure	136.0	150.0	165.0	180.0	200.0	831.0
Development Expenditure	36.0	450.0	1,000.0	793.5	793.5	3,073.0
Total Expenditure	172.0	600.0	1,165.0	973.5	993.5	3,904.0
Estimated Foreign Aid	—	400.0	850.0	159.0	328.0	1,737.0
Local Finance	172.0	200.0	315.0	814.5	665.5	2,167.0

Projects and Expenditures in the
ii. Kenyan Mines and Geology Department

	Expenditure in K£'000					
Project Name and Number	1973/74	1974/75	1975/76	1976/77	1977/78	Total 1974/78
2703020000 00 Provincial Offices Development Total Expenditure	—	—	35.0	35.0	36.0	106.0
2703030001 00 Base Metals Investigation Total Expenditure	—	14.3	14.3	—	—	28.5
Import Content	—	4.0	4.0	—	—	8.0
2703030002 00 Copper Investigation Total Expenditure	—	7.3	7.3	—	—	14.6
Import Content	—	2.0	2.0	—	—	4.0
2703030003 00 Western Kenya Gold Drilling Total Expenditure	—	27.3	27.2	—	—	54.5
Import Content	—	16.0	—	—	—	16.0

source: Republic of Kenya, Development Plan, 1974 - 1978

Appendix D, cont'd.

Project Name and Number	Expenditure in K£'000					
	1973/74	1974/75	1975/76	1976/77	1977/78	Total 1974/78
2703030004 00						
Prospecting Units						
<i>Total Expenditure</i>	—	—	—	71.5	71.5	143.0
<i>Import Content</i>	—	—	—	31.0	31.0	62.0
2703030005 00						
Geochemical Surveys						
<i>Total Expenditure</i>	—	—	—	37.5	37.5	75.0
<i>Import Content</i>	—	—	—	7.0	7.0	14.0
2703030006 00						
Geophysical Surveys						
<i>Total Expenditure</i>	—	—	—	34.5	34.5	69.0
<i>Import Content</i>	—	—	—	13.0	13.0	26.0
2703030007 00						
Mineral Dressing						
<i>Total Expenditure</i>	—	—	—	16.3	16.3	35.6
<i>Import Content</i>	—	—	—	—	—	—
2703030009 00						
Mineral Section						
<i>Total Expenditure</i>	—	—	—	5.0	6.0	11.0
<i>Import Content</i>	—	—	—	1.5	—	1.5
2703030010 00						
Building Materials Section						
<i>Total Expenditure</i>	—	—	—	—	1.5	1.5
2703030011 00						
Fuels Section						
<i>Total Expenditure</i>	—	—	—	8.2	8.3	16.5
<i>Import Content</i>	—	—	—	3.5	—	3.5
2703030012 00						
Mineral Economics Section						
<i>Total Expenditure</i>	—	—	10.5	10.5	10.5	31.5
<i>Import Content</i>	—	—	1.5	—	—	1.5
2703030013 00						
Mineral Feasibility and Survey						
<i>Total Expenditure</i>	—	—	142.0	142.0	142.0	426.0
<i>Import Content</i>	—	—	35.0	20.0	—	55.0
2703030201 00						
Seismology/Vulcanology						
<i>Total Expenditure</i>	—	—	—	20.2	20.3	40.5
<i>Import Content</i>	—	—	—	12.5	12.5	25.0
2703030202 00						
Geological Mapping						
<i>Total Expenditure</i>	—	—	50.0	75.0	75.0	200.0
<i>Import Content</i>	—	—	20.0	30.0	—	50.0
2703030203 00						
Laboratories Development						
<i>Total Expenditure</i>	—	—	—	42.0	42.0	84.0
<i>Import Content</i>	—	—	—	36.0	30.0	66.0
2703030204 00						
Mineralogy Research						
<i>Total Expenditure</i>	—	—	18.0	35.0	35.0	88.0
<i>Import Content</i>	—	—	10.0	25.0	25.0	60.0
2703030205 00						
University Research						
<i>Total Expenditure</i>	—	5.0	10.0	10.0	15.0	40.0

Appendix D, cont'd.

PROJECTS IN MINES AND GEOLOGICAL DEPARTMENT PROGRAMME (Contd.)

Expenditure in K£'000

Project Name and Number	1973/74	1974/75	1975/76	1976/77	1977/78	Total 1974/78
2703030206 00						
Technical Records						
<i>Total Expenditure</i>				9.5		9.5
<i>Import Content</i>				1.0		1.0
2703030207 00						
Stratigraphic Nomenclature						
<i>Total Expenditure</i>					1.5	1.5
2703030301 00						
Advanced Training Univ						
<i>Total Expenditure</i>		1.3	1.3	1.3	1.3	5.0
2703030302 00						
Mineral Technician Training Univ						
<i>Total Expenditure</i>				0.8	0.8	1.6
2703030303						
In-Service Training						
<i>Total Expenditure</i>			45.0	47.0	47.0	139.0
<i>Import Content</i>			1.5	1.5	1.5	4.5
2703030304 00						
Airborne Geophysical Survey						
<i>Total Expenditure</i>		400.0	898.5			1,298.5
<i>Import Content</i>		400.0	872.0			1,272.0

BIBLIOGRAPHY

Primary Documents

- United Nations General Assembly, Permanent Sovereignty Over Natural Resources,
A/Res/1803/XVII December 19, 1962.
- _____, Declaration on the Establishment of a New Economic Order,
A/Res/3201/S-VI May 9, 1974.

Books and Monographs

- Bancroft, J., Mining in Northern Rhodesia, Bedford, U.K.: The Sidney Press, 1961.
- Blais, R.A., et al. Earth Sciences Serving the Nation, Ottawa: Information Canada, 1971.
- Bonini, W.E., et al. The Role of National Governments in Exploration for Mineral Resources, Ocean City, New Jersey: the Littoral Press, 1964.
- Bosson, R. and Varon, B., The Mining Industry and the Developing Countries, New York: Oxford University Press, 1977.
- British - North America Committee, Mineral Development in the Eighties, New York: 1976.
- Brooks, D.B., Resource Economics: Selected Works of O. C. Herfindahl, Baltimore: Resources for the Future Inc., 1974.
- Brooks, P.R., Geobotany and Biogeochemistry in Mineral Exploration, New York: Harper and Row, 1972.
- Brown, R., and Faber, M., Some Policy and Legal Issues Affecting Mining Legislation and Agreements in African Commonwealth Countries, London: Commonwealth Secretariat, 1974.
- Bruneau, T.C., et al. CIDA: The Organization of Canadian Overseas Assistance, Montreal: McGill University, 1979.
- Carman, J., Obstacles to Mineral Development, B. Varon, editor, New York: Pergamon Policy Studies, 1979.
- Cobbe, J., Governments and Mining Companies in Developing Countries, Boulder, Colorado: Westview Press, 1979.
- Cooper, C., Science, Technology and Development, London: Frank Cass Limited, 1973.
- Crommelin, M., and Thompson, A.R., Mineral Leasing as an Instrument of Public Policy, Vancouver: University of British Columbia Press, 1977.

Bibliography (continued)

- Cunningham, G., The Management of Aid Agencies, London: Overseas Development Institute, 1974.
- Dobrin, A., Introduction to Geophysical Prospecting, Toronto: McGraw-Hill, 1960.
- Elbrond, J., Decision-Making in the Mineral Industry, Toronto: Canadian Institute of Mining and Metallurgy, 1971.
- Girvan, N., Corporate Imperialism: Conflict and Expropriation, White Plains, New York: M. E. Sharpe, Inc., 1976.
- Goulet, D., The Uncertain Promise, New York: International Development Organization, 1977.
- Govett, G.J.S., and Govett, M.H., World Mineral Supplies, New York: Elsevier Scientific Publishing Co., 1976.
- Gupta, R.K., Planning Natural Resources, New Delhi: Navayu Traders, 1971.
- Herfindahl, Natural Resource Information and Economic Development, Baltimore: Johns Hopkins University, 1969.
- _____, Resource Economics: Selected Works of O. C. Herfindahl, D. B. Brooks, editor, Baltimore: Resources for the Future, 1974.
- _____, and Kneese, A., Economic Theory of Natural Resources, Columbus, Ohio: Charles E. Merrill, 1974.
- International Bank for Reconstruction and Development, Kenyan Economic Memorandum, Report # 2331 KE Washington: 1979.
- International Geological Congress, Earth Science Aid to Developing Countries, Montreal: 1973.
- Kaplan, I., et al, Area Handbook for Kenya, Washington: American University, 1976.
- Laming, D. and Akajaiye, A., New Directions in Mineral Development Policies, Ibadan: the Caxton Press, 1979.
- Leavy, E.H., The Economic Development of Kenya, Baltimore: Johns Hopkins University Press, 1963.
- Lloyds Bank Limited, Economic Report: Kenya, London: 1977.
- MacKenzie, B.W., The Theory of the Mining Firm, Ann Arbor, Michigan: University Microfilms, 1977.
- Malhorta, S.P., Canadian Mineral Assistance and Private Investment, Ottawa: Department of Energy, Mines and Resources, 1974

Bibliography (continued)

- Mikesell, R.F., Foreign Investment in the Petroleum and Mineral Industries, Baltimore: Johns Hopkins University Press, 1971.
- _____, Non-Fuel Minerals: U. S. Investment Policies Abroad, Beverly Hills: Sage Publications, 1975.
- _____, New Patterns of World Mineral Investment, London: British - North America Committee, 1979.
- Moran, T., Multinational Corporations and the Politics of Dependence: Copper in Chile, Princeton: Princeton University Press, 1974.
- Murphy, E.J., History of Civilization in Africa, New York: Dell, 1972.
- Neale, E.R.W., Some Guides to Mineral Exploration, London: British Commonwealth Geological Survey, 1964.
- Nossin, J.J., Surveys for Development, Amsterdam: Elsevier Scientific Publications Limited, 1977.
- Ochala, S.A., Minerals in African Underdevelopment, London: Bogle - L'ouverture, 1975.
- Parasnis, D.S., Mining Geophysics, London: Elsevier Scientific Publications Limited, 1973.
- Peters, W.C., Exploration and Mining Geology, New York: J. Wiley and Sons, 1978.
- Smith, D., and Wells, L., Negotiating Third World Mineral Agreements, Cambridge, Mass.: Ballinger Publications, 1975.
- Sklar, R. L., Corporate Power in an African State, Berkeley, University of California Press, 1975.
- Smith, W.L., Remote Sensing Applications for Mineral Exploration, Stroudsburg, Penn.: Dowden, Hutchinson and Ross, Inc., 1977.
- Solo, R.A., Organizing Science for Technology Transfer in Economic Development, Ann Arbor, Michigan, Michigan State University Press, 1975.
- Stewart, F., Technology and Underdevelopment, London: MacMillan, 1977.
- Strassmann, W.P., Technological Change for Economic Development, New York: Cornell University Press, 1968.
- Szentes, T., The Political Economy of Underdevelopment, Kisdoo: Budapest Akademia, 1971.
- Taylor, M.C., Taxation for African Economic Development, London: Hutchinson Educational Limited, 1970.
- Tilton, J.E., The Future of Non-Fuel Minerals, Washington: Brookings, 1977.

Bibliography (continued)

Telford, W.M., et al., Applied Geophysics, London: Cambridge University Press, 1976.

United Nations, Mineral Resources Development with Particular Respect to the Developing Countries, New York: 1970.

_____, Negotiation and Drafting of Mining Development Agreements, London: Mining Journal Books, 1974.

United States National Academy of Sciences, Remote Sensing From Space: Prospects for Developing Countries, Washington: 1977.

Vogely, W.A., Economics of the Mineral Industries, New York: American Institute of Mining, Metallurgical and Petroleum Engineers, 1976.

Walton, W.C., Groundwater Resource Evaluation, New York: McGraw-Hill, 1970.

Warren, K., Mineral Resources, Devon: David and Charles Limited, 1973.

Articles

Armstrong, W., "The Future for Mining Investment in Africa", African Development, vol. 10, # 6, June, 1976.

Bailey, P.A., "Mineral Exploration Philosophy", Mining Congress Journal, vol. 58, # 4.

Bergsten, C.F., "The Threat from the Third World", Foreign Policy, # 11, Summer, 1973.

de Montbrial, T., "For a New International Economic Order", Foreign Affairs, vol. 54, # 1.

Derry, D.R., "Exploration Expenditures, Discovery Rates and Methods", Canadian Institute of Mining and Metallurgy Bulletin, vol. 63 # 695.

Espie, F.F., "The Bougainville Copper Project", Australian Institute of Mining and Metallurgy Proceedings, # 238, 1971.

Farmer, B.H., "The Environmental Sciences and Economic Development", Journal of Development Studies, vol. 7, # 3, 1971.

Ferguson, N., and Haclin, G., "Is There Enough Money in Mining", The Bankers, September, 1976.

Department of External Affairs, Government of Canada, "Resource Surveys - A Canadian Specialty", External Affairs, vol. XVIII, # B, 1966.

Bibliography (Continued)

- Heath, K., "Mineral Gains of World Mining", Optima, vol. 19, # 1.
- Hughes, H., "Mineral Exploitation: Economic Bents and Distribution of Gains", World Development, vol. 3 # 11, 1975
- Mackenzie, B.W., "Investment in Information for the Assessment of Mineral Value: Some Guidelines for Mineral Leasing Policy", in Crommelin and Thompson, Mineral Leasing as an Instrument of Public Policy.
- Mikdashi, Z., "Collusion Could Work", Foreign Policy, # 14, Spring, 1974.
- Powell, R.G., "LAMCO: A Case Study of a Concession Agreement", Proceedings of the American Society Of International Law, vol 61, 1967
- Ridge, J.D. , "Emerging Nations: Their Politics and Economics and the Future of Mineral Supplies", Journal of Metals, # 25, 1973.
- Rostad, O.H., "Changing Concepts, Approaches and Techniques in Mineral Exploration", Natural Resources Forum, vol. 3, # 3, 1979.
- Roberts, J., "Engineering Consultancy, Industrialization and Development", Journal of Development Studies, vol. 9, 1972.
- Sengupta, M., "International Trade in Minerals and Economic Development", Canadian Institute of Mining and Metallurgy Bulletin, vol. 69, # 774, 1976.
- Smith, B., "Security and Stability in Minerals Markets - the Role of Long Term Contracts", The World Economy, vol. 2, # 1, 1979.
- Takeuchi, K., et al, "Investment Requirements in the Non-Fuel Mineral Sector in the Developing Countries", Natural Resources Forum, vol. 1, # 3, 1977.
- Tilton, J., "The Impact of Market Instability for Mineral Materials", The World Economy, vol. 1, # 4, 1978.
- Varon, B. and Takeuchi, K., "Developing Countries and Non-Fuel Minerals", Foreign Affairs, vol. 52, # 3, 1974.
- Walthier, T.N. , "The Shrinking World of Exploration", Mining Engineering, vol. 28, # 4, 1976.
- Walton, K., "Satellite Remote Sensing of Natural Resources: Some Issues to be Resolves", Natural Resources Forum, vol.1, # 3, 1

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