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Application of Resource Assessment Data to Policy Decisions in Developing Countries

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Information about a nation's mineral resource potential is important in regional and national development planning. Unfortunately, it is usually not possible to determine the optimum levels of investment in mineral resource assessment activities in a developing country. In addition, there is a tendency for governments to initiate expensive resource assessment projects without an understanding of the types of decision that may be influenced by the assessment data. This paper examines ten major policy issues where decisions can be substantially influenced by resource assessment information. Governments can expect to increase their benefits from investment in resource assessment activities by linking resource assessments to specified policy decisions.

1. INTRODUCTION

A mineral resource assessment is a systematic attempt to evaluate discovered and undiscovered minerals of economic interest. An assessment may include a sequence of activities beginning with a broad-based regional appraisal of mineral resources and concluding with a detailed assessment of one or more subregions of greatest economic potential. Alternatively, a resource assessment can be undertaken at a particular stage of data accumulation. A first approximation of the mineral resources in a region can be made prior to any detailed geologic surveys by any one of a number of assessment techniques including extrapolation or analogy. Geologic maps, along with geochemical, geophysical, and drill core data, and if available, detailed feasibility studies of specific deposits, may be used to conduct a more detailed resource assessment. Expenditures for resource assessment activities vary widely, ranging from thousands to millions of US dollars, and taking a few days to several years to complete. In general, resource assessments use existing data in order to produce estimates of the quantity of economic minerals that may exist in an area. For use in economic planning, this information is generally converted into financial units.

The purpose of this paper is not to compare various resource assessment methodologies, but rather to illustrate how resource assessment estimates may be used in development planning. The focus throughout the paper is on governments of developing countries that are considering how much of their own financial resources to spend on mineral resource assessments. To introduce the reader to the major resource assessment

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treatment plant which was designed with a capacity of 3 mgd has never been operated at more than 30% of the capacity because of a gross over-estimation of the yield of the supply source. The over-pumping and associated saltwater contamination of aquifers has occurred in several islands.

With considerable financial and technical difficulties, water utility management in a small island environment is inevitably a frustrating experience, compounded by political interference and inadequate remuneration levels. A shortage of trained staff is therefore common, especially in critical areas such as financial and technical management.

Institutional deficiencies now represent a major obstacle to the financing of capital expansion and system improvement works which are so urgently required in many of the small Caribbean islands. Development banks and other aid agencies are understandably reluctant to provide financial assistance to institutions which are poorly managed and which are unable to generate adequate revenues to cover even essential operation and maintenance costs. Most of the utilities now find themselves in a vicious circle. As the quality of service deteriorates, public resistance to tariff increases become more vociferous and reinforces the already strong political resistance to these increases. In order to obtain financial assistance to expand and improve the quality of service, however, increased tariffs are required to ensure financial viability.

An ineffective approach to the conservation of water resources is common throughout the islands and is closely related to existing institutional deficiencies. This problem is further aggravated by the absence of clearly defined objectives in the area of water resources management and comprehensive legal codes for the control of land and water resources. With a general shortage of trained staff and limited finances, the functions which are crucial to the conservation of water resources are completely neglected. Freshwater lenses are therefore developed without a complementary monitoring programme to ensure that pumping wells do not become affected by saltwater contamination. There are no effective catchment controls and as a result, several catchment areas have become subject to flash floods, high sediment loads in streams, and a serious reduction in dry weather flows caused by indiscriminate deforestation. The effects of agricultural land use on water quality have not yet been systematically evaluated.

6. CONCLUSIONS

This paper has attempted to review the status, problems and strategies of water resources development in the smaller islands of the Caribbean. Because of small size water resources in these islands are severely limited in quantity and occur under unfavourable hydrological and topographical conditions. In some islands, surface streams are non-existent and groundwater is of poor quality. A heavy reliance is therefore placed on roof catchments and desalination.

Although some progress has been made in the islands in the development of water resources, a new and more efficient approach is now needed, especially in the management of water supply agencies and the conservation of water resources.

The need for a more efficient approach is demonstrated by the deteriorating situation in the water supply sector which manifests itself in poor planning and system operation procedures, a diminishing resource base and severe difficulties in obtaining financial assistance for capital expansion and system improvement works.

The immediate requirement is for well managed and financially viable institutions operating within a rational legal framework.

In the islands with serious supply deficiencies, there is some scope for the use of rainwater catchment schemes utilizing low cost materials both for the catchment and the storage facility. In this regard, there is a need for the dissemination of information on available materials which can minimize the cost of such schemes.

methodologies, brief descriptions are given below (Vogely, 1983):

(1) *Analogy Models.* There are two common assessment techniques in this category, geographic and geologic. Analogy by geography uses the known and evaluated resources of a well-explored, high-developed region, and applies the volume of discovered resources per unit area to lesser developed areas. This may provide an indication of the total amount of minerals to be discovered. Geologic analogy uses mineral production and reserve amounts from a highly developed area to predict the quantity of mineral resources to be found in geologically similar, underdeveloped regions. Resource assessments by analogy are relatively simple to do; however, they are dependent on sufficient mineral commodity data and, for geologic analogies, geologic information.

(2) *Time Rate Analysis.* This method is based upon the statistical observation that a mineral deposit generally exhibits a normal bell-shaped curve for production over the life of the deposit. If the bell-shaped function is assumed for production of a mineral from all deposits taken together, the time series of production compared to the time series of discoveries will indicate when production becomes greater than discoveries. Using the form of the bell-shaped curve, the inflection point of the production curve can be predicted, which in turn enables a calculation of lifetime production. This method was popular in the early 1970s for oil and gas estimates; however, it is not widely used today because of difficulties in generalizing from specific known deposits to all deposits.

(3) *Crustal Abundance Models.* This group of assessment techniques relates the crustal abundance of a mineral (the average amount of the mineral contained in a cubic mile of the earth's crust) to the ultimate recovery of that mineral. By using the cumulative production plus reserves for a mineral, and its crustal abundance as the basis, a relationship between tonnages of reserves and crustal abundance can be determined. The potential reserves for any mineral in a large cubic volume of the earth's crust can be estimated by using this relationship. Problems arise when using this type of assessment technique due to the uncertainty of the relationship between potential reserves and crustal abundance, and on the difficulty of estimating crustal abundance.

(4) *Deposit Modelling.* Deposit modelling uses the concept of geologic analogy. The estimation of the mineral resources of a specific geologic environment is based on an analysis of the physical characteristics of known and evaluated deposits in geologically similar environments. Variations used in oil and gas assessments include field size distributions and discovery rates (Clark, 1983). The accuracy of deposit model estimates is a function of the quality of the geologic data used and the understanding of the relationship between ore deposits and specific geologic environments.

(5) *Subjective Probability Analysis.* This is one of the most commonly used resource assessment methodologies, primarily because it is rapid and relatively inexpensive. In this type of analysis, the resource evaluation is based on a combination of iterative collective opinions, such as in the Delphi method. Resource estimates made directly by one or more geologists familiar with mineral occurrences in specific geologic regions are used to assess the potential of economic resources by region. The reliability of such estimates is a function of the available mineral resource information, and the knowledge and experience of the geologists.

Each one of these resource assessment methodologies has strengths and weaknesses. Selection of a particular assessment technique should depend on; (1) the type and form of information required by the assessment user; (2) availability of geological geochemical, geophysical, and drill core data; (3) financial and technical resources for the assessment; and (4) time available to complete the resource assessment.

Although most geologists and policy makers agree that knowledge about a nation's mineral resource potential is desirable, there is no general consensus on the type, amount, and timing of resource assessments to best meet the needs of decision makers. Considerable attention has been given to the important areas of developing and comparing various techniques for mineral resource assessments; however, failure to consider adequately the specific needs of government policy makers may have resulted in many mineral resource assessment studies in search of a

problem. It is tempting to justify resource assessments on the basis of their contribution to the general knowledge about a nation's mineral resources without consideration of the policy decisions that will result from the assessment. This problem is of particular concern in developing countries where severe constraints on financial resources and technical expertise are common. Mineral resource assessments conducted for the primary purpose of increasing knowledge can result in a misallocation both of governments funds and of technical expertise.

One way resource assessments can play a more effective role in the development planning and decision-making process of developing countries is by linking most assessment activities to specific policy questions. One problem that might result by doing this is that a government may fail to obtain an appreciation of the total resource potential of the nation. Therefore, some resource assessment activities should focus on evaluating national resource potential.

For regional or national mineral resource assessments based on geologic maps, a scale of 1:250 000 to 1:500 000 is required. The value of nationwide geologic maps larger than 1:250 000 in scale is questionable in cases where developing country governments are paying for the mapping. Large scale maps of 1:10 000 to 1:125 000 should be restricted to localized areas of high minerals potential.

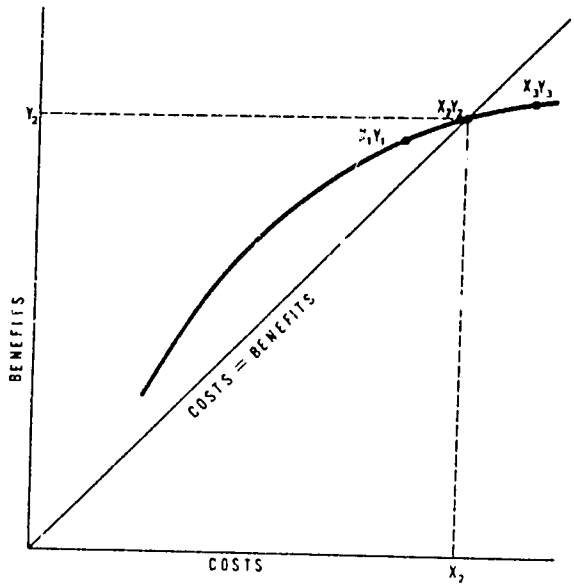

Fig. 1. The optimum level of expenditure for gathering resource information is X_2Y_2 where the present value of a unit of cost (expenditure) equals the present value of a unit of expected benefits (revenues). At points beyond X_2Y_2, such as X_3Y_3, a unit of cost generate less than a unit of benefits, and additional expenditures for information gathering are not justified. For points before X_2Y_2, such as X_1Y_1, a unit of cost produces more than a unit of benefits, therefore additional expenditures are justified.

12. OPTIMUM INVESTMENT IN MINERAL RESOURCE ASSESSMENTS

An important concern of development planners (generally economists and rarely geologists) is deciding how much money to spend on gathering mineral resource information. Most geologists will argue that more information is better; however, from an economic perspective, more information is not always better. Expenditures for obtaining resource information should continue as long as an additional unit of expenditure is expected to generate one or more units of benefits (benefits and costs discounted to the present). This is illustrated in Fig 1.

In practice, it is not possible to calculate the optimum levels of investment in gathering information about a nation's mineral resource potential. However, a partial solution to the question of how much governments should invest in resource assessments activities can be determined. If the types of policy decisions that are going to be based on resource assessment data are specified beforehand, geoscientists can focus their information collecting activities on increasing the amount of policy-relevant data. If this is done, estimates can be made of the minimum cost of obtaining the resource information needed to make those decisions. This can lead to an acceptable practical solution to the question of how much a government should invest in information gathering and analysis.

3. POLICY ISSUES INFLUENCED BY RESOURCE ASSESSMENT DATA

The following ten policy issues are important to

many governments of developing countries. Decisions concerning these issues can be directly affected by resoucre assessment data.

3.1 Ranking resource projects

Mineral resource projects can be ranked according to a number of criteria including size, economic potential, expected employment, possible linkages to other sectors of the economy, and/or prestige value. In the majority of cases mineral resource projects are examined with respect to their revenue-generating potential. From a government's perspective, the major objective is usually to maximize the net present value of its revenues. Determining the revenue-generating potential of a project is almost always difficult since the products of many resource assessments are in physical, rather than financial, units, and the estimates are subject to error.

Even with limited information, project rankings can often be made by using geologic and economic expertise to estimate the likely physical and financial characteristics of projects. The analysts may only have access to limited geochemical and/or geophysical data and a basic knowledge of mineral deposit sizes to guide their analysis. In other cases, detailed data may be available allowing greater accuracy in estimates.

3.2 Regional development planning

In planning for the long-term development of selected regions of a country, it is important to know the economic potential of these areas. Factors such as existing infrastructure, labor availability, and the agriculture, timber, and water resources of a region are usually included in regional development plans; however, rarely is systematic attention given to evaluating and including estimates of the undiscovered mineral resource potential of a region. The minerals information that may be included is usually restricted to an inventory of the known mineral deposits. Yet, in poorly-explored regions, the undiscovered mineral resources may be larger than the discovered resources. By ignoring this potential in long-term planning, there is increased risk that poor development choices will be made. Estimates of the mineral resource potential of an area can be incorporated into the planning of long-term infrastructure needs, such as roads, railroads, water supplies, plower plants, schools, and hospitals. At only modest additional costs, it may be possible to adjust the location and size of infrastructure facilities in order to increase exploration opportunities and promote minerals development in a region. This, in turn, increases the probability of greater economic development in a region. An example of using mineral resource assessment data in regional planning was the evaluation of the minerals potential of the areas bordering several possible railroad routes in the Canadian Northwest: the assessment demonstrated that the estimated mineral resource potential along one route was substantially larger than the alternatives (Harris *et al.*, 1970).

3.3 Diversification of regional economic and political power

A significant problem faced by some governments is the division of power between the central and regional governments. In cases where one region of a country produces a large share of the nation's economic wealth, this region tends to have a disproportionately large share of political power that can be divisive to national development and unity. Through diversification of economic activities, the dominance of any one region may be reduced. This is particularly relevant in smaller developing countries where a misallocation of government funds could result in an imbalance of economic development among regions.

Increased attention to mineral resource assessment activities in the less-developed regions increases the probability that undiscovered resources will be discovered and developed. In Papua New Guinea, the discovery and subsequent development of a major copper—gold deposit on Bougainville island appears to have substantially increased the political and economic power of the Bougainville provincial government. The subsequent discovery and development (currently in progress) of the major Ok Tedi gold—copper deposit in the Western province is likely to significantly reduce the influence of the Bougainville province.

3.4 Attracting investment

One commonly used argument in support of

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government expenditures on mineral resource assessments is that the resulting data will stimulate private sector interest in minerals exploration in the nation. The argument is valid; however, the problem is how to determine the necessary level of government expenditure to provide the appropriate catalyst for increased investment. Private companies want as much information supplied by government as possible; although in many cases additional information will have little additional influence on overall investment in mineral exploration in a country. The investment process in exploration is complex, and is a function not only of the availability of resource assessment data and geological information, but also of mineral commodity prices, terms for mineral investment, and perceived political stability in a country.

As a generalization, private companies desire basic geochemical, geophysical, and drill core data, along with geologic maps, and are less interested in broad-based regional assessment estimates. Companies usually want to do their own geological interpretation from basic data. High levels of private sector investment take place in some developing countries that have been geologically mapped at a 1:250 000 scale or smaller (for example, Papua New Guinea). Therefore, it does not appear that more detailed maps are necessary for accelerated private sector minerals exploration.

3.5 Establishing the Terms for Development of Mineral Deposits

Governments can either negotiate the terms for individual mineral developments or can establish terms in general legislation. In both cases, knowledge of the physical and economic characteristics of specific resources places government in a better position to establish terms for maximizing its expected benefits. The objective of some governments of developing nations is to establish the fiscal terms at a level such that the investor can achieve an expected internal rate of return from the project close to this target rate of return.

An example of this type of decision was encountered during negotiations for a petroleum agreement in an east African country in the late 1970s. A major petroleum company wanted to undertake a substantial petroleum exploration programme, but the company required that the government agree to terms for both exploration and development of any commercial discoveries prior to exploration. At the time, government officials did not know what fiscal terms would be in the best interest of the nation. A comparison of agreements from several other countries provided some guidance, but left government officials uncertain as to which agreement among the wide range of existing petroleum agreements was most appropriate for their country.

To solve the problem, a European petroleum consulting firm was hired to develop a petroleum field financial model to include the most probable range of commercial petroleum field sizes (30, 100 and 300 million barrels of recoverable petroleum). The range in petroleum field sizes and assumptions in costs were estimated by the consultants through the use of available geophysical data and through comparisons with geologically similar environments in other countries. Mineral resource economists evaluated several taxation regimes for the three petroleum field sizes in order to determine the taxation option that would meet the petroleum company's minimum profit criteria and technical concerns, while providing the maximum expected net present value of revenues to government. This financial model provided a foundation for proceeding with negotiations. The assessment provided an analytically defendable basis for the fiscal terms that were agreed upon in negotiations, an essential factor in obtaining cabinet-level government support for the agreement.

3.6 Reservation of Land Areas

For a number of reasons, governments may wish to restrict exploration and mining activities on selected areas of land. These may include the establishment of a state or national park, the construction of a major infrastructure project such as a dam, or the building of a military base. A further reason for limiting minerals development may be to allow time for a government to evaluate more thoroughly the options for development of selected land areas.

In each of these cases, an assessment of the minerals potential of the land is necessary where there is a reasonable probability that the area may

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contain economic mineral resources. A comparison of the assessments of the various resources in a region will provide a more consistent basis for determing the most valuable use for the land area.

3.7 Designing Resource Processing Plants to Meet Future Needs

Prior to the discovery of domestic sources of raw materials, a developing country may construct refining or processing plants (steel mills, copper, bauxite, and petroleum refineries, etc.) dependent on imported minerals. Mineral processing plants are designed to meet the specifications of raw material inputs with physical characteristics within a defined range. Before designing costly processing plants based on imported raw materials, a government should assess the chances that commercial deposits will be discovered and, if possible, consider the most likely physical characteristics of such resources. If such assessment information is obtained, it should be taken into account before deciding on the size, process specifications, and location of processing plants that may be used at a future date to process locally produced minerals.

3.8 Diversification of Commodity Exports

Diversification of commodity exports had taken on increasing importance in recent years as governments have attempted to stabilize export earnings in light of increasing volatility of international commodity prices. Mineral resource assessments can provide an indication of the broad range of mineral commodities that may exist in a country, thereby enhancing the prospects for diversification of mineral commodity exports and greater income stability.

There is a tendency for both government and industry exploration programmes to focus on finding more of those mineral resources that are already known and evaluated in a country. Broadly-based mineral resource assessment programs can inform governments and industry on the prospects for diversifying mineral commodity exports.

3.9 Depletion Rate of Resources

Resources depletion can be viewed in either a physical or an economic framework. Physical depletion is defined as the physical exhaustion of a mineral resource. Economic depletion is the exhaustion of minerals that can be mined at a profit, and usually occurs before physical depletion (Tilton, 1977). In the context of development planning, economic depletion is most important to a nation.

Governments have long been concerned with the rate of exploitation of exhaustible resources, not only in developed countries but also in many developing nations. The concern appears to revolve around the issue of how to provide for future generations while also meeting the needs of the present. In some cases, an export-oriented economy can lose economic benefits by delaying the development of its exhaustible mineral resources (Mikesell, 1976). This is because in many developing countries, the expected rate of increase in the mineral commodity price is lower than the rate of interest in alternative investments. Therefore, the profits from mining today can be reinvested to generate more profits than would be earned if the mineral was mined at a future date.

However, regardless of the economic argument for unrestricted development of exhaustible mineral resources, at least three overriding factors will cause most governments to be concerned about depleting their nation's exhaustible mineral resources. First, the majority of a nation's population may not believe arguments that a rapid rate of depletion of their exhaustible mineral resources is in their best interest. A common argument of opposition political parties (those parties presently out of power) is that the government in power is not properly managing the nation's exhaustible mineral resources. A typical argument that may gain considerable public support is that foreign companies are rapidly depleting the nation's valuable inventory of mineral resources.

Second, most governments of raw commodity exporting nations have a long-term goal of increasing domestic processing in order to: (1) increase the value added to export commodities; (2) provide for their own future mineral commodity requirements; and (3) increase employment. Therefore, a portion of most nations' exhaustible resources will be reserved for the future.

An incorrect assessment of a nation's mineral

resources can lead to poor policy decisions. For example, between 1938 and 1960 there was an embargo on iron ore exports from Australia based on an assessment that the nation's small iron ore reserves were only adequate to meet domestic needs (Barnett, 1979). The federal government restricted the development of the Australian iron ore industry because it was feared that "Australia was running out of iron ore" (Barnett, 1979 p.199). Subsequent huge iron ore discoveries have placed Australia among the world's leading iron ore producers.

Finally, closing down a mineral resource project when the economic reserves are depleted may result in substantial unemployment problems in a region. Governments are sensitive about the political implications of closing a mine and the resulting employment, as well as the possible secondary negative economic impacts on nearby towns. Therefore, they may undertake efforts to adjust mining rates and even taxation level to extend the economic lives of mines.

If a government slows the rate of depletion of known reserves, based on ignorance about potentially large undiscovered resources, the nation is likely to fail in maximizing its benefits from development of its exhaustible resources. Such issues demonstrate the need for governments to examine depletion rates in conjunction with an understanding of both their identified and undiscovered mineral resources.

3.10 EFFICIENCY IN RESOURCE DEVELOPMENTS

Related to the question of depletion rate is the issue of cut-off grade with respect to exhaustible mineral resources. In maximizing company profits during the production of minerals from a deposit, 'high-grading' can occur when lower grade ore that could have been economically recovered is left behind as waste. The problem can result from company profit maximizing strategies, but may also be caused by the form and level of taxes applied to mineral resource projects. Taxes or royalties based on sales or gross value increase the cut-off grade because they are a direct cost of producing a mineral resource.

An example is the case where a government receives a high-profit share in a production-sharing agreement. Such an agreement may be ideal for the occasional large petroleum discovery, but makes smaller petroleum reservoirs sub-economic. This has the direct consequence of raising the minimum size exploration target, and can result in incomplete exploration of prospective areas. The result may be a financial loss to a nation but not necessarily to the investor who will adjust exploration strategies to maximize profits within government fiscal constraints. A resource assessment program can provide governments with a clearer indication of the physical characteristics of possible petroleum fields in an area, which can be useful in establishing more appropriate fiscal regimes.

4. CONCLUSIONS

In this paper it has been suggested that long-term national development and economic planning strategies should be facilitated by appropriate mineral resource assessments. However, resource assessment activities are not an assurance of achieving development planning goals. Two major problems are that optimum levels of assessment expenditures can seldom be determined, and resource assessment estimates are subject to error.

Geological surveys almost always argue that greater expenditures for gathering mineral resource information are desirable. However, development planners are faced with the task of determining how much their nation can benefit from a given level of expenditure in gathering more resource assessment information. There is no practical way to determine whether there is too little or too much being spent on information gathering, primarily because the potential economic benefits to the nation are difficult to measure in financial terms.

One practical solution to this dilemma is to link most mineral resource assessment activities to policy issues where decisions can be influenced by assessment data. This allows governments to select resource assessment programmes that can provide the required level and quality of information at minimum cost.

Another problem is that the current understanding of the geologic parameters controlling the size, grade, and distribution of mineral resources, is incomplete. No model can be constructed to accurately predict these physical characteristics.

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Therefore, resource estimates for undiscovered mineral resources are subject to a relatively wide margin of error. To be effective in development planning, the degree of uncertainty associated with estimates must be considered.

Resource assessment information, gathered without consideration of the specific policy decisions that might be influenced by the data, may not be used regardless of the quality of the assessment. This may partially explain why so much of the mineral resource information gathered in developing countries is never used to make any substantive policy decisions. Despite the inherent errors in resource assessment methodologies, planners and policy makers can more effectively establish long-term development strategies for a nation by considering estimates of the economic potential of discovered and undiscovered mineral resources.

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