The Economic Value of Industrial Minerals and Rocks for Developing Countries: A Discussion of Key Issues

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The Economic Value of Industrial Minerals and Rocks for Developing Countries: A Discussion of Key Issues

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Abstract: This paper provides a few general comments on the nature and economic value of industrial minerals and rocks and the need for an increased exploitation and use of these materials in developing countries. These materials are of great economic value as main raw materials for the construction, glass, abrasive, paper, chemical, ceramics, metallurgical and agricultural industries. Developing countries dispose of many of these materials, and could derive greater economic benefits from them. Per capita consumption of industrial mineral products continues to grow in developed countries and part of this demand could be met by exports from developing countries. The paper describes some of the issues to be addressed and steps to be taken if developing countries are to gain from industrial minerals and rocks.

Keywords: Economic value industrial minerals and rocks, consumption industrial minerals and rocks, production industrial minerals and rocks, developing countries benefit minerals and rock

JEL: Q30, O13, Q32, O21, Q38, O17, Q31

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Editor's Note

This paper was given to me in 1993 by its author, Dr. Tetevi Bahun Wilson, as he was going back to his home country in Africa after many years of study in the USA. Its original title was "**The Economic Value of Industrial Minerals and Rocks for Developing Countries".** My understanding is that the paper was put together to pitch for a consulting job with a ministry of mining of an African country, which should remain unnamed.

I think the paper is a very good piece for a nontechnical audience. Although I lost contact with the Dr. Wilson, I held on to his paper, reading it more than once until it started to fall apart. This edition is my attempt to save the paper. Dr. Wilson holds a bachelor's degree in Economic Geology, and Master's and PhD degrees in Mineral Economics. There are issues, both technical and mundane, that I would have liked to raise, but without the author's permission I should not as doing so may alter the paper. Also the original version did not have any references; I include a few papers by the author and his coauthors, as well as some classic readings that I am certain Dr. Wilson is not only familiar with, but would have approved as well. *All* credit must go to him. Editorial and other errors are mine alone.

0. Summary Comments

This paper provides a few general comments on the nature and economic value of industrial minerals and rocks and the need for an increased exploitation and use of these materials in developing countries.

Industrial minerals and rocks are a group of naturally occurring, mostly non-metallic minerals and rocks, including materials such as sand and gravel, stone (e.g., limestone, dolomite, granite, serpentinite and quartzite), glass sands, feldspar, phosphate, sulfur and potash (NTIS, 2000). At an appropriate opportunity cost these materials are of great economic value as main raw materials for the construction, glass, abrasive, paper, chemical, ceramics, metallurgical and agricultural industries.

In developed countries such as the United States, the annual dollar value of industrial mineral production has since surpassed that for metals and continues to grow rapidly. Due to high income levels per capita consumption of industrial mineral products in developed countries exceeds that in developing countries. While in developed countries industrial minerals and rocks provide inputs in many industrial processes, in some developing countries with little industrial infrastructure significant portions of their foreign exchange derive from exports of industrial minerals and rocks. Thus, industrial minerals and rocks are of great economic value to developed and developing economies alike.

Some industrial minerals are high volume and low unit value commodities. For example, the economic value of sand and gravel depends on the availability of markets, their location relative to markets, transportation costs, their physical and chemical characteristics, and the required degree of processing and end use. Developing countries dispose of abundant industrial resources, and could derive greater economic benefits from them than they do now. Per capita consumption of industrial mineral products continues to grow in developed countries and part of this demand could be met by exports from developing countries.

The following are some of the things that developing countries might do to derive greater economic benefits from their industrial mineral resources than they are doing currently:

(a) State geological surveys should collect data on the occurrence, distribution, quality, and potential uses of all accessible industrial mineral occurrences in their territories.[1]

(b) Countries that already export these materials should attempt to export few unprocessed raw materials and more processed materials. For example, less

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[1] See Dr. Wilson's other writings.

phosphate rock may be exported while increasing exports of phosphoric acid and phosphoric fertilizers.

(c) The following two characteristics of industrial minerals and rock should be exploited in order to increase the utilization of these materials: (i) The use of one industrial mineral in a production process often involves the use of several others, e.g., the production of glass from glass sands requires limestone etc; and (ii) a single type of mineral or rock could provide the raw material for several industries. This feature is well illustrated by limestone which is a raw material source for the construction, chemical, metallurgical, refractory, glass, fillers, and agricultural industries. That is, a country with limestone deposits that meet the requisite specifications could engage in some of these industrial activities as long as there are markets for their products, and production costs are competitive.

To support the efforts just listed, Government should encourage the establishment of small scale mining operations and should be ready to provide miners with technical assistance in the areas of exploration, extraction, and product marketing. Product marketability is a critical element in the process of evaluating the economic viability of an industrial mineral project. This suggests that deposits must also meet specifications laid down by consumers, and that production and transportation costs must not be excessive. However, even when the conditions for a profitable operation are met, a producer may face a continually changing market in which the demand for his product may be rising or falling. Hence, the necessary adjustments must be made to ensure the survival of the business.

I. **Introduction**

Industrial minerals and rocks are a group of naturally occurring materials excluding gemstones, metallic ores, groundwater and fuels (coal, oil and gas). A few metallic ores such as chromite, alumina, and pyrolusite, when used for certain purposes such as refractories in high temperature furnaces may also be classified as industrial minerals. This paper first provides a few general comments on these minerals and rocks, focusing mainly on (a) their importance to the economies of developed and developing nations, (b) the need for increased exploitation and use of these materials in developing countries, and (c) the factors affecting the economic viability of industrial mineral projects. As a second objective, the paper describes the steps for an economic analysis of mine projects.

Industrial minerals are commonly occurring minerals and rocks that are widely used in industry, sometimes undergoing very little processing. Most are high volume and low unit value commodities and their economic importance depends on the availability of markets, market location, transportation costs, their physical and chemical characteristics, and the degree of processing required for end use. A notable feature of these minerals and rocks is that a single material may form the basis for a wide range of industries, starting from low technology processes producing low value products to higher technology industrial units producing high value products for export markets. A developing country with abundant resources and little know-how may start by producing low unit value products for the home market, followed eventually by high value products for export markets. A good example is provided by a resource like limestone or dolomite which initially may be a source of construction material (cement, aggregate and dimension stone) and later a raw material for agricultural, metallurgical, and chemical industries.

For developing countries, the prospects for selling industrial minerals on the export market are good. This is because of a combination of high and growing per capita consumption of goods produced from industrial minerals as well as high income levels in developed countries. More important still, the domestic production of some industrial minerals in developed countries will increasingly be a small fraction of total demand. Earnings from foreign trade could be increased by limiting exports of unprocessed raw materials. For example, a government may decide to export less phosphate rock while increasing exports of phosphoric acid and phosphatic fertilizers. How much effort and money is needed to catalog national industrial minerals and rocks is a difficult, costly, but not impossible task.

II. Groups of Industrial Minerals and Rocks

Industrial minerals may be classified based upon different factors, but in this paper group membership depends on end-use and economic factors. One classification identifies the following six groupings: construction materials, ceramic materials, metallurgical and refractory materials, abrasive materials, general manufacturing materials, and chemical and fertilizer materials.[2] These six categories have been collapsed into three broad groups here. The first group, known as *construction materials*, includes sand, gravel, clays and stone (e.g., limestone, dolomite, granite, serpentinite and quartzite). Stone is both a source of crushed and dimension stone. This group is characterized by materials that are valued for their physical attributes, are very widespread in nature, are very bulky, and have low unit value, even as they require minimal processing before use. These attributes have a profound effect on the economic value of industrial mineral deposits. Commodities with high bulk and low unit value must be located close to markets to be economic, while less common materials with unique properties have a high unit value and may be profitably sold at high prices in distant markets.

The second group, referred to as *process materials*, includes a wide range of minerals and rocks possessing special characteristics that allow them to be used in specialized areas. This group includes (i) *ceramic materials* made up mainly of clays but also silica, limestone, dolomite, feldspar, quartz, and bauxite; (ii) *abrasive materials* like garnet, silica, and especially chalcedony, chert, quartz, quartzite, sandstone, and silica sand; and (iii) *refractory and metallurgical materials* like magnesite, fire clay, graphite, bauxite, silica, and dolomite. Materials in the third group include *optical materials* like quartz; *absorbent materials* like atapulgite, bentonite and diatomite; *fillers* like asbestos, bentonite, gypsum, kaolin, limestone, and vermiculite; *glass materials* like glass sands, soda ash, limestone, dolomite, feldspar, borax, and gypsum; and *oil drilling materials* like asbestos, barite, atapulgite, bentonite, limestone and dolomite. Materials in this group are valued mostly for their physical properties. They are less bulky, have higher unit values than construction materials and can be sold on the export market.

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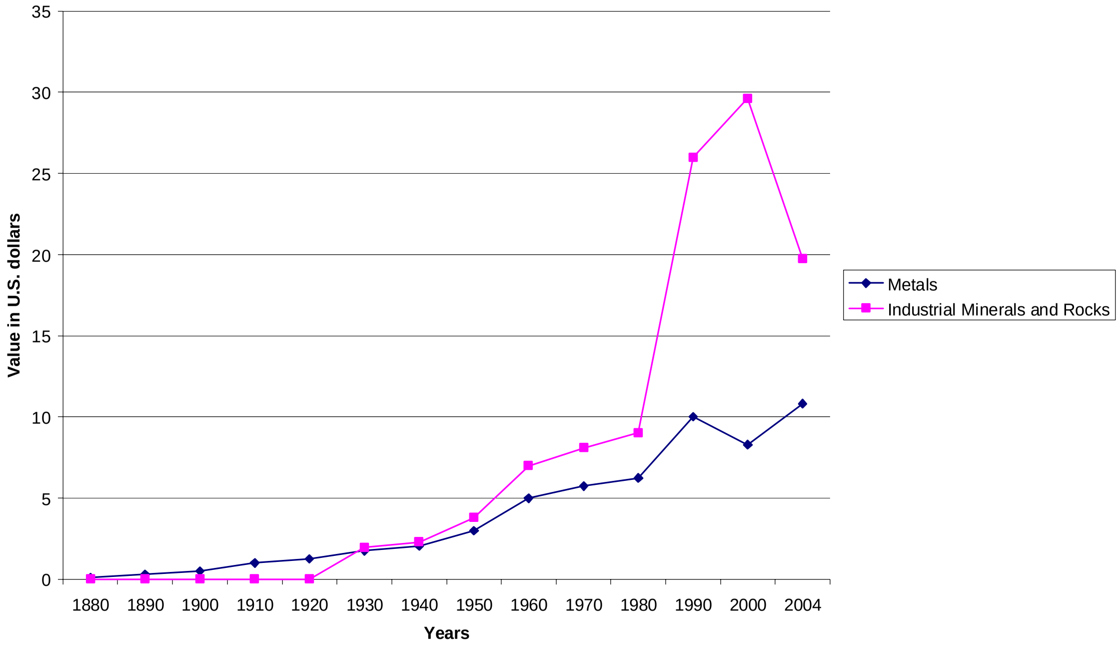
[2] This classification is an operational one as Dr. Wilson is aware of *translation* and *truncation* problems involved in resource definition and classification (See, Harris, 1984).

Figure 1 - Value of U.S. annual production of metals and industrial minerals and rocks, 1880-2004 (billion current dollars)



III. Role of Industrial Minerals in the National Economy

Worldwide, it is estimated that sand, gravel, limestone, clay, sulfur, salt, and phosphate make up 90% of the total tonnage of all industrial minerals and rocks produced and 60% of total value.

The widespread use of industrial minerals and rocks is in large part due to the following two characteristics of these materials. Firstly the use of a single mineral in one production process often involves the use of several others. For example, the production of glass from silica sands may require the use of soda ash, limestone, dolomite, feldspar, borax, gypsum and fluorspar. Secondly, a single mineral or rock may form the basis for a large number of industries. A very good example is limestone which may be used in the construction, metallurgical, agricultural, and chemical industries. Lime, a product derived from limestone, is itself a raw material used in the production and processing of a myriad of products such as glass, steel, chemicals, paper, sugar, paint, water and food. Other major industries like chemicals, fertilizers, ceramics, and metallurgy depend on industrial minerals and rocks as a source of raw materials. Above all, these minerals and rocks provide the raw materials for infrastructure development in which large volumes of sand, gravel, clay, crushed and dimension stone are consumed. Economic research supports a strong correlation between economic performance and investment in infrastructure and other physical capital stocks (De Long, 1991).

Materials consumption per capita is much higher in developed than in developing countries. While consumption of these materials in developing countries is dominated by high bulk low unit value commodities that require little processing like sand and gravel, substantial portions of the foreign exchange earnings of some of these countries derive from exports of high value commodities like potash and phosphate (cf. Smail Khennas, 1992, Amavilah, 1995). These countries hope to increase earnings from their industrial mineral resources starting with the manufacture of basic materials like cement, bricks and tiles for the local construction industry and eventually establishing downstream industries to transform materials like limestone into higher value products for local as well as export markets.

The impact of this transformation on economic performance and employment is not difficult to demonstrate; the stability of earnings from the transformation is less certain at this point. However, data from developed countries shows an increasing value of industrial minerals production compared to metal production. Refer back to Figure 1 for the USA (Klein, 1993, Langer, 2006, Karlsen and Sturt, 2000, NMA, 2003, NTIS, 2000). This is not surprising given the decreasing role of metal industries in these economies, a fall attributable to the declining material intensity of use of manufactured products (Roberts, Tilton,). On a per capita basis, industrial mineral consumption in developed countries is higher than in developing countries because not only is the consumption of the low unit value high volume materials like sand, gravel and crushed stone high, but higher incomes allow high consumption of finer goods (luxuries) such as glassware, quartz watches, and cosmetics.

IV. Economic Feasibility of Industrial Mineral and Rock Projects

The basic elements of a mine feasibility study include the following: general project description, deposit geology description, mining and milling procedures, financial analysis, market study, and environmental impact analysis. This section focuses on the elements of a market study.

- ***The need for a market study***

A market evaluation attempts to determine whether there is demand for a commodity produced in a specified location at a given time and cost. It is important to establish that the output from a new mine will be sold given that the same material is produced in mines in several other localities. Locational factors are important because the impact of transportation costs on market price is also an important factor, and because the long lead times between project conception and completion matter. It is, therefore, essential to ensure that there will be demand for the material when the project begins production.

An industrial mineral or rock may be of the highest quality, but will be of no economic value if there are no markets for it. The main objective of a market study is to identify the markets for a commodity and to estimate the expected market price and quantities of the commodity to be sold. Given the projected quantity and price, income can then be computed from which profit estimates are made after costs (mining, processing, transport, marketing, sales, and other transactions) are accounted for. Again, the object of a market study is to estimate quantities to be sold, and project the following: market prices, total revenues to be generated from sales, total costs of generating revenues, profits, and return on investment. Thus, on the basis of such a study, it is possible to determine whether or not the project can yield sufficient income to allow for the recovery of the cost of the project and to show a reasonable return on investment. These results provide a decision-maker with a basis for selecting to invest or not to invest in the project.

- ***Summary of market factors***

In conducting a market evaluation of an industrial mineral project answers to the following questions must be sought: What are the uses of the commodity? What and where are the markets for the commodity? What are the mining, processing, and transportation costs? What is the underlying structure, behavior, and performance of identified markets? The economic value of an industrial mineral commodity is affected by bulk, unit value and location relative to markets. High-bulk and low-value commodities must lie close to consuming centers and generally serve local (domestic) markets. Higher-value commodities may be traded internationally. Assuming that a deposit of sufficient size (tonnage) and quality (grade) has been proved, a market study that includes the following elements is essential:

(1) *Availability, size and location of markets:* For a profitable operation, existing markets should permit sufficient amounts of the commodity to be sold to generate enough revenues to cover all costs, and to allow a reasonable return on invested effort, capital included. Note that at the time of entry, markets for the commodity may be expanding and stable. An expanding market is preferred, but the other possibilities (e.g., a shrinking market) must be anticipated.

(2) *Industry structure:* Where markets are competitive profits are generally low; in highly specialized product markets there is less competition and high monopoly rents (profits).

(3) *Supply/demand balance:* This involves the examination of the historical and forecast relationship between supply and demand. The historical relationship may explain the observed price. Projected relationships will be affected by anticipated technological developments that decrease or increase demand for the product.

(4) *Mining, processing and transportation costs:* The cost of the product depends on whether the operation is open-pit or underground [Most industrial minerals and rocks are open-pit]. Market price, the cost of the raw material delivered to market, is production cost at the mine plus transportation and other costs. Transportation cost may be high for materials with low mining cost. The cost of the final product may depend on grade; higher cost mines may possess higher grade. In addition, government must take steps to control the environmental, safety and health factors involved in the mining and use of industrial minerals. The problems of noise, dust, disease from materials such as asbestos and silica, and the harmful side effects of fertilizer use are potential cost concerns. The costs of compliance with environmental, health and safety regulations also affect the product cost. Cost

estimates must be as accurate as possible to avoid expensive errors. A precondition for accurate mining and processing cost estimation is a correct estimation of deposit tonnage and grade, followed by appropriate metallurgical testing of representative samples.

(5) *Chemical and special specifications demanded by consumers:* Industrial minerals are valued for their physical properties. They must therefore conform to the specifications of consuming industries. These specifications may be very rigorous and relate to chemical purity for chemical materials, and physical integrity and properties like color, hardness, grain size, and specific gravity for process and construction materials.

(6) *Effects of technological change:* New technology may expand existing markets by creating new uses for existing materials, or it may cause market loss by creating new or substitute materials with better performance specifications.

V. Toward Increased Utilization of Industrial Minerals and Rocks in Developing Economies

It is the task of government to lay down the guidelines for the beneficial exploitation and use of a country's mineral resources. In a developing country where mineral lands are publicly owned, it is also the task of government to search for funds for the exploration and development of mineral resources. Given the importance of industrial minerals in world trade, and the widespread occurrence of these materials in developing countries (as in developed countries where markets are fully functioning), the governments of these countries could increase their share in trade by gradually building up an industrial infrastructure based upon these raw materials. Government and its agencies should do the following:

(a) Government geological surveys should make a complete inventory of all industrial minerals and rocks in a country. A national transportation network should be planned with the location of mineral deposits in mind.

(b) Government should identify materials and determine all possible uses for each.

(c) Government should make a list of industrial minerals and industrial products imported into the country and when possible reduce import levels by the local production of certain goods for the home and export markets (import substitution).

(d) Government should promote industrial development by developing downstream industries based on local raw materials. For example, exports of unprocessed raw materials like phosphate may be limited.

VI. Establishing Downstream Industries

The following two characteristics of industrial minerals and rocks may be beneficially exploited by governments in developing countries. The first is that the production and use of one mineral requires the use of several others. Secondly, a single mineral or rock may provide the raw material for several downstream industries. This point is well illustrated by limestone which is one of the most useful of all industrial minerals. Depending on end use and specification the value of limestone may vary from as little as $3.00 per ton when used as crushed stone for aggregate construction to $200 per ton when pure and used as a filler. Between the two extremes lie a series of prices that depend on the specification and use of the material.[3] The following is a list of industries that depend on limestone as a source of raw material:

(i) ***Construction industry***: Making cement, aggregate for concrete, roads, and railroads, raw material for terrazzo chips, paint and dimension stone.

(ii) ***Agricultural lime***: Limestone, and to a lesser degree dolomite when ground to a fine powder, may be used to condition clayey soils and neutralize acid soils in order to promote plant growth. Note that rocks used in this form are not true lime, but rather pulverized rock.

(iii) ***Chemical and metallurgical industry***: Lime manufacture, as fluxstone in glass manufacturing, in ceramics and in steel industries.

(iv) ***Refractories***: Calcined dolomite is used as a refractory material to line metallurgical furnaces.

(v) ***Glass manufacturing industry***: Limestone or dolomite, together with silica sand and soda ash, are used in glass manufacturing.

(vi) ***Filler manufacturing industry***: Ground calcium carbonate is used as a filler in paint, paper and plastics. The quality and price of filler vary with particle size.

(vii) ***Lime manufacturing industry***: Note that lime from limestone is itself a raw material used in the production and processing of many products including metallurgical fluxes, chemicals, glass, soil stabilizers and neutralizers, paper, and water treatment.

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[3] William Langer (2006) estimates that crushed limestone can sell for $10/ton, rare earths for $6,000/ton. Industrial diamonds can fetch $200/carat up to $1,000,000/ton. Limestone calcined into lime costs $100/ton; refined to precipitated calcium carbonate the same stone goes for $1,000/ton (pp.4-5).

VII. Challenges in Industrial Mineral Markets

Industrial mineral consumption per capita continues to grow in developed countries, and Third World producers could benefit from this growth by selling in these markets. However, even when deposits are favorably located relative to markets and reasonable prices prevail, a producer may still face a continually changing market in which demand for his product may be expanding or contracting. A producer must therefore keep abreast of these changes to ensure the survival of his business.

One example of change in the marketplace is the shift from one raw material source to another, such as the shift from the Frasch process as a source of sulfur to energy materials like oil and gas, leading to a loss in market share by producers using the Frasch process. Secondly, special attention must be paid to the material specifications laid down by consumers because the degree of processing of these minerals depends on them. When clean and unambiguous, these specifications may be met readily by producers. Sometimes, however, they are unclear or change constantly, and consequently compliance is more difficult and there is a risk of market loss. Thirdly, producers must anticipate and deal with market expansions or contractions due to technological changes that create new products or new materials that may be substitutes for existing ones.

For new producers, entry into some markets may not be easy as users prefer to keep to traditional sources of supply. For some materials, price cuts are not a solution to the problem especially if raw material price is a small fraction of the final product cost. In other markets, however, similar price incentives produce the desired results and materials from one source may be replaced by one from a less expensive producer.

To maintain and possibly expand market share, industrial minerals producers must keep a close watch on present and potential future markets for their product. Whenever possible, product diversification should be employed as an instrument of survival in mineral markets. For example, dimension stone producers may subject extracted stone to several different finishes to yield products with different characteristics and different uses. Stone may be polished, ground polished, tooled or bush-hammered. With each stone type, each finish results in a different product with a different price[4] - economists call advantage from

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[4] I raise two questions here: (1) it is true that the difference between a minimum market price of crushed limestone at $3/ton and a maximum price of $200/ton for limestone derivate filler represents potential gains from forward integration of processes. The question is: At what cost? Without knowledge of the cost how can we be sure of the policy implications of this proposal (cf. Amavilah, 1990). (2) Most developing countries failed to integrate their metal industries even where they dominate production (bauxite in

variety economies of scope (Panzar and Willig, 1981).

VIII. Outline of Economic Analysis of Mineral Projects

1. Background Information

The objective of an economic analysis of a mineral project is to provide information for investment decision-making.[5] A mining project life-cycle consists of three phases, namely:

(a) a pre-investment phase, in which extensive studies are carried out to prove the economic value of the property;

(b) an implementation phase, in which plant design, construction, and commissioning occur; and

(c) a startup and production phase, in which actual production takes place.

This outline focuses on activities that occur in the pre-investment phase, or investigative phase, in which the property is studied in great detail to determine economic value. This phase consists of a maximum of three stages, *viz.*,

(i) a conceptual stage, in which historical data and comparative methods are used to arrive at quick and approximate cost (capital and operating) estimates for the new mining project;

(ii) a preliminary economic analysis stage, in which some critical preliminary data (geologic, economic, engineering) on the ore body are used to determine the desirability of further investments in the project. If positive results are obtained, the study proceeds to the final feasibility stage; and

(iii) a feasibility study stage, in which the technical and economic parameters of the deposit are analyzed in greater detail. This stage is based upon a larger, more reliable and verifiable database than the pre-feasibility study.

The data requirements, report content, and other details considered in each of the three stages of the pre-investment phase follow below.

Guinea), reserve (cobalt in Zaire), and both production and reserve (copper in Chile). Why should anyone believe they can do so with industrial minerals? (3) How does capital cost in standard industrial mineral projects compare to metal projects? (4) My understanding is that beneficiation costs are higher for most industrial minerals than for metals, because you must spent a lot of money to generate a unit increase in the grade of industrial minerals.

[5] The outline draws upon Gentry and O'Neil (1984).

2. Conceptual Phase of Mine Projects

In this phase no direct information is available on the prospective ore body. However, historical data on similar ore bodies is available, and can be used to approximate costs and expected profits from a deposit of specified size.

3. Preliminary Feasibility Analysis

This step in the evaluation process is more detailed than the last one and it is based upon preliminary, but critical information (tonnage, cost, and price) on the prospective ore body. The information may be obtained by drilling and assaying. The evaluation of the preliminary data, e.g., by the discounted cash flow method, provides a basis for deciding whether or not to continue the evaluation process to the final detailed feasibility stage.

- ***Requirements and contents of preliminary economic report***

    - *Technical data required for study*

Some of the data used at this stage is preliminary and uncertain. It consists mainly of geologic (tonnage, grade) and economic (cost, price) information on the deposit and includes the following items:

(a) Deposit tonnage and grade
(b) Capital costs (acquisition, exploration, development)
(c) Operating costs
(d) Depreciation schedule and depletion allowance
(e) State and federal tax requirements
(f) Recoveries: mining, milling, smelting, and refining
(g) Royalty payments
(h) Discount rate, inflation rate
(i) Timing events

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    - *General Outline of content of preliminary report*

Statement of project objectives

Project description: State location, what will be produced and what it will be used for. State reservations, if any.

Summary of results of study: Use tables, graphs to present main results. Exclude recommendations unless asked for. Report should be understandable by nontechnical readers.
Description of tonnage and grade: Briefly characterize ore body geology, structure, tonnage and cut-off grades.
Production rates: State mine and mill products, recovery and production rates.
Capital cost estimates: Preproduction capital and production mine and mill costs.
Operating cost estimates: Mine, mill operating costs.
Revenue estimates: State expected revenue stream
Financing and tax data: Type of financing and tax rates.
Cash Flow: Annual cash flow for project life. Project acceptability is based on after tax cash flow. Acceptability measures like internal rate of return, net present value (NPV), payback, and so on should be included in the report.

4. The Feasibility Study

❖ *Introducing the feasibility study*

A detailed feasibility study is called for only if the results of the preliminary economic analysis are favorable. The feasibility study is a comprehensive document that demonstrates with documents and verifiable data that the mining project meets all the economic criteria set down by the owners and financing organizations. Based on the information provided in this study, a financing institution decides to finance or reject the project. The signs (mine, mill, etc.) specified in this report will form the basis for subsequent construction work on the project.

❖ *Organizing the feasibility study and required expertise*

The preparation of a feasibility study requires the collaboration of experts in the areas of law, geology, mining engineering, geotechnical engineering, metallurgical engineering, mineral economics, and environmental science. All this expertise is seldom available within a single organization. Consequently, the services of outside consulting agencies may be sought. In practice, therefore, a company charged with a feasibility study may assign different parts of the work to outside consultants. The firm decides what parts to contract out, defines the scope of the work to be done, the costs and completion dates. When all tasks are contracted to outside firms, the work must be subject to internal review by the contracting firm. For a small firm lacking the requisite personnel or a firm without an established reputation, it may be advantageous to contract out studies to a more reputable firm. It is especially desirable to contract out the following technical responsibilities: (a) ore reserve estimation and mining method determination, (b) metallurgical assays, and mine and mill plant design, and (c) plant layouts, equipment listing, and capital and operating cost calculations.

5. Contents of a Feasibility Report Outlined

When properly executed and written up, a feasibility report should consider the following areas:

a) *Project location*: Population, topography, infrastructure and prospective plant and dump sites.

b) *Geologic information*: Geology, structure, mineralogy and deposit genesis; sampling for metallurgical and other assays, drilling, geophysical and geotechnical surveys; analysis and estimation of ore tonnage, grade, and waste-to-ore ratios.
c) *Mining information*: Mine type, plan, ore dilution, preproduction and production development, waste management and disposal, equipment and labor requirements, equipment replacement schedule.
d) *Metallurgical information*: Extraction process, pilot plant tests, recovery rates, final product, metallurgical plant design, flow sheet, recoveries.
e) *Supporting services*: Access, transportation, water, fuel, workshops, offices, laboratories, other buildings, equipment (mine, employees and other social services).
f) *Capital cost information*: Mine and mill equipment lists, capital costs, construction schedules and costs, cost of labor and materials, other costs, e.g., taxes, freight, licenses, fees, duties, contingency costs, working capital, preproduction interest on debt, equipment replacement schedule, and the anticipated capital expenditures.
g) *Operating cost information*: Number of workers, pay rates, supplies (power, explosives, fuel), overhead costs.
h) *Marketing information*: Purchases of product, quantities, transportation costs, product price forecasts.
i) *Property acquisition and other legal issues*: Acquisition costs, rents, royalties, mining and water rights, employment laws, worker rights, etc.
j) *Financial and tax information*: Business type, e.g., corporation, sole ownership, or joint venture/partnership; loan terms, depreciation and depletion allowances, tax rates,

and so on.

k) *Environmental information*: Environmental report, pollution permits, restoration plans, and such.
l) *Revenue and profit information*: Mine, mill production schedules, annual costs, revenues. Depreciation, cash flow, measure of profitability, such as NPV, rate of return, payback, sensitivity analysis.
m) *Conclusions*: Strengths and weaknesses – implications for policy and further study.

IX. Conclusion

The cost of bringing industrial minerals and rocks into full use in developing countries is likely high. However, corresponding benefits are also potentially significant. This paper sought to prod developing countries into policy action. In the process the paper provided an easy to understand outline for preparing for a mining project. The high level of generality begs for case studies, yet there is enough evidence that industrial minerals and rocks are reasonable sources of income for many developing countries.

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