Corporate Exploration Strategies

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SYNOPSIS

The mineral exploration environment has observable economic characteristics, the assessment of which provides guidelines for exploration planning in the mining company. The long-term survival of the mining company is directly dependent on successful exploration. Exploration planning contributes to successful exploration through the development of exploration strategies. The objective of exploration planning is to select exploration environments which will enable the mining company to realize best possible profit and corporate risk conditions. Thus, the formulation of exploration strategies is based on profit and corporate risk criteria. Strategic considerations include the selection of commodities as exploration targets, geographic concentration of exploration effort, the realization of acceptable survival conditions, and the structuring of an exploration programme to optimize the economic benefits of the exploration investment process.

INTRODUCTION

In recent years much progress has been made in analyzing the economics of mineral exploration. This has included the development of quantitative mineral occurrence and search models, assessments of the risks and returns of exploration, and descriptions of exploration philosophy. However, little direct attention has been given to the application of quantitative concepts to exploration planning in the mining company. This paper suggests a decision framework for exploration planning, developing economic criteria for exploration investment and applying these criteria to the formulation of exploration strategies.

Three assumptions are made:

(i) There is common ground between quantitative concepts and realistic applications and, thus, theoretical analysis can assist with the solution of practical problems.

(ii) The mining company of today and tomorrow requires a formal planning framework to contend effectively with changing economic conditions.

(iii) The mineral exploration environment possesses observable quantitative dimensions which can provide guidelines for the development of corporate exploration strategies.

The paper focuses on the relationship between mineral exploration and the mining company. Initially, the mineral exploration environment is analyzed to define observable and relevant economic characteristics. Then the role of exploration within the mining company is described to establish terms of reference for exploration planning. These provide bases for developing profit and corporate risk criteria for exploration investment which are then applied to the formulation of exploration strategies.

THE MINERAL EXPLORATION ENVIRONMENT

The mineral exploration environment comprises the distribution of undiscovered mineral deposits in nature and the exploration techniques and skills available for their discovery. Specific environments are defined by geological setting, deposit type, and geographical area.

In the exploration environment, search targets are successively narrowed and the level of detail of information increased by proceeding sequentially through a number of information-gathering investment stages. The techniques of applied geology constitute the search method. In general, five sequential exploration stages may be distinguished, namely, regional selection, area selection, area exploration, follow-up ground exploration, and detailed exploration. Exploration continues as long as the analysis of information at the end of each stage provides economic justification for further investment. Ultimately, economic mineral deposits are sufficiently well explored to permit a mine development decision to be made.

To provide a quantitative basis for exploration planning, assessments must be made of the economic characteristics of the exploration environment. For this purpose, three environmental parameters are of fundamental importance:

(i) *the cost associated with discovering a mineral deposit*,

(ii) *the environmental probability of discovering an economic mineral deposit*, and

(iii) *the return resulting from an economic discovery*.

The definition and measurement of these parameters presents many practical difficulties. In general, mineral exploration is characterized by a very low probability of economic discovery, and a very large return given an economic discovery relative to the exploration costs associated with discovering a deposit.

Exploration cost is the least difficult environmental parameter to assess. The costs of individual exploration techniques are well documented in the literature; see, for example, exploration cost break-downs in Morgan (1963), Peters (1969) and the CONSAD study (1969). Exploration cost will also depend on the particularities of both the exploration environment and the mining company. In this respect the mining company will have its own cost experience upon which to draw. Thus, costs can be estimated on a unit rate basis for each exploration technique. The costs of individual techniques together with a knowledge of the information responses they provide and the overall programme suitable for a specific exploration environment, provide the bases for assessing *the cost associated with discovering a mineral deposit*. For this purpose exploration discoveries could be defined as deposits where initial drilling indicates the possibility of mineralization and a mineable width, for example, anomalies which justify more than one drill hole. Discovery costs would include any drilling costs resulting directly from the initial intersection, for example, inclusive of the first few drill holes. Subsequent exploration costs, more closely associated with economic discoveries, would be charged against the returns resulting therefrom.

For example, consider the following hypothetical geophysical exploration programme for copper-zinc deposits in the Canadian Shield region. Initially, favourable 300-square mile areas are selected for airborne electromagnetic survey and flown with a quarter-mile spacing. Airborne survey costs average $30 per line mile. Following airborne work, a variable

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number of airborne anomalies are selected for investigation on the ground. In an area containing a large number of promising anomalies as many as 80 zones might be selected whereas in an area showing fewer responses only 40 anomalies might be selected; say, on the average, 60 anomalies are selected. Follow-up ground exploration includes property acquisition, line cutting, electromagnetic and magnetic surveys, and geological mapping, with costs averaging \$4 000 per square mile. Follow-up grids average 0.2 square miles. On the average, one-third of the follow-up anomalies show favourable geophysical responses and geological settings, and are drilled. Of the anomalies drilled, 95 per cent are rejected after the first hole. The remainder give sufficient encouragement to justify an additional four holes on the average. Drilling averages 200 ft per hole and costs \$10 per foot.

Airborne survey cost = 1 200 (30) = \$36 000
Follow-up cost = 60 (0.2) (4 000) = \$48 000
Drilling cost = 20 (200) (10) + 4 (4) (200) (10) = \$72 000
Total discovery cost = \$156 000
Number of deposits discovered = 1
Cost of an exploration discovery = \$156 000.

The environmental probability and return parameters are more difficult to assess because the economic characteristics of undiscovered deposits are not known. However, these characteristics can be estimated either by using mineral occurrence models or by analyzing past exploration results.

Mineral occurrence predictions for this purpose should give the expected number of deposits in feasible tonnage-grade categories on a unit area basis. Given terrain and cover type, empirical revenue and cost functions can be used to simulate the economics of developing predicted deposits within each area. An example of this type of mineral occurrence model is the subjective probability approach developed by Harris, *et al* (1970) and applied in the Canadian northwest. Thus, *the environmental probability of discovering an economic mineral deposit* would be estimated by the ratio of the predicted number of undiscovered economic deposits (defined on the basis of minimum acceptable size and profitability criteria) to the predicted total number of undiscovered deposits. *The return resulting from an economic discovery* would be measured by the size and profitability distributions for the economic deposits.

For exploration environments with a reasonable history of exploration, the economic characteristics of undiscovered deposits can be estimated on the basis of past exploration results. Thus, *the environmental probability of discovering an economic mineral deposit* is estimated by the historical trend in the ratio of economic discoveries to total discoveries. Economic discoveries could be defined as those known deposits which would satisfy minimum acceptable size and profitability criteria if developed under present-day conditions. It may not be possible to measure the total number of past discoveries directly, but this parameter can be derived if total pre-discovery exploration expenditures and the cost associated with a single discovery can be estimated for a particular exploration environment. Roscoe (1970), on the basis of the work of Derry (1970), used this approach for the case of metallic mineral exploration in Canada during the period 1950 to 1970. His results indicate a decline in the probability of economic discovery from 0.01 in 1950 to 0.001 in 1970. *The return resulting from an economic discovery* would be assessed by the size and profitability distributions for past economic discoveries if developed under present-day conditions.

The economic characteristics of the exploration environment are changing constantly. The development of new exploration techniques, and the increasing depth and decreasing grade of undiscovered deposits alter the costs and information responses associated with the exploration process. Changes in market and cost conditions shift the probability and return parameters. Each geographical area, geological environment and deposit type will have its own unique characteristics. Thus, assessment of economic parameters for the exploration environment is required for each time and place.

THE ROLE OF EXPLORATION WITHIN THE MINING COMPANY

The mining company is concerned with the development and operation of mines and, more importantly, with the strategic decisions which lie beyond current operations. The most important problem for most mining companies is mine replacement. The mine replacement problem is the result of the certainty of exhaustion for currently operating mines coupled with the very low probability which characterizes new economic discoveries. Thus, mineral exploration is fundamental to the long-term success of the mining company.

Mining company planning, as described by the author (1969), is based on three objectives. These are profit, survival and growth. Corporate resources consist of capital and managerial and technical skills. Corporate planning is concerned with the development of strategies to guide the investment of resources for the realization of objectives. Exploration strategies guide corporate investment in the exploration environment.

For the small mining company, the relationship between limited corporate resources and the low probability of economic discovery is dominant. To succeed, resources must be concentrated on the discovery of economic deposits. Success will result in the development and operation of an increasing number of mines with consequent increases in corporate resources. Thus, as the mining company grows, its mine replacement problem eases. At the same time, market opportunities and constraints become increasingly important. These factors result in a shift of emphasis from exploration towards markets. Forward processing and diversification will be encouraged. Nevertheless, there will be a continuing important role for exploration to support the company's processing and marketing activities and to the extent that exploration offers relatively attractive investment opportunities.

The large mining company has three basic alternatives, which are exploration, forward processing, and diversification, for investing resources to realize its profit, survival and growth objectives. The role of each alternative is a function of tradition, the balance sought between profit, survival and growth and the number and characteristics of investment opportunities in each area. For example, emphasis on profit may give a predominant role to exploration while emphasis on survival and growth may encourage processing and diversification.

The role of exploration within the mining company determines the level and proportion of total corporate resources which should be allocated to exploration. According to Morgan (1969), large mining companies generally spend between three and twenty per cent of their pre-tax cash flow on exploration and research, but the outlay by small mining companies, in efforts to survive, must often exceed this range. A survey of 11 base metal mining companies described by Ensign (1969) shows an average exploration expenditure of five per cent of pre-tax cash flow. Kruger (1969) quotes exploration expenditures as a proportion of gross value for selected mining companies during the period 1954 to 1968 showing ranges of 0.1 to five per cent for small and medium size companies and 0.5 to three per cent for large companies. These surveys indicate that mining companies allocate from five to forty per cent of their post-tax cash flows to exploration investment.

Given an allocation of corporate resources to exploration based on growth alternatives, exploration planning should be based on profit and survival considerations. From a profit viewpoint, corporate exploration strategies will be acceptable only if they generate investment opportunities which satisfy a minimum expected profitability condition and a minimum size condition. The minimum expected profitability condition will be the corporate cost of capital as reflected in the opportunity cost of alternative investments. For example, Ensign (1969) states that the Copper Range Company has sufficient copper reserves at White Pine to expand current mine capacity. Their exploration investment is, therefore, directed towards discoveries which can offer a greater expected profitability than investment in the White Pine expansion. The minimum size condition ensures that exploration investment opportunities are sufficiently large to make a significant contribution to overall company performance. Thus, the minimum size condition will be related directly to company size. For example, the Copper Range Company accepts exploration targets only if they have the potential to make an annual contribution of at least 20 cents per share, equivalent to annual earnings of \$400 000.

While exploration strategies are guided by profit criteria, they also are, in another important respect, strategies for corporate survival. Survival for the mining company is associated primarily with solving the problem of mine replacement. The long-term survival of the mining company is directly dependent on successful exploration. But if resources are limited and the probability of economic discovery very low, the mining company assumes the risk that it will expend resources without success. Corporate risk is measured by the relationship between exploration resources and the economic parameters of the exploration environment. Obviously, the importance of survival and corporate risk considerations is an inverse function of company size. Nevertheless, corporate exploration risk may still be significant for large companies under favourable profit conditions.

PROFIT CRITERIA

Long-term exploration decisions are based on expected profitability and size criteria. In more general terms, the profit potential of exploration investment is measured by expected value, that is, the average value that the exploration environment will yield in the long term, balancing the successes and failures of a large number of investments. For illustrative purposes:

$$EV = pR - C,$$

where EV = expected value,
p = probability of an economic discovery,
R = return resulting from an economic discovery,
C = cost of discovering a deposit.

If C comprises all exploration costs up to and including the first few drill hole intersections, then subsequent exploration costs associated with delineating deposits for the purpose of determining whether there is economic justification for development must be deducted in the assessment of R. R represents the net present value of an economic discovery; the difference between discounted positive cash flows and discounted investments (including exploration costs beyond C) using a rate which reflects the corporate cost of capital.

Expected value conditions will depend on specific environmental conditions as well as the particularities of the individual mining company, including the minimum acceptable size of exploration target. For example:

(i) small mining company

p = 0.02
C = \$150 000
R = \$10 000 000
EV = 0.02 (10 000 000) − 150 000 = \$50 000

(ii) large mining company

p = 0.005
C = \$150 000
R = \$35 000 000
EV = 0.005 (35 000 000) − 150 000 = \$25 000

The expected value concept has been advocated by Preston (1960), Grayson (1960), Brant (1968), and others, as a useful technique for assessing the favourability of exploration investment. The higher the expected value, the more attractive the investment. Usually an expected value greater than zero is regarded as a necessary condition for investment. However, in some cases a 'windfall' strategy may guide exploration. If R is very large in relation to C, a characteristic of exploration as well as sweepstakes, a mining company may undertake at least a limited number of investments, even if it knows that expected value is negative, because of the possibility of a spectacular return. Such a strategy is, of course, ultimately ruinous and can be justified only in the short term. If the mining company is lucky, and smart enough to quit when it is ahead, efforts under such conditions can be rewarding for some.

Expected value is a function of the three environmental parameters, the assessment of which has been described in a foregoing section. Since these parameters are usually estimated as frequency distributions to reflect variations in the value of economic discoveries and the multistage nature of the exploration investment process, the expected value function is modified as follows:

$$EV = \Sigma p_i R_i - \Sigma q_j C_j,$$

where $\Sigma p_i = p$
$\Sigma q_j = 1$

If sufficient information is available, the expected value concept may be refined to assess expected profitability and size. This is useful because these are the common criteria for exploration investment decisions. If expected profitability is measured by the present value ratio, investment and positive cash flow values are discounted to the present point in time using the corporate cost of capital and the ratio between discounted net return (expected value) and discounted investment (including both exploration and mine development expenditures) is calculated. Note that the discounting procedure has been embodied in the definition of R. Thus:

$$EP = \frac{EV}{pI + C} = \frac{\Sigma p_i R_i - \Sigma q_j C_j}{\Sigma p_i I_i + \Sigma q_j C_j},$$

where EP is the expected profitability as measured by the present value ratio, and I is the investment required to develop an economic discovery, discounted to a present value using a rate reflecting the corporate cost of capital.

The size criterion can be assessed by several parameters including R, average R per year, or I (reflecting mine capacity).

Economic discovery is defined by the minimum expected profitability and size limits which the company sets for exploration investment.

CORPORATE RISK CRITERIA

An important characteristic of the mineral exploration environment is the low probability associated with economic discovery. Under this condition the application of limited corporate funds does not insure the realization of expected value and exploration resources may be expended without success. The corporate risk associated with the realization of expected value introduces a survival element into the development of corporate exploration strategies. This risk may be quantified by applying the classical problem of the gambler's ruin.

The classical problem of the gambler's ruin concerns a gambler with limited capital who wagers against a 'house' with essentially unlimited resources. The gambler is ruined and the game terminates if at any point his capital balance falls to zero. Survival is the complement of ruin. The gambler survives if his capital balance is maintained above zero. The problem is to determine the gambler's probability of ruin.

If the mining company is to survive beyond the life of its current operations, it must search for and discover economic mineral deposits. This activity is analogous to a gambler wagering on a chance device. The mining company is the gambler, nature is the opponent, and exploration the chance device. The cost of discovering a deposit is the wager. Each discovery has a probability of success, in which case a return is realized by the company, and a probability of failure, in which case the company loses its wager. The company allocates some limited amount of capital to the search activity. What is the corporate risk associated with survival?

Allais (1957), Slichter (1960), and Brant (1967) consider the application of a special case of the gambler's ruin problem to exploration investment, the probability of zero successes in n successive wagers. However, the mining company may also be ruined after one or more successes. This broader concept of gambler's ruin applied to corporate risk assessment for the development of exploration strategies is shown in Fig. 1. It is assumed that a proportion 'e' of the return R resulting from an economic discovery is reinvested in exploration, equivalent to an amount $E = eR$.

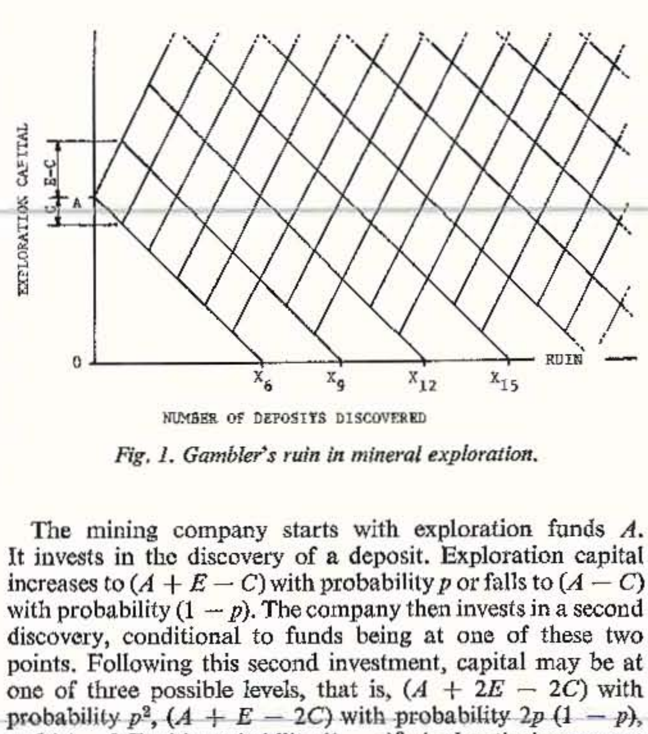

Fig. 1. Gambler's ruin in mineral exploration.

The mining company starts with exploration funds A. It invests in the discovery of a deposit. Exploration capital increases to $(A + E - C)$ with probability p or falls to $(A - C)$ with probability $(1 - p)$. The company then invests in a second discovery, conditional to funds being at one of these two points. Following this second investment, capital may be at one of three possible levels, that is, $(A + 2E - 2C)$ with probability p^2, $(A + E - 2C)$ with probability $2p(1 - p)$, and $(A - 2C)$ with probability $(1 - p)^2$. And so the investment process continues.

Each grid intersection represents a possible capital level. The grid is bounded by lines representing straight runs of success and failure. When the boundary representing failure in every investment reaches the zero capital level, the grid is bounded by the zero capital axis, an absorbing state which represents ruin of the mining company. To the right the grid remains open, implying that the company will invest in exploration indefinitely. The summation of the probabilities associated with the ruin points along the zero capital axis, each representing a unique number of successes, failures, and total investments, is the mining company's probability of ruin.

Uspensky (1937) developed a variation of the gambler's ruin problem which has been applied by the author (1968) to the mining company's survival conditions in the exploration environment. The derivation of the solution for this application is described in the Appendix.

Assuming that initial exploration funds are large in relation to discovery cost and that the expected value of costs and returns *to* exploration $(pE - C)$ is positive, then

$$Pr = \theta^A.$$

Here θ is that root of

$$p\theta^{E+1} - \theta + q = 0$$

for which $0 < \theta < 1$. In these expressions Pr is the probability of the mining company's being ruined, that is, $Pr = (1 - Ps)$ where Ps is the probability of survival. Also, A denotes the initial exploration funds of the mining company measured in discovery units, that is, number of discoveries afforded, $C = 1$ is the cost of an exploration discovery, E is the amount reinvested in exploration from each economic discovery measured in discovery units, $E = eR$, where R is the return to the mining company given an economic discovery, and e is the proportion reinvested in exploration. Finally, p is the probability of an economic discovery and q is the probability of uneconomic mineralization, $q = (1 - p)$.

These relationships provide the basis for estimating the corporate risk associated with exploration, given assessments of environmental parameters and corporate funds available for exploration.

For example:

p = 0.01
C = \$150 000
R = \$45 000 000
E = \$21 000 000
θ = 0.994 861 4

Exploration investment	*Probability of survival*
\$1 500 000	0.05
\$9 000 000	0.27
\$15 000 000	0.40
\$37 500 000	0.72
\$75 000 000	0.92
\$150 000 000	0.99

'WHAT TO LOOK FOR' STRATEGIES

In the long term, exploration investment is guided by long-term market trends for specific mineral commodities in relation to their resource potentials. The more favourable the relationship, the more attractive the commodity as an exploration target. A study by Booth (1971) determines relationships between the natural abundance of metals in the earth's crust, trends in annual production, and trends in price, for various metals over the past decade. Availability of a metal is measured as the product of natural abundance and price, and degree of exploitation by abundance divided by annual production. Metals having a relatively high availability factor and a relatively rapidly decreasing exploitation factor are regarded as the most attractive exploration targets, reflecting high natural abundance, high price and rapidly increasing demand. On this basis copper, nickel and tin ranked highest as attractive exploration targets. Although relative differences in exploration, production and processing costs for the metals are neglected, this type of analysis provides general guidelines in selecting commodities as exploration targets.

However, the selection of commodities for exploration also depends on the particularities of the individual mining company, such as profit and corporate risk criteria, forward processing requirements, product research and development activities, market control for specific commodities, and marketing, exploration and processing skills. For example, it is for both general commodity and specific corporate reasons that International Nickel has concentrated on nickel as an exploration target, that an aluminium company explores for fluorspar, or that a petroleum company explores for uranium.

Given that a particular commodity is acceptable in terms of corporate policy, the attractiveness of exploring for it depends on forecast trends in supply, demand and price. These trends are reflected in the R parameter, the return given an economic discovery. Thus, the long-term attractiveness of a mineral commodity is expressed in the expected value and expected profitability criteria. The higher the expected assessments, the more attractive the commodity as a target for exploration investment.

Long-term profit criteria will be the primary consideration for mining companies which are sufficiently large to ensure the realization of expected values. Smaller companies must also consider corporate risk conditions, selecting those commodities which offer relatively low discovery costs and a relatively high probability of economic discovery. By searching for this type of target, and accepting relatively small and marginal deposits as economic discoveries, the small company may have the best chance of survival.

'WHERE TO LOOK' STRATEGIES

Geographical concentration of exploration is based on geological concepts for the types of deposits sought as exploration targets. Good geological concepts are fundamental to exploration success and should be the focal point for geographical concentration. Geological concepts are a function of time, information and experience. The mining company with the best geological concepts will concentrate exploration in areas having the highest probability of economic discovery.

Sullivan (1968) and Michener (1970) have described the associations between particular types of mineral deposits and particular geological environments. Accordingly, the contact between rhyolites and andesites provides a favourable setting for copper-zinc deposits, nickel and asbestos deposits are associated with particular types of basic and ultrabasic igneous rocks, and copper-molybdenum deposits occur in porphyry stocks or in surrounding metamorphosed skarn zones.

Within the set of geologically favourable areas, geographical selection is based on mineral occurrence and economic and political factors. Michener (1969) provides a subjective assessment of these factors in a large number of countries for the purpose of ranking them in terms of overall exploration favourability. In this assessment, Australia, Canada, Mexico, South Africa, New Zealand and Spain have the best ratings while Liberia, Bolivia, Venezuela, Haiti and Nigeria have the lowest.

For area selection from geologically favourable regions within a particular country, attention must be given to both mineral resource potential and economic factors. At this level, mineral occurrence models may be of assistance in predicting area resource potentials. Economic differences between regions due to differences in local taxation, transportation facilities, regional development incentives, power costs and manpower considerations, must also be assessed.

As in the case of commodity selection, geographical concentration will also be based on corporate particularities, namely, traditional exploration regions, balance required between a stable political environment and a favourable geological environment, and corporate marketing considerations. For example, Hudson Bay Mining and Smelting, a regionally-based smelter company, has concentrated exploration in the greenstone belts of northwestern Manitoba. On the other hand, International Nickel's global exploration strategy, as described by Zurbrigg (1971), has major exploration programmes in most countries of the non-communist world with nickel potential including Canada, United States, Australia, Indonesia, Guatemala, New Caledonia and Southern Africa.

Individual corporate assessments of geographical favourability will differ markedly. Armstrong (1970) of Cominco views the Canadian Cordilleran and the Shield area of the Canadian Arctic as the most geologically favourable areas for exploration in a country which he prefers to the United States and Australia in the economics of exploration. Futterer (1970) has described Noranda's exploration philosophy which has resulted in international exploration on an expanding scale and the investment of 25 per cent of its total programme in Australia. Holmes (1971) advocates the metallogenic belts of Western Europe and the Middle East as exploration areas of traditional neglect and high potential.

Short-term survival considerations will also influence geographical selection for small mining companies. Small companies, perhaps a generation or two ahead of the economics, often lead the way in remote-area exploration. Small discoveries will be of significance to the small company and their high grade may overcome adverse economic factors associated with remote locations.

SURVIVAL STRATEGIES

Survival is a primary objective of the mining company. For purposes of exploration planning this objective may be expressed as a probability of survival confidence limit. The corporate risk criterion can be used to determine the combinations of environmental parameters and corporate exploration funds required to achieve the company's survival objective. For example, Fig. 2 shows the necessary conditions to attain a probability of survival objective of 0.90. The asymptotic values for individual curves have important implications for the mining company's survival strategy. They give critical values for the allocation of exploration funds, and the amount reinvested in exploration from each economic discovery, below which the corporate survival objective cannot be realized.

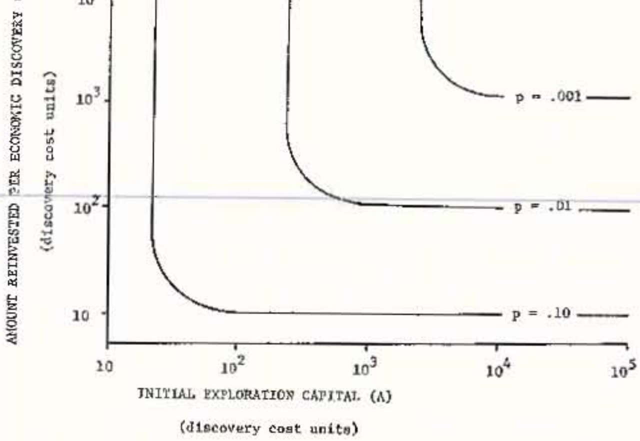

Fig. 2. Exploration survival conditions.

The mining company's survival strategy centres on one of the following questions:

(i) What environmental probability of an economic discovery should the company seek to fulfil its survival objective?

(ii) What changes in amount reinvested from each economic discovery would be required to balance a change in the probability of an economic discovery in order to maintain the company's survival position?

(iii) How much capital should the company allocate to exploration to realize its survival objective?

Answers to these questions may be obtained from the corporate risk functions as illustrated in Fig. 2. In general terms it is clear that low probabilities of economic discovery are manageable only for large companies, that is, as the probability of an economic discovery is reduced, there must be a compensating increase in return given an economic discovery and amount reinvested from each economic discovery to induce firms to participate; also, higher levels of exploration funds are required for lower probabilities of economic discovery.

To this point, it has been assumed that exploration is financed internally. When internal resources are insufficient to realize the company's survival objective, it may be suitable for the company to pool its resources together with other companies in joint ventures. Joint ventures are commonly used in mineral exploration, primarily as a survival strategy. It is a reasonable strategy provided that control is not diluted excessively.

The ratio of internal exploration funds to the total amount required to realize the company's survival objective represents the joint venture participation which the company should seek. For example:

p = 0.01
C = \$150 000
R = \$45 000 000
E = \$21 000 000
Ps objective = 0.90.

Internal exploration funds	*Required joint venture participation*
\$5 000 000	7%
\$25 000 000	35%
\$50 000 000	70%
\$75 000 000	100%

Many mining companies are not large enough for joint ventures to offer a reasonable alternative. These companies must seek other survival alternatives. At the limit the total return from economic discoveries can be reinvested in exploration. This helps only after the first economic discovery has been made. Alternatively, attention may be focussed on special exploration environments, such as commodities with very limited demand, surface deposits, and remote areas, where environmental parameters encourage survival. Also, the small mining company may invest in deposits which have been discovered and rejected by larger companies. These will usually be small, marginal deposits which do not meet the minimum acceptable conditions of the larger companies. In some instances fully-fledged economic discoveries which have not been perceived by the discoverers may be acquired.

'HOW TO LOOK' STRATEGIES

The fundamental issue in structuring an exploration programme is the balancing of available exploration funds between direct investment in discovering deposits and investment in the level and quality of skills in the exploration group. The larger the allocation to direct exploration investment, the larger the number of discoveries and the better the company's chances of realizing expectations. The benefits which result from increasing exploration group investment are in the selection of exploration environments with superior economic characteristics. This will result from better geological concepts, and more informed assessments of mineral resource potential and the economic characteristics of exploration environments. A more highly skilled exploration group will increase the company's probability of economic discovery. The optimum balancing of exploration funds will maximize the company's chances of realizing its exploration objectives.

Because a low probability of economic discovery is associated with each exploration investment, a sequential investment strategy is used to limit the cost of failure by breaking the exploration investment into a number of components each of which is associated with a particular sequential stage. The cost of discovering uneconomic deposits is reduced when these discoveries are determined to be uneconomic and are rejected before being fully explored. A three-stage sequential example is shown in Fig. 3. The cost associated with discovering and exploring a deposit fully is F. The boundary condition for continuing investment is assumed to be an expected value greater than zero. The boundary condition defines two zones; these are a zone of favourable expectations, in this case representing positive expected values, and a zone of unfavourable expectations representing negative expected values. Assessments of p, R and expected further exploration costs (xF) are made on completion of each stage. Exploration investment continues until either the assessment of expected value is negative or until the probability of an economic discovery justifies a mine development decision. The starting point for an investment, S, represents a fixed cost, $0.1F$, that is incurred in defining the exploration opportunity. Three failure paths for the exploration opportunity are shown. If exploration investment had been in a single stage, the cost of the three failures would have been 3.0 F. The three-stage sequential process has limited the cost of the failures to 1.6 F.

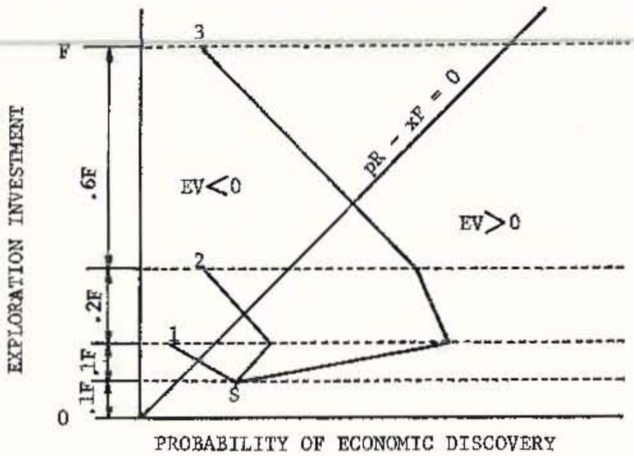

Fig. 3. Sequential exploration investment.

The benefits of the sequential process, in terms of limiting the exploration investment in uneconomic deposits, must be balanced against the opportunity cost associated with rejecting economic discoveries. It is this benefit-cost relationship which determines the optimum boundary condition for accepting and rejecting opportunities at the end of each sequential stage. The selectivity should be such that combined direct and opportunity costs are minimized. This is known as the problem of 'skimming' and it is of critical importance in determining the economics of exploration investment to the mining company.

In the sequential exploration process the prior probability distribution of the expected profitability of a discovery is relatively flat to begin with. On the other hand, the successive posterior distributions as more and more exploration has been completed are more and more sharply peaked or concentrated in a more limited range and, therefore, there is better and better information for deciding on acceptance or rejection and a basis for increasingly rigorous decision criteria. In the early stages, the expected profitability is much less sharply defined than it is later on and overly rigorous decision criteria will result in the rejection of economic discoveries. As deposits are carried through the sequential stages, the less promising are gradually eliminated as information is accumulated.

Skimming is used to minimize costs and, thereby, optimize the exploration investment process. It may not maximize the number of economic discoveries. Skimming should mean that a high proportion of the deposits fully explored are economic with the early elimination of a high proportion of total discoveries. The possibility that economic deposits are rejected is clearly increased as the number of deposits fully explored is reduced, since the nature of skimming involves accept-reject decisions on less than conclusive evidence.

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APPENDIX

Uspensky (1937) developed a variation of the gambler's ruin problem which has been applied by the author (1968) to the mining company's survival conditions in the exploration environment.

Two opponents, A and B, play a series of games, the probability of winning a single game being p and $q = (1 - p)$, respectively, each game ending in a loss for one of them. If the stakes in a single game are C for A and R for B, and the players' respective fortunes are A and B, what is the probability that one of the players will be ruined, in the sense that at a certain stage his fortune is less than a single game stake? No limit is set for the number of games.

Let P_x be the probability for A to be ruined by the lack of sufficient funds to set a full stake C when his fortune amounts to x and, consequently, his adversary's fortune is $A + B - x$.

Considering the result of the game immediately following the situation in which the fortune of A amounted to x, it is possible to establish an equation in finite differences that P_x must satisfy. If A wins this game, his fortune becomes $x + R$ and the probability of being ruined later is P_{x+R}. By the theorem of compound probability, the probability of this case is pP_{x+R}. But if A loses, his fortune becomes $x - C$ and the probability of being ruined later is P_{x-C}. The probability of this case is qP_{x-C}. Now, applying the theorem of total probability, P_x is a solution of the equation in finite differences:

$$P_x = pP_{x+R} + qP_{x-C} \quad \ldots\ldots (1)$$

To determine P_x completely, in addition to (1) there are two boundary conditions:

(i) if the fortune of A becomes less than C, he is ruined;

(ii) it is impossible for A to be ruined if the fortune of B falls below R.

Equation (1) is an ordinary equation in finite differences of the order $C + R$. It has particular solutions of the form θ^x, where θ is the root of the equation:

$$p\theta^{C+R} - \theta^C + q = 0 \quad \ldots\ldots (2)$$

Equation (2) has two positive roots, $\theta = 1$, and another which is either greater or smaller than unity, according to whether the expected value of the game to A is negative or positive, that is, $pR - C < 0$ or > 0. That is, the positive root of (2) different from unity is > 1 when single games are favourable to B and < 1 if they are favourable to A. In the case of equitable games, both positive roots coincide and $\theta = 1$ is a double root. All other roots are negative or imaginary.

The general solution leads to a complicated expression for P_x. However, simple lower and upper limits for P_x can be established that are close enough, provided the fortunes of the players are large in comparison with their stakes. Taking $x = a$, the following limits are obtained for the probability of ruin for player A, P_r:

$$\theta^A \frac{\theta^{B-R+1} - 1}{\theta^{A+B-R+1} - 1} \leqslant P_r \leqslant \theta^{A-C+1} \frac{\theta^B - 1}{\theta^{A+B-C+1} - 1} \quad \ldots (3)$$

Assuming that nature has essentially unlimited resources, that the mining company will invest in exploration indefinitely and that only a portion of the returns from economic discoveries will be reinvested in exploration, the mining company's probability of being ruined can be determined.

Let A be the mining company, B the nature, $C = 1$ the cost of an exploration discovery, R the return to the mining company given an economic discovery in cost units and E be the amount reinvested in exploration from each economic discovery measured in cost units, $E = eR$, where e is the proportion of R reinvested. Also, denote by p the probability of an economic discovery, by q the probability of uneconomic mineralization, $q = (1 - p)$, and by A the initial exploration funds of the mining company measured in cost units, that is, number of discoveries afforded. Let nature's resources $B = \infty$. Finally, EV' is the expected value of costs and returns *to* exploration in cost units, $EV' = pE - 1$, and Pr is the probability of the mining company being ruined, $Pr = (1 - Ps)$ where Ps is the probability of survival.

Substituting in (2):

$$p\theta^{E+1} - \theta + q = 0 \quad \ldots\ldots (4)$$

and in (3):

$$\theta^A \frac{\theta^{\infty-E+1} - 1}{\theta^{A+\infty-E+1} - 1} \leqslant P_r \leqslant \theta^A \frac{\theta^{\infty} - 1}{\theta^{A+\infty} - 1}$$

If EV' is positive for the mining company, then $\theta < 1$ and the above expression reduces to:

$$P_r = \theta^A \quad \ldots\ldots (5)$$

If EV' is equitable or negative for the mining company then $\theta \geqslant 1$ and:

$$P_r = 1. \quad \ldots\ldots (6)$$

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