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On the Economic Evaluation of Individual Regional Mineral Exploration Projects

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With 4 figures

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Summary

Regional mineral exploration, the most strategic and risky phase in the mineral supply system, is a dynamic process which converts undiscovered geological resources into ore reserves. Despite the crucial role of exploration, the economic performance of individual projects, which are (like any other economic activity) subject to economic principles, is usually rather difficult to measure since clear criteria are frequently hard to define.

A regional exploration project evolves by successive "go/stop" decisions which are governed by perceptions of costs, risks and possible returns, and are subject to the elementary decision matrix for the testing of statistical hypotheses. To minimize running the risk of investing in the detailed exploration of uneconomic prospects and to quantify the project risk on all decision levels, analytical financial models based on geology are thought to constitute the best management tool.

Zusammenfassung

Regionale Lagerstättenprospektion bildet als risikoreichste und strategisch wichtigste Phase der Montanwirtschaft einen dynamischen Prozeß, der unentdeckte geologische Ressourcen in potentielle Erzreserven umwandelt. Trotz dieser überragenden Bedeutung läßt sich der wirtschaftliche Erfolg individueller Projekte nicht immer leicht bestimmen, da klare Erfolgskriterien oft schwer definierbar sind.

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Ein regionales Prospektionsprojekt entwickelt sich über eine Folge sukzessiver „go/stop" Entscheidungen, die von Beurteilungen von Projektrisiko, Kosten und wirtschaftlichen Erfolgschancen gesteuert werden. Zur Minimierung des Risikos falscher Entscheidungen am Ende der regionalen Prospektionsphase, d. h. zur Vermeidung von Investitionen in die Detailexploration unwirtschaftlicher Mineralvorkommen, dürften finanzanalytische Modelle auf geologischer Basis die beste Entscheidungshilfe bilden.

1. Introduction

Mineral exploitation forms an essential part of the economic foundation of any advanced society, and has invariably been one of the first steps in economic development from the early civilizations to the modern oil sheikdoms in the Middle East. A continuous supply of both nonfuel minerals and fossil sources of energy is critical to the world economy and its ever increasing population.

The mineral supply system is a complex interrelationship of geological, technical, economic, and political factors and constraints (Fig. 1). Regional mineral exploration, essentially "the location of mineral deposits of possible economic importance" or "the identification of mineral deposits and demonstration of their possible

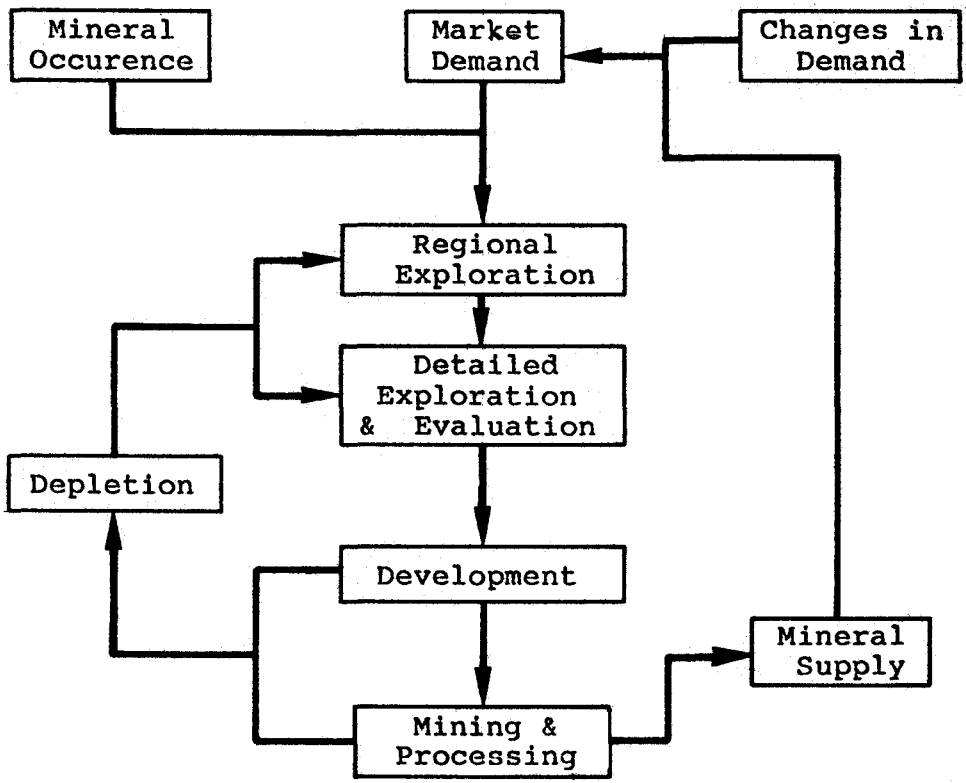

Fig. 1: General Presentation of the Mineral Supply System.

economic importance" constitutes its first and most strategic phase. Regional exploration can therefore be defined as a dynamic process of converting unknown geological resources into potential ore reserves (SNOW & MACKENZIE 1981). It represents the phase with the highest risk during mineral development. This risk is compensated, however, by the large possible returns from an economic discovery, while the major investments in mineral development are made at considerably lower levels of risk.

2. Basic Conception

Any regional mineral exploration project represents an economic activity and is therefore subject to basic economic principles, which measure economic success in terms of revenues and related expenditures.

The costs of an individual project are easily determined. The value of its results is more difficult to measure in monetary terms because the discovery of an orebody which needs further detailed exploration and development to become a producing mine has no definite monetary value per se.

Therefore the most elementary definition of the economic principle, "the necessity to achieve a desired result, i. e. the discovery of a mineral deposit, which justifies further exploration and development, with the minimum of effort", is more suitable for evaluating individual projects.

The determination of the economic potential of a mineral discovery and of the probability of meeting corporate investment criteria therefore forms an integral part of any project; the resulting elementary decision matrix, illustrated in Fig. 2, is similar to the general theory on the testing of statistical hypotheses.

DECISION		MINERALIZATION	
		ECONOMIC	UNECONOMIC
FURTHER INVESTMENT INTO DETAILED EXPLORATION	CONTINUED	CORRECT DECISION	ERROR 2nd KIND
	DISCONTINUED	ERROR 1st KIND	CORRECT DECISION

Fig. 2: Decision Matrix.

Since no returns are assured in mineral exploration, funds must be provided strictly as risk capital. Therefore errors of the 1st kind, in other words the rejection of economically viable prospects, cause a loss of investment opportunities (see also YUILL 1985); consecutive errors of the 2nd kind (i. e. the investment of venture capital under conditions of high risk in detailed exploration of uneconomic prospects), will however lead to the rapid depletion of the limited financial resources available for exploration. To survive gamblers' ruin in this high-risk environment, it is essential that decisions aim to minimize running the risk of continuing to explore

prospects which prove to be uneconomic. The risk of rejecting a viable orebody (1st kind error) can not be eliminated and is represented in the statistical theory by a significance level which depends in our case on exploration saturation and on the data available for decision-making.

Due to the limited amount of data which are available after regional exploration, this initial appraisal is based on numerous qualitative or semi-quantitative assumptions and estimates; it evolves by dynamic "go/stop" decisions which are also subject to the decision matrix in Fig. 2 and which reflect successive assessments of economic potential and risk of the project.

Since a complex project yields positive results with a minimum of effort only if an optimum structure is maintained, the efficiency of the project structure and implementation constitutes an additional, easily definable evaluation criterion.

3. Structure of Regional Mineral Exploration Projects

3.1. Overall Structure of Mineral Exploration

A regional exploration project evolves, as illustrated in Fig. 3, by successive exploration decisions reflecting perceptions of costs, risk, and returns associated with the project. The initial project identification and evaluation is followed by a generative stage involving programme design and target selection, and by the implementation of this programme: i. e. the exploration of the target area by the most appropriate combination of integrated geological, geophysical and geochemical methods, which define and characterize country rock and mineralization. If technically successful, it culminates in the discovery of a mineral deposit, and the concluding appraisal of its economic potential.

If the discovery's economic potential justifies detailed exploration, the dimensions, geometry and grades of the ore body are established in more detail to permit the assessment of the project's feasibility. If the results are encouraging, mine development and exploitation eventually convert the geological ore potential identified by regional exploration into marketable mineral commodities.

3.2. Project Identification

The decision to initiate mineral exploration and development in accordance with overall corporate objectives and strategies may commit substantial capital resources. It therefore presupposes a rigorous initial economical, geological and technical appraisal designed to identify the project opportunities with the best economic potential.

Future supply, demand and price trends for the envisaged mineral commodity are of paramount importance for this decision, since a reasonable probability must exist that adequate demand is present and will be sustained at adequate prices over the life of the mining venture. Realistic assessments are needed of the supply which is likely to become available from competing sources, of price trends and of the possible impact of technological and economical changes or of substitutes on final markets. The decision to embark on exploration and the identification of project oppor-

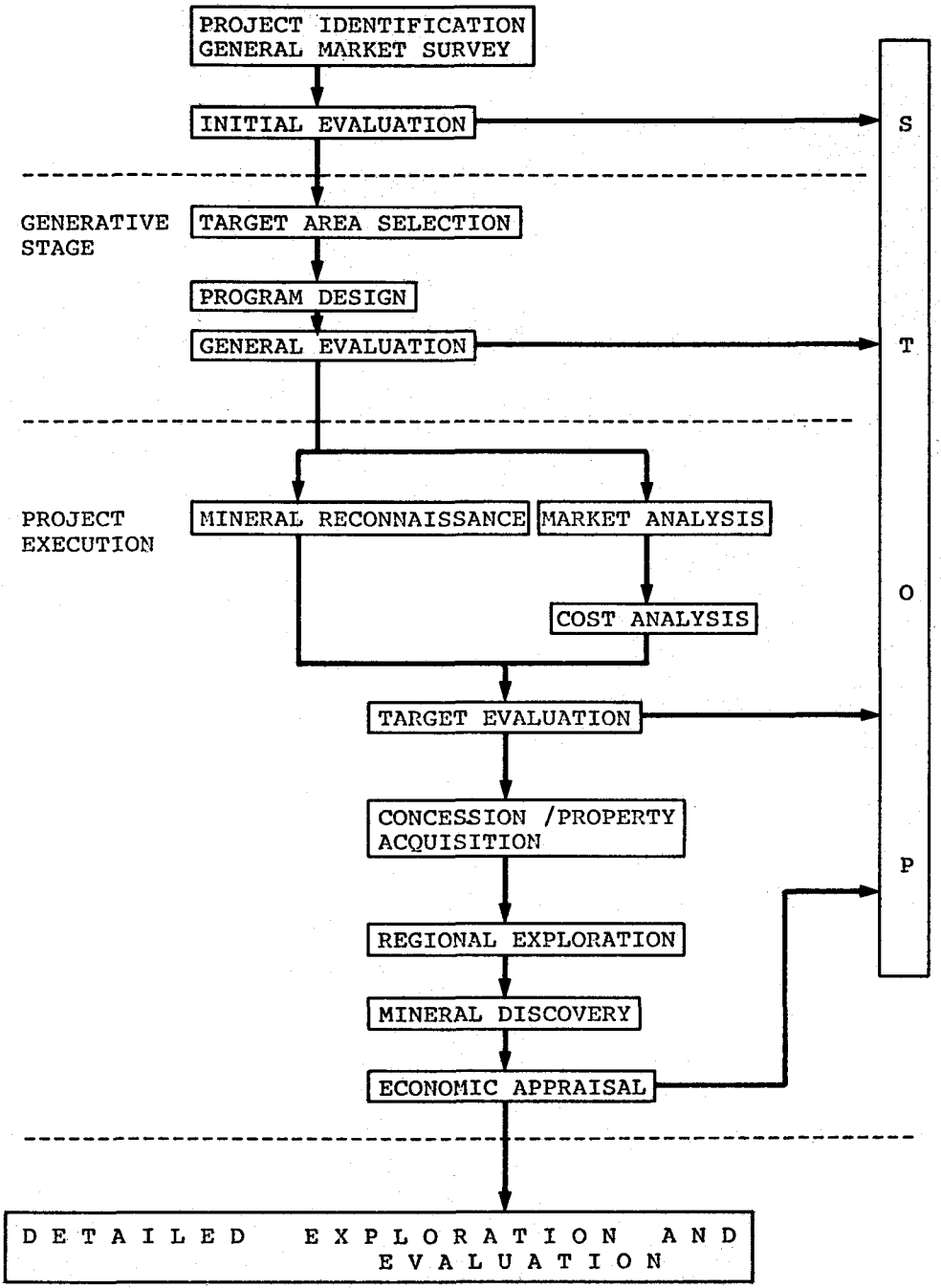

Fig. 3: Structure of Regional Mineral Exploration Projects.

tunities thus requires the evaluation of a series of interdependent geological, technical, economic, financial, legal and political factors.

3.3. Generative Stage

The objective of this stage is primarily the selection of areas favourable for mineralization in various geological environments.

Traditionally this selection can be influenced to a considerable extent by intuitive geological analogy, subjective considerations, time-honoured rules of thumb and even random guesses. However, valid geological concepts and exploration techniques are fundamental to successful exploration, and should therefore form the core of this generative stage.

Theoretical models to assist in optimum target area selection have focussed since the first determination of probabilistic mineral potential distributions by ALLAIS (1957) on the general probability of project success (e. g. SCHWARTZ 1984, SAMES & WELLMER 1981, the comprehensive view of NEUBAUER 1971, KOCH & LINK 1971, BRANT 1968), or on quantitative statistical or metallogenetic resource appraisal models (e. g. the detailed review by HARRIS & AGTERBERG 1981 with a comprehensive list of references, or WHITNEY 1975, HARRIS 1973, DEGEOFFROY & WIGNALL 1970 and 1971, and DEGEOFFROY & WU 1970).

All these models, however, only assist in solving the basic problem of estimating with reasonable accuracy a still undiscovered mineral potential on the basis of valid geological and genetic concepts. This estimate by professional judgment or by mathematical/geological models forms together with the selection of the most appropriate combination of exploration techniques one of the most critical decisions for successful regional exploration.

3.4. Project Execution

Detailed discussions of the state-of-the-art geological, geophysical and geochemical exploration techniques and of the technical efficiency of their application exceed the scope of this paper (see e. g. WELLMER 1984). As illustrated in Fig. 4 (modified from SNOW & MACKENZIE op. cit.), continuous verification and adjustment of the geological concept established during the generative stage takes place during project execution. This updated geological concept has to be translated into economic perceptions of risks, costs, and returns after the completion of each exploration phase; otherwise the exploration process becomes arbitrary from the economic viewpoint, and the benefits which could accrue from various planning alternatives are neglected.

The moment of technical and geological success in regional mineral exploration is the discovery of a potential ore body. This term refers to a mineralization where reconnaissance drilling, pitting or trenching physically indicate that potentially economic ore grades exist over mineable widths and extents under technically acceptable conditions (see also FETTWEIS 1983). Since this mineralization will usually

have to satisfy both minimum profitability and acceptable size criteria, the concluding appraisal involves the selection of the mineralization perceived to have the highest economic potential or the highest probability of meeting corporate exploration criteria.

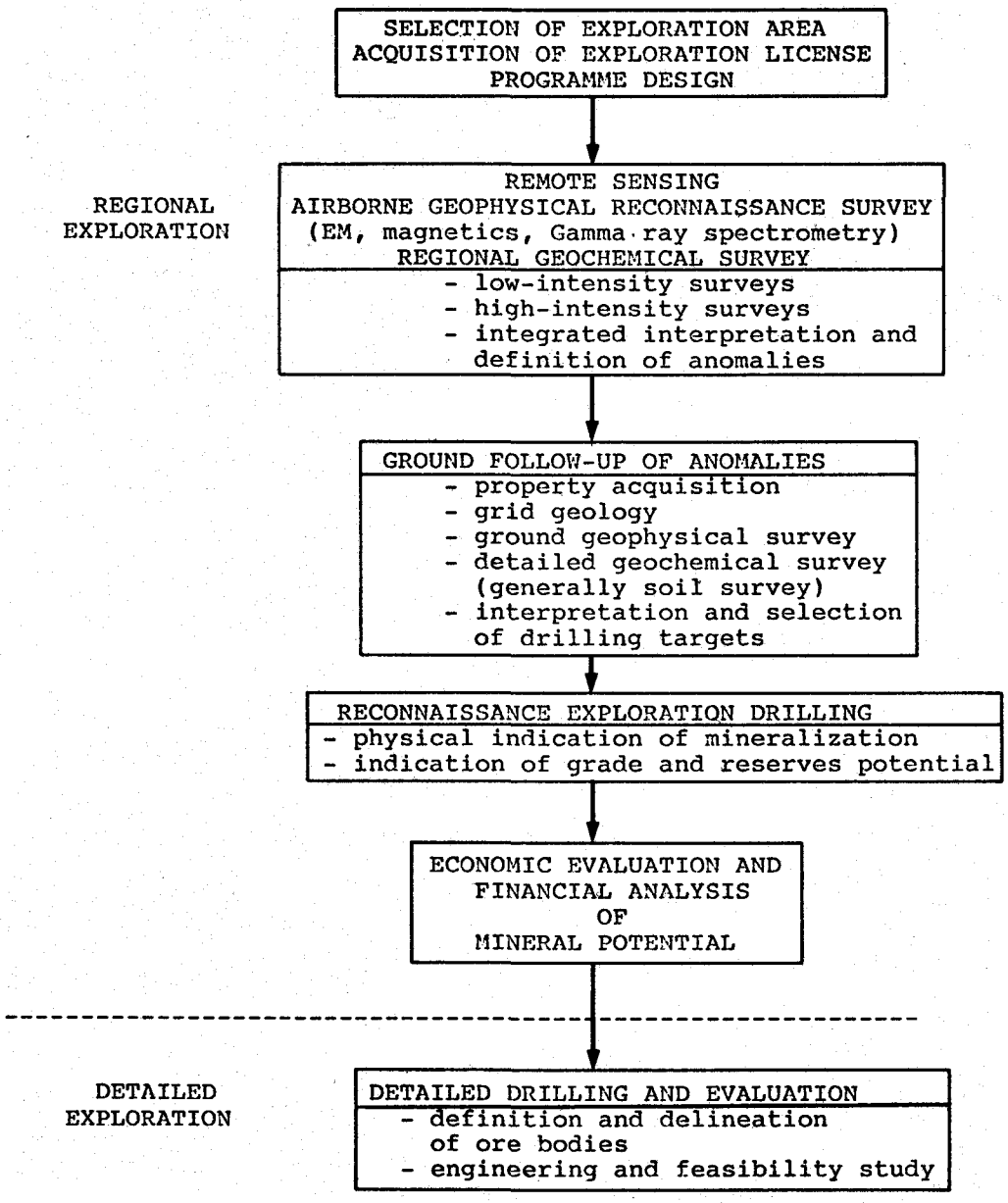

Fig. 4: Execution of Regional Mineral Exploration.

4. Economic Project Analysis

The successive decisions which govern the exploration process reflect assessments of economic risk, costs and potential returns at different levels of accuracy. To be economically significant, the relevant geological and technical data have to be expressed in economic terms for the financial analysis of the project.

Probabilistic models for the project risk on the basis of the law of gamblers' ruin forecast project success as a mathematical relationship involving specific exploration expenditure per area unit, statistical probability of ruin, and the probability of the existence of a mineral deposit. Such concepts, however, neglect the impact of superior geological concepts and exploration skills on the assessment of geological environment, costs, risks and returns which cause the success of efficient organizations. The human factor, however, leads also to intuitive risk assessments which are no substitute for quantitative analysis and review of the technical and economic viability of developing a mineral discovery.

This analysis must consider the uncertainty of crucial input data for this financial assessment, in particular recoverable ore reserves, ore grade, future production, investment costs, operating and capital costs, and future sales and earnings. The discussion of the methods of financial analysis or capital budgeting techniques under such conditions exceeds the scope of paper (see for instance WILKES 1977, HELFERT 1982). In general, the future cash-flows expected to be generated by a project have to meet specific investment criteria; since the probabilistic input parameter and returns from the project are not known with certainty, the parameters most suitable for such evaluations on the basis of discounted cash-flows are expected net present value (NPV) and expected yield (= internal rate of return). Forecasts of earnings and costs enter this financial analysis either as fixed deterministic values, possibly supplemented by a sensitivity analysis, or as stochastic distributions.

An elementary decision tool for exploration management could combine the minimum expected yield with the following ratio:

$$\frac{\text{expected project NPV} \times \text{estimated probability of project success}}{\text{NPV of exploration costs} \times (1 - \text{probability of project success})}$$

These parameters could serve as the basis for budgeting further exploration expenditures, assessing success breakeven probabilities, evaluating risks and focussing further exploration on the most sensitive project parameters. Expected NPV and yield result from the "most likely" input parameter in deterministic models, or from probabilistic distributions such as are obtained from Monte Carlo simulations. The probability of success either derives from statistical models on resource endowment or represents the entrepreneurial perception of the project risk.

Naturally this analytical model does not eliminate exploration or overall investment risk. Its application is, however, preferable to an intuitive decision to continue the exploration of a mineral deposit, since financial analysis quantifies and defines the geological, technical and economical input data and the associated risks; it leads on all decision levels to a quantification of the risks, sensitivities and expenditures for the subsequent detailed exploration of the property. This model for evaluating regional exploration projects is partly oversimplified, but any refinement regarding

such items as debt-equity structure, financing strategy, cost structure, or political risk and investment climate – to name but a few – are only variations of this basic concept, which attempts to integrate the key notions discussed earlier into an elementary outline of geological, technical and financial tools in regional mineral exploration management and project evaluation.

Acknowledgements

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Bibliography

ALLAIS, M.: Method of appraising economic prospects of mining exploration over large territories: Algerian Sahara case study. – Management Sci. **3**, 285–347, 1957.

BOSSON, R. & VARON, B.: The mining industry and the developing countries. – 292 p., The World Bank, University Press, Oxford 1977.

BRANT, A. A.: The pre-evaluation of the possible profitability of exploration prospects. – Mineral. Dep. **3**, 1–17, 1968.

DEGEOFFROY, J. & WIGNALL, T. K.: Statistical decision in regional exploration: Application of regression and Bayesian classification analysis in the Southwest Wisconsin zinc area. – Econ. Geol. **65**, 769–777, 1970.

– : A probabilistic appraisal of mineral resources in a portion of the Greenville Province of the Canadian Shield. – Econ. Geol. **66**, 466–479, 1971.

DEGEOFFROY, J. & WU, S. M.: A statistical study of ore occurrences in the greenstone belts of the Canadian Shield. – Econ. Geol. **65**, 496–504, 1970.

FETTWEIS, G. B.: Bergmännische Überlegungen zur Exploration im allgemeinen und zum Stand der Kohlenexploration in Österreich im besonderen. – Berg- u. Hüttenmänn. Mh. **128** (4), 93–106, Springer Wien–New York 1983.

HARRIS, D. P.: A subjective probability appraisal of metal endowment of Northern Sonora, Mexico. – Econ. Geol. **68**, 222–242, 1973.

HARRIS, D. P. & AGTERBERG, F. P.: The appraisal of mineral resources. – Econ. Geol. 75th anniv. vol.: 897–938, 1981.

HELFERT, E. A.: Techniques of financial analysis. – 290 p., copyright R. Irwing Inc. 1977, license print Navotas, Manila 1982.

KOCH, G. S. & LINK, R. F.: Statistical analysis of geological data. – 2 vols. J. Wiley, New York 1971.

NEUBAUER, W. H.: Kosten der Lagerstättenerschließung und Probleme ihrer Finanzierung. – Berg- u. Hüttenmänn. Mh. **116** (8), 279–293, Springer Wien–New York 1971.

SAMES, W. & WELLMER, F. W.: Exploration 1: Nur wer wagt gewinnt – Risiken, Strategien, Aufwand, Erfolg. – Glückauf **117** (10), 580–589, 1981.

SCHWARTZ, M. O.: Risiko der Exploration von Porphyry-Copper-Lagerstätten. – Erzmetall **37**, 65–72, 1984.

SNOW, G. G. & MACKENZIE, B. W.: The environment of exploration: economic, organizational and social constraints. – Econ. Geol. 75th anniv. vol.: 871–896, 1981.

VOGELY, W. A. (ed.): Economics of the mineral industries. – 3rd ed., 863 p., Am. Inst. Mining, Metal. & Petrol. Engs., New York 1976.

WELLMER, F. W.: Kosten-Nutzen-Analyse von Explorationsmethoden. – Erzmetall **37**, (I) 52–57 and (II) 144–150, 1984.

WEST, M.: Economics, politics and engineering. – Trans. IMM **91:** A 95–100, London 1982.
WHITNEY, J. W.: A resource analysis based on porphyry copper deposits and the cumulative copper metal curve using Monte Carlo simulation. – Econ. Geol. 70, 527–537, 1975.
WILKES, F. M.: Capital budgeting techniques. – 424 p., J. Wiley, New York 1977.
YUILL, W. G.: The importance of being small. – Pres. address Trans. IMM **94:** B 107–114, London 1985.

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