Fundamental Issues in Quantitative Estimation of Mineral Resources
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Several issues considered to be fundamental in quantitative estimation of mineral resources and selection of mineral targets are addressed. Integration of multiple data sets, either by experts or by statistical methods, has become a common practice in estimation of mineral potential. Several major problems in data integration must be solved to significantly improve mineral resource estimation. Issues related to randomness of mineral endowment, basic statistical tools, exceptionalness of ore, and economic truncation and translation are discussed in the first part of the article. A number of important technical problems in data integration are also identified; they include data compilation, information enhancement, information synthesis, and target selection.

Key words:
Mineral resource estimation
Information synthesis
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Introduction

Various multivariate models and techniques have been used over the past two decades to relate geological variables to some aspects of mineral occurrence. Conventional objective methods for mineral resource assessment have estimated either mineral endowment or discoverable mineral resources of a particular type of deposit in a region. The mineral endowment of a region usually refers to that quantity of mineral in accumulations that meets specified physical characteristics, such as grade, size, and depth. A multivariate endowment model is essentially characterized by a particular information extraction strategy for the so-called optimum combination of those geological features most related to spatial variations of endowment (Pan and Harris, 1991). Most of these models estimate mineral resources based upon the principle of analogy; that is, the resources in a study region are estimated by a model that is established on a control area by assuming different regions with similar geological environments have similar endowment (Bolbol and others, 1978; Agterberg, 1981; McCammon and others, 1983; Harris, 1984; Harris and Pan, 1991; Pan and Harris, 1991).

Most of these models have employed a grid of regularly spaced cells (intergrid areas) for information reference and have dealt in one way or another with resource favorability, probability, mineral wealth, or density of mineral occurrence. We are especially interested in those models that describe uncertainty about these estimates, such as the probability for occurrence of mineral deposits within a cell. These studies seem to have been a necessary step in the evolution of the science of mineral resource prediction, because geologists in general have been slow to adopt quantitative methods and even slower to substitute objective and quantitative analysis for all or part of subjective analysis. Thus, it was necessary to demonstrate quantitative methods that could be used to estimate undiscovered mineral resources. To some extent, this reluctance to use quantitative methods represented the dissatisfaction of geologists for the low, and sometimes trivial, level of geoscience information represented by the quantitative variables and related to mineral occurrence by the multivariate models. Simply stated, mineral resource estimates by quantitative and objective methods will not improve significantly until more geoscience information is related in more appropriate ways to the various descriptors of mineral resources.

The concept of mineral resource is many-faceted, and includes physical and chemical properties of mineral deposits as they occur naturally in the earth's crust and economic properties created by man's sociotechnical production system and the demands for mineral materials derived therefrom. The discussion presented here focuses on several aspects of mineral resources that are fundamental considerations in the effective information synthesis for mineral resource estimation: randomness of mineral endowment, basic statistical relations, scarcity, economic truncation and translation, and spatial continuity. Some major issues in quantitative mineral resource estimation are addressed, including information enhancement and information synthesis, as well as target identification. Information synthesis is central to both mineral exploration and resource estimation.

Randomness of Mineral Endowment

Most of the past and current studies on mineral resource estimation have been constructed and applied on the basis of a common assumption that mineral endowment descriptors and at least some of the related geological processes behave more or less according to certain stochastic rules. The assumption is seldom challenged, although controversies have continued for three decades, for example, about the types of the stochastic laws that govern the true distributions of geochemical element concentrations (Vistelius, 1960; Brinck, 1972; Harris, 1984). This indicates that the assumption that some geological processes are to some extent stochastic and follow certain stochastic laws has been widely accepted, although it is premature to assert that all of the geoscience features are stochastic. It is useful to examine this notion before investigating specific stochastic laws for particular geological events, the use of statistical models to estimate mineral resources, and probabilistic descriptions of resource descriptors.

In his famous Ideal Granite Model, Vistelius (1972) showed that the crystallization of minerals, such as potassium feldspar, quartz, and plagioclase contained in the "ideal granite," can be modeled by stochastic functions that vary in space and time. It has been proved mathematically that there is a three-dimensional "packing of particles" such that the three mutually perpendicular directions can be described according to the Markov property in each direction with identical transition probability matrices in the three directions (Vistelius and Harbaugh, 1980). Vistelius (1981) also developed his gravitational stratification package model. In the study of red beds of the Cheleken Peninsula, under certain assumptions, Vistelius showed that the sequence of red beds with two distinct states, S (arenaceous beds) and A (argillaceous beds), can be treated as a homogeneous reversible Markov chain of second order, with the partial transition through A being first-order Markov and the partial transitions through S being second-order Markov.