



Short Course Introduction to Quantitative Mineral Resource Assessments

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Short Course Introduction to Quantitative Mineral Resource Assessments

By Donald A. Singer

This is an abbreviated text supplementing the content of three sets of slides used in a short course that has been presented by the author at several workshops. The slides should be viewed in the order of (1) Introduction and models, (2) Delineation and estimation, and (3) Combining estimates and summary. References cited in the slides are listed at the end of this text.

The purpose of the three-part form of mineral resource assessments discussed in the accompanying slides is to make unbiased quantitative assessments in a format needed in decision-support systems so that consequences of alternative courses of action can be examined. The three-part form of mineral resource assessments was developed to assist policy makers evaluate the consequences of alternative courses of action with respect to land use and mineral-resource development. The audience for three-part assessments is a governmental or industrial policy maker, a manager of exploration, a planner of regional development, or similar decision-maker. Some of the tools and models presented here will be useful for selection of exploration sites, but that is a side benefit, not the goal.

To provide unbiased information, we recommend the three-part form of mineral resource assessments where general locations of undiscovered deposits are delineated from a deposit type's geologic setting, frequency distributions of tonnages and grades of well-explored deposits serve as models of grades and tonnages of undiscovered deposits, and number of undiscovered deposits are estimated probabilistically by type. The internally consistent descriptive, grade and tonnage, deposit density, and economic models used in the design of the three-part form of assessments reduce the chances of biased estimates of the undiscovered resources.

What and why quantitative resource assessments: The kind of assessment recommended here is founded in decision analysis in order to provide a framework for making decisions concerning mineral resources under conditions of uncertainty. What this means is that we start with the question of what kinds of questions is the decision maker trying to resolve and what forms of information would aid in resolving these questions.

Some applications of mineral resource assessments: To plan and guide exploration programs, to assist in land use planning, to plan the location of infrastructure, to estimate mineral endowment, and to identify deposits that present special environmental challenges.

Why not just rank prospects / areas? Need for financial analysis, need for comparison with other land uses, need for comparison with distant tracts of land, need to know how uncertain the estimates are, need for consideration of economic and environmental consequences of possible development.

Our goal is to provide unbiased information useful to decision-makers.

A short history: 1957 “Method of appraising economic prospects of mining exploration over large territories—Algerian Sahara case study” by M. Allais, 1974-75 beginning of three-part assessments in Alaska (Richter et al., 1975, Singer, 1975).

Three-part resource assessments: (1) General locations of undiscovered deposits are delineated from a deposit type’s geologic setting, (2) Frequency distributions of tonnages and grades of well-explored deposits serve as models of grades and tonnages of undiscovered deposits, (3) Number of undiscovered deposits are estimated probabilistically by type.

The nature of mineral resources: Only a few deposits account for most resources, most important is tonnage—not grade in estimating total resources, few deposit types account for most resources.

Required Deposit Models

Integrated mineral deposit models are at the core of three-part assessments because they reduce uncertainty about locations, amounts, and values of resources.

General modeling: A model is a way in which the human thought process can be amplified. The way to describe a model is first by thinking about what it is for, about its function, not the list of items that make up its structure. What is surely needed as a minimum is an information system that will help the policy makers to make their decisions (Churchman, 1968). Desirable to define and use the same set of rules for all deposits in the model, these same set of rules apply to all of the undiscovered deposits that are estimated.

Descriptive models: Focus on observations, only use theories of origin to guide what to observe, observations must be available at scale of assessments.

Beginning of digital models: Documented and reproducible, do not miss the obvious and, can be used in classification and prediction.

Grade and tonnage models: The purpose of grade and tonnage models is to provide unbiased representations of the grades and tonnages of undiscovered mineral deposits in a tract or belt. Grade and tonnage models used in three-part assessments represent the premining grade and tonnage of a deposit. This means that current resources at the lowest cutoff grade are added to past production.

Grade and tonnage models use resource figures to represent the mineralized material in a deposit in order to allow for possibly different technologies and mining costs to be assumed.

Spatial rules for models: For deposit models, a spatial rule should be used to determine which ore bodies should be combined. For example, ore bodies of both kuroko and Cyprus type massive sulfides were combined into single deposits based on a 500-m rule of adjacency. Map scale affects what is called a mineral deposit, for some deposits legal or geographical boundaries affect what is reported as a deposit.

Sources of errors in grade and tonnage models: Mixed geologic environments, poorly known geology, data recording errors, mixed deposit / district data, mixed mining methods, incomplete production / resource estimates.

Deposit density models: A robust method to estimate the number of undiscovered deposits is a form of mineral deposit model wherein numbers of deposits per unit area from well-explored regions are counted and the resulting frequency distribution is either used directly for an estimate or indirectly as a guideline in some other method. Although only three deposit types have detailed density models developed at this time, the combination of these studies with other density studies shows that the deposit density relationships can be generalized across deposit types (Singer, in press). The relationship between size of permissive tract and size of deposit estimated can be used to estimate the number of deposits for any deposit type.

Cost models: Models of capital and operating costs required to build and operate a mine and mill, and infrastructure that supports them. Models do not estimate costs of preproduction exploration, permitting, environmental studies, taxes, corporate overhead, site reclamation, concentrate transportation, or smelter and refinery charges. Although not all costs are included and the estimates are rough, these models serve to discriminate clearly uneconomic from clearly economic deposits at an early assessment stage. Daily capacity is the key variable in these models, mine life is calculated from capacity, capital and operating costs are a function of capacity, the equations vary with mining and milling methods.

Delineation of Tracts and Estimating Number of Deposits

We now can use geologic maps to divide a large region into parts that could contain different kinds of mineral deposit and we know that these different kinds of mineral deposits are significantly different in the amounts and qualities of minerals of interest to society. The differences in amounts and qualities of these kinds of deposits affect chances that the deposits will be sought, found, and exploited by society.

A brief overview of the supply and demand of mineral resources provides perspective to help understand why certain aspects of resources are of greater importance than others. In particular, we show that only certain kinds of deposits have dominated supply. In addition, only the largest deposits of a kind are important to global supply.

Mineral deposit models are at the core of three-part assessments. None of these models has any useful meaning except in the context of the other related models of the same deposit type. It should also not be forgotten that construction of these models is an iterative process. It is the internal consistency of these models that provides the strong foundation upon which unbiased assessments can be made—the same internal consistency means that much time-consuming work is required for their proper construction.

Mineral deposit models can be used to reduce uncertainty about locations, amounts, and values of the resources. Mineral deposit models are the keystone in combining the diverse geoscience information on geology, mineral occurrences, geophysics, and geochemistry used in resource assessments and mineral exploration.

Principles of delineation: In order to be able to consistently assess undiscovered mineral resources of regions, areas are delineated where geology *permits* the existence of deposits of one or more specified types. Focus is on what types of deposits *could* be in the region rather than upon what types of deposits are *known* to occur.

Delineation of covered areas: The boundaries of mapped rock units form the primary basis for drawing boundaries of the tract. These preliminary tract boundaries should then be extended using geophysical surveys, such as aeromagnetics, to identify where permissive rocks are concealed by younger rocks or sediments.

An assessment: Pre-meeting: deposit typing, testing-building, delineation; discussion of ground rules, purpose, and goals; review geology, known deposits geophysics, geochemistry, and exploration history; review geologic settings of deposit type; delineate tracts permissive for deposit type; review grade and tonnage models and other appropriate guidelines; make estimates of number of undiscovered deposits; review estimates—revise if appropriate.

Estimating undiscovered mineral deposits: Estimates of number of deposits explicitly represent the probability (or degree of belief) that some fixed but unknown number of undiscovered deposits exist in the delineated tracts. As such, these estimates reflect both the uncertainty of what may exist and a measure of the favorability of the existence of the deposit type.

Guides for estimating number of deposits: Grade and tonnage model; deposit density models; statistical guides—coefficient of variation; counting and assigning probabilities to anomalies; process constraints; relative frequencies of related deposit types; area spatial limits; total known metal; exploration extent and efficiency.

Guidelines and some examples are provided to reduce biases in estimates of numbers of deposits. Experience from meteorology suggests that consensus schemes perform better than individual estimators and that the best estimates are made when objective estimates such as those from guidelines are part of the information supplied to subjective estimators (Murphy and Winkler, 1984).

Appropriate grade and tonnage model? It is sometimes believed that local deposits represent a special subtype or new type because they are almost never exactly the same as the "typical" deposit in every respect. Sometimes the global model is accepted without considering whether it is appropriate. There are two dangers in these two approaches: (1) Every deposit is considered to be unique and therefore prediction is not possible; (2) A new model may be necessary to provide unbiased estimates of grades and tonnages of the undiscovered deposits. To avoid both dangers, well-explored deposits that follow the spatial rules in the local area should be tested to see if they are statistically different from the general model (*t* test at the 1% level). Statistical tests are performed in order to help ensure that the grade and tonnage model selected will be representative of the grades and tonnages of the undiscovered deposits.

Biased estimates of number of deposits: There are estimation process issues that can point to bias such as the expert not following normative statistical or logical rules

(Meyer and Booker, 2001). The most straightforward way to identify bias in estimates of number of deposits is to use the same tools that are available as guidelines for the estimates. Number of deposit estimates that are inconsistent with the guidelines should at the least raise questions about possible bias. Significant biases can be introduced by flawed grade and tonnage models, or by lack of consistency of estimated number of deposits with grade and tonnage model.

Example of estimation of number of deposits is provided.

Combining Estimates and Economics

Expected amounts of undiscovered metals can be estimated mathematically from the grade and tonnage models and estimates of number of deposits by making some assumptions.

A decision-maker needs to be keenly aware of the expected outcome and the probabilities of other outcomes.

A goal of three-part assessments: Provide decision-makers with unbiased information about the expected values and probabilities of other values/outcomes of undiscovered mineral resources. Expected values and probabilities of amounts of metals or economic value can be estimated via equations if certain assumptions are made.

The algorithms developed by Dave Root (Root et al., 1992) freed us from the assumptions of the Poisson and the lognormal distributions and provided distribution-free methods of calculating probabilities of number of deposits, tonnages, and quantities of contained metal in a Monte Carlo simulation in MARK3.

EMINERS, developed by Joe Duval (2001) used Root's algorithms and allowed adding new models by user and use of some economic filters.

Cost Models: Developed by USBM (Camm, 1991; Smith, 1992) based on detailed costing of 3-6 mines per mining/milling method. Tested and refined with general costs and mining rates from 10-40 mines per mining/milling method (Singer, Menzie, and Long, 1998, 2000; Long and Singer, 2001).

MARK3/EMINERS summary: For most models tested MARK3/EMINERS are able to capture the expected amounts and probabilities of different amounts of metal due to effects of estimated number of deposits, tonnages, and grades. For simplified cost models, work needs to be done to see that the proper mining methods are applied and the current costing algorithms are used.

Summary of quantitative mineral resource assessments:

What was covered: Quantitative resource assessment (3-part)

The nature of mineral resources

A short history

Mineral deposit models

Descriptive

Grade and tonnage

Deposit density

Costs

Delineation and estimating number of undiscovered deposits

Combining grades, tonnages, number of deposits, and costs and summary

Three-part assessments are desirable because they: Respond to most customer needs, produce unbiased estimates, allow use of variety of information types, allow use of many methods, explicitly represent uncertainty, and are designed for economic analysis.

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