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DECISION POINTS AND STRATEGIES IN QUANTITATIVE PROBABILISTIC ASSESSMENT OF UNDISCOVERED MINERAL RESOURCES

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ABSTRACT

Quantitative probabilistic assessment of undiscovered mineral resources requires a set of generally sequential decisions and each decision requires one or more strategies. This report describes a common set of decision points used in such assessments and appropriate strategies for each decision. The main purpose of this report is to emphasize that (1) these decision points represent choices and (2) quantitative probabilistic mineral-resource assessment is not a linear, certain-outcome process.

The decisions are: **1.** Decide if the situation calls for a quantitative probabilistic mineral-resource assessment. **2.** Decide if mineral-resource assessment tract(s) can be defined in the area/region. **3.** Decide if probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract are appropriate. **4.** Decide what the probabilistic estimate(s) of the number(s) of deposit(s) of each type are for each tract. **5.** Decide how the above probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract is/are to be used. **6.** Presuming that the estimate(s) is/are to be used in a mineral-resource-endowment simulator, decide how the results/outputs are to be reported. **7.** Decide how the selected-alternative result(s)/output(s) is/are to be used in economic or other analysis. All of these decisions are subjective to some greater or lesser degree. Some of the outcomes selected are not.

These decisions group into five categories: (1) Decision 1 is a policy-based judgement made by management based in part on its consideration of the potential end-users' needs; thus this part of the process is management-dominated. (2) The decisions and strategies used at points 2, 3, and 4 are the responsibilities of the geologists, geochemists, and geophysicists involved in the study; thus this part is geoscience-dominated. (3) Decision 5 involves both policy and geoscience; thus this part requires both management and geoscientists. (4) The strategy used in response to the decision at point 6 is inherent in the simulator used; thus this part is "black-box-" or simulator-dominated. (5) The strategy used in response to the decision at point 7 consists of various calculations; thus this part is calculator- or spread-sheet-dominated.

This description of the probabilistic quantitative mineral-resource assessment process is based largely on the author's firsthand experience and does not represent any "official" or "approved" U.S. Geological Survey procedure. There is no such procedure; the Survey has used a variety of methods in mineral-resource assessment in the past and will probably continue to do so in the future.

[Explanatory note: The format of this report is different than what you are used to. Most of it is written as an expanded outline.

As in this example, the main ideas are stated first, secondary ideas second, and so on.

The reader need not read any farther into the lower rank headings than interest dictates.

Similarly, each major section elaborates on the previous main section, and the detailed supplementary material is last.]

The process of quantitatively and probabilistically assessing undiscovered mineral resources involves a set of sequential decisions.

These decision points are listed in the next section of this report and are summarized in figure 1.

The first main purpose of this report is to call attention to the critical decision points, as their significance may be overlooked in some situations.

The decision points represent choices and(or) alternatives; and therefore quantitative probabilistic mineral-resource assessment is not a linear, certain-outcome process. Instead, it should be a dynamic and flexible process, itself subject to revision and improvement, that reflects a variety of factors and which has several different outcomes.

The second main purpose of this report is to describe a strategy appropriate to each of the decision points.

The strategies described are subject to several important limitations.

There is no single right strategy at any point, nor is there a wrong strategy. Each strategy is the result of subjective judgement and each assessment process will have its own special considerations. The group doing an assessment should work out its own procedures, and those strategies and procedures may not closely resemble the ones described here. This report is intended to stimulate groups to consider the decision points and to work out what is appropriate to their need.

Working out and recognizing strategies is important for three main reasons.

(1) Strategies provide a common basis of understanding within the assessment group.

(2) They provide a basis for documenting how judgements and decisions were reached, including how specific boundaries were drawn and specific estimates were made.

(3) They emphasize and validate the responsibilities of the assessment group.

The third main purpose of this report is to emphasize that some of the decisions are geoscientific judgements and some are organizational-policy judgements.

The approach used here is to first identify the critical decision points in the quantitative probabilistic undiscovered mineral-resource assessment process, then to note what the general outcomes of the decisions may be, and then to present an appropriate strategy to arrive at an outcome at each point. The difference between geoscience-based and policy-based decisions is not considered at length any further.

This description of the probabilistic quantitative mineral-resource assessment process is based largely on the author's firsthand experience as a field geologist involved in the process and does not represent an "official" or "approved" U.S. Geological Survey procedure. There is no such "official" or "approved"procedure, although common threads run through most Survey assessments. The U.S. Geological Survey has used a variety of approaches in mineral-resource assessment in the past and will probably continue to do so.

This report draws on several sources, specifically:

The author's firsthand experience, as a regionally oriented field geologist with a strong interest in mineral deposits, in four separate and different quantitative probabilistic undiscovered-mineral-resource assessments in southeastern Alaska; his experience in the quantitative probabilistic assessment of oil spills in the marine environment related to the then-proposed Trans-Alaska hot-oil pipeline (Brew, 1972); other similar-type assessments elsewhere in Alaska; a general similar-type assessment of a group of Wilderness Areas in the western United States; two studies concerned with the assessment of undiscovered uranium resources; and some general papers on resource assessment.

Beginning in the mid-1970's, efforts started to describe the undiscovered mineral resources in different parts of southeastern Alaska in quantitative and probabilistic terms.

Among the first efforts of the author were those concerned with the Tracy Arm-Fords Terror Wilderness Study Area (Brew and others, 1977; Grybeck and others, 1984) and the Glacier Bay National Park region (Brew and others, 1978; Grybeck and Brew, 1979). These were followed by studies in the Petersburg project area (Brew and others, 1989), a preliminary study of the Sitka quadrangle (Ford and others, 1989), and a comprehensive study of all of southeastern Alaska (Brew and others, 1991; Brew and Drinkwater, 1991). Other in-part similar studies in the same region during this period are those of Berg and others (1978) and of Berg (1984).

Somewhat similar efforts during the same period concerned other parts of Alaska.

Among these are the Nabesna area studies by Richter and others (1975), the Alaska Peninsula and adjacent areas studies by Cox and others (1981(1982)), the Steese-White Mountains area (Smith and others, 1987; Weber and others, 1988), and a study of the tin resources of the Seward Peninsula by Reed and others (1989).

Other studies of general interest that describe rationales and procedures are Singer and Ovenshine (1980), Singer and Mosier (1981), Mathews and others (1983), Drew and others (1986), Ovenshine (1986), Finch and McCammon (1987), and Bliss and others (1990). There are many other pertinent papers that are cited in the articles referenced here.

The rest of this report presumes acquaintance with three important publications, the first two defining resources for the purpose of mineral-resource assessment, and the third providing an essential component of the information needed for a quantitative probabilistic assessment.

The first two reports are the joint U.S. Bureau of Mines-U.S. Geological Survey definition of mineral resources (McKelvey, 1972; U.S. Bureau of Mines and U.S. Geological Survey, 1980). Figure 1 of the 1980 report is reproduced here (Fig. 2). The resources that the U.S.G.S are concerned with are the undiscovered resources shown on the right-hand side of the diagram. As defined there and elsewhere in that report, the probability of their occurrence ranges from hypothetical to speculative and their economic value ranges from economic to subeconomic.

The third report is the Cox and Singer (1986) compendium of descriptions and tonnage and grade curves for some 60 different mineral deposit types. The information in this report is essential from several aspects. The written descriptions of the deposit types define the settings and other characteristics of the deposits and thus are definitions of the different deposit types. The tonnage and grade curves define the size and grade of the deposits that have been described. These are important points because these are the deposits that are in the collective mind of the assessment group as it makes probabilistic estimates; in other words any deposit judged to be present at any probability level has the characteristics and fits the tonnage and grade models given in the Cox and Singer (1986) report.

Some other reports currently nearing publication will provide additional information on quantitative probabilistic assessment of undiscovered mineral resources from both real and theoretical approaches (Singer, ed., 1992; Bliss and others, 1992; Root and others, 1992).

There are some other aspects of quantitative probabilistic assessment of undiscovered mineral resources that are not considered in detail here, but are important to discuss and understand in any given assessment effort.

One aspect concerns the scale of the assessment. Clearly, a state-wide or similar large-area assessment that integrates, or "aggregates", all of the undiscovered resources into a single entity is very different from an assessment of an individual specific area; this second type is sometimes referred to as "disaggregated". An example of the first type is that of Drew and others (1986); and example of the second is that of Brew and others (1991a,b). In preparing this report, the second or disaggregated type was uppermost in mind..

Another such aspect concerns the differing capabilities of individual geologists, geochemists, and geophysicists to make probabilistic estimates. Limited research suggests that although most individuals are capable, there are some who are not, even though they understand the assessment process and all of its components (W.D. Menzie, oral comun., 1990). The reason(s) are not known. This would be perhaps analogous to the inability of some colleagues to do petrographic work under any conditions.

Following up on the above observation, there is an anecdote that during World War II a quantitative probabilistic assessment group attempted a very unusual and difficult type of prediction. They used the available fragmentary information on the location and frequency of surfacings of Nazi U-boats in the Atlantic Ocean, together with knowledge of the performance characteristics of the different classes of U-boats, to attempt to predict where the next surfacing would occur. The anecdote has it that only geologists were audacious enough to attempt such predictions!

Five additional important introductory points to keep in mind as background material are:

(1) Although the decisions described here are sequential in that none can actually be made without the information from the preceding decision in hand, in reality all of the policy- and management-based decisions have to be anticipated in advance of actual decision. The first decision, that to decide if the situation calls for a quantitative probabilistic mineral-resource assessment, should involve consideration of all potential end users' needs and should include anticipation of the other, later, management-involved decisions.

(2) Quantitative probabilistic assessment of undiscovered mineral resources is imperfect, and is still evolving. In this it is no different than any number of other geoscientific endeavors. What is being done now has a much better basis than what was done 10 to 20 years ago, and what will be done in the future should be even better. The decision points that are the focus of this report may change and the outcomes and strategies will surely change. The more assessments and related research done, the more rigorous and better the process will become. There probably is no "perfect" way of making quantitative probabilistic assessments of undiscovered mineral resources. The challenge is to continually refine the process by revising procedures, improving documentation of how judgements are made, and increasing our fundamental understanding of the genesis and characteristics of mineral deposits. McKelvey (1972) described this situation succinctly.

(3) Groups involved in quantitative probabilistic assessment of undiscovered mineral resources are not alone with their problems. Within the U.S. Geological Survey, somewhat similar difficulties face the groups responsible for geologic hazard assessment (R.L. Christiansen, oral comm., 1992), for geothermal resource assessment (L.J.P. Muffler, oral comm., 1992), and, of course, for oil and gas resource assessment (Drew, 1990). Outside the Geological Survey, similar difficulties face the individuals and groups responsible for the assessment of resources in the National Forests, such the Nation's largest, the Tongass National Forest of southeastern Alaska. There, assessment procedures and processes concerned with the quantification of fishery, scenic, timber, recreational, and wildlife resources are subject to the same subjectivity and uncertainty that attend the assessment of undiscovered mineral resources (S.R. Brink, Leader, USFS Tongass National Forest Land Management Plan Revision Team, oral comm., 1991)

(4) All of us have been using (generally nonquantitative) probabilistic short-term weather predictions in our own lives for several years now. These predictions are in a way analogous to the estimation of discovered mineral resources in mining districts. Long-term weather predictions, meaning those a week or more in advance, are in a way analogous to the assessment of undiscovered mineral resources. Our personal experience with both types of predictions should provide us with an appreciation of the uncertainties that accompany the assessment of undiscovered resources.

(5) Most past quantitative probabilistic assessments of undiscovered mineral resources have had as their outcomes aggregated values for a whole study area, a 1:250,000-scale quadrangle, a county, a state, or for a region. The study concerned with the Tongass National Forest and adjacent areas (Brew and others, 1990) was the first U.S.G.S. study to present results for individual mineral-resource-assessment tracts. The decision to do so was based on the U.S. Forest Service's need for information specific to those areas for use in detailed planning for land-use classification. Most persons concerned with resource assessment recognize, the greater statistical strength of the assessments of the larger areas, the lesser statistical strength of the smaller individual areas, and users' developing needs for assessment of individual tracts (D.P. Cox, written comm., April, 1992). However, little if any research is available about these relations.

Finally, I wish to acknowledge the interest and encouragement of W.J. McMillan of the British Columbia Ministry of Energy, Mines, and Petroleum Resources Geological Survey Branch; and of R.B. McCammon and L.J. Drew of the U.S. Geological Survey. Dennis P. Cox provided a helpful and insightful technical review. Cox, D.A. Singer, and S.D. Ludington discussed several sticky points with me, but bear no responsibility for the outcomes.

CRITICAL DECISION POINTS AND GENERAL OUTCOMES

Figure 1 is a decision tree graphically summarizing this section. It can be used as a map to keep you located in the remainder of this report.

1. Decide if the undiscovered-mineral-resource situation calls for a quantitative probabilistic assessment.
No=Decide if some alternative type of assessment is appropriate, or quit.
Yes=Proceed with assessment.

2. Decide if mineral-resource assessment tract(s) can be defined in the area/region.
No=Fall back to decision Point 1.
Yes=Define mineral-resource-assessment tract(s) for appropriate mineral-deposit types.

3. Decide if probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract are appropriate. If decision for individual tract is:
No=Fall back to Point 2 for that tract.
Yes=Proceed with estimate(s) for that tract.

4. Decide what the probabilistic estimate(s) are of the number of deposits of each type in each tract.

5. Decide how the above probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract is/are to be used.
Select from the alternatives available.

6. Presuming that the estimate(s) is/are to be used in a mineral-resource-endowment simulator, decide how the results/outputs are to be reported.
Select from the alternatives available.

7. Decide how the selected-alternative result(s)/output(s) is/are to be used.
Select from the alternatives available.

Some of these decisions are made on geoscientific grounds and some are made on an organizational-policy basis.

(1) Decisions at Points 2 through 4 are geoscience-based judgements. They should be wholly scientific and independent of organization policy.
(2) Decisions at Points 1, 6, and 7 are essentially policy-based judgements. They require guidance and counsel from organization management; such guidance should consider the needs of all potential end users of the assessment.
(3) The decision at Point 5 involves both the judgment of the assessment group and policy-related guidance from organization management.

Recognizing that these different decisions involve the geoscientists and organization management in different ways, once the decision have been made the assessment process can be thought of as consisting of five major parts or steps, each being dominated by a different factor:

(1) Decision 1 is, as noted, a policy-based judgement made by management; thus the dominant factor in this part of the process is management or policy.
(2) The decisions and strategies used at Points 2, 3, and 4 are the responsibilities of the geologists, geochemists, and geophysicists involved in the study; thus the dominant factor in this part of the process is geoscience.
(3) Decision 5 involves both policy and geoscience; thus this part requires both management and geoscientists and the dominant factors are geoscience and management or policy.
(4) The strategy used in response to the decision at Point 6 is inherent in the mineral-resource-endowment simulator used; thus the dominant factor in this part of the process is the "black-box" or simulator.
(5) The strategy used in response to the decision at Point 7 consists of various calculations; thus thus the dominant factor in this part of the process is the calculator or spread-sheet.

CRITICAL DECISION POINTS, STRATEGIES, AND MORE DETAILED OUTCOMES
[Points are numbered as above.]

1.0. Decide if the situation calls for a quantitative probabilistic mineral-resource assessment.

1.1 Decision Factors:
What are the potential users' desires/requirements?
What are the USGS management stategies and guidance?
Is there an experienced Grass-Roots-Group (GRG) of geologists, geochemists, and geophysicists available for the task?

1.2 Outcome:
Quantitative probabilistic mineral-resource assessment not appropriate=Quit.
Quantitative probabilistic mineral-resource assessment not appropriate, but some other type may be=Proceed with that type of assessment.
Quantitative probabilistic mineral-resource assessment is appropriate=Proceed with assessment.

2.0 Decide if mineral-resource assessment tract(s) can be defined in the area/region.

2.1 Decision Factors and Process:
Define deposit types. See "Supplement to Point 2" for details.
Define tract boundaries. See "Supplement to Point 2" for details.

2.2 Outcome:
If tract deposit types and boundaries can't be defined=Quit.
If tract deposit types and boundaries can be defined=Define them!

3.0 Decide if probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract are appropriate.

3.1 Decision Factors and Process:
Evaluate significance and weight of factors involved in the definition of the tract(s). See "Supplement to Point 3" for details.

3.2 Outcome:
3.2.1 If a probabilistic estimate of the number(s) of deposit(s) of each type in each tract is not appropriate=Fall back to Point 2.
3.2.2 If a probabilistic estimate of the number(s) of deposit(s) of each type in each tract is appropriate=Proceed with estimate(s).

4.0 Decide what the probabilistic estimate(s) are of the number(s) of deposit(s) of each type in each tract.

4.1 Decision Factors and Process:
Evaluate the applicability of the available descriptive and tonnage and grade models. See "Supplement to Point 4" for details.
Make estimate(s). See "Supplement to Point 4" for details.

4.2 Outcome:
Proceed to Point 5.

5.0 Decide how the above probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract is/are to be used.

5.1 Decision Alternatives: What are the USGS management strategies and guidance at this point? They are a factor as well as the assessment group's judgement.
Leave as is, no further processing.
Take to USBM ROCKVAL mineral-resource-endowment simulator.
Take to point-estimates of numbers of deposits times mean T and G calculation
Take to USGS MARK3 mineral-resource-endowment simulator.
Other?

5.2 Outcome:
Decide from the alternatives available.

6.0 Presuming that the estimate(s) is/are to be used in a mineral-resource-endowment simulator, decide how the results/outputs are to be reported.

6.1 Decision Alternatives:
Probability-distribution function.
Mean of probability-distribution function.
Median of probability-distribution function.
Other?

6.2 Outcome:
Decide from the alternatives available.

7.0 Decide how is/are the selected-alternative result(s)/output(s) to be used.

7.1 Decision Alternatives:

Leave as is, no further processing.
Take to formal mineral-economic analysis.
Take to "informal" mineral-economic analysis.
Take to Gross-In-Place Value (GIPV)/ Metal-In-Ground Value (MIGV) calculation.
Other?

7.2 Outcome:

Decide from the alternatives available.

SUPPLEMENT TO POINT 2.: Decide if mineral-resource assessment tract(s) can be defined in the area/region.

S2 This decision requires making the following three decisions, the second two interdependently and simultaneously:

S2.1 Define meanings of the terms
S2.1.1 "Mineral-resource-assessment tract" (MRAT)
S2.1.2 "Undiscovered deposits"
S2.2 Define deposit types in a possible tract.
S2.3 Define tract boundaries in a possible tract.

S2.4 Decision Requirements:
S2.4.1 Grassroots group made up of regional geologists, economic geologists, geochemists, and geophysicists with experience in the area under consideration, possibly together with a "resource assessment specialist".
S2.4.2 A group leader, meaning a leader; not necessarily the most-senior, the most-field-experienced, or the most-geologically-knowledgeable person, but one who understands the goals, methods and procedures, and limitations of the quanitative probabilistic mineral-resource assessment process and can facilitate the group's efforts.

S2.4.3 All available geologic information, including:
S2.4.3.1 Surficial geology
S2.4.3.2 Regional bedrock geology, including:
S2.4.3.2.1 Rock units and their "permissiveness" for different types of deposits
S2.4.3.2.2 Structures
S2.4.3.2.3 Tectono/magmatic setting
S2.4.3.3 Metallogenic belts are defined on the basis of the above factors, together with economic geologic information; therefore they are not a separate information factor.

S2.4.4 All available economic-geologic information, including:
S2.4.4.1 Thorough knowledge of the descriptions and tonnage and grade models for different deposit types
S2.4.4.2 Distribution and characteristics of known prospects and occurrences/indicators
S2.4.4.3 Distribution and characteristics of known "mines" without production and of mines with production, and how much production
S2.4.4.4 Overall general level of knowledge of prospects, occurrences/indicators, "mines", and mines
S2.4.4.5 Certainty of identification of prospects, occurrences/indicators, "mines", and mines with a specific deposit type
S2.4.4.6 Exploration history

S2.4.5 All available geochemical information (USGS, LASL/NURE, State, etc.), including:
S2.4.5.1 Distribution of and anomalous patterns defined by:
S2.4.5.1.1 Bedrock samples
S2.4.5.1.2 Stream-sediment samples
S2.4.5.1.3 Panned-concentrate samples
S2.4.5.2 "Agreement" of geochemical signatures or patterns with those associated with different deposit types

S2.4.6 All available geophysical information, including:
S2.4.6.1 Aeromag for lineaments, plutons, and magnetite concentrations
S2.4.6.2 Gravity for plutons and lineaments
S2.4.6.3 Aeroradioactivity for lineaments, plutons, and radiogenic-mineral concentrations
S2.4.6.4 Telegeology for linears, "arcuars", and alteration

S2.4.7 Pre-assessment meeting and distribution of all of the above material.

S2.4.8 Time for, and individuals' committment to,:
S2.4.8.1 Pre-meeting study
S2.4.8.2 The actual assessment meeting
S2.4.8.3 Review of the results of the assessment in pre-final form

S2.5 Decision Process:

S2.5.1.1 Regarding the meaning of the term "mineral-resource-assessment tract" (MRAT): review previous definitions and group members' individual definitions and arrive at concensus.

One example of this definition is:

"A mineral-resource assessment-tract (MRAT) is an area judged to contain undiscovered mineral resources in undiscovered deposits, on the basis of known geological, geochemical, and geophysical features."

Another example is:

"A mineral-resource assessment-tract (MRAT) is an area where the probability of existence of a mineral deposit is greater than zero." (D.A. Singer, oral comm. to D.P. Cox, April, 1992)

S2.5.1.2 Regarding the meaning of the term "undiscovered deposits": review previous definitions and group members' individual definitions and arrive at concensus.

One example of this definition is:

"Undiscovered deposits are mineral deposits that are not known or identified, but are judged to exist, based on surface geological, geochemical, and geophysical data. They are deposits that could/would be discovered using conventional surface geological, geochemical, and geophysical exploration methods."

Another example is exactly as the above, except that it omits the second sentence concerning discovery on the grounds that an assessment should estimate only the probability of existence and should not be constrained by exploration and discovery considerations (D.P. Cox, written comm., April, 1992).

In my opinion, this is unrealistic and most assessments should contain some kind of exploration- and discovery-related factor; either of the type given here, or a depth factorof some kind.

This is because we are (a) assessing the types of deposits that are known at the surface or at relatively shallow depths, and (b) there are real-world constraints on what can be discovered and exploited.

There are two critical aspects to this and similar definitions.

The deposits referred to are of a type already recognized somewhere in the world.

They are not "unconventional" or as-yet-unrecognized deposit types.

The conventional surface geological, geochemical, and geophysical exploration methods referred to are those currently in use.

They do not include future, yet-to-be-developed, methods.

Thus, I believe that future recognition of currently unknown deposit types and future development of currently unavailable exploration methods will both affect quantitative probabilistic assessment of undiscovered mineral resources. Assessment operates with information that is now available and today's conclusions will change as information and levels change and new knowledge is gained.

S2.5.2 and
S2.5.3. Defining the deposit types in a possible tract and drawing the boundaries of the tract is a circular and iterative process where both decisions are made interdependently and simultaneously.

Basically what transpires is the definition of recognition criteria for different deposit types in the area under consideration and then the application of those criteria to the tract.

S2.5.2/3 Here, in a very generalized way, is a sequence of steps that the process requires:

S2.5.2/3.1 A preliminary presentation by the economic geologist(s) and, if present, mineral-resource assessment specialist(s) of the descriptions and tonnage and grade characteristics of the mineral deposit type(s) that are already known or expected to occur in the area under consideration.

S2.5.2/3.2 Presentation by the regional geologist(s), economic geologist(s), geochemist(s) geophysicist(s), and resource-assessment specialist, of the details of their particular contributions.

S2.5.2/3.2.1 The regional geologist should emphasize the distribution of rock units judged to be permissive for the occurrence of different types of deposits.

S2.5.2/3.2.2 The economic geologist should emphasize the characteristics of the known deposits, including host rocks, structures, controls, deposit type, and production history; as well as exploration history of the tract and his/her impressions of the area's map units in relation to permissiveness.

S2.5.2/3.2.3 The geochemist should emphasize those subareas not associated with known deposits where geographic distribution of elemental values, cluster analysis, and deposit-signature elements define patterns suggesting the presence of anomalous concentrations or depletions of elements associated with different deposit types. The geochemist also would point out the location and magnitude of "zingers", meaning isolated, but high values for specific elements.

S2.5.2/3.2.4 The geophysicist should emphasize the presence/absence of anomalies and gradients that, by analogy with other areas, may indicate the presence at depth of rock types likely to somehow be associated with mineral deposits.

S2.5.2/3.2.5 The resource-assessment specialist should interact with all of the others to contribute what s/he infers from the presentations, and to contribute to their knowledge of the different deposit types; information on clustering of deposits and the dimensions of individual deposits is important at this point.

S2.5.2/3.3 The group at this point decides, based on all of the above information, either:

S2.5.2/3.3.1 What the recognition criteria are for the different mineral deposit types that are likely to in the tract, but are as-yet undiscovered. Those criteria should be listed and described thoroughly enough so that there is general understanding and documentation before proceeding. <u>OR</u>,

S2.5.2/3.3.2 That is is not possible to develop criteria, based on the available information; if this is the case, then obviously, no tract would be defined for the area under consideration.

S2.5.2/3.4 Presuming that recognition criteria were developed, the group should collectively draw the boundaries of the mineral-resource-assessment tract, using the developed criteria.

S2.5.2/3.5 This recognition criteria approach contrasts with two other approaches.

S2.5.2/3.5.1 In what is actually a variant approach, the geologically permissive tract is reduced in size by excluding those parts judged not to contain undiscovered deposits. This obviously also requires the development of criteria.

S2.5.2/3.5.1 In an alternative approach, the mineral-resource-assessment tract is built outwards in the geologically permissive tract from known deposits, occurrences, geochemical anomalies, and the like.

SUPPLEMENT TO POINT 3.: Decide if probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract are appropriate.

S3 This decision requires examining all of the information discussed in the regard to Point 2 rigorously, as this and the next decision point are probably the two most critical in the process of assessing undiscovered mineral resources.

What follows is one strategy for making this decision. The strategy starts with three questions, the negative answer to any of which may indicate that probabilistic estimate(s) of the number(s) of deposit(s) of each type in a specific tract are NOT appropriate. If the answers indicate that such estimates are appropriate, then the strategy proceeds to an evaluation and weighting of all of the information factors discussed previously under point 2.

S3.1 Question 1: Is the tract large enough to justify probabilistic estimate(s) of the number(s) of deposit(s) of each type?

S3.1.1 Decision factors:

In general, smaller tracts are less likely to contain undiscovered mineral resources than are large ones. Subjective judgement here must integrate the characteristics of the expected deposit types with the size of the tract to arrive at a decision.

S3.1.2 Decision outcomes:

S3.1.2.1 If the tract is judged too small, then no estimate is justified, so fall back to Point 2 outcome.

S3.1.2.2 If the tract is judged large enough, go to question 2.

S3.2 Question 2: Assuming that there is only one expected deposit type in the tract, is there a tonnage and grade model available for it?

S3.2.1 Decision Factors:

A tonnage and grade model is needed if all of the characteristics of a deposit type are to be known.

If there is no model, then three options are available: (a) quit and fall back, as noted below; (b) construct a provisionary model based on available data; or (c) agree within the assessment group as to the approximate tonnages and grades involved, so that all members are envisioning and working with the same information.

Regional or local tonnage and grade models based on data from deposits in and near the tract or in a similar geologic environmentmay be used instead of the world-wide models in Cox and Singer (1986), if sufficient data are available.

S3.2.2 Decision Outcomes:

If there is no tonnage and grade model and none can be constructed or envisioned, then no estimate is justified, so fall back to Point 2 outcome.

If there is a tonnage and grade model or one can be constructed or envisioned, go to question 3.

SUPPLEMENT TO POINT 3.: Decide if probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract are appropriate--Continued.

S3.3 Question 3: Has the tract already been so well explored that no undiscovered deposits are present?

S3.3.1 Decision factors:

Thorough modern exploration of a tract should have discovered all of the deposits.

Subjective judgement must here integrate the characteristics of the expected deposit types with the known exploration history.

S3.3.2 Decision outcomes:

S3.3.2.1 If the tract is judged to be thoroughly explored, then no estimate is justified and fall back to Point 2 outcome.

S3.3.2.2 If the tract is judged to be essentially unexplored to moderately explored, then evaluate all of the information factors discussed under point 2 and decide whether or not to make probabilistic estimates.

S3.3.2.2.1 One way of facilitating this decision is contained in ¶S3.4, below. It provides a scheme for evaluating and weighting of all of the information factors discussed under point 2.

S3.4 A weighted-factor evaluation (to decide if probabilistic estimate(s) of the number(s) of deposit(s) of each type in a specific tract are appropriate) is one way to proceed. It is also a way to document the decision. Other ways are possible!

Decision factors and some suggested weights are listed on the following page. The explanation of the weighting procedure is as follows:

The listed factors are self-explanatory; the weighting is not.

Each factor is assigned weighted points in the evaluation. These points are summed to give a total for the tract.

The "Weighted Points" are in four categories in this scheme: NA=Not Applicable; No/Mn Info=Either no information or minimum information available for the factor; Level 1 Info=A moderate amount of information available for the factor; and Level 2 Info=A large amount of information available for the factor.

Other abbreviations used on this evaluation form are: O's=Occurrences; P's=Prospects; M's=Mines with little, if any production; M*'s=Mines with significant production.

The decision outcome for an individual tract consists of the sum of the weighted individual factor evaluations. Suggested relations between those sums and the decision are shown at the bottom of the following page.

WEIGHTED-FACTOR EVALUATION TO DECIDE IF PROBABILISTIC ESTIMATE(S) OF THE NUMBER(S) OF DEPOSITS OF EACH TYPE IN A SPECIFIC TRACT ARE APPROPRIATE

TRACT NAME OR DESIGNATOR:______________________________

EVALUATORS:______________________________ DATE:__________

	Weighting Points			
	NA	No/Mn Info	Level 1 Info	Level 2 Info
REGIONAL-GEOLOGIC FACTORS				
Surficial geology (as applied to geochemical interpretation)	0	0	1	2
Bedrock geology				
Rock units' "permissiveness"	0	4	8	12
Structures' "permissiveness"	0	4	8	12
Tectonomagmatic setting's "permissiveness"	0	1	3	5
ECONOMIC-GEOLOGIC FACTORS				
Knowledge of applicable tonnage and grade models	0	1	3	5
Abundance of occurrences/indicators and prospects	0	0	2	4
Abundance of mines with and without production	0	0	1	2
General level of information on O's, P's, M's, and M*'s	0	1	3	5
GEOCHEMICAL FACTORS				
Abundance/distribution of USGS bedrock samples	0	0	2	4
Abundance/distribution of USGS stream-sediment samples	0	0	3	5
Abundance/distribution of USGS panned-concentrate samples	0	0	2	4
Abundance/distribution of LASL/NURE samples	0	0	1	2
Agreement of geochem signatures with deposit-type signatures	0	3	6	9
GEOPHYSICAL FACTORS				
Aeromag for lineaments, plutons, and "magnetite"	0	2	4	6
Gravity for plutons and lineaments	0	1	3	5
Aeroradioactivity for plutons, lineaments, and radiogenic minerals	0	1	3	5
Telegeology for linears, arcuars, and alteration	0	1	3	5
TOTAL FOR THIS TRACT:_______				
[For reference: maximum total for each column:	0	22	56	92]

OUTCOME:

SUGGESTED LIMITS FOR DECISIONS:
(1) Total <~20 = No estimate, fall back to Point 2
(2) Total ~20>~40<~60 = Reexamine, then fall back or proceed
(3) Total >~60 = Make estimate, proceed to Point 4

SUPPLEMENT TO POINT 4: Decide what the probabilistic estimate(s) are of the number(s) of deposit(s) of each type in each tract.

S4 Presuming that the assessment has reached this point, here is the single, most critical step in the whole process. It integrates all of the information used and decisions made up to this point to produce an estimate of the number of deposits present at different probability levels. In the past, estimates have commonly been made at the .10, .50, and .90 levels. More recently estimates have been made at .05, .10, .50, .90, and .95 and at .01, .05, .10, .50, .90, .95, and .99 levels. In the future .001 and .005 levels will probably be used also. The U.S.G.S. MARK3 and the U.S.B.M. ROCKVAL mineral-resource-endowment simulators construct a probability density function from these estimates and at least three probability values are desirable.

The assessment group should realize that these are quantified subjective expert judgements.

S4.0.1 Here are examples of the the kind of output the process is aimed at producing:

Probability that there is/are at least this number of deposits of this type in this tract:

	.99	.95	.90	.50	.10	.05	.01
Deposit type A	0	0	0	1	2	2	3
Deposit type B	1	1	2	3	4	4	6
Deposit type C	0	0	0	0	0	0	1

S4.1 In making these estimates, it is important to realize that the estimates are for "at least this number of deposits". The assessment group members need to have it clear in their minds exactly what they are estimating.

S4.2 In making these estimates, it is absolutely critical that the assessment group understand that they are estimating the probability of occurrence of one or more deposits of exactly the type, tonnage, and grade described in the model descriptions and depicted by the tonnage and grade curves.

S4.2.1 Regarding the tonnage and grade curves, this means that half of the deposits estimated to exist will be larger than the median tonnage and grade of the model and half will be smaller.

S4.3 The estimates can be made individually and independently and then compared and discussed, or they can be made in an open discussion. The goal is concensus, and the leader should exert no pressure regarding his/her personal preference regarding the tract under discussion; and should moderate extreme-pressure positions taken by any of the participants.

S4.4 In practice, there are three subdecisions that are being made in this step. The first two are equally critical and are derived entirely from the foregoing parts of the process, the third is equally critical, but it is guided in part, in some cases, at least, by available knowledge about the frequency distribution of different types of deposits in tracts.

S4.4.1 The first subdecision essentially replays the process of Point 3 and asks if the group does indeed judge that there is at least one undiscovered deposit of the specified type in the tract. The minimum estimate, indicating judgement that there is at least one deposit, but indicating that the probability of more is excruciatingly low, would be one (1) deposit at the .01 probability level. This is commonly referred to as the default estimate, because it is the lowest possible. (See the example for deposit type C in ¶ S4.0.1, above.)

S4.4.1.1 If the assessment group, in replaying the process of Point 3, does indeed judge that there is no undiscovered deposit of the specified type in the tract, then the process goes back to Point 2.

S4.4.2 The second subdecision is to decide, subject to the cavaet given in ¶ S4.1, above, where in the probability range that one deposit should be assigned. The minimum-estimate case is discussed immediately above. Experience indicates that this subdecision is in many cases best approached by discussing whether the assignment should be at 50 percent probability; this approach usually produces a preliminary group concensus with one of the three likely outcomes: (1) the 50 percent assignment is appropriate; (2) that assignment is too low, that is, the group judges that there is a greater than 50 percent probability of one deposit, or (3) that assignment is too high, that is, the group judges that there is less than 50 percent probability of one deposit. With one of those three outcomes as a preliminary concensus, then the group can discuss the assignment more specifically.

S4.4.3 The third subdecision follows the second; it is to decide the distribution of the numbers of undiscovered deposits at lower probabilities. Obviously, in the case of the minimum estimate there will be no other deposits estimated. In all other cases, however, the group will have to arrive at a distribution of the numbers of undiscovered deposits at other probabilities. Current research (Bliss, 1992; Singer, 1992) indicates that in areas analogous to tracts the numbers of some types of deposits have log-normal distributions, others have Poisson distributions, and still others have uncertain distributions. Here knowledge of the deposit type under consideration is very important. As examples: (1) podiform chromite deposits tend to be small and clustered, and the estimate of one deposit implies the existence of numerous other similar deposits at lower probabilities; (2) porphyry systems tend to be large and widely distributed, and the estimate of one deposit implies the existence of only a few other similar deposits at lower probabilities.

S4.4.2/3 D.P. Cox (written comm., April, 1992) suggests two main methods of obtaining the probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract They are not mutually exclusive, and they should give consistent outcomes.

S4.4.2/3.1 "Sites representing geochemical and(or) geophysical anomalies, unevaluated occurrences, intrusive contacts, etc., can be counted. The number of conceivable exploration targets or plays can be counted. The probability that each site represents an undiscovered deposit can be estimated and a distribution of numbers derived."

S4.4.2/3.2 "The geology, geochemistry, and geophysics of the tract can be compared with another part of the earth that has been well explored for minerals. The frequency of occurrence of deposits in the analogous area can be applied to the tract, and the probabilistic estimate(s) of the number(s) of deposit(s) of each type in the tract derived to reflect the closeness of fit between the two areas."

S4.5 Documentation of the decision on the probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract is important.

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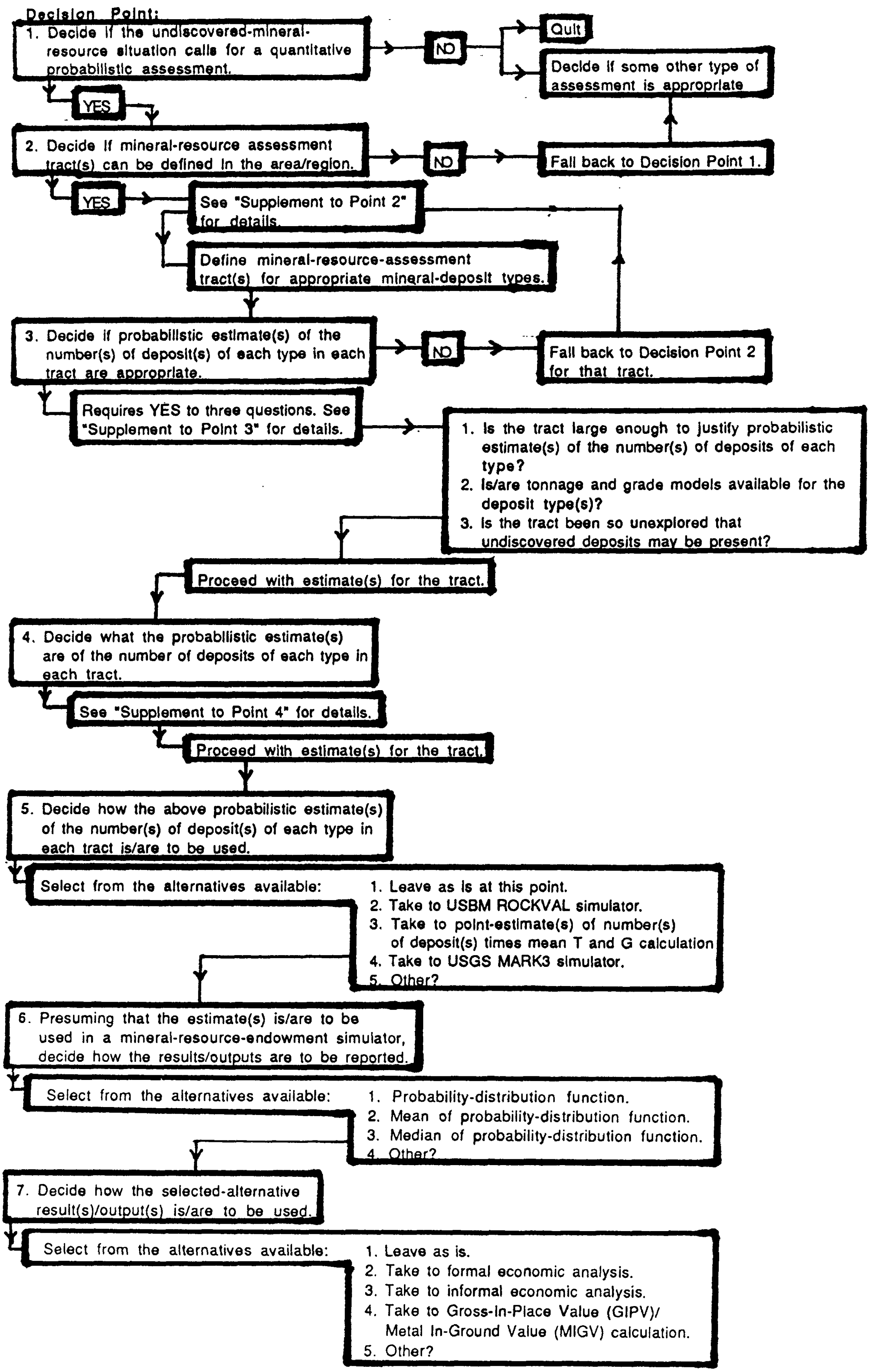

Decision Point:
1. Decide if the undiscovered-mineral-resource situation calls for a quantitative probabilistic assessment.
NO
Quit
Decide if some other type of assessment is appropriate
YES
2. Decide if mineral-resource assessment tract(s) can be defined in the area/region.
NO
Fall back to Decision Point 1.
YES
See "Supplement to Point 2" for details.
Define mineral-resource-assessment tract(s) for appropriate mineral-deposit types.
3. Decide if probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract are appropriate.
NO
Fall back to Decision Point 2 for that tract.
Requires YES to three questions. See "Supplement to Point 3" for details.
1. Is the tract large enough to justify probabilistic estimate(s) of the number(s) of deposits of each type?
2. Is/are tonnage and grade models available for the deposit type(s)?
3. Is the tract been so unexplored that undiscovered deposits may be present?
Proceed with estimate(s) for the tract.
4. Decide what the probabilistic estimate(s) are of the number of deposits of each type in each tract.
See "Supplement to Point 4" for details.
Proceed with estimate(s) for the tract.
5. Decide how the above probabilistic estimate(s) of the number(s) of deposit(s) of each type in each tract is/are to be used.
Select from the alternatives available:
1. Leave as is at this point.
2. Take to USBM ROCKVAL simulator.
3. Take to point-estimate(s) of number(s) of deposit(s) times mean T and G calculation
4. Take to USGS MARK3 simulator.
5. Other?
6. Presuming that the estimate(s) is/are to be used in a mineral-resource-endowment simulator, decide how the results/outputs are to be reported.
Select from the alternatives available:
1. Probability-distribution function.
2. Mean of probability-distribution function.
3. Median of probability-distribution function.
4. Other?
7. Decide how the selected-alternative result(s)/output(s) is/are to be used.
Select from the alternatives available:
1. Leave as is.
2. Take to formal economic analysis.
3. Take to informal economic analysis.
4. Take to Gross-In-Place Value (GIPV)/ Metal In-Ground Value (MIGV) calculation.
5. Other?

Figure 1.

Cumulative Production	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range (or)	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Other Occurrences	**Includes nonconventional and low-grade materials**

FIGURE 2.