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794 University Avenue, Basement
Fairbanks, Alaska 99701

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794 University Avenue, Basement
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[1]Exxon Production Research Co., Basin Exploration Division, P.O. Box 2189, Houston, Texas 77001
[2]U.S. Bureau of Mines, Division of Minerals, Policy and Analysis, 2401 E. Street N.W., Washington, D.C. 20241
[3]Alaska Division of Geological and Geophysical Surveys, 794 University Avenue Basement, Fairbanks, Alaska 99701

FOREWORD

Mineral-resource assessments should provide useful information on the quantities and potential values of mineral resources in selected areas. Such information can be used by land managers, policymakers, and administrative agencies as a basis for land-use decisions. Of particular interest is the use of such assessments for economic forecasting at local, state, and federal levels and for analysis of national concerns, such as the availability of critical and strategic minerals.

The ability to make quantitative resource assessments was developed largely for application to oil-and-gas resources. These assessments are now used routinely by industry and local, state, and federal agencies. Quantitative assessment of metallic minerals in an analogous fashion is a relatively new technique, particularly when applied in areas where exploration has been minimal. The Kantishna Hills assessment---using a computer simulation model known as ROCKVAL---is the first application of this technique in Alaska.

Alaska has a wealth of minerals, but the questions of 'where' and 'how much' must be answered to determine the role and importance of that mineral wealth to the future of the State and the Nation. Thus, knowledge of the mineral potential of relatively unexplored areas of the United States, particularly Alaska, is critical. ROCKVAL represents the initial effort to obtain such knowledge.

Ross G. Schaff
State Geologist and Director

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EXECUTIVE SUMMARY

The ultimate goal of mineral-resource assessment is to provide useful, decision-oriented information concerning the quantities and values of potentially valuable mineral resources within an area. Experts such as Zwartendyk (3) and decisionmakers in industry and at the state and federal level have pointed out the importance of explicitly including economic factors in such assessments. Furthermore, assessment results must be presented in a format suitable for use by public resource analysts, land-use planners, decisionmakers, and others not trained in interpreting geologic maps, mine plans, and other technical information.

Driven by requirements to make mineral assessments for major land-use decisions in a state with a vast land area and considerable mineral-resource promise, the Division of Geological and Geophysical Surveys (DNR/DGGS) of the Department of Natural Resources, Alaska, and the U.S. Bureau of Mines (BOM) jointly developed a methodology to quantitatively assess the potential for undiscovered, economically recoverable minerals within a mineralized terrane or region. The ROCKVAL* methodology bridges the gap between the qualitative assessment of an area's favorability for mineral-deposit occurrence and a mineral-commodity inventory for the area by explicitly considering the engineering and economic processes that are necessary to transform the mineral resources of a particular region into mineral products---a logical final step in the mineral-resource-assessment process.

ROCKVAL is conceptually based upon the analytical approach developed in 1979 by the Office of Minerals Policy and Research Analysis in the U.S. Department of the Interior to evaluate the oil-and-gas resources of the National Petroleum Reserve in Alaska and the Arctic National Wildlife Range. Like the oil-and-gas model, ROCKVAL provides a rigorous procedure for disaggregating the assessment problem into a set of technical judgments that focus on and capture the important geologic, engineering, and economic factors that affect the occurrence and economic viability of mineral resources. This procedure requires geologists and engineers to express what they know about an area in terms of standard geologic and engineering parameters, which are then combined in a simple grade-tonnage format to generate quantitative estimates of regional resource potential. The methodology further provides for the explicit incorporation of uncertainty in the values of these geologic and engineering parameters; thus the assessments resulting from application of the methodology are also expressed as probability distributions and directly indicate the limitations in the data base and knowledge of the region. Similar geologic and engineering parameters have often been estimated in quantitative form. In fact, similar resource-assessment methodologies incorporating expert estimation of geologic parameters have been developed and utilized in the U.S. public and private sectors (4, 10, 11, 12) and in Canada.

*This acronym was based on a conversation with the Alaska's State Geologist, Dr. Ross Schaff, during which time he commented "all rocks have value, it's just that some are more valuable than others."

Application of ROCKVAL draws on all available data for the region being assessed, as well as other information that may be relevant, such as general grade-tonnage relationships. Geologic, mineral-terrain, and mineral-potential maps, for example, are all extremely useful in reducing the uncertainty surrounding the geologic and engineering values, as are geochemical and geophysical studies. Indeed, a major advantage of ROCKVAL is its capability to synthesize all of the assorted technical data and information from maps and studies that, by themselves, tell only part of the story and are often difficult for decisionmakers to interpret. Substantial experience since 1979 with petroleum assessments has demonstrated the analytical merit of this type of disaggregrated-process modeling, especially for areas with limited data availability. A distinct advantage of this approach over other, more aggregate or qualitative approaches (for example, mineral-potential maps) is that any technical disagreements, confusions, or implicit assumptions are much more likely to surface, allowing for their reconciliation or, at a minimum, their recognition.

Furthermore, by explicitly capturing the best current understanding of the important factors affecting resource viability, excellent documentation of the resource-assessment process results---a major determinant of credibility. When new data become available, explicit changes in the appropriate factor values may be estimated and a new resource assessment generated. An important side benefit of such 'updating' is that the reduction in uncertainty resulting from improved information provides an excellent demonstration of the value of collecting additional information.

It must be emphasized that the ROCKVAL methodology is not a substitute for field work and other data-gathering efforts. Rather, it provides a guide for field work by establishing a model that geologists and engineers will keep in mind as they conduct their field work and other investigations.

In conclusion, the ROCKVAL approach to mineral assessment provides a vehicle that permits a substantial increase in the utility of the information that geologists, economists, and engineers can make available to others interested in the mineral potential of an area. ROCKVAL represents a major advance toward a more sound assessment process that begins with field work and data collection, proceeds to technical studies and the compilation of reports and maps, and finally results in an assessment of potentially recoverable resources, which integrates all available information into a useful decision-oriented product. Without this last step, a true resource assessment has not been provided, a fact that decisionmakers are becoming increasingly aware of.

Kantishna Hills Application

In November 1983, the ROCKVAL methodology was applied to an assessment of the mineral resources of the Kantishna Hills, an area of approximately 200,000 acres within the Denali National Park and Preserve in Alaska. The Kantishna Hills contains recognized mineralization (gold, silver, lead, and zinc) and is a historic mining district. After its inclusion within the expanded boundaries of the park, the National Park Service was charged with the responsibility of developing a management plan for the area and preparing the requisite Environmental Impact Statement (EIS). The key policy issue in the future management of the Kantishna Hills area was the tradeoff between allowing continued access to the mineral resources and protecting the wildlife and scenic resources also present in the area.

To assess the undiscovered mineral potential of the area, DGGS and the BOM assembled a team of 10 experts familiar with the Kantishna Hills, including geologists and engineers from DGGS, the BOM, the U.S. Geological Survey (USGS), C.C. Hawley and Associates, and Salisbury and Dietz, Inc. The assessment process consisted of six basic steps: 1) compilation of the geologic data base for the area; 2) inspection of all existing geologic and engineering data relevant to the formation and production of mineral deposits within the Kantishna Hills area; 3) identification of the types of undiscovered deposits expected to exist within the area; 4) estimation of the geologic, engineering, and economic factors appropriate to each identified deposit type; 5) use of a computer simulation to provide probability distributions for the major outputs of the assessment; and 6) review of the results by the experts.

Summary results of the Kantishna Hills evaluation are presented in tables 1, 2, and 3. The major products of the appraisal process included estimates of the area's resource endowment, the proportion of that physical endowment that may be economically recoverable assuming the area was fully explored, and the gross dollar value of the potentially recoverable commodities within the region (table 1). Based on the analysis, six commodities are potentially economically recoverable from undiscovered deposits of various types in the Kantishna Hills area: gold, silver, tungsten, lead, zinc, and copper. The total gross recoverable value of undiscovered mineral resources in the area was estimated to range from $375 million to $1,260 million at the 95-percent and 5-percent confidence levels, respectively. The results of this and other resource studies of the area were instrumental in the decision by the joint Federal-State Alaska Land Use Council to recommend the expansion of mineral-development opportunities in the Kantishna Hills by instituting a locatable mineral-leasing system on unclaimed land in a portion of the study area.

Implementation Requirements

There are at least two requirements for future successful applications of the ROCKVAL methodology. First, the methodology may be unfamiliar to most individuals participating directly in the assessment process. Because many individuals will not have had experience in assessing quantitative probabilities, a subjective probability tutorial should be provided at the beginning of each assessment session. The tutorial should include a discussion of basic statistics and potential biases that can enter into the judgmental process and feedback concerning the accuracy of the judgments of the experts for a number of sample exercises. This orientation will provide exposure, education, and training in the technique being used and increase the credibility of the assessments.

Second, efficient implementation of this methodology requires a strong multidisciplinary approach. A major challenge in implementation is to put together a smooth, functionally integrated technical team for each appraisal.

Table 1. Summary results of the Kantishna Hills area assessment.

Resource endowment[1]

Commodity	Average	Fractiles 95%	50%	5%
Gold (10E3 oz)	821.6	399.4	752.4	1,423.9
Silver (10E3 oz)	34,215.1	16,388.1	30,637.0	62,318.0
Tungsten (10E3 tons)	0.8	0.1	0.5	2.3
Lead (10E3 tons)	167.6	53.9	118.3	328.0
Zinc (10E3 tons)	186.5	27.3	64.1	253.7
Copper (10E3 tons)	4.0	0	0	3.9

Recoverable resources[2]

	Average	Fractiles 95%	50%	5%
Gold (10E3 oz)	551.3	213.4	479.3	1,112.4
Silver (10E3 oz)	31,349.1	14,304.0	28,597.6	58,022.9
Tungsten (10E3 tons)	0.6	0	0.3	2.1
Lead (10E3 tons)	115.0	39.1	95.5	259.4
Zinc (10E3 tons)	139.4	19.8	51.7	151.8
Copper (10E3 tons)	1.8	0	0	0

Gross recoverable value[3]
(in million dollars)

	Average	Fractiles 95%	50%	5%
Gold ($416.25/ton)	229.5	88.8	199.5	463.0
Silver ($12.10/oz)	379.3	173.1	346.0	702.1
Tungsten ($13.50/lb)	16.1	0	9.1	56.5
Lead ($0.19/lb)	43.7	14.8	36.3	98.6
Zinc ($0.41/lb)	114.3	16.2	42.8	124.5
Copper ($0.80/lb)	2.9	0	0	0
Aggregate Value	785.8	374.5	682.4	1,261.3

[1] The resource endowment consists of those resources in the ground subject to mode of occurrence and limits on minimum grade and tonnage (10E3 = one thousand).

[2] Recoverable resources are those portions of the resource endowment amenable to exploitation within certain engineering and cost limits (10E3 = one thousand).

[3] Gross recoverable value is calculated using September 1983 E&M Journal prices.

Table 2. Definitions for mineral resource appraisal data.

Regional parameters	
Factors 1-5:	A point estimate of the likelihood that geologic control necessary for the formation of deposits of a specific type is regionally present. Up to five independent controls may be assessed for each deposit type.
Regional favorability:	A point estimate of the likelihood that all the geologic controls necessary for the formation of deposits of a specific type are regionally present (RF = $P_{f1} * P_{f2} * P_{f3} * P_{f4} * P_{f5}$).
Drillable prospect:	A prospect, occurrence, or anomaly of sufficient interest to cause a prudent exploration geologist to commit to a drilling program.
Endowment Thresholds	
Cutoff tonnage:	A threshold tonnage level set to distinguish between anomalies and deposits to be included in estimates of resource endowment.
Cutoff depth:	A threshold depth level set to define a lower boundary on the assessment.
Cutoff grade:	A threshold grade level associated with each mineral contained in a prospect set to distinguish between anomalies and deposits to be included in estimates of resource endownment.
Deposit Parameters	
Deposits:	A mineral prospect exceeding a specific (cutoff) ore tonnage, grade, and depth.
Probability prospect ≥ cutoff tonnage:	A point probability estimate of the likelihood that a randomly selected prospect will contain ore in excess of the cutoff tonnage.
Deposit size:	The estimated range in deposit sizes above the cutoff tonnage for the terrane.

Table 2. (con.)

Probability prospect ≤ cutoff depth:	A point probability estimate of the likelihood that a randomly selected prospect will lie above the cutoff depth.
Probability deposit can be surface mined:	A point probability estimate of the likelihood that a deposit would be surface minable.
<u>Commodity Parameters</u>	
Commodity:	A mineral of potential economic interest that may be present in a deposit.
P or S:	P = primary commodity. S = secondary commodity.
Occurrence probability:	A point probability estimate of the likelihood that the particular commodity is present in a randomly selected prospect above the cutoff grade level.
Recovery factor:	The percent of a contained commodity in a deposit that may be efficiently recovered from the ore during benefication.
Average grade:	The estimated range in average grade for each commodity present above the cutoff grade.

Table 3. Economically recoverable resource summary results for the Kantishna Hills area assessment.

Deposit type	Recoverable resources[1] Average	Fractiles 95%	Fractiles 50%	Fractiles 5%	Gross recoverable value[2] ($ millions) Average	Fractiles 95%	Fractiles 50%	Fractiles 5%
Gold vein								
Gold (10E3 oz)	187.9	35.7	150.7	464.9	78.2	18.9	62.7	193.5
Silver (10E3 oz)	2,318.8	272.0	1,673.4	6,424.6	28.1	3.3	20.2	77.7
Tungsten (tons)	583.1	0.4	324.8	2,074.2	15.7	0.6	8.8	56.0
Silver vein								
Silver (10E3 oz)	28,939.4	12,660.4	26,017.7	55,307.2	350.2	153.2	315.5	669.2
Gold (10E3 oz)	217.3	70.8	182.0	475.0	90.4	29.5	75.8	197.7
Lead ((10^3 tons)	114.6	39.1	95.5	259.3	43.5	14.4	36.3	98.6
Zinc (10E3 tons)	59.6	18.4	50.7	129.3	48.9	15.9	41.6	106.1
Alluvial placer								
Gold (10E3 oz)	35.0	0	19.0	118.8	14.6	0	7.9	49.4
Silver (10E3 oz)	10.4	0	4.4	42.4	0.1	0	0.1	0.5
Tungsten (tons)	12.6	0	0	72.9	0.3	0	0	2.0
Bench placer								
Gold (10E3 oz)	105.1	0	4.1	557.6	43.8	0	1.7	232.1
Silver (10E3 oz)	43.0	0	0.8	259.6	0.5	0	0	3.1
Shale-hosted stratiform								
Lead ((10^3 tons)	0.4	0	0	0	0.5	0	0	0
Zinc (10E3 tons)	78.6	0	0	0	68.4	0	0	0
Spruce Creek stratiform								
Gold (10E3 oz)	5.9	0	0	0	2.5	0	0	0
Silver (10E3 oz)	37.2	0	0	0	0.4	0	0	0
Copper (10E3 tons)	1.8	0	0	0	2.9	0	0	0
Zinc (10E3 tons)	1.2	0	0	0	1.0	0	0	0

Table 3. (con.)

Regional totals	Recoverable resources[1]				Gross recoverable value ($ millions)[2]			
		Fractiles				Fractiles		
	Average	95%	50%	5%	Average	95%	50%	5%
Gold (10E3 oz)	551.3	214.3	479.3	1,112.4	229.5	88.8	199.5	463.0
Silver (10E3 oz)	31,349.1	14,304.0	28,597.6	58,022.9	16.1	0	9.1	56.5
Tungsten (tons)	595.6	0	335.4	2,092.9	16.1	0	9.1	56.5
Lead (10E3 tons)	115.0	39.1	95.5	259.4	43.7	14.8	36.3	98.6
Zinc (10E3 tons)	139.4	19.8	51.7	151.8	114.3	16.2	42.8	124.5
Copper (10E3 tons)	1.8	0	0	0	2.9	0	0	0
Aggregate value					785.8	374.5	682.4	1,261.3

[1] Recoverable resources are those portions of the resource endowment amenable to exploration within certain engineering and cost limits (10E3 = 1000)

[2] Gross recoverable value is calculated using September 1983 E&M Journal prices.

Ideally, such a team would include geologists, geochemists, geophysicists, and engineers familiar with the area to be appraised as well as economists, computer scientists, decision scientists, and users of the assessment. Because no single agency has the required expertise (expertise resides in the BOM, the USGS, the Bureau of Land Management, the U.S. Forest Service and state agencies), the most efficient way of organizing the assessments at this time may be to form task forces composed of representatives of agencies that contain the necessary expertise. The head of the task force would be the primary user of the assessment results.

INTRODUCTION

This paper presents an overview of the ROCKVAL method of quantitatively estimating the undiscovered, potentially recoverable resources within a mineralized terrain or region and the application of this method to the Kantishna Hills area in Alaska, including selected summary results of that analysis. Appendix A presents a more detailed discussion of the Monte Carlo model developed to synthesize the various geologic, engineering, and economic estimates provided by experts in the assessment process and describes the required data. Appendix B presents the alternative management options for the Kantishna Hills area.

OVERVIEW OF THE ANALYTICAL APPROACH

The traditional approach to regional mineral assessment has been to first conduct field work and collect data, then to perform technical studies on the samples collected (for example, geochemical and geochronologic analyses), and finally to prepare reports and maps that show the qualitative or comparative mineral-resource potential of an area. This approach emphasizes collection of basic scientific data and qualitative interpretations and generally stops short of providing quantitative estimates of an area's mineral potential. Its products are typically technical in nature and include geologic base maps, maps of known deposits or occurrences, and tables and maps of anomalous geochemical samples. While of substantial utility to technical experts such as exploration geologists, technical geologic data are generally of limited use to most public resource analysts, planners, and decisionmakers who, because of broader responsibilities, can rarely afford to become experts in any one particular field. In some cases, derivative products are developed such as 'potential maps,' which visually display tracts having high, medium, or low favorability or potential. However, because of a lack of uniform criteria and rating procedures, an enormous latitude in interpretation is possible. As a result, there is confusion and inconsistency regarding definitions of high potential, medium potential, and low potential, and this type of product is also often difficult for decisionmakers to use.

Central to a balanced consideration by decisionmakers of the resource trade-offs in an area is an estimate of its mineral potential that they can understand and compare to other resource values. To meet this need, given the limitations of traditional approaches to appraising the undiscovered mineral potential of an area, DGGS and BOM jointly designed a methodology called ROCKVAL to provide quantitative mineral-resource estimates in a format amenable to further economic and policy analysis. The ROCKVAL methodology bridges the gap between a qualitative assessment of an area's favorability for mineral-deposit occurrences and a mineral-commodity inventory by explicitly considering the engineering and economic processes necessary to transform the mineral endowment of a particular region into mineral products. Experts such as Zwartendyk (3) and many decisionmakers have pointed out the importance of explicitly including economic factors in resource assessments.

The procedures developed and applied to assess minerals were designed to achieve an analytical melding of geology, engineering, and economics; the objective was to develop a mineral-assessment methodology for a large area (under conditions of substantial uncertainty) that integrated all available information into a useful decision-oriented product. The approach taken is a disaggregated-process approach conceptually similar to that developed in 1979 by the Office of Minerals Policy and Research Analysis (OMPRA) of the U.S. Department of the Interior to quantitatively evaluate the petroleum resources of the National Petroleum Reserve in Alaska (10). The OMPRA methodology was subsequently applied to evaluate the petroleum potential of the Arctic National Wildlife Range (14) in response to a joint request by U.S. Senators Jackson and Hatfield in May 1980.

The disaggregated-process approach developed by DGGS and BOM to evaluate the undiscovered mineral potential of a region directly incorporates expert geologic, engineering, and economic judgments in a probabilistic format, and therefore explicitly reflects the substantial uncertainty inherent in mineral-resource appraisals of large areas with limited data. Figure 1 presents an overview of the analytical approach. The basic unit of analysis in the assessments is the deposit type, that is one or more prospects in a common or relatively homogeneous geologic setting that can be explored by using geological, geochemical, and geophysical techniques. Several deposit types, such as shale-hosted stratiform deposits, alluvial placer deposits, skarn deposits, and porphyry-copper deposits, will usually be present within a particular region. Any number of deposit types can be considered. For the purposes of the analytical approach, resource endowment is defined as the sum of the physical quantities of each mineral contained in undiscovered deposits of specified types subject to limits on minimum grade and minimum tonnage. The proportion of the resource endowment that would be potentially recoverable if the region were fully explored is estimated by overlaying a series of engineering and economic constraints, or 'screens,' on the endowment potential.

The critical factors affecting the endowment potential of a region and its potential for economic recoverability include the number of deposit types likely to occur, the likelihood that all the geologic controls necessary for the formation of deposits of a specific type are present in the region (geologic favorability), the number of drillable prospects of a specified type, the likelihood that a prospect is indeed a deposit (that is, satisfies minimum-grade, minimum-tonnage, and maximum-depth conditions), and the deposit size. Additional critical factors include the assorted minerals likely to be present above specified grade thresholds within a deposit of a particular type, the average grades of the minerals, the efficiency of the recovery of the minerals during beneficiation, the expenditures necessary to

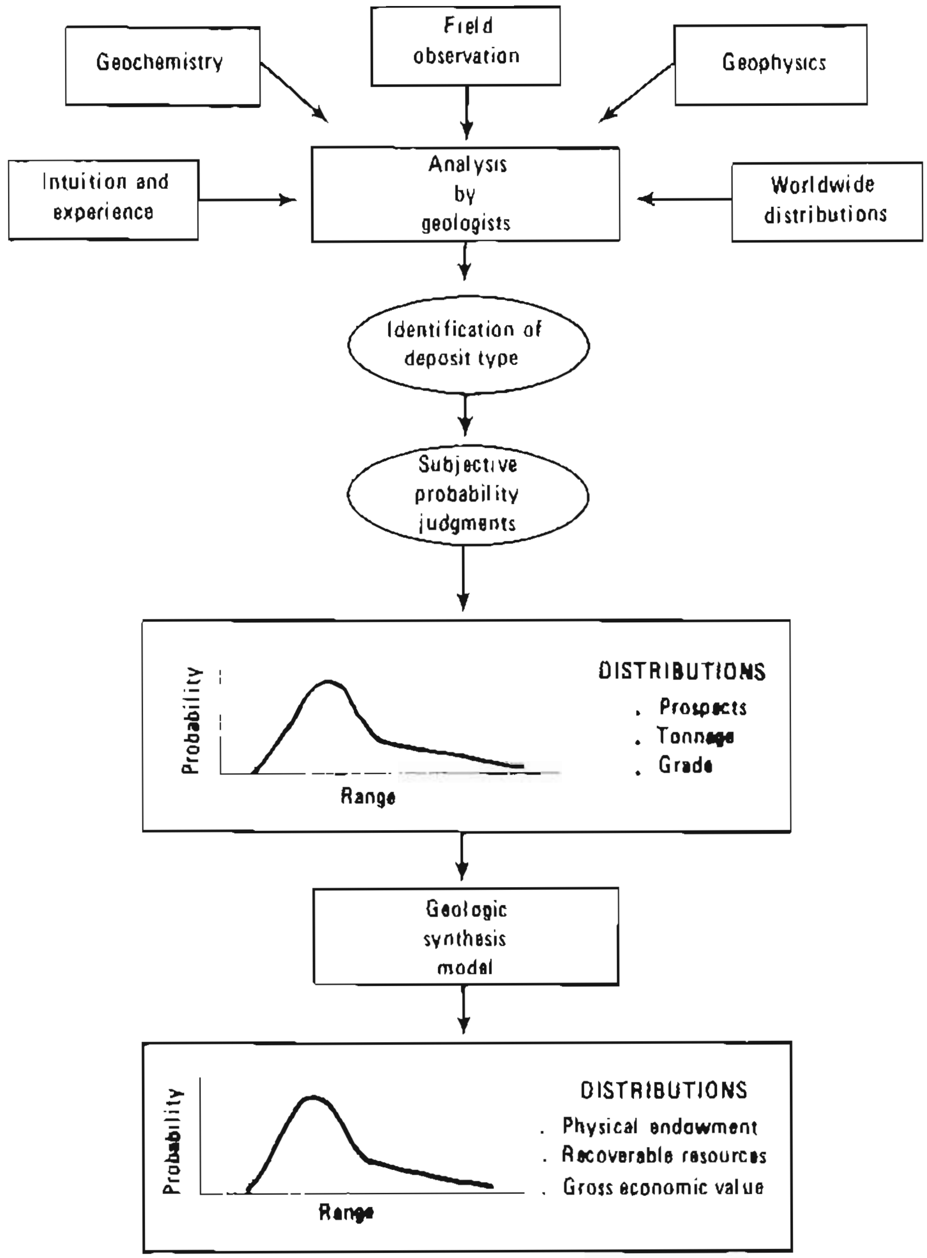

Figure 1. Mineral-resource assessment.

establish a mining operation, and the variable costs and rate of return necessary to mine, beneficiate, and transport the ore.

Because direct measures of many of these critical factors can, at best, be obtained only by using expensive exploration techniques such as drilling or bulk sampling, mineral-resource estimation often depends on quantitative estimation of the factor values by experts based upon indirect data derived from local surface geologic, geochemical, geophysical, and engineering investigations, as well as analysis of subsurface data derived from contiguous and analogous areas. Experience with a similar challenge of estimating undiscovered oil-and-gas resources in large areas (10) has shown that these estimates may be made most efficiently by expert geologists, mining engineers, and mineral economists familiar with the region and the deposit types using a technique that elicits their estimates of the range of possible values and associated probabilities for these factors relevant to the formation and economic recoverability of mineral deposits in the region.

Once the possible ranges of these factors have been assessed, the estimates may be used in a Monte Carlo sampling process to simulate the quantities of potentially recoverable resources in an area. Repeated samples from the factor ranges (distributions) can be incorporated in a simple grade-tonnage model to estimate the number, size, composition, and grades of deposits likely to exist. The characteristics of each simulated deposit can then be compared against engineering and economic screens to estimate if its resources may be considered economically recoverable. This process can be repeated many times by selecting values for the geologic factors with a frequency that reflects the experts estimated probabilities that the values do occur. The products of such an appraisal process will include quantitative estimates of both the mineral endowment and the recoverable resources within the region of interest as well as the distribution of these resources in terms of both physical quantities and gross values measured in dollars. The following section presents a more detailed picture of the appraisal methodology.

APPRAISAL METHODOLOGY

The conceptual framework for the economic appraisal of undiscovered but potentially valuable mineral-deposit types predicted to exist within a region consists of four components: 1) a geologic model of endowment, 2) a set of engineering screens, 3) a set of economic screens, and 4) a statistical process to express the major geologic and economic results as probability distributions.

Geologic Model

The geologic model of endowment divides the geologic characteristics of a particular deposit type into four sets of physical factors or parameters: 1) regional parameters, 2) endowment thresholds, 3) deposit parameters, and 4) commodity parameters. Definitions of these parameters are presented in table 2.

The first set of factors, the regional parameters, address the geologic factors or processes required for a particular type of deposit (for example, skarn deposits) to occur within the region. The regional factors assessed are the regional-favorability and the number of drillable prospects. The regional-favorability factor incorporates a number of basic geologic characteristics of the region, including evidence of a source, transport, or migration of mineralizing fluids; a favorable depositional site; the actual formation of ore concentrations; and preservation of concentrations. This factor may, in fact, be disaggregated into its component parts, if considered necessary or useful. The simultaneous occurrence of these attributes is a necessary but not sufficient condition for a drillable prospect to be considered an actual deposit.

The second set of parameters, the endowment thresholds, establishes lower boundary conditions for estimates of the mineral endowment contributed by each deposit type. The endowment thresholds are set by the appraisers and provide minimum-tonnage and minimum-grade levels to distinguish deposits that may be of potential economic interest from anomalies. These threshold values are set well below the current engineering and economic cutoff points to allow for future technological advances.

The third set of factors, the deposit parameters, address the geologic factors required for a specific prospect to actually be an ore deposit. The two parameters assessed are deposit likelihood and deposit size. The deposit likelihood is the probability that a randomly selected drillable prospect will contain mineralized ore in excess of the endowment tonnage threshold and contain at least one primary commodity above its grade threshold.

Finally, the commodity parameters provide estimates of the occurrence and average grade of the minerals that may be present in a deposit of a specified type. Some of the minerals assessed may be potential coproducts with their production being dependent on the production of the primary product. Many deposits would not, in fact, be economic if they did not contain valuable coproducts.

The disaggregation of geologic factors in the assessment process has several advantages. First, the separation of regional from site-specific risk accounts for the fact that a favorable terrane will often contain many prospects and more than one deposit; yet after exploration and evaluation, not all prospects turn out to be actual deposits. Second, an explicit statement of the threshold (or cutoff) tonnage, depth, and grade above which a prospect, occurrence, or anomaly can be considered a deposit avoids much confusion in defining endowment. Third, treating 'prospects' separately from 'deposits' greatly facilitates the analysis of exploration behavior. Finally, the disaggregation of factors explicitly documents the fundamental geologic characteristics that must be evaluated if the results of the appraisal are to be amenable to further engineering and economic analyses.

Probability judgments concerning the regional, deposit, and commodity parameters are developed by experts familiar with the geology of the region of interest. The experts first review all existing data relevant to the evaluation, including results of field work, analog grade-tonnage, or contained-metal distributions, geologic maps, geochemical studies, and evaluations of known deposits. They then identify possible deposit types within the region, and for each identified deposit type, they establish the endowment thresholds and make subjective probability judgments concerning the regional, deposit, and commodity parameters. Collective judgments of the parameter values for each of the potential deposit types that could exist in could exist in the region under consideration are elicited, and these judgments are entered by each expert on a mineral resource appraisal data form. An attempt is made to reach a concensus, but where differences in parameter estimates exist, estimates are averaged. An example of a mineral resource appraisal form is shown in figure 2. Cumulative probability distributions are approximated for parameters such as deposit size and deposit depth by seven points (probability fractiles): the 1.00 and 0.00 fractiles, that is, the minimum and maximum values by which the distribution is bounded, and the values for the 0.95, 0.75, 0.50, 0.25, and 0.05 fractiles. An example of a completed form is shown in figure 3.

Engineering Screens

A recovery factor or the percent of a contained commodity in a deposit that may be efficiently recovered from the ore during beneficiation is employed to incorporate current technological limitations on the proportion of the mineral endowment that may be reasonably exploited. This factor takes into account the likely mineralogy, grain size, and deposit geometry as well as available technology. The impacts of technological improvements in both beneficiation and mining methods may be estimated simply by changing this factor.

Economic Screens

Two economic screens are employed to directly incorporate current (or projected) economic limitations on the proportion of the mineral endowment that may be reasonably exploited. First, the minimum gross value of ore in a deposit is estimated. This estimate takes into account the fixed costs necessary to establish a mining operation in the area under consideration.

Second, the minimum unit value of ore in a deposit is estimated either on a per-ton or a per-cubic-yard basis. This estimate takes into account the variable costs and rate of return necessary to mine a unit of ore. For the mineral resources in a deposit to be considered potentially economically recoverable rather than just part of the endowment, both the gross and the unit cutoff values for the deposit must be equaled or exceeded.

Monte Carlo Simulation

Once the geologic factors and engineering and economic screens discussed above have been assessed by the experts, they are synthesized in a Monte Carlo simulation model to provide probabilistic estimates of mineral endowment and recoverable resources in terms of both physical quantities and values measured in dollars. In overview, the model simulates one possible state of geologic nature by sampling from the probabilities assessed for each of the basic geologic factors and uses the resulting values to compute an

Assessor: ______________________ Deposit type: ____________________

Date: ______________________ Terrane: ____________________

Region: ______________________ Commodities: ____________________

Known deposits: ____________________

	Parameter	Assessed value							Comments
Regional parameters	Factor 1:								
	Factor 2:								
	Factor 3:								
	Factor 4:								
	Factor 5:								
	Regional-favorability probability								
		Probability of ≥ (%)							
		100	95	75	50	25	5	0	
	Number of drillable prospects								
Deposit parameters	Probability prospect size ≥ cutoff tonnage		Cutoff tonnage						
		Probability of ≥ (%)							
		100	95	75	50	25	5	0	
	Deposit size (K tons)								
	Probability prospect size ≤ cutoff depth		Cutoff depth						
	Probability prospect could be surface mined								

	Commodity	P or S	Cutoff grade %	Occurrence probability %	Recovery factor %	Average Grade							
						Probability of ≥ (%)							
						100	95	75	50	25	5	0	
Commodity parameters													

Figure 2. Mineral resource appraisal data form.

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Assessor:
Date: 10/24/84
Region: Example

Deposit type: Hypothetical
Terrane: Hypothetical
Commodities: Zn, Pb, Ag
Known deposits: No

Parameter		Assessed value							Comments
Endowment thresholds	Cutoff tonnage (K tons)	1×10^6							
	Cutoff depth (feet)	500							
Regional parameters	Regional-favorability probability	0.4							
		Probability of ≥ (%)							
		100	95	75	50	25	5	0	
	Number of drillable prospects	0	0	1	1	2	3	7	
Deposit parameters	Deposit likelihood	0.25							
		Probability of ≥ (%)							
		100	95	75	50	25	5	0	
	Deposit size (K tons)	1	2	5	10	20	50	100	
	Deposit depth (feet)	0	0	10	25	50	100	500	

		Endowment			Average grade							
	Commodity	Cutoff grade %	Occurrence probability %	Recovery factor %	Probability of ≥ (%)							Comments
					100	95	75	50	25	5	0	
Commodity parameters	Zn	1	1.0	.95	1	2	4	6	10	15	25	
	Pb	0.5	0.8	0.9	0.5	1	2	4	7	10	15	
	Ag (oz/ton)	0.01	0.2	0.75	0.01	0.2	0.75	0.01	0.5	0.9	1.0	

Engineering/ economic screens	Recoverable depth cutoff (feet)	500
	Gross deposit value cutoff (S)	$100,000,000
	Unit value cutoff (S)	$100/ton

Figure 3. Completed mineral resource appraisal data form.

amount of ore and contained commodities for deposits of a particular type. The characteristics of each simulated deposit are then compared against the engineering and economic screens to estimate if its resources may be considered economically recoverable. This process of simulating a particular state of nature, called a 'pass' is repeated many times, and the results are stored, aggregated, and used to build a probability distribution for each of the desired products. The model also aggregates the results across all deposit types being assessed in a region to provide total estimates for each commodity possible in the region. Appendix A provides a more detailed description of the simulation model, and an example of the output for a vein deposit is provided in table 3.

APPLICATION: THE KANTISHNA HILLS ANALYSIS

As described by Bundtzen (1983), the Kantishna Hills is an area of approximately 200,000 acres located within the expanded boundaries of the Denali National Park and Preserve in Alaska. It contains recognized mineralization and is a historic mining district. Placer gold was first discovered in the area in 1903. A small-scale gold rush followed, involving several thousand miners, most of whom left by 1906. Discovery of lead, antimony, and other sulfide cobbles caught in placer-mining sluice-box riffles prompted exploration for hard-rock deposits and led to the first shipment of antimony from the area in 1905. By 1919, numerous mineralized-vein faults had been discovered containing antimony, silver, lead, zinc, gold, copper, arsenic, and tungsten. Silver production continued in the 1920s, and base metals were extracted in the late 1930s, and early 1940s. Antimony has been mined sporadically in the area, primarily during wartime when prices were elevated. Placer-gold mining has continued since the discovery of gold in 1903 and has increased substantially in recent years. The total cumulative mineral production of the Kantishna Hills is estimated at 85,500 oz of gold, 270,000 oz of silver, 5 billion lb of antimony, and several million pounds of lead and zinc.

At the time the Kantishna Hills study was initiated in 1983, there were 15 to 20 placer-gold-mining operations and two small-scale lode-mining operations active in the area. Other land uses of the Kantishna Hills were tourism, subsistence hunting and trapping, and hiking and fishing.

Early in 1983, pursuant to Section 202(3)(b) of the Alaska National Interest Lands Conservation Act (ANILCA:P.L. 96-487) as enacted on December 2, 1980, the Alaska Land Use Council (ALUC) was charged with evaluating the Kantishna Hills area. The ALUC Kantishna Hills study and resultant report were directed to "evaluate the resources of the area, including but not limited to fish and wildlife, public recreation opportunities, wilderness potential, historic resources, and minerals, and to include those recommendations respecting resources and other relevant matters which the Council determines are necessary." In addition, because it had been included within the expanded boundaries of the Denali National Park, the National Park Service was charged with developing a management plan for the Kantishna Hills and preparing the requisite Environmental Impact Statement (EIS). A key issue in the future management of the Kantishna Hills area was the benefits of allowing continued access to the mineral resources and the impact of mining on various degrees of protecting the wildlife and scenic resources also present in the area. In fulfilling its obligation to Congress, the ALUC designated the Alaska Department of Natural Resources and the National Park Service as coleaders for the Kantishna Hills study project. Other member agencies of the study group included the Alaska Department of Fish and Game, the U.S. Bureau of Mines, the U.S. Geological Survey, and the U.S. Fish and Wildlife Service.

As directed by the ALUC and in conjunction with other state and federal agencies, the study group conducted the appropriate studies during 1983. Six alternative management strategies were formulated by the study group to represent the full range of reasonable alternatives for mineral development and protection of park resources as required by ANILCA and NEPA. The proposed alternatives covered the spectrum of reasonable land-use possibilities: 1) maintain status quo (no action), 2) acquire all mining claims, 3) offer term operating rights, 4) allow additional time for perfecting claims, 5) expand mineral-development possibilities, and 6) remove mineralized areas from the park. Brief summaries of these management options are presented in Appendix B.

Central to a balanced consideration by land-use decisionmakers of the resource tradeoffs within the Kantishna Hills area was an objective estimate of its discovered and undiscovered mineral resources. An earlier estimate had been made by the DGGS of the economic potential for the area's discovered mineral resources (1). The ROCKVAL methodology, developed during 1982 and 1983 by DGGS and the BOM, was used to evaluate the undiscovered mineral resources of the area. The application of this methodology and selected summary results of the analysis are discussed below.

Assessment Procedure

In November 1983, DGGS and the BOM assembled a team of experts familiar with the Kantishna Hills area to appraise its undiscovered mineral resources. Ten geologists and engineers from DGGS, BOM, USGS, C.C. Hawley and Associates, and Salisbury and Dietz, Inc., participated in the resource appraisal. Most of the appraisal team had just completed a 16-month, $1.5-million study of the Kantishna and Dunkle Preserves, which was funded by the Bureau of Mines and resulted in two major geologic reports. The assessment procedure consisted of five basic steps:

1. Inspection of all existing geologic and engineering data relevant to the formation and production of mineral deposits within the Kantishna Hills area.

2. Identification of the major types of deposits expected to occur in the area.

3. Estimation of the regional parameters, endowment thresholds, deposit parameters, commodity parameters, and engineering and economic screens appropriate to each type of deposit predicted to occur.

4. Use of a computer simulation to provide probabilistic estimates of the mineral endowment and the commodities that could be economically produced from each deposit type.

5. Review of simulation results by the experts, and revision of input estimates, if necessary.

During the initial step of the analysis, all existing geologic and engineering data relevant to the undiscovered mineral potential of the Kantishna Hills were compiled and presented to the assessment team. The data base included the results of substantial field work including mapping, sampling, and diamond drilling conducted in the area in 1983 by BOM, existing geologic maps (1), analog grade-tonnage and contained-metal distributions (16), evaluations of known deposits, and the results of geochemical and other past studies in the area (1). The data were interpreted by the assessment team, and the favorable and unfavorable indications of mineral-deposit occurrences were identified and discussed. A brief description of the geology of the Kantishna mining district, summarized from Bundtzen (1), follows.

The basement rocks north of the Hines Creek strand of the Denali fault system consist of four regionally metamorphosed rock units ranging in age from Precambrian to late Paleozoic. These rocks are a small part of the large complex known as the Yukon Crystalline Terrane (Tempelman-Kluit, 1976) that appear in eastern Alaska and Yukon Territory of Canada. The oldest rocks are the polymetamorphic Birch Creek Schist, which underlies about 85 percent of the Kantishna Hills study area and consists of variable amounts of quartzite, quartz-mica schist, marble, and greenstone. Protoliths of the coarse-grained schist were probably formed in shallow-water miogeosynclinal sedimentary environments on a continental shelf. The Birch Creek Schist hosts several high-grade antimony deposits and has geology favorable for the occurrence of stratiform lead-zinc deposits.

Chloritic and graphitic schist, marble, and felsic metavolcanic rocks of the Spruce Creek sequence are mainly exposed in a tectonic window underlying Birch Creek Schist units from Eldorado Creek to Moonlight Creek. This volcano-sedimentary package probably represents an early Paleozoic rift environment formed on top of the shelf deposits now represented by the Birch Creek Schist. According to Bundtzen (1), a large majority of the structurally controlled vein-ore deposits of gold, antimony, and silver in the Kantishna mining district are hosted in the Spruce Creek sequence, and geochemical, geologic, and petrologic evidence suggest that precious-metal-enriched volcanogenic copper-lead-zinc deposits in the Spruce Creek sequence constitute a source bed for much of the Kantishna mining district mineralization. Hence, its evaluation has become a focal point of investigations.

The youngest crystalline units in the Kantishna Hills study area are metasedimentary and metavolcanic rocks of the Keevy Peak and Totatlanika Schist Formations of Late Devonian to Mississippian age. Although the Totatlanika Schist is mainly exposed in the northern Kantishna Hills outside the study area, geologic relationships suggest that the formations interfinger locally. Lithologies of similar age are exposed discontinuously from the Brooks Range to Nevada and may be part of an extensive orogenic belt that formed along the North American continent in response to the Antler Orogeny and related orogeny of the North American cordillera. The Totatlanika Schist has stratiform massive-sulfide potential.

Undeformed mafic- to felsic-dike swarms of early Tertiary age intrude the metamorphic stratigraphy preferentially along the crest of a major fold structure, the Kantishna anticline. Middle to upper Tertiary coal-bearing sandstone and shale overlie older lithologies, often in structural grabens. The layered rocks have been successively deformed into isoclinal to open folds and thrust and high-angle faults. The region has been uplifted with the Alaska Range since middle Tertiary time, and shallow gravel thicknesses and steep bedrock canyons indicate that the region is still undergoing uplift. Modern stream alluvium, some of it bearing placer gold, is being deposited in many streams.

Although at least four ages of late Pleistocene till and outwash blanket much of the southern portion of the study area, most of the rugged upland was not glaciated during Wisconsinan time (the last 100,000 yr). Outwash gravels on the benches have potential for large-volume, low-grade placer deposits.

Based on interpretations of the geologic data, undiscovered deposits of the following six geologic types were predicted to occur within the region:

1. Alluvial placer deposits - Au, Ag, W
2. Bench placer deposits - Au, Ag
3. Shale-hosted stratiform deposits - Pb, Zn, Ag
4. Spruce Creek stratiform deposits - Cu, Pb, Zn, Au, Ag
5. Spruce Creek vein (Au) deposits - Au, Ag, W
6. Spruce Creek vein (Ag) deposits - Au, Ag, Pb, Zn

During the third step in the analysis, the study team completed a 'Mineral resource appraisal data form' (fig. 2), for each of the identified deposit types. Their collective judgment on the endowment threshold, regional, deposit, and commodity parameters, and engineering and economic screens was elicited for each of the potential deposit types. All geologic, engineering, and economic data relevant to the various deposit types being assessed were carefully considered. In most instances, a consensus estimate was established quickly; in others, more discussion was required. Where differences remained, individual judgments were averaged.

The fourth step in the analysis was to use the Monte Carlo simulation discussed earlier to provide probabilistic estimates of the mineral endowment and recoverable resources of the Kantishna Hills area in terms of both physical quantities and gross values measured in dollars. Alternative states of geologic nature in the Kantishna Hills area were simulated by sampling from probabilities assessed for each of the basic geologic factors and the resulting values were used to compute an amount of ore and contained commodities for deposits of a particular type (for example, alluvial placer deposits) as described in appendix A. The characteristics of each simulated deposit were compared against the engineering and economic screens established for the particular deposit type to determine the economic feasibility of recovery. The dollar values of economically recoverable commodities were estimated by multiplying the physical quantity of each recoverable commodity by its current unit price.

The process of simulating and evaluating a particular state of nature in the Kantishna Hills was repeated 3,000 times (passes) for each of the six deposit types predicted to exist in the area. The results of each pass were aggregated and used to build probability distributions of the quantities and gross dollar values for the commodities expected to be recoverable from each deposit type and from the Kantishna Hills area as a whole. The range of values associated with each of the output distributions provides an explicit statement of the uncertainty regarding the physical quantities and gross dollar values of the resources that might in fact be recovered from the Kantishna Hills area---the wider the range of values, the greater the uncertainty. The uncertainty is a reflection of the quantity and quality of the data available for the region and can be reduced by obtaining additional data.

The fifth and final step in the analysis was to present the results of the Monte Carlo simulation to the members of the assessment panel for their review. For deposit types where the output distributions did not appear to present a reasonable estimate of the mineral endowment or recoverable mineral potential, the 'Mineral resource appraisal data forms' were revised, and the Monte Carlo simulation was rerun with the modified data set.

Results

Table 3 presents the economically recoverable resources for the six deposit types predicted to exist within the Kantishna Hills area. The most potentially productive deposit types are the Spruce Creek vein deposits, which are silver and gold deposits. In all cases, more than one commodity is expected to be produced from each of the six deposit types evaluated. The results of this study indicate that the total gross recoverable value of the undiscovered mineral resources within the Kantishna Hills study area ranges from $375 million to $1,260 million at the 95-percent and the 5-percent confidence levels, respectively. The results of this and of other resource studies of the Kantishna Hills area were instrumental in the decision by the Kantishna Hills study group to recommend a modified 'Expand mineral-development possibilities' land-management strategy to the ALUC. This 'preferred alternative' included the implementation of a locatable mineral-leasing program for both placer and lode mineral deposits on unclaimed land in those portions of the Kantishna Hills study area designated in figure 4. The ALUC accepted the recommendation of the study group.

CONCLUSION

This paper has presented an overview of a methodology jointly developed by the DGGS and the BOM that can be used to quantitatively assess the undiscovered mineral potential of a terrane or region under conditions of substantial uncertainty; all available information is integrated into a useful decision-oriented product. The disaggregated-process approach to mineral assessment for large regions or mineralized terranes was selected for several reasons. First, it provides a rigorous procedure for decomposing the

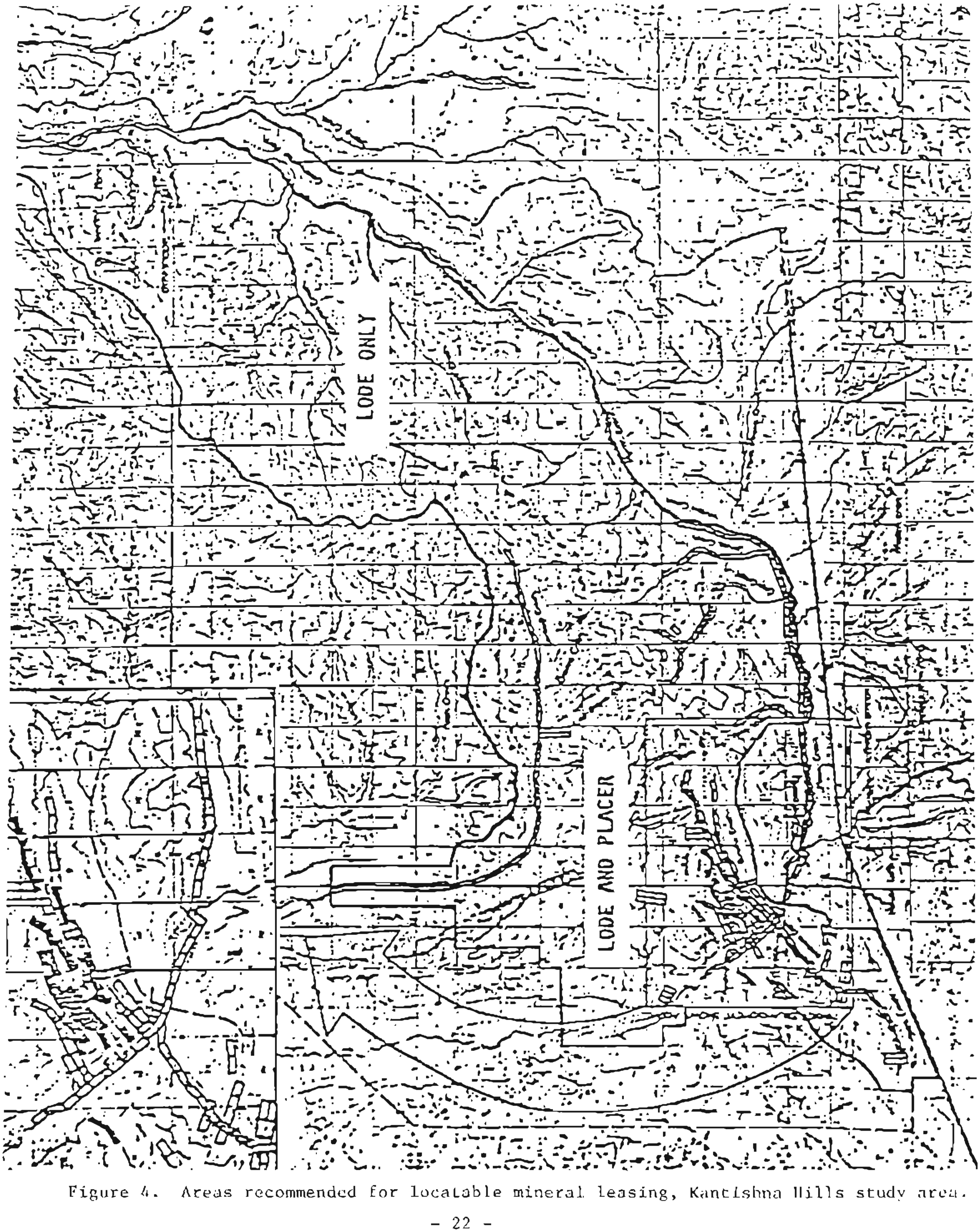

Figure 4. Areas recommended for locatable mineral leasing, Kantishna Hills study area.

assessment problem into a set of technical judgments that capture the important geologic, engineering, and economic factors that affect the economic viability of mineral resources within a particular region. It thereby provides a mechanism for the various experts (geologists, engineers, and economists) to focus directly on the fundamental factors that determine the presence or absence of potentially valuable resources. Second, it provides for direct incorporation of expert judgment on each important factor. While analogs are certainly of great use to the geologist in judgments concerning the geologic characteristics of an area, final judgments in this assessment process are tailored explicitly to the information and perceptions of the target area. Because the methodology provides for the explicit incorporation of uncertainty in the judgments, the outputs resulting from application of the methodology to a particular region directly indicate the limitations in the data base and knowledge of the region. The methodology does not require actual discoveries in an area for assessment purposes; judgments may be based on whatever data exist and explicitly reflect the uncertainty in the data. When new data become available, explicit changes in the appropriate factor values may be estimated and a new resource assessment generated. Finally, the separate geologic, engineering and economic factors can be synthesized in a formal model that can be reviewed and improved. Improvements in the specification of the geologic, engineering, and economic processes that influence the formation and recoverability of mineral resources in a particular region can easily be incorporated in a disaggregated model structure.

Future Work

Analysis of the Kantishna Hills applications suggests several ways that the ROCKVAL methodology can be improved. First, more geologic research is needed to develop background distributions related to the occurrence of specific deposit types. Second, the economic screens should be expanded to include simple development, production, and transportation models. Such refinements are facilitated by the fact that the geologic state of nature has been depicted in such a way that exploration, development, production, and transportation can be analyzed as a function of the endowment characteristics of a particular region. Finally, the outputs of the appraisal could be integrated with a geoprocessing capability to provide the results in geographic or map form.

Implementation Requirements

There are at least two requirements for the successful implementation of the ROCKVAL methodology. First, for many appraisers the methodology is new and unfamiliar. Because most individuals will not have assessed quantitative probabilities, a probability tutorial should be presented at the beginning of each assessment session. The tutorial should include discussions of basic statistics and potential biases that can enter into the judgmental process and feedback to the experts concerning the accuracy of their judgments for a number of sample exercises. This orientation will provide exposure, education, and training in the technique being used as well as increase the credibility of the assessments made.

Second, efficient implementation of this methodology requires a strong multidisciplinary approach. A major challenge in implementation is to put together a smooth, functionally integrated technical team for each appraisal. Ideally, such a team would include geologists, geochemists, geophysicists, and engineers familiar with the area to be appraised as well as economists, computer scientists, decision scientists, and users of the assessment. Finally, no single agency has the required expertise; portions reside in the BOM, the USGS, the Bureau of Land Management, the U.S. Forest Service, and the state agencies. The most efficient way of organizing the assessments at this time may be to form task forces composed of representatives of those agencies that contain the necessary expertise. The head of the task force would be the primary user of the assessment results.

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APPENDIX A
THE ECONOMIC APPRAISAL OF UNDISCOVERED MINERALS MODEL

The objective of the (ROCKVAL) model is to quantitatively estimate the mineral endowment and potentially recoverable resources within a mineralized terrane or region and the distribution of these resources in terms of both physical quantities and gross dollar values. ROCKVAL provides explicit, structured, repeatable methods of combining specific probability estimates of geologists, mining engineers, and mineral economists in the form of an automated Monte Carlo simulation. This model has been developed through a joint effort by the State of Alaska Department of Natural Resources' Division of Geological and Geophysical Surveys (DGGS) and the U.S. Bureau of Mines (BOM). The model (see fig. 5 for flowchart of ROCKVAL) has been programmed in Fortran 77 and currently runs on a Data General MV 8000 under the AOS/VS operating system.

In overview, ROCKVAL first selects a value for each of the geologic factors assessed by the experts and calculates an estimate of the undiscovered mineral endowment. Specific engineering and economic screens are then used to estimate the portion of the physical endowment that could be economically recoverable. Each repetition or 'pass' of the model consists of establishing the regional presence or absence of mineral resources for a particular deposit type, the number of deposits (productive prospects), the deposit ore tonnage and average grade of each mineral present, and the mineral endowment and economically recoverable resources for each deposit. Quantity and value calculations are made only for those passes in which the deposit type is simulated as potentially productive. When the desired number of passes is completed, the aggregate data for the deposit type are presented as probability distributions as well as statistically analyzed. This process is repeated for each deposit type being assessed in a region with the results aggregated to provide probabilistic resource and gross-value estimates for each commodity possible in the region.

The basic steps in the model are as follows:

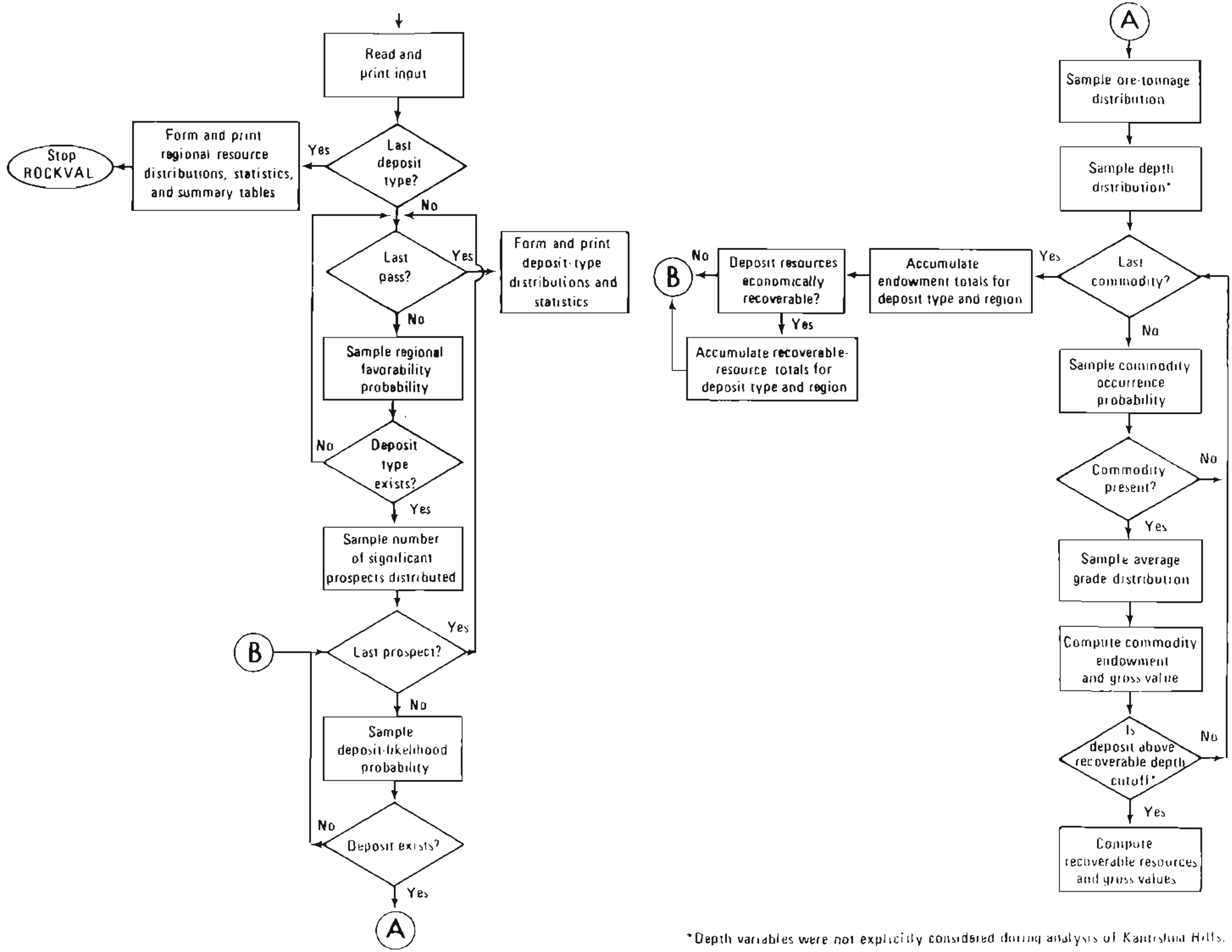
1. Select a deposit type.

2. Sample against the regional-favorability probability to simulate whether or not deposits of this type exist.

3. If the area is simulated as favorable for this particular type of deposit, sample from the number of prospects distributed to determine the number of prospects to be simulated.

4. For each prospect simulated to exist, sample against the deposit-likelihood probability to determine if the prospect will be simulated as a deposit.

5. If a prospect is simulated as a deposit, sample against the deposit-size distribution to determine the tonnage of ore to be simulated as present.



*Depth variables were not explicitly considered during analysis of Kantishna Hills.

Figure 5. Flowchart of ROCKVAL.

6. Sample against each primary-, and secondary-commodity occurrence probability to determine which commodities will be simulated as present in the deposit above the cutoff grade in the deposit.

7. Sample from the average grade distribution for each commodity simulated as present.

8. Compute the commodity endowment as grade multiplied by tonnage.

9. Compute the recoverable commodity as endowment multiplied by the recovery factor.

10. Compute the gross economic value of each commodity as the quantity of the recoverable commodity multiplied by price.

11. Compute the gross deposit value as the sum of all the commodity values.

12. Compute the deposit unit value as gross deposit value divided by tonnage.

13. Determine whether the deposit resources will be considered as economically recoverable by comparing gross and unit values against the cutoff values.

14. Accumulate totals across all deposits of each type and all deposit types.

15. Calculate summary statistics and print results.

ROCKVAL Input Documentation

The following documentation is intended to provide the user with a description of the data elements, model options, and their variable names. Two data files are required. The first file is a geologic-data file and contains the model options and data entered on the 'Mineral resource appraisal data forms.' The second data file is a commodity-price file and contains data specific to the commodities identified during the assessment process. This latter file must be named PRICES. The variables for each data file are listed below in the order in which they must be read in.

Geologic-data file

Variable name	Description	Type & format
1. ISEED	Starting seed value for the random-number generator (ISEED >0).	Integer (line 1, I10)
2. NPLAYS	Number of deposit types to be processed (NPLAYS ≤10).	Integer (line 2, I4)

Variable name	Description	Type & format
3. N	Number of probability fractiles output for each deposit type and for the region (N ≤7).	Integer (line 2, I4)
4. MPASS	Number of Monte Carlo passes (500 ≤MPASS ≤3000).	Integer (line 2, I4)
5. NPFLAG	Marginal regional deposit-type-favorability probability switch.	Integer (line 2, I4)
NPFLAG = 2	a. Read in marginal probability.	
6. NPRINT	Input file print switch	Integer
NPRINT negative	a. Stop after printing input file.	(line 2, I4)
NPRINT = 0	b. Print input file before simulation.	
NPRINT = 1	c. Do not print input file.	
7. IOUT Pass output switch	Integer	
IOUT = 0	a. None.	(line 2, I4)
IOUT = 1	b. Print results of each pass.	
8. NOTES	Number of lines of comment to be read in (NOTES ≤40).	Integer (line 2, I4)
9. IVPRINT	Value information print switch	Integer
IVPRINT = 0	a. Do not print value information.	(line 2, I4)
IVPRINT = 1	b. Print value information.	
10. TITLE	Title of assessment	Alphanumeric (line 3, A80)
11.	Probability fractiles	
FA (7)	a. For deposit type and region.	Real (line 4, 7F10.3)
IFA (7)	b. For deposit type and region.	Integer (line 5, 7I4)
12. MESSAGE	Comments to be printed (if any).	Alphanumeric (lines 6-46, A80)
13. DTYPE (I)	Deposit type.	Alphanumeric (line 47, A20)
14. TERR (I)	Terrane.	Alphanumeric (line 47, A20)

Variable name	Description	Type & format
15. MPROB (I)	Marginal regional-favorability probability.	Real (line 47, F5.3)
16. CDPROB (I)	Deposit-likelihood probability.	Real (line 47, F5.3)
17. NCOMMODS (I)	Number of minerals that may occur.	Integer (line 47, F5.3)
18. CDEPM (I)	Gross deposit value cutoff.	Real (line 48, F10.0)
19. CTONM (I) CTONM (I) = 0.0 CTONM (I) = 0.0	Unit value cutoff a. Endowment run. b. Economically recoverable run.	Real (line 48, F7.2)
20. PLCR (I) PLCR (I) = 0 PLCR (I) = 1	Placer-deposit switch a. Not a placer deposit. b. Placer deposit.	Integer (line 48, I1)
21. PROS (7,I)	Number of drillable-prospect distributions.	Real (line 49, F10.3)
22. CDTON (7,I)	Conditional deposit-size distribution for the terrane.	Real (line 50, 7F10.3)
23. CSYMB	Commodity symbol (such as Au for gold, Pb for lead).	Alphanumeric (line 51, A2)
24. OCCPROB (J,I)	Commodity-occurrence probability.	Real (line 51, F6.3)
25. PRCVR (J, I)	Percentage recovery of commodity from ore.	Real (line 51, F6.3)
26. AVGGRD (7, J, I)	Average grade distribution.	Real (line 51, 7F10.6)

Notes: (1) Items 23 through 26 are repeated NCOMMODS(I) (see item 17) times, for example, once for each potentially recoverable commodity.
(2) Items 13 through 26 are repeated NPLAYS (see item 2) times, for example, once for each deposit type.

Commodity-price file (must be named PRICES)

Variable name	Description	Type & format
1. CNAME	Commodity name	Alphanumeric (line 1, A20)
2. CSYMB	Commodity symbol	Alphanumeric (line 1, A2)
3. CFCTR	Grade-conversion factor	Real (line 1, F4.2)
4. PRICE	Commodity-unit price	Real (line 1, F10.3)
5. KOUNITS	Output units label indicator	Integer (line 1, I2)
KOUNITS = 01	a. (10^3 tons)	
KOUNITS = 02	b. (10^3 oz)	
KOUNITS = 03	c. (tons)	
6. CFCTR	Unit-conversion factor	Real (line 1, F9.6)
7. OUTPRICE	Output price label, for example $0.19/lb, $12.10/oz	Alphanumeric (line 1,A12)

Note: Items 1 through 7 are repeated for each potentially recoverable commodity assessed.

APPENDIX B
ALTERNATIVE MANAGEMENT OPTIONS FOR THE KANTISHNA HILLS

In order to meet the legislative mandate of ANILCA and NEPA, six alternative management options were formulated by the Kantishna Hills study group to represent the full range of reasonable land-use alternatives for an area with mineral-development potential and major park resource values. The alternatives address a spectrum of reasonable possibilities that range from an option of precluding mining within the study area by purchasing all claims to an option of reopening areas of significant mineralization to mineral development by removing these areas from the park.

Considerations addressed in the formulation of the management alternatives included the benefits of additional mineral exploration and development, the mining regulations that apply to mineral development in national parks, the varying levels of environmental protection, and the determination of valid existing rights.

Brief summaries of the six alternative management options are presented below. The alternatives are discussed in greater detail in the Kantishna Hills Environmental Impact Statement.

Alternative 1 - Maintain Status Quo (No Action)

This alternative would allow mining operations and mining-related activities to continue on existing patented and valid unpatented placer and lode claims. In addition, subject to approved plans of operations, other mining activities could commence on previously undeveloped patented and valid unpatented claims. Actions under this alternative would apply to the 195 unpatented placer claims, five unpatented lode claims, and 34 patented lode claims assumed to be valid in the Kantishna Hills study area.

Mineral development and mining activities would continue to be managed under existing NEPA authorities and regulations, general and specific park stipulations, and normal permitting and approval requirements of other regulatory agencies. These activities, including adequate and feasible access, would continue to be subject to approval of mining plans of operations with regard to protection of significant natural and cultural resources and other park values and to a determination of claim validity. Pursuant to standard claim-validation procedures, those unpatented claims deemed invalid would revert to public-park status, and any mining operations and related activities associated with these claims would be terminated.

Claim acquisition would occur only on a willing-seller or donation basis except in those cases where it could be determined that mining would result in a significant adverse effect on park lands. Acquisition of mining claims other than by donation would be subject to the appropriation of funds.

Alternative 2 - Acquire All Mining Claims

All patented and valid unpatented mining claims in the Kantishna Hills area would be acquired by the federal government under this alternative, subject to a formal determination of validity.

This alternative assumes the claims presented in Alternative 1 are determined to be legally valid through standard validation procedures. Therefore, implementation of this alternative would necessitate purchasing a maximum of 190 unpatented and 34 patented placer and lode claims in the Kantishna Hills.

Alternative 3 - Offer Term Operating Rights

Under this alternative, the claimant holding an unpatented placer or lode claim or claim group that had proven production on or before December 2, 1980, could elect the right to operate on the claim or claim group for 25 yr. No validity determination would be made by the government on these claims. The right would expire at the end of the 25-yr period or upon the claimant's death, whichever occurred first. In addition, the right to operate would terminate if there were no proven production within 5 yr following election of this right or if there were a lapse in proven production for two consecutive seasons thereafter. This right could apply to 13 claimants holding up to 185 unpatented placer claims and five unpatented lode claims in the Kantishna Hills area.

Alternative 4 - Allow Additional Time For Perfecting Claims

Under this alternative, all claimants holding unpatented placer and lode claims in the study areas that are unperfected would be granted an additional 5 yr to explore and achieve a valid mineral discovery within the meaning of the mining laws of the United States.

If the claims are determined to be valid, mining operations could proceed, subject to NEPA regulations. If the claims cannot be perfected and are determined to be invalid, the claims would revert to ownership of the federal government.

Alternative 5 - Expland Mineral-development Possibilities

Under this alternative, those portions of the study area with significant mineral resources would be opened to locatable-mineral leasing. Those areas containing significant metalliferous minerals could be opened under a leasing program for a set period for exploration and discovery. From the date of discovery, lessees would have a set period of time to begin production. Production of minerals could continue on valid leasing until the mineral resources were exhausted or the leases were relinquished. All leased lands would continue to be administered by the National Park Service.

Prior valid rights would be protected during the leasing process, and existing and future mining operations and related activities could continue on valid unpatented and patented mining claims in the Kantishna Hills area.

Alternative 6 - Remove Mineralized Areas From The Park

Under this alternative, the existing park boundary in the Kantishna Hills area would be adjusted to exclude mineralized portions of the study area from the park and administration of the National Park Service. This action could involve approximately 115,000 acres in the Kantishna Hills area.

However, a condition of removing this area from the park could be that the land would be exchanged for other areas of significant natural, cultural, or recreational values currently outside the park. Pending final judgment on the value of the land, the National Park Service could exchange portions of the study areas for appropriate land that is continguous with the present boundary, if such land were available.